

R. J. FORBES
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METALLURGY IN
ANTIQUITY



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Printed in the Netherlands

METALLURGY IN ANTIQUITY

A NOTEBOOK FOR ARCHAEOLOGISTS
AND TECHNOLOGISTS

BY

R. J. FORBES

WITH 98 ILLUSTRATIONS



LEIDEN

1950

1950

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LIST OF ABBREVIATIONS USED IN THE TEXT

- AAA: *Annals of Archaeology and Anthropology* (Liverpool)
 AfO: *Archiv für Orientforschung*
 AJSL: *American Journal of Semitic Languages and Literatures*
 Ant. J.: *Antiquaries Journal* (London)
 AO: *Der Alte Orient* (Leipzig)
 APAW: *Abhandlungen der Preussischen Akademie der Wissenschaften*
 AR: J. H. BREASTED, *Ancient Records of Egypt* (Chicago, Third Imp. 1927)
 ARL: D. D. LUCKENBILL, *Ancient Records of Assyria and Babylonia* (Chicago, 1926)
 BA: *Beiträge zur Assyriologie*
 B.A. report: *Report of the British Academy* (London)
 BK: see KB
 Bab. Miz.: F. H. WEISZBACH, *Babylonische Miscellen*
 CAH: *Cambridge Ancient History*
 CT: *Cuneiform texts from Babylonian tablets, etc. in the British Museum*
 DP: *Délégation en Perse*, edit. J. DE MORGAN
 FALKENSTEIN: A. FALKENSTEIN, *Archaische Texte aus Ur* (Leipzig, 1936)
 HWB: ERMAN-GRAPOW, *Handwörterbuch der ägyptischen Sprache*
 ILN: *Illustrated London News*
 ITT: *Intendaire des tablettes de Tello*
 JEA: *Journal of Egyptian Archaeology* (London)
 JEOL: *Jaarbericht Ex Oriente Lux* (Leyden)
 KAH: *Keilschrifttexte aus Assur historischen Inhalts*
 KAR: *Keilschrifttexte aus Assur religiösen Inhalts*
 KAVI: *Keilschrifttexte aus Assur verschiedenen Inhalts*
 KB: H. H. FIGULLA-E. F. WEIDNER, *Keilschriften aus Boghazkoi*
 OLZ: *Orientalische Literatur Zeitung* (Leipzig)
 PW: PAULY-WISSOWA, *Real-Encyclopädie der klassischen Altertumswissenschaft*.
 RA: *Revue d'Assyriologie* (Paris)
 ŠL: DEIMEL, *Sumerisches Lexikon* (Rome)
 SETHE, Urk.: *Urkunden des ägyptischen Altertums*, edit. K. SETHE
 VAB: *Vorderasiatische Bibliothek* (Leipzig)
 YOS: *Yale Oriental Series, Babylonian texts*.

CHAPTER ONE

A NOTE TO THE READER

“Whate'er my craft can promise, whatso'er
Is wrought with iron, copper or lead,
Fanned with the blast, or molten in the bed,
Thine be it all.”

(VIRGIL, *Aeneid* VIII, 471-475)

This will be a book of facts and fancies. The facts are about ores, metals and their properties, how they were won and worked in Antiquity in the Near East. But the facts which can be gathered from archæological, historical, philological and technical documents and books are not sufficient to form a continuous story. Therefore, let the facts be the warp and fancy the woof of this story.

For the facts, though far from complete, are abundant. They can be found in magical and religious texts, the economic documents of Antiquity abound with them, historical and geographical handbooks contain them and even ancient scientific and technological texts of some importance can be found. And just as maps shall supplement the dryasdust lists of ancient deposits of ores, so the texts shall be given in full to show the metallurgical facts in the context in which the ancients saw them. “Let the texts speak!” should and shall be our motto, for only too often the story of metallurgy, that important factor in ancient material civilisation, has been neglected. Which of our large handbooks either archæological or technical contains more than generalities on this subject, and only too often wrong facts that are taken over from one handbook into another? How few are the books on ancient history whose table of contents contains references to metals or metallurgical products, as if these never played a part in political history in those times as they do now! And again, why is not the proper technical and scientific information available to the archæologist and are his data not presented in the proper context to the technologist, who is usually put off with old, superannuated facts?

If we will try to undo these wrongs, at least partly, we must warn the reader that repetition of certain facts was found necessary. For wrong facts are the most tenacious things to destroy and the only remedy is *frappez toujours!* Then repetition was necessary too

to avoid those horrible cross-references which make the reader run through the whole of the book before he has finished one chapter. We have tried to present every chapter of the story of metallurgy as a whole in itself and to treat every aspect of a certain fact in its proper place. But the main purpose of this repetition remained bringing out the importance of certain vital facts which dominate ancient metallurgy and which are, alas, only too often forgotten.

Our path was often difficult to find for there is a sore lack of proper information on many details. No good, up-to-date geological handbooks or maps on the Near East exist and the maps of the deposits of different ores had to be compiled from publications varying greatly in trustworthiness. There is no uniformity in the spelling of geographical and historical names and many archæological publications lack proper indexes or do not mention metals in their table of contents and force the reader to run through the entire text! Analytical data on ancient metals and alloys are spread over many technical and archæological journals and books and often published in journals which can only be obtained with the greatest difficulty. The very important data collected by the Sumerian Copper Committee and its successor, the Ancient Metal Objects Committee, have not yet been properly published in detail. Archæologists have until now given little attention to such important metallurgical finds as furnaces, slags and ores and often their descriptions are non-committal or misleading, only too often experts should have been called in to examine and describe these and other details. Even the description of museum objects can not always be trusted as long as they have not yet been properly analysed. But even the registration of those points on which proper information is lacking may be helpful to future students of this subject.

The reader should also be warned of the perils of chronology. The chronology of the Ancient Near East and in fact that of prehistoric Europe which is linked up with it, remains very uncertain before 1500 B.C. We have followed the chronology used by most handbooks until very recently which is based on a date for the reign of king Hammurabi of Babylon of 1955-1912, that is about 1900 B.C., but of late documents have been found that force us to bring this date back to 1792-1749 B.C.! This means that the whole of the earlier chronology will have to be telescoped back accordingly and even our estimate of prehistoric periods will have to be shortened considerably. The reader, therefore, should use the dates previous to 1500 B.C. as

relative dates only, which are given to present a frame of reference for the technical data. This holds good even more for the tentative dates of prehistoric events, which may be 500 years wrong or even more! These early historical and prehistorical dates shall therefore be used and quoted with the greatest care so that no one should misunderstand their relative value!

For the correct interpretation and translation of the technical terms occurring in these chapters or in other publications we can refer the reader to two useful and rather unknown publications, viz. ALBERT H. FAY's *Glossary of the Mining and Mineral Industry* (Washington, Govt. Printing Office, 1920) and SCHLOMANN-OLDENBOURG's *Eisenhüttenwesen* (Illustrierte Technische Wörterbücher in sechs Sprachen, Oldenbourg, Berlin).

Acknowledgements should be made to the numerous friends who helped the author over his archæological and etymological difficulties. If they are not mentioned here individually, his thanks are no less sincere. Thanks are also due to Prof. GORDON CHILDE, the late Prof. CAMPBELL THOMPSON, the late Dr. LUCAS and Dr. CLINE whose writings have often inspired the author, as the careful reader will notice, and who thus unwittingly find him their grateful pupil.

The main purpose of this book was to bring the archæologist and the technologist in contact with each others results, to help them over the gulf that still separates them from cooperating in the study of a fascinating aspect of ancient civilisation. If this object were only partly achieved by these notes the author will find himself amply rewarded. For after all, the compilation of these notes was in itself a delightful task and without drawing immodest parallels with that eminent ancient historian, the author should like to say with LIVY in the Preface to his *Ab Urbe Condita*:

"I, on the other hand, shall look for a further reward of my labours in being able to close my eyes to the evils which our generation has witnessed for so many years; so long, at least, as I am devoting all my thoughts in retracing those pristine records, free from all the anxiety which can disturb the historian of his own times even if it cannot warp him from the truth."

Amsterdam, 1942.

Note: The printing of this book, completed during the Second World War, was delayed for various reasons. The author has refrained from incorporating the latest evidence which is not yet completely at his disposal.

CHAPTER TWO

SYNOPSIS OF EARLY METALLURGY

"We cannot but marvel at the fact that fire is necessary for almost every operation. By fire minerals are disintegrated and copper produced, in fire is iron born and by fire it is subdued, by fire gold is purified!"

(PLINY, *Nat. History* 36.200)

In tradition and in reality the *Metal Ages* play a large part. The idea of dividing the history of the world in different periods named after metals is probably of Iranian origin. The same sequence of "Metal Ages" as given in Dan. 2.31-45 is found in the Avesta and it recurs in Buddhist doctrines. Greek poets and philosophers have taken up the idea, HESIOD mentions it in his *Works and Days* (109-201) though he inserts a Heroic Age between the Bronze and the Iron Age. But generally the series consists of a Golden, Silver, Bronze and Iron Age from PLATO's *Republic* onwards upto CLAUDIANOS (400 A.D.). Still often one of the metals is missing, as in the writings of ARATOS, CICERO, JUVENAL, FESTUS or OVID (*Metamorphoses* I. 89-150). But in these writings the Metal Ages are used to depict the progress or often the decline of mankind, they are used to illustrate the loss of primeval simplicity and bliss by the achievements of material civilisation and the moral sins of mankind.

Gradually as Christian writers take over this idea they use it to describe the coming of the Last Judgement. Slowly the division of the history of mankind into four Metal Ages is given up and we find a division into four World Empires, which idea is to dominate medieval historiography and even philosophy of history for many more centuries.

But the idea of the four Metal Ages as the progress of material civilisation, each metal more or less characterizing the period called after it is a far later one though we find the earlier stages of this conception in PLATO's *Protagoras* (322) and LUCRETIUS' *De rerum natura* (V. 925).

These early philosophers have quite correctly realised that the advent of metallurgy meant a great step in the history of mankind. Still we must not exaggerate and pronounce metallurgy to be the prime factor in the transition from Stone to Metal Age.

For the rise of metallurgy forms only part of that "prelude to urban revolution" as GORDON CHILDE has so aptly called the transition of Stone to Metal Age. The moving force of this revolution is the invention of the plough and the great change from food-gathering to food-production and the enlargement of diet which accompany it. In the wake of this raising of the standard of living and the production of surplus food to feed a minority of the population no longer bound to agriculture follow many achievements that belong to the necessities of modern life. There are the invention of the wheel with its consequences, wheeled carriages and wheel-turned pottery. The invention of the sun-dried and the baked brick and the production of quarried natural stone lead to architecture. Wheeled cart and sailing craft go to establish long-distance communications. For many ages already semi-precious and precious stones and native metals had been sought for their magical properties and in other branches of mining we can also prove that there were centres of production in the Neolithic or Stone Age whose products were the objects of international trade if perhaps only passed from tribe to tribe. But the new means of communication break down the isolation of settled groups, they establish lasting contacts with the nomads and the direct transmission of trade goods over long distances. The growing knowledge of the physical and chemical properties of metals and ores, the conquest of new smelting and working processes stimulate this trade. As most ores are far from common their demand leads to a revolution of neolithic economy. The surplus of agricultural products of the peasant civilisations in the river-valleys is bartered for the mineral products of the mountain dwellers. Already the small region of the Aunjetitz civilisation has yielded more than 600 Kgrs. of metal finds which surely represent only a fraction of what existed in this era formerly!

The centres of production are either the mining districts, the metallurgical centres (smelting sites and forges) but the itinerant smiths must also have played a part. Once the magical transsubstantiation of copper ores with carbon and fire was achieved and had become common knowledge, similar experiments with other stones led to the discover of more metals.

The smith more and more becomes an important factor in international trade. In the earlier stages of the history of metallurgy mainly finished products were exported from the great producing centres but by the Iron Age either raw materials or semi-manufactured articles become the trade stock and the itinerant smith became more important

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to local needs than the producer. Since the Bronze Age ever growing specialisation leads to the formation of different types of smiths, the growth of a factory system of manufacture is already noticeable in the period of the New Kingdom of Egypt when standard types of metal objects become more common at the cost of style. Still this process cannot be stopped and it is developed by the Roman capitalists to something very near our factory-systems.

It would be important to study the routes of early metal trade. Very valuable material would be got by the study of the depot finds. From the four types of depots of metal objects two are of no use to this subjects for either domestic or votive hoards have nothing to do with metal trade, but founder's hoards (made up of old implements, broken



Fig 1 The oak sample-case of a Bronze Age itinerant smith found in Pommern (Germany) after FRANZ, JÄGER, etc)

objects, cakes and ingots) and commercial hoards (raw and half-finished tools, weapons, and ingots, but often very like the show-collection of a commercial traveller!) would certainly yield valuable clues.

Again one must not exaggerate the importance of metallurgy in these early societies. The progress of metallurgy was slow, for no doubt not all metals were better than stone and it took a long schooling of generations of smiths and smelters to produce something like bronze which was definitely better than flint or polished stone. Still in the long run metallurgy had profound influence on early economy. For metallurgy accompanies the rise of urban civilisation and the formation of the first empires in history. Many of these empires were imposed on the original peasant civilisation of Neolithic times by invading warrior tribes and the rise of metallurgy enabled the dominating classes to assemble riches in the form of metal rings, bars, etc. What had been hardly possible in Neolithic times, the formation of social

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classes based on relative riches, became a possibility now. Metals traded by the weight, served as the earliest form of money after corn, cattle or hides had failed as a means of barter for long-distance trade. We find that ingots of metals acquire standard shapes and weights though only many centuries afterwards the bankers of Lydia hit on the idea of coining precious metals, that is to say to ensure the user constant value by purity of metal, constant weight and a guarantee-sign stamped on the coin. Still the lumps of metal served well in international trade and the rôle of metals as a means of the accumulation of wealth in the hands of few cannot be denied by any serious student of Antiquity. And indeed much of ancient history



Fig 2 A typical Bronze Age hoard found in Brandenburg (Germany)
(after FRANZ, JÄGER, etc.)

could be rewritten as a struggle for the domination of quarries and ore-deposits or metal-supplies!

But as we have pointed out, important as it may be, metallurgy was neither the prime nor the most important factor in the rise of urban civilisation. It is also accompanied and stimulated by the evolution of the calendar, writing, arithmetic and measurement, which guided and controlled by the primitive mind and its belief in the harmonious cosmos, formed the foundations of modern science. The doctrines of pre-Greek science had a profound influence on everything which we call applied science, and therefore on the evolution of mining and metallurgy too. It accounts for the eagerness of the early Sumerians to study nature and its products, to apply the "fire test" and many other experimental means of discrimination to ores, etc. and to arrange the results in their lists with the clear nomenclature which is such a help to our understanding of these ancient texts.

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Thus metallurgy can be said to be one of the important factors in the rise of urban civilisation, which in its turn profoundly affected it. The historian of metallurgy cannot afford to ignore the social, economic, religious and material aspects of the civilisation in which metallurgy played a part of growing importance. He will then find that these factors account for the seemingly illogical developments of metal technique which are strewn on his path and that they impart a sudden and unexpected meaning on seemingly dull facts.

If then the use of such terms as "Bronze Age" and "Iron Age" has become common among archæologists and others, we must realize

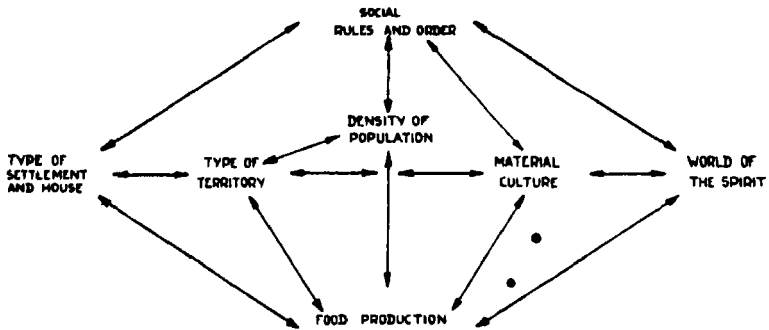


Fig 3 Important factors in primitive society

that they were nothing but names for certain contexts of archæological finds, prompted by the impression which metal objects make over pottery and other excavated objects. Indeed, these terms as applied to certain periods of civilisation have become paradoxes as our knowledge of Antiquity grew. For one can truly say that at present the Bronze Age is the period in which bronze gradually ousts copper from its prominent place in metallurgy and when at the end of the Bronze Age bronze has come into general use, the first signs of its younger rival, iron, are found. Thus the poet's words that "each age is a dream that is dying or one that is coming to birth" is made true even in the story of the material equipment of mankind.

Even their sequence did not prove to hold good everywhere in the world. The series Copper Age, Bronze Age and Iron Age was originally built up on the evidence of European prehistory and as the excavations of the Near East yielded their masses of material this idea was found to hold good there too. We know that this was because we

are quite near the original centre of metallurgy here and that the theoretical sequence holds good for primary and secondary centres and some of the further ones, but that we must be very careful of pitfalls. African metallurgy remained a puzzle until it was realised that here the Iron Age preceded the Bronze Age. Again in other parts of the world there was no Bronze Age at all. Neolithic tribes of Assam and Burma came into contact with our modern Steel Age before they had known any copper or bronze, and it would be easy to multiply these examples.

As long as we remember well that these terms are only convenient names for certain aspects of civilisation characterised by many more

- I Native metal as stones
- II Native metal stage (hammering cutting etc)
(copper gold silver meteoric iron)
- III Ore stage (from ore to metal alloys
composition as primary factor)
● (lead silver copper antimony tin bronze brass)
●
- IV Iron stage (processing as primary factor)
(cast iron wrought iron steel)

Fig 4. Evolution of Metallurgy

things than just the use of bronze or iron, we may go on using them for the lack of better ones.

But we must also remember that they are no indication of the evolution of metallurgy in that particular region or anywhere because they do not represent the true *stages of metallurgy*. These stages are characterised not by any particular metal but by many processes and methods going hand in hand, by a complex of discoveries and inventions guided by some leading ideas.

(The earliest metals collected by man were native metals (copper, gold, silver and meteoric iron) which occur as such in nature. During a long time they were not recognised as a special kind of stone, but simply treated as the common stock of raw materials then used, viz. stone, bone or wood. By and by it was realised that these "strange stones" had some very individual properties, that they could be reshaped by heating and hold their shape when cooled. Some of the

earlier processes applied to native metals remained in use, others were modified to suit the new way of treating them. Thus arose a complex of which hammering, tempering, cutting and grinding are typical methods. This must be considered to be the earliest stage metallurgy which we might call the *native metal stage*. As we will have occasion to prove a new step was the discovery of the reduction of ores followed by the discovery that metals could be melted and cast. This led to a total change of the methods of metallurgy and the rise of what we should like to call the *ore stage*. Its methods are casting, welding, soldering and many other new processes together with the reduction of ores and the manufacture of alloys. At this stage mining and metallurgy go their own way and are no longer in one hand. Now a series of new metals are discovered (lead, silver, antimony, etc.) and the manufacture of alloys are taken in hand either by working ores or smelting a metal with an ore, later on by mixing two metals. In the latter case a distinct improvement was achieved, as it was now possible to make alloys of a composition wavering only within close limits, which advantage was, however, to become valuable only as the use of certain alloys for certain very specific purposes came to the fore. In earlier times bronze in general was already a sufficient improvement on copper, and keeping the composition of bronze within certain limits would not have impressed itself as a necessity. Generally speaking the alloys and their manufacture are characteristic for this "ore stage".

The next stage is the "*iron stage*" which practically coincides with the "Iron Age" of tradition. But though the wrought iron and steel (and perhaps also the chance cast iron!) were in reality alloys of iron and carbon their properties were much less dependent on their composition but generally speaking determined by their treatment. Here hammering, tempering, quenching and annealing were far more important than variations in the composition. Therefore the "iron stage" means the discovery and mastering of quite a new complex of processes and treatments, the details of which will be discussed later on. Once we start using the metal technique of a certain period as a criterion and no longer the kind of metal or alloy, we see that the development in every region becomes a succession of stages or phases each of which are complete in themselves. Seeing that each of these stages has its own complex of processes and techniques we need not wonder that the transition from one period to another is much less smooth than generally supposed.

Before we go on discussing discoveries and inventions and the

evolution of material culture we must state quite clearly what we mean by these terms which are often so loosely employed. To this end we can do no better than reproduce the gist of HARRISON'S brilliant essay on this subject (*Report Brit. Assoc. Advanc. Sci.* 1930, pp. 137-159). By the aid of *methods*, often dependent upon extraneous *means*, man employs *materials* for the achievement of *results*, many but by no means all of which persist as artefacts or other products. Food was the only material which man had always to seek, but apart from this only the obtrusive materials attracted him, being under no compulsion to consider them. Therefore metal made its first impression as a fascinating luxury, from which evolved a need.

Now the idea of human progress is a fairly recent one, it became popular in the XVIIIth century only. But in reality man's progress is hardly that slowly rising line which lurks in the back of our mind when we talk of it. Man invents his ways as well as his means, but means are far older than man; they may be called "pure methods" indeed. Substance is the static warp, method the dynamic woof of man's material culture. But aims and ends as well as ways and means were and are the product of evolution.

Now we can define evolution as due to action and reaction in a developing brain and versatile hands in an expanding environment if we do not forget that this is just a statement but not an explanation!

For unconditioned foresight does not happen and directed research is apt to be overrun by invention, though the inventor only appears to be looking ahead! Artefacts then arose out of the rough and tumble of environment growing with knowledge and the accumulation of knowledge and artefacts. Chemically speaking the endproduct of the reaction is a catalyst, which enhances the speed of reaction and causes the formation of still more endproduct. In other words once the process of manufacture of artefacts started, the ball went on rolling quicker and quicker. The invention of script and the use of human speech have greatly enhanced the process by linking up the future and the past. In many cases we do not know how certain inventions took place. For instance there is still a gap between the discoveries of two properties of clay (plasticity and baking properties) and the production of the first earthenware pot, which is only more or less bridged by our "plastered pot" theory. In treating discovery very seriously we are often prone to forget that human mind is very prone to skid on trifles. Products of *discovery* are all artificially extracted, prepared and compounded materials which have no significant form impressed

on them but which are merely the raw materials for future production. But *inventions* are all shaped or constructed artefacts. Many simple types therefore are merely products of discovery, a subjective event which may be applied to objective application. But invention which is really applied discovery is always objective.

In metallurgy we often have quite a series of discoveries. For instance the use of bronze for tools and weapons starts with the discovery of the hammering of copper and ends at the discovery of the casting of bronze. The discovery of the new alloy is followed by the directional effort towards repetition, than a search is made for the ameliorating impurity in the copper, once this cause has been established, which again provides the basis for experimental smelting or directed research.

Then the transfer of ideas in technique is analogous to cross-mutation. The discovery of the *cire-perdue* process of casting bronze not only presupposes knowledge of bronze and casting methods but also the behaviour of waxes and fats when melted and cooled again. This brings up the old question of diffusion of achievements of material culture or the possibility of invention of the same process in different kinds of the world. Simple primary discoveries such as plasticity and malleability may be repeated, but every artefact that consists of a series of discoveries is more likely to have been diffused than reinvented! We must not forget that not need but prosperity is the mother of invention and that the early metal worker was not pushed along the path of progress because he had no idea that it was a path at all. Such an achievement as the production of bronze is already sufficiently surprising and if we would be led to suppose that it evolved independently in the New and the Old World our wonderment would be simply doubled!

Thus there is no progress by small changes but a rather spasmodic evolution directed by creative invention, by the presence of the motives of intention and insight in the utilisation of the material world. Even the word metal still holds something of this directed research. Though older philologists like RENAN and RIEDENAUER have looked for a Semitic root for this word, CURTIUS and BEZZENBERGER have searched rather for an Indo-European root, but SCHRADER believed in neither. It is now, however, held with LIDDELL-SCOTT that this word is connected with the Greek *metallao*: to search (after other things), thence *metalleia*: searching for metals, *mining* and *metallon*: mine, quarry (originally probably meaning "place of searching"). It is curious to notice that HOMER never uses the word *metallon* but always

metallao instead! When speaking of gold ores, PLINY has a somewhat similar explanation of the word, saying (*Nat. Hist.* 33.96): "Wherever one vein is found another is not far to seek". This is the case also with many other ores and seems to be the source of the Greek name *metalla* thus giving this word (*met'alla*) the literal meaning "one after another."

The loose way of thinking in the past led to many a difficulty. Once a certain term like Copper Age or Bronze Age is used forgetful of the fact that it is (or at least should be) used to denote a specified complex of metal techniques, but not just the common use of a certain metal, inconsistencies are apt to occur.

For instance the term *Copper Age or Chalcolithic* is often used to denote the period between Neolithic Age and the "advent of Bronze", or if a true neolithic is absent, the gap between Mesolithic and the "Bronze Age". But the term Copper Age is also very often used in cases where the influence of the knowledge of metal is suspected only from the other archæological remains of the period. Just as PEAKE complained more than ten years ago, the Neolithic seemed to grow to be a Metal Age⁸ without metal. Even areas into which metal objects have been carried by trade need not themselves be in the Metal Age. Unless smiths are imported to work there, the Stone Age must be said to continue.

Now SIMONS (*Caesurae in the history of Megiddo in Oudtestamentische Studiën* vol. I, 1941, p. 32) has proposed to use the term Chalcolithic for "a culture which without exhibiting the character of a true neolithic still precedes the first knowledge of metallurgy". Thereby he separated the term and its original meaning. FRANKFORT has already stated that if the term Copper Age was to have any force at all, it must indicate a period when tools and weapons were generally made of copper. Not only should these early metallurgists possess the knowledge of reducing ore, but also that of remelting, casting and hammering this metal, all manipulations to be discovered. Unless these new possibilities were used, copper implements would hardly be better than stone ones and could not come into general use. But the first copper implements which were better than stone ones are limited to certain shapes implied by these techniques and the properties of the metal. He further stated that we find a true Copper Age in Hissarlik I, Anau and Yortan, Susa I and Egypt (before SD. 63) and everywhere here the metal types go back to bone prototypes. Shortly afterwards Cyprus, Early Minoan I and Early Cycladic I show the

presence of copper, probably all of them colonisations radiating from Southwest Asia Minor. But as regards the first series of centres mentioned by FRANKFORT we think that his "Copper Age" is better covered by our term "native metal stage", though in the case of the islands around Asia Minor analyses have shown that the earliest settlers had already entered our "ore stage".

Now SIMONS' definition covers our "native metal stage" as well as kindred civilisations where few copper or none at all have yet been found, but where their influence is suspected. But in the "native metal stage", though this represents the first steps on the path of metallurgy, metal products are still few and their influence is still small. Hence it might be clearer to add our definition of the material side to the "archæological" definition of the term Chalcolithic given by SIMONS.

For it is even better to use this term than to fall back upon the old "Copper Age". Not only is the gap between the earliest use of copper and that of bronze widely different for every region, but as we have seen the classical sequence Copper-Bronze-Iron holds good only for certain well-defined areas like the Ancient Near East. Metallurgically speaking there is no gap at all for ore-extracted copper is to bronze what iron is to steel. They represent sequent phases of one stage of metallurgy. Though bronze is in fact a new material, a new "artificially produced copper", as the ancient inventor would have called it, it merely represents a successful sideline in the development of copper metallurgy, which again forms part of the "ore stage" of metallurgy.

Now MONTELIUS suggested long ago to drop the terms Copper Age and Bronze Age and to adopt the word "Erzzeitalter", but as the word "Erz" can not be replaced by a similar term in English or any other language, it might be better to use the term *Metal Age* for the period between mesolithic (and/or neolithic) and the Iron Age, in which the regional civilisation shows the existence and influence of copper metallurgy or any other non-ferrous metal. If necessary a "Chalcolithic" could be intercalated. This "Metal Age" would show, metallurgically speaking, all the aspects we have ascribed to the "ore stage" discussed above, being the stage between the use of native metal and the introduction of iron metallurgy.

But whatever term we use, whether we say "Metal Age" or continue to use the older "Bronze Age" we must never forget that the alloy bronze is only part-aspect of a type of civilisation which we try to

describe with this term. The archæological complex which we call Bronze Age is not defined when we know where and when copper and tin were mined and worked or whether bronze was in general use. For a long time during this period the use of bronze was not, as SPENGLER aptly remarked, common practice. Only the rich and the craftsmen would possess bronze and copper tools and weapons, the majority of the population being quite content with stone or wooden tools and implements which as the result of a long series of experiments were often quite good. A few tons of copper must have been quite sufficient to meet the world's demand every year. Copper implements are not always decidedly better than stone ones and only bronze is decidedly superior but it had to prove its worth first, before it was universally accepted it was tested in the hands of several critical generations. The older Neolithic materials survived for quite a long time and copper remained like gold and silver an object of trade in luxuries. Its rarity in the earlier periods may even account for its rapid spread in small quantities. As SPENGLER put it: "If a chieftain in Spain possessed a copper sword or dagger, this would be the talk of ten villages!" Again as technique improved the older copper and bronze objects may have been recast and reworked as many obsolete and broken pieces in depot finds (founder's hoards) prove. Therefore as DE MORGAN says, many chalcolithic stations have been classed as neolithic simply because copper was absent, as the metal was extremely precious and handled with the greatest care. The features of a Bronze (or Metal) Age are thus not marked by the presence of metal only; many other characteristics may be found in the type and form of the pottery, architecture, etc.

We have already mentioned that metallurgy can not be spread by trade only but that the possibilities of diffusion are associated with the spread of the craftsmen themselves. We have also brought forward strong arguments for the diffusion of metallurgy and this brings us to the question whether we can fix or at any rate guess the original centre the *birthplace of metallurgy* with some reasonable certainty.

For the Near East this problem has often been discussed and many suggestions have been made. MONTELIUS ascribed the invention of copper metallurgy to the Sumerians, NAVILLE to the Hamites of Southern Arabia, O'LEARY to the Armenoid race round Mount Ararat, whence it spread to Mesopotamia and Egypt. HALL suggests that copper came from Asia and reached Egypt and Cyprus by the

Syrian coast, but ELLIOT SMITH claims that Egypt knew copper far earlier than Cyprus, that it was in fact invented in Egypt in Wadi Alaqi and that all the stages of its evolution can be found in Egypt. SIDNEY SMITH thinks that both Egypt and Mesopotamia derived their knowledge of copper metallurgy from Cappadocia but that each developed it independently. ROSTOVITZEV pointed out the importance of the Transcaucasian mines both for Sumer and Caucasia. He considers copper industry to have arisen simultaneously in Turkestan, Elam, Caucasia, Mesopotamia and Egypt and maintains that the "animal decoration" is characteristic for this early metallurgical period. FRANKFORT is one of the most fervent exponents of the "Armenian-Transcaucasian" centre, whence the early copper types spread to Europe over Hissarlik II or occasionally by the way of the Russian steppes. He is even inclined to see its influence radiating by the way of south-western Persia to China following the "painted pottery" belt. In a later publication he says: "All stylistic evidence suggest quite clearly that there existed already an important centre of metallurgy well before 3000 B.C. somewhere south of the Caucasian mountains with which the Sumerians were in contact. (To FRANKFORT the bearers of the highland civilisation were Sumerians.) CHILDE rightly distinguishes between reactive regions where discoveries were made and shapes evolved and the mining regions in later use. The first movement from Asia to bring copper to the Aegean started in South-West Asia Minor. The Caucasian region or at least some region of the southern or eastern littoral of the Black Sea was exporting copper objects and not metal only. Forms found in China suggest that the knowledge of copper working spread from the Persian-Caucasian province".

CHILDE also believes in this ancient centre in the highlands of Armenia, Transcaucasia and Persia. As the river-valleys lack the necessary ores, the early invention of the production of copper, etc. led to trade relation with the löss regions and river valleys. Incidentally this trade led to urban civilisation in Asia Minor, Anatolia and Cyprus being drawn into the process around 3000 B.C., then somewhat later Troy I, the Cyclades and Crete. But by 3000 B.C. Egypt and Mesopotamia already possessed separate schools of metallurgy, the early Sumerian school being certainly superior to the Egyptian as it knew bronze and used core casting! Again the majority of European metal forms go back to early prehistoric or Sumerian models which numerical preponderance of diffused Sumerian types considerably weakens the theory of Egyptian origin of metallurgy (ELLIOT SMITH, PERRY, etc.).

The main evidence on the original centre of metallurgy, however, depends on the prehistoric relations of Egypt and Mesopotamia and their relative dates. At any rate the barbarians north of the Balkans do not start to use metals much before 2000 B.C.

On the other hand a specialist on Caucasian archæology, HANČAR, is of the opinion that copper industry in these regions is not as old as supposed by FRANKFORT and others. He considers the Copper Age of Kuban, Egypt and Mesopotamia individual growths on a common base, but connects Kuban with Tureng Tepe and more closely with Tepe Hissar III. He admits that FRANKFORT's metallurgical centre in Armenia and Transcaucasia is proved by weapons, ornaments and other influences in Sumer, Northern Syria, Crete, Egypt and even Europe for early dynastic times (2900-2500 B.C.) but at the same time we should not forget that we must look east for the sources of Sumerian copper!

And this is what DE MORGAN said already many years earlier: "Only Chaldea, Susa, Egypt and the Aegean islands are entitled by their antiquity to harbour the country of the origin of copper. But only Elam and the Iranian plateau have yielded traces of pure neolithic civilisation (at that time!) not Mesopotamia. Neither in Chaldea nor Iran were the first metallurgical essays made, nevertheless, it is highly probable that Western Asia is at least one of the principal secondary centres where the knowledge of metal was propagated."

But early metal traffic was not effected by caravans but the metal went from hand to hand. This trade was very active from Mesopotamia to the Phoenician coast. The earliest settlers in Crete and Cyprus were metallurgists introducing copper in the fourth millennium B.C. and bronze in the third.

Even WITTER, who stoutly upholds his theory of a separate Middle European metallurgical school of independent growth and even one of the same date as those in the Ancient East, points to the east for the sources of Sumerian metallurgy and stresses the necessity of further excavations in Baluchistan and the Makran to investigate the common source of Sumerian and Indus civilisation.

It would then seem to us that the results of the excavations of the last ten years go far to prove the origin of metallurgy. Of course the chronology of early Western Asia is far from settled nor is the relative dating Egypt-Mesopotamia fixed beyond doubt, but the general lines seem clear and we are more concerned with relative dates here as there is no sense in giving exact dates for the different stages of metal-

lurgy, transitions existing though probably of rather short duration.

Long before the Al Obaid culture of Mesopotamia the inhabitants of Anau Ia possessed copper, especially borers. The description of these copper tools does not permit us to decide whether they had already reached the "ore stage", but they certainly could work native copper.

Copper is more frequent in Anau Ib and the contemporaneous Chisme Ali I. At Tepe Hissar Ia (Chisme Ali II) we have reached the *Al Obaid culture*, which continues at Tepe Hissar upto IIa and is found at Susa I and I bis, Ur pit below 5.20 M, Uruk 18-15, Niniveh II b and II c, Arpachiyah 5-10, Tepe Gawra 25-15, Chagar Bazar 16-14, Tell Halaf 6-10, Karkemiš 18-20 M, Ugarit IV and which corresponds roughly with the Tasian, Badari and Naqada I of Upper Egypt and the Merimde and Maadi of Lower Egypt.

At Susa we immediately find true "metal" forms, copper seems to have been prepared from very pure malachite and "teemed" in open moulds after melting. In the North Tepe Hissar Ib, Chisme Ali III, Syalk yielded copper daggers, knives, nails and needles as well as copper seals. The true Sumerian peasant civilisation (see VAN DER MEER, *The Al Obeid culture and its relations to the Uruk and Djemdet Nasr periods*, JEOL, 1942, pp. 708-721) spreads from Southern Iran into Mesopotamia penetrating far north as it seems from this evidence.

Tholoi-shaped pottery kilns found by WOOLLEY at Karkemiš seem to belong to this period as well as a cast axe found by MALLOWAN at Arpachiyah, though many consider this piece to belong to the Uruk period. At Tell Halaf an axe, a lance-head and an arrow-point of copper are said to belong to this period. It is remarkable that up to this moment no copper objects have been found in the south, for instance at Ur, Uruk and Al Obeid itself. CHILDE has suggested that most of the copper has been reused and recast in later periods, which seems quite possible. Beyond doubt we have found only a fraction of the copper that existed formerly; its presence is noticeable in many other features of the Al Obeid culture. At Badari we find the earliest copper which seems to be all native hammered copper. In Egypt no progress is made in the production of copper, whilst at Susa chisels, needles, and mirrors are manufactured and in the North the art seems to have penetrated along the mountain ranges.

In the following *Uruk period* we find invaders of Armenoid type from the mountains of the North and the North-West dominating Mesopotamia, but soon the powerful substratum of Al Obeid population seems to reassert itself in the Al Obeid phase of Uruk

civilisation. Though tools and weapons are still mainly made of flint and obsidian we find many new copper types; needles and seals abound and every aspects points to a strong growth of the copper industry. In the North Tepe Hissar IIa and Tureng Tepe show this stronger position of copper. New forms such as rings, arm- and footbangles, pins, seals, etc. abound. In Susa Ic and Id we find such intricate castings as the socketed transverse axe!

The Uruk period is represented by Ur pit 8.30-5.20 M, Uruk 14-6, Tel Barsip 13-303 cm, Niniveh III, Tell Arpachiyah 1-4, Tepe Gawra 14-11, Chagar Bazar 10-12, Tell Halaf 1-6, Ugarit III b, Alishar Hüyük 19-12 Megiddo 7-4, and Tell Beit Mirsim "J". The Uruk period roughly corresponds with Naqada II and Gerzean in Egypt.

In Northern Mesopotamia copper is now in regular use, apart from the objects from Arpachiyah and Tell Halaf, which may belong to this period instead of being Al Obeid, we must mention a copper pin found at Niniveh. In the south finds at Uruk and Ur prove the same.

The subsequent Sumerian Renaissance of the *Djemdet Nasr* period corresponds to Amri and the earlier remains of the Indus civilisation, it is found at Tepe Hissar III, at Susa II, Uruk 4-3, the lower strata of Chafadje and Eshnuna, Niniveh IV, Ugarit IIIa to mention but a few places. It corresponds roughly with the Predynastic period of Egypt (SD 60-82), when we find the earliest copper made from ore in that country.

In this period copper implements come in increasing numbers and forms as do gold and silver utensils and ornaments. At Tepe Hissar moulds were found and intricate castings in animal form in copper, silver and gold. Seals of lead and copper have parallels in India and Mesopotamia. Copper picks, double-axes (such as we meet in Crete much later), bowls, rings, tubes, mirrors and many other forms were found. This is also true for Northern Mesopotamia where most objects seem to consist of pure copper, whilst in Southern Mesopotamia as alloy with about 10 % of lead is also fairly common. There we find more techniques that in the North, forging, casting, soldering are well-known. Cups, axes, fishhooks, forks, and socketed axes are common types. The Indus civilisation has less specialised and more primitive tools and weapons, but both copper and bronze are very common at Mohenjo Daro at a slightly later date.

The *Early Dynastic period* corresponding with the Mohenjo Daro finds shows that Sumerian metallurgy around 3000 B.C. was well developed. Not only are both copper and bronze in use, but the

Sumerians know filigrain-, granulation- and incision-technique, they use forging, engraving and inlay-techniques, they solder and practise different forms of casting such as core casting, cire-perdue, open and

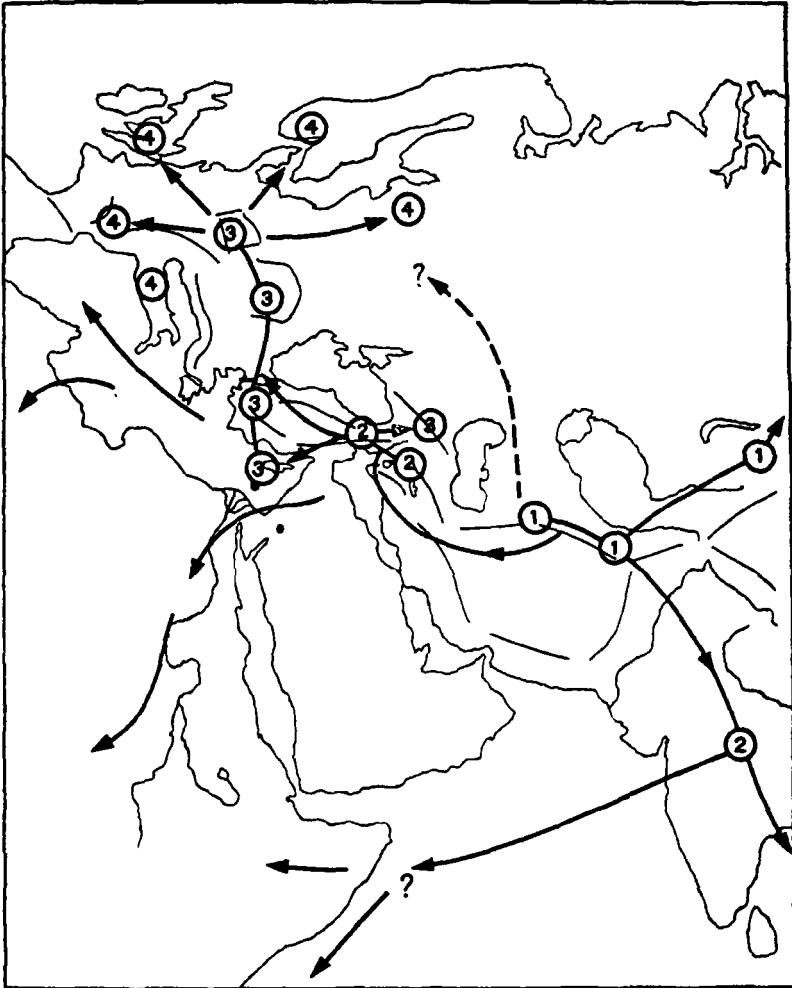


Fig. 6. The diffusion of early metallurgy

closed mould casting, etc. It is decidedly superior to contemporary Egyptian technique and the Egyptians do not yet use bronze for many a generation. It is also more advanced than the Indus civilisation metallurgy.

Though we must deplore the lack of proper analyses of early metal objects in this region and these future results may shift our conclusions a bit, it would seem on archæological grounds (and ethnological proofs strengthen our argument) that the Sumerians brought their copper industry in the early "ore stage" from their original home in Southern Iran and Baluchistan which must have been near to the original centre of metallurgy of which Anau may have been but one of the most western outposts.

From this centre along the northern slopes of the mountains between Caspian and Baikal Sea, which abound with the necessary native metals, minerals and ores, fuel and water and where the earliest metal remains were found, metallurgy has spread to secondary centres, perhaps to the north to the Ural mountains (where the yet insufficiently explored mines of the mysterious Chudes are known to abound), to the south to Baluchistan and Central India and to the West to the Armenian-Caucasian-Persian highlands. This latter secondary centre became an important focus because of its position with regard to the ancient civilisations of Mesopotamia and Egypt. Possibly metallurgical knowledge went from there to Egypt, it certainly went north to the Caucasus and also to other important tertiary centres such as Cyprus, Troy, the Danube Valley and Central Europe. From Central Europe and by the way of the Mediterranean many further centres such as Spain were formed. The Far East probably received its knowledge directly from the birthplace of metallurgy.

The metal industries of Mitanni, Northern Syria, Western Iran, Phrygia, Lydia and Argolis are tertiary centres which may have partly depended for their metal supply on the richer secondary centre. But by then mining ores and smelting them were no longer in one hand and the trade in metal ingots or cakes had already partly supplanted the earlier supplies in the form of finished metal objects.

The search for the birthplace of metallurgy is, this seems clear, mainly an archæological-chronological problem. The same can be said for the *problem of Central European metallurgy*.

This problem often put forward under the guide of the priority of Asia over Europa or vice-versa is a chronological problem too. Only too often authors forget that European prehistorical chronology which must be used to arrange the metallurgical data, is a framework of relative dates, some of which can be linked up with absolute or relative dates of the chronological frame of the Ancient Near East. It is absolutely impossible to separate these European and Near Eastern chronologies, which are interdependent and it is also impossible to

antedate events of cultures in Europe without taking any notice of the links with Near Eastern dates! We can not discuss the question here as it falls outside the scope of this book, but we should like to give a few remarks for the benefit of the reader.

WITTER has proved in a series of brilliant analyses that Central European metallurgy grew up independently and found its own methods in working its specific ores. His collaborators have tried to fix the date of the origin of this Central European metallurgy in the period of "the Copper Age in the Near East" and to prove that this industry was an original growth not founded by knowledge diffused from the Near East. But many of his countrymen (FRANZ, QUIRING, and many others) do not believe in this antedating fixed on the dates given by KOSSINNA and they agree with the many publications by GORDON CHILDE in deriving this Central European industry from the Near East. There is no doubt as CHILDE proved repeatedly that at least five of the earliest European metal types go back to Sumerian originals and WITTER has not succeeded in proving that no trade routes could have been used from the Near East to Central Europe either by the way of the south, west or south-east, because he uses the inflated dates of KOSSINNA's chronology which stand without proof. The archæological arguments for early Near Eastern and European chronology have again been expounded by GORDON CHILDE in a masterly essay on the Orient and Europe (*Report Brit. Assoc. Advanc. Sci.* 1938, p. 182). The fact of imports of early metal types from the East and such secondary arguments as the existence of an Aryan word for copper derived from the Sumerian URUDU (a substance known very early to the Sumerians as they wrote it with a simple ideogram!) go to prove CHILDE's contention that Central European metallurgy was founded somewhat before 2000 B.C., by influences penetrating by the way of Anatolia, Troy II and the Danube valley and occasionally by the way of the Russian steppes from Caucasia. The Central European bronze industry of Elbe and Saale starts in Danubian IV and though Aunjetitz traditions form its base, Britannico-Hibernian models from the West and perhaps even immigration of Irish craftsmen played their part. The bell-beaker folk were tradesmen and craftsmen who as bands of armed merchants and prospectors did much to spread metallurgical knowledge in Europe. Though there is a general but far from exact correlation between the distribution of metals and the foci of megalithic architecture the extreme rarity of metals in megalithic tombs is a fatal objection to the theory of PERRY and the Manchester school that these megalith-building people were Egyptian metallurgists

spreading the knowledge when prospecting in prehistoric Europe. Though the details are not yet absolutely certain, yet it can no longer be doubted that metallurgy, at least its elements, was brought to Central Europe along the lines sketched by CHILDE. That Central Europe subsequently formed an independent centre with its own growth can no longer be doubted either after reading WITTER's books and papers. If he doubts CHILDE's results because he doubts the results of the typological method in general, he falls in the same pit and uses typological proofs with a wrong frame of relative dates, drawing in such arguments as the antiquated theory of the similarity of early European axes and Egyptian axes once put forward by FLINDERS PETRIE, but never accepted by other archæologists. Again he has not proved his contention that CHILDE's arguments would hold for simple ores only but not for the complex ores of Central Europe.

We have gone into these chronological problems to some length because they form a pitfall for the unwitting reader who would try to find his way in these variable and seemingly disconnected dates and chronologies.

We must now needs return to metallurgy and discuss some details of the three stages which we have given in outline.

The "native metal stage" is an interesting phase which has not yet been studied sufficiently.

The advantages of metal over stone were obvious. There were not only the colour and gloss, more important to primitive man than to us, but also its malleability, its permanency as compared with stone or wood or bone and the faculty of keeping its sharp edge better. Its malleability when hot was an important factor and when its fusibility was discovered and the subsequent solidification after cooling the metal acquired some of the merits of potter's clay, there was no longer any restriction to shape or size and it could be remelted for reuse.

But casting was an achievement of the true metallurgy of the "ore stage". This phase meant a widening range and better utilisation of the four essential elements of metallurgy: 1) ores, 2) fuel and fire-making, 3) the production of blast air by draught and 4) the necessary tools, furnaces and crucibles. All of these elements wanted careful adapting to the new conditions or discovery if still unknown. Only then could the discoveries of the smelting of ores and the melting of metals be followed up. Only then could the discoveries

of new metals and alloys be achieved. Even the most important technique of these days, casting, is so intricate a process that we may well wonder at its early inception. With this technique which uses the most typical characteristic of metals true metallurgy is born. Then the alloys were inventions which possessed some outstanding feature. Not only was their gloss generally more constant but they had a lower melting point than the components which meant easier casting, especially valuable in regions like the Ancient Near East where fuel was expensive from the earliest times onwards at least in the river-valleys. Again the extreme hardness of bronze was constant as it was not achieved by hammering of the cutting edge as in the case of copper and therefore was not a property that was lost during use of the implement. As soon as the composition of the alloys was well controlled by the smelter he could count on a range of constant properties just as in the case of pure metals, but very often this was not an essential as long as the variation was limited.

But the characteristics of the "native metal stage" and the "ore stage" can be far better illustrated in discussing the early metallurgy of copper, though the details are not yet always clear. We choose copper for though gold is the earliest metal discovered and used by mankind in many countries as far as evidence goes, its production entails so little difficulties that we can not expect that it had any stimulating effects on the development of the very earliest metallurgical methods. For gold occurs either as nuggets of native metal in the detritus of goldbearing rocks or else gold-bearing minerals enclose these small particles of comparatively pure metal and not compounds of gold to be smelted. The production of gold, therefore, boils down to the collection of this goldbearing ore, its crushing, separation of the gold particles from the fragments of enclosing rocky material by washing or panning and melting the gold dust or nuggets together into a workable lump. Gold production could never lead to that most important discovery in metallurgy, the working of ores for the production of metals!

But copper apart from comparatively widely scattered deposits of native copper, occurs mainly in the form of ores, e.g. of compounds of copper and other substances, partly chemically bound, partly a physical mixture. We can divide the copper ores into two groups. First of all come the easily reducible oxide and carbonate ores (including the silicate chrysocolla) then the more complex ores of the sulphide type, all compounds of sulphur and copper mixed with

varying quantities of sulphides of such other metals as iron, antimony, arsenic, etc., the working of which entails more manipulations than the first group demand.

We distinguish the following phases of copper metallurgy:

- I — Shaping native copper.
- II — Annealing native copper.
- III — Smelting oxyde and carbonate ores.
- IV — Melting and refining copper.
- V — Smelting sulphide ores.

Technical details of the processes will be discussed when we deal with the metallurgy of copper in the Ancient Near East (Chapter X). We must, therefore, leave the proofs until later and content ourselves with a summary of the more important features of these phases.

I—Copper metallurgy started when primitive man noticed large lumps of dark stone in the gold-bearing river-beds which when hammered looked like gold. He soon tried to work the malleable metal by hammering, cutting, bending, grinding and polishing, e.g. by applying all those processes which he used when working bone, stone or fibres. This phase which can not be called more than an introductory phase of copper metallurgy, entails no special ingenuity, it simply is the discovery of a new natural material. This phase was never left behind by the pre-Columbian Indians, who though working and knowing copper must be said to be truly Neolithic people. There is no sense in talking of a Copper Age in America as long as the specific qualities of copper are not shown to have been appreciated and used by the Indians before their contact with the whites. It seems that this discovery of copper was made among the cattle-raising inhabitants of the plains and mountain ranges east of the Caspian, who perhaps also dominated Turkestan and Tibet. MENGHIN gives a tentative date, the sixth and fifth millennium B.C., which must remain until further excavations in these regions have proved this hypothesis and furnished a closer date. It should be remembered that these regions are rich in mineral deposits and that native gold, silver, copper and iron are known to occur rather frequently.

II—The phase of annealing native copper was the first phase of true metallurgy. WITTER and others have supposed that this new property of copper was discovered when copper borers were heated in a fire to facilitate penetration or by the accidental dropping of a lump of copper in a fire by a primitive smith. It then appeared to him that copper when hot was much more malleable and easy to shape and

thenceforwards tempering or annealing of copper followed by hammering was common practice. It had the advantage over hammering without heating, that the copper remained tough and did not become brittle. Also more forms of native copper, which hitherto resisted working because of their natural brittleness, could be worked with good results.

This discovery must have been made around 5000 B.C. for the technique was common knowledge of the peasant culture that had spread over South-Western Asia and North Africa by the fourth millennium B.C. After studying the early copper axes of these regions Marples states expressly that the early agricultural squatters had trifling quantities of copper but did not know how to fuse or melt them.

III—Recent experiments by COGLAN have proved that the discovery of the melting of copper was preceded by the discovery of the production of copper from oxyde ores. Until recently most authors, even WITTER, thought that melting and with it that knowledge of casting came first. Putting the reduction of copper ores first might seem an illogical link in the chain of reasoning. COGLAN, however, proved that the favourite camp fire, which was thought to be linked so intimately with the discovery of casting copper and the reduction of copper ores, could not possibly be used for any production or melting of copper on a larger scale. The temperature of a wood fire is hardly higher than $600-700^{\circ}$ C, whilst oxydes and carbonates of copper can not be reduced below $700-800^{\circ}$ C and copper does not melt below 1085° C. The only thing that could be achieved in a camp fire would be the heating of copper lumps before hammering or the heating of several smaller nuggets to be forged together into a larger piece. Primitive pot-bowl or "hole-in-the-ground" furnaces of the type advocated by GOWLAND for Bronze Age copper smiths will not give the necessary high temperatures unless aided by the blowpipe or bellows, natural draught being insufficient. COGLAN made it most probable that the reduction of copper ores was discovered by the reduction of blue copper frit or glaze in a pottery kiln, the only primitive furnace, which yields the requisite high temperatures as experiments proved. Afterwards the pottery furnace was used to melt copper. Both technical conditions and kiln constructions suitable to produce the reducing atmosphere point towards the pottery kiln as the instrument in which the first ores were smelted and the first copper melted. These two

steps (phases III and IV) must have followed in rapid succession, for the earliest remains in Iran already yield cast copper objects.

A large variety of theories have been brought forward to explain the first reduction experiments of copper ores. It is often said that malachite was a pigment used in Neolithic times long before even native copper came into use. WITTER claims that the presence of blue and green stones was noticed near the native copper and some early smith hit on the idea of submitting these brightly coloured stones to the "fire test". ELLIOT SMITH and many others locate this invention in the eastern desert of Egypt (where no early copper mining was ever proved!) and he supposes that a lump of malachite chanced to fall into a camp fire and was reduced to the glittering red metal! Apart from the infrequency of such occurrences as RICKARD



Fig. 7. Seal from Susa said to depict smiths using the blowpipe to smelt metals (after SCHFIL)

already noticed from the observations of ethnologists studying African metallurgy, we have had occasion to point out the extreme improbability of this theory, seeing that the technical conditions for the reduction of ores are hardly ever reached in camp fires. SPIELMANN who holds with PETRIE that the ancient Egyptians came from a region in the Caucasus between the rivers Iora and Kura and that they brought their knowledge of copper with them, thinks that it was discovered by the natural action of burning petroleum or petroleum gases!

GSELL, quoting MUCH (*Die Kupferzeit*, p. 298) tries to prove that copper was discovered when pyrites were heated to make gold in early times. It is true that under special conditions copper pyrites mixed with charcoal may when heated in an air blast give copper in one stage only, but this does not seem to be a natural result as such a smelting will usually yield a crude copper still rich in sulphur, which has to be retreated. Indeed it is considered most probable that the primitive smiths were not able to smelt sulphides in one stage, no single example of such smelting having been ever found

Therefore, GSELL's further claim that crucible melting and casting were used as soon as pottery making was discovered is false too. As long as no counterproof is brought forward, it would seem to us that COGHLAN's experiments and exact temperature measurements have proved beyond doubt that the reduction of copper ores of the oxidic type was discovered in the pottery kiln when applying the blue frits of copper ore and that the idea of casting copper followed rapidly.

CHILDE has very aptly called this discovery of the transmutation of the blue, green, red or grey ores to tough red metal one of the most dramatic leaps in history. Now the primitive smith who had discovered the annealing of native copper was confronted with a complex of processes connected with the reduction of ores and the production of copper in a molten form. Had annealing copper allowed him to fashion this metal better than by the application of neolithic methods, now he found in casting a process that relieved him of a large part of this fashioning job. Again it allowed him to evolve forms that were more natural to metal, that used the inherent properties of the metal more efficiently and deviated from the earlier shapes of metal objects which were hardly more than crude imitations in metal of Neolithic stone implements and weapons.

Again WITTER pointed out that the discovery of reduction and casting is intimately linked with the evolution of smithing as a job, the earliest craft in human history that became a full time job and led to the recognition of the smith as the earliest craftsman, as we shall see. It is important to remember the intimate connection between this phase of metallurgy and the pottery kiln. Only a civilisation that made well-baked pottery requiring a high baking temperature would possess the technical equipment that made the reduction of ores possible. We find the people of Al Obeid and kindred cultures in possession of this knowledge and even in the earlier Anau I culture not only a coarse type of pottery akin to that on earlier generations of inventors of this craft occurs, but also a well-baked, finely decorated type which shows that the Anau people possessed from the first good pottery kilns. Among these early agriculturists the earliest clans of smiths must have grown out of the earlier workers of native copper, as free men honoured and feared as the master-magicians of a new craft gradually acquiring that peculiar social and religious state which we shall have occasion to discuss later on. The intricacy of their craft forced them to devote their

entire time to their job, being left to be fed and clothed by their kinsmen, a departure indeed from the ordinary life of a neolithic self-supporting peasantry, which goes far to explain their peculiar social status in later ages.

IV—The reduction of oxyde and carbonate ores like malachite, lazurite and the like had been the discovery of a new process, a new way of obtaining a substance already known. The knowledge of melting copper which followed it so closely being linked to the same technical apparatus, proved a new way of fashioning metal objects. Molten copper could be cast into forms hitherto undreamt of and practical tests very soon led to those specific "metal" types which contrast very much with the earlier metal imitations of stone tools. Henceforwards the way of the smith deviated from that of the flint-worker and stonemason. His became a new dramatic and mysterious cycle of melting, casting and solidifying. This art not only required a high temperature like the reduction of ores but also a knowledge and ability to manufacture crucibles, tongs and means of developing blast air (Blowpipe, bellows).

When we study archæology we find that both stages had already been reached in early Near Eastern prehistory, the first traces having been found in the Al Obeid culture, full development was certainly reached at the end of the Uruk period. We may roughly speaking, date their discovery about 4000-3500 B.C.

V—The last stage, the reduction of sulphide ores, certainly falls in historic times, though its exact beginning is still obscure. It is quite possible, as WITTER suggested, that the early metallurgists were started in this line because the blue and green copper ores which they worked until then occurred in close association with the yellow, grey and black sulphides, which generally occupy the deeper strata in the same mines. Submitting them to the "fire test" would be a logical consequence of their curiosity of the secrets of nature. Heating experiments figure largely in the "chemical" texts of the Assyrians for instance. Heating these sulphides would yield a black glassy "matte", that was fusible, contained small particles of copper and turned green when attacked by humidity. A second smelting with charcoal would yield copper. The two stages of roasting and smelting could not be combined in ancient technology, though a similar result might be reached under very special circumstances as discussed above. However, the two-stage way of producing copper in the different types of furnaces each suited to one of the stages, was the common

way of the ancient metallurgists. Finds of such specialised furnaces and lumps of semi-refined and pure copper both in the Near East and such European metallurgical centres as Mitterberg, etc. prove this.

The easily workable oxyde ores gradually gave out and though we must reckon with many widely distributed small deposits of poor quality ore, many of them must have been finished early in historical times so that we can no longer locate them. The difficulty of fixing the period of transition of oxyde to sulphide ores lies in the lack of proper analytical data of ancient copper objects. RICKARD very correctly remarked that each copper relic should be subjected to microscopic (and we would add spectrographic) examination to ascertain its texture and to conclude from the inclusion of particles of oxyde or slag whether the metal has gone through the fire or whether it is native metal. Thus not only the transition from phase II to III could be fixed correctly for every region and the results linked up chronologically to prove the spread of this new technique, but we would be able to fix the transition from phase III to V too. Now we can only say for certain that the Romans treated sulphide ores as in their times the simpler ores has given out, but as far as the scanty evidence goes the transition of phase III to V must be pushed back to the Late Bronze Age and perhaps earlier. Technical skill and equipment of the Amarna Age would certainly permit the working of copper pyrites.

QUIRING connects the working of pyrites with the invention of bellows, which he dates around 1580 B.C., as that is the date of the earliest picture (on Egyptian monuments). His conclusions are, however, based on the analyses of early copper objects and they too lead him to fix a date around 1500 B.C. for this transition.

The rough estimates of other authors are not very different from the tentative and relative dates given above. ROLFE thinks that the Copper Age begins around 6000 B.C. (our phase I). MONTELIUS held that the earliest copper was produced from ores or melted from native copper around 4000 B.C. in the Near East as well as in India (our phases III and IV). RICKARD holds that there was between the Stone Age and the Metal Age a twilight zone when the metals were used as stones, a period which he would like to call chalcolithic and which might have lasted two or three millennia. Then there comes another interval of one millennium before copper or any other metal was reduced from its ores. This critical event appears to have happened between 4000 and 3500 B.C. according to RICKARD.

Such dates as well as those given above should be handled with care. They have no absolute validity and are given just to show the relative duration of the different phases. Exact absolute dates can hardly be given for prehistory whether in the Near East or anywhere and even these relative dates depend on certain key-dates and have but orientating value. Now that the key-date of Hammurabi's reign is under discussion because of new evidence, it is quite possible that this date will have to be fixed several centuries later and therefore

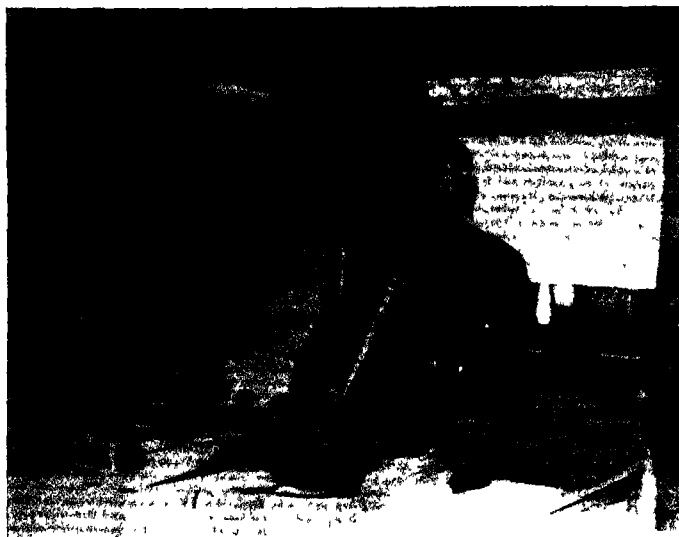


Fig 8 A Batak goldsmith using the blowpipe (photo K.V Indisch Instituut, photograph taken by TASSILO ADAM)

the whole of the chronological scheme given above should be condensed accordingly!

The *iron stage of metallurgy* is another important revolution. The Iron Age of the Near East is rung in by the migrations of about 1200 B.C. accompanied by the rise of the prices of corn and general articles. Gradually, however, the prices fall back as the cheaper and better iron implements are used more generally. Iron ores are widely distributed and as soon as they could be smelted and the iron produced showed properties at least equal to those of bronze, everybody could afford and would buy iron tools. Economically speaking iron-smelting first made metal tools so cheap that they could be universally used for clearing forests and draining marshes and other heavy work.

It is certain that the advent of iron changed the face of the world not only as a new material for arms but also by equipping man better in his struggle with nature.

It may seem strange that copper should be the oldest metal produced from ores for though the melting point of copper is only 1085° and that of pure iron is 1530° C, the reduction temperature of copper oxides is higher than that of iron oxides, which means in plain language that it is easier in principle to produce iron from iron ores than copper from its ores when smelting with charcoal as the primitive smelters did.

For this reason many archæologists and even technologists like BECK have supposed that iron was produced and known earlier than copper but for several reasons did not become popular and had to wait its turn. However, we now have overwhelming archæological and other evidence that iron came later than copper in the near East and in prehistoric Europe, though in Africa iron preceded both copper and bronze. The smithing (and mostly the smelting too!) of iron is found nearly everywhere in the Old World among both agricultural and pastoral peoples, but it lacks among those in the New World and in Oceania. Its production and working spread far beyond the region in which copper and bronze were used when iron was invented and it ousted these two as the main material of the metal worker.

At first sight there seems no reason for the developments of copper metallurgy. Iron ores are more abundant and more widespread than copper ores and far more so than tin ores. Iron, at least its "steely" form, has many obvious advantages over bronze, it is stronger and more elastic and will both take and keep a finer cutting edge. The reason is undoubtedly that the working of iron awaited a quite new series of experiments and discoveries generally distinct from those habitually employed in the smelting of copper and tin. To understand this it is imperative to view the process of iron-smelting from the point of view of a copper-smith, thus FORDE, whose excellent reasoning we follow in these lines.

Throughout two or more millennia the burning of certain kinds of coloured stones in a furnace to produce a flow of reddish metal had become a fixed pattern. Experiments with other stones must have been made, but they yielded no flow of metal. From the point of view of a copper-smith the smelting of iron ore would appear a complete failure, it would result in a bloom, a spongy mass of

fused stone full of air-holes and as unmetallic a product as can be imagined, for the pasty small globules of iron would be embedded and concealed in the mass of slag and cinders. When hammered cold the bloom would be of no use, when hammered hot it would give no quick result, that could be appreciated!

The great centres of the bronze working of the Ancient East with their specialized smelting and smithing methods offered neither good chances for lucky accidents with iron ore, nor rewards to deliberate experiments along traditional lines. Nevertheless iron objects were made and used during these times. The number may be quite small, but it is definite! Nearly all the early objects that were recovered were ornaments not tools! Both the rarity and the ornamental use indicates fairly clearly that there was not at this time any established technique *for smelting the abundant ores of iron. The meteoric origin of these early finds has been established beyond doubt in most of these cases.*

But from the fourteenth century onwards iron rapidly becomes more abundant throughout the Ancient East, more especially between 1200 and 1000 B.C. Tools and weapons are now made of it and within a few centuries important centres of manufacturing spring up in many cities. Shortly before this time the essential discovery must, therefore, have been made. It does not demand a hotter furnace but it does require a larger and more continuous body of heat and a suitable flux with which the impurities of the ore can combine. A larger furnace and a more powerful blast are therefore essential to maintain the smelting process. Furthermore the product must be subjected to a far more prolonged hammering at red-heat than was customary among copper workers in order to beat out the slag and cinders and to consolidate the metallic mass. Greek traditions coincide with the fact that iron working was invented in the mountains between Taurus and Black Sea, or as the legends have it, by the Chalybes. By 1200 local smelting was developed in Anatolia, Phrygia, Syria and perhaps Cyprus. By 800 it had reached Assyria, Persia, India, Egypt, Crete, Greece and Central Europe and Italy. It had remained inferior to bronze as long as the furnaces were not hot enough or the forging and reheating was not intense enough to cause some of the carbon of the charcoal to combine with the iron and produce a low carbon steel which could be hardened by forging and quenching in water. Quenching alone would have had no effect unless the iron had been carburised (or forced to take up carbon) in the forge-fire. Though this *seems* to have been understood by some primitive smiths since

about 1400 B.C., the device was often used with ordinary wrought iron, such as was produced directly from the ore, without any effect of course. Even in the Dark Ages this principle of carburizing does not seem to have been generally understood and swords often bent in battle and had to be straightened underfoot! To produce iron (read: steel!) objects as tough as bronze required either knowledge of the carburizing-quenching technique or an ore, that contained certain impurities, which might give the iron the properties of steel such as a manganiferous ore. This was the main advantage of the ores of Noricum, which yielded a "natural steel" and thus made the Hallstatt civilisation famous!

Though some have tried to prove the opposite, iron is certainly not an original African invention. The earlier iron-workings of the Egyptian provincial town of Meroë in Nubia are hardly older than 700 B.C. From this point the craft of the African smith seems to have spread slowly southwards to the Sudan and further. The use of copper and bronze appears never to have crossed the Sahara in pre-iron days.

Thus the iron production of Africa and the Old World almost certainly derive from a single Near Eastern centre, in which the essential discoveries and inventions were made during the period of 1400-1200 B.C. Essential for the development of the Iron Age were the following technical achievements, each of which embraces a number of methods and receipts:

a) The correct slagging of the iron ore. Every ore contains *gangue*, that is the ore contains non-metalliferous or non-valuable metalliferous minerals, which endanger the efficiency of the smelting and the purity of the iron produced. For ores are always *smelted*, that is they are radically transformed by means of heat, air and charcoal and produce a (fairly pure) metal from a metallic compound, the ore. This process should never be called *melting* which is just liquefaction and nothing else. Therefore, we *melt* metals if we want to cast them, but we *smelt* ores (even though we could melt them in some cases) if we want to obtain the metals enclosed therein. But to smelt ores efficiently we must get rid of the gangue. This may be done in some cases by pounding and washing the ore, but generally the mixture is so intimate, that we must add a substance that binds the gangue in some way to form the slag. Sometimes the gangue slags easily, that is it separates from the metal produced and the main part is liquified and drops away from the metal and the rest of the slag and cinders which together form the mass we call a *bloom*. But often the molten slag is too viscous

to separate readily from the metal and this would endanger the economy or even the success of the process. This is why a proper *flux* is selected that is a salt or other mineral added in smelting to assist fusion of the gangue by forming more fusible compounds. Thus for instance we add lime to iron ores containing siliceous gangue. The flux differs with the gangue of the ore and as there are a large variety of iron ores, each ore differing in gangue according to the deposit, the selection of the correct flux is an important item in iron-working. It is true that the ancients often smelted iron ore without a flux at the expense of a large part of the iron, so that later generations could



Fig. 9. Primitive iron-smelters at Bijapath (India). Note the furnace with hole for withdrawing the slag. The old smith works the bellows and supports himself on a stick, in front of him is a diggingstick, near the bellows two pairs of tongs, behind him a fourth man is breaking up lumps of ore with a hammer. To the right of the furnace a van used for filling the furnace, a hack used in digging ore and a basket full of charcoal (after JOHANNSEN)

be quite content to resmelt the old slags! But a large part of the ancient iron-smelters did use a flux and this selection entailed a good deal of skill and experience.

b) *The handling of the bloom.* The bloom had to be reheated and rehammered to get rid of the enclosed slag and cinders and to consolidate the mass of iron globules. This was not only a tedious work and cost a lot of fuel, but it meant the development of tools to handle such large, heavy and red-hot masses, tools which were entirely different from those used for copper or bronze, where casting was the most important way of turning finished products.

c) *The technique of carburising, quenching and tempering.* To turn the soft ductile wrought iron into the hard, tough steel, which

alone was really superior to bronze, the iron had to be reheated and reforged, followed by quenching. The first operation, reheating and reforging, led involuntarily to carburising. It is still an open question whether the ancients really grasped what happened, but the practical result could be achieved and was achieved first by chance, then by experience, until carburising and giving the wrought iron a widely varying carbon content was a common technique. Then quenching was discovered, the importance grasped of cooling quickly (and not very slowly in the air) after carburising at high temperatures. Then in



Fig. 10. The Greek smith at work (after BLÜMNER, *Technologie*, etc.)

Roman times a further nicety was added to the list of discoveries, the effect of annealing or tempering, which enabled the smith to soften the hardening effects of quenching, to take away some of the brittleness (and some of the hardness!) of hard steel and to give it some of the toughness required for its work. The regulation and the interplay of the three techniques determined the success of the ancient smith and devoid as he was of modern apparatus and above all of modern temperature control, we need not wonder that he often failed.

It is, however, clear that iron-working embraced three groups of technical niceties, which demanded a new set of experiments before they were sufficiently appreciated and a different skill and experience than that which the ancient copper smiths had accumulated in the course of age. The Iron Age is a new metallurgical stage, a technical

world of its own. In the Copper Age the stress lies on the *composition* of alloy (or impurities in the metal) but in the Iron Age the properties of the iron are much less determined by its carbon content or accidental or natural impurities but far more by its *handling*, by the temperature to which it has been heated, by the way and speed of quenching, the time and temperature of tempering or annealing. It is the true age of the smith!

But we must avoid getting ahead of our story and enter here into details of the particular metals, lest our reader should cry out like the companion of a long-winded smelter on an old Egyptian relief:

“Air for my brother and beer for Sokaris, o, King!”

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CHAPTER THREE

SHORT HISTORICAL SURVEY OF EARLY MINING

He putteth forth his hands upon the rock,
he overturneth the mountains by the roots;
He cutteth out rivers among the rocks;
and his eye seeth every precious thing.
He bindeth the floods from overflowing;
and the thing that is hid bringeth he forth to light.
(Job 28 9-11)

We shall have to review early mining for a better understanding of the facts of early metallurgy and though we are of course concerned with the mining of ores in particular we can not avoid touching some of the broader aspects of mining.

The terms "mine, mining and mineral" and similar words in French, Italian, Spanish, etc. are said to have been derived from the Celtic *méin*, *mainach* (meaning crude metal) and the Cymric *mwyn*. The classical word for a mine was *metallon* or *metallum*, the origin of which we have already discussed.

Early mining is so complicated a matter that it should form the subject of a special study as most of the earlier works are out of date in the light of modern evidence. It is a regrettable fact that the technical details of ancient mining have been sorely neglected by modern excavation reports. In general our knowledge of the subject is small when compared even with the meagre facts on early metallurgy. This pertains particularly to the details of the evolution of special forms of mining and their tools and methods, but enough is known to allow us to survey the general outline.

Ancient texts dealing with the subject are very scarce, they give few details on mining methods and are generally limited to the description of some deposits or mines and a few details on the ores or minerals mined, their outward appearance and characteristics and their use. These few facts are mostly given by philosophers, historians or geographers like ARISTOTLE, HERODOTUS, STRABO, AGATARCHIDES and DIODOR, or compilers like PLINY, who seldom have any inside knowledge of mining and mining technique.

We have a good but small essay by THEOPHRASTUS, *On the Stones*, and further fragments of ancient petrology by NICIAS and others.

A few passages in the Bible, more particularly Job 28, 1-11, betray practical knowledge of mining but there are, unfortunately, few details. The finds as they are embodied in museum exhibits and excavation reports suffer from the lack of proper nomenclature and determination of the nature of the specimen found, which makes the discussion of the subject very difficult and is apt to lead to wrong ideas about the distribution and use of certain minerals and precious stones in Antiquity. A notable example is the history of the pearl which was recently investigated by BOLMAN (*The Mystery of the Pearl*, Leiden, 1941), who succeeded in doing away with many wrong notions on the subject. The writings of BECK have also done much to prepare the field for further studies. We also directly need better descriptions of the mines themselves and of ancient mining technique, on which subject the works of DAVIES and SAGUI should be recognised as pioneer essays.

But apart from the fragments of ancient writers we possess valuable evidence in the German textbooks on mining of the early sixteenth century such as AGRICOLA's *de re Metallica*, which though giving a description of the mining methods of their period, supply us with details of many classical and even pre-classical methods which survived upto that period and even longer. Thus we are able to piece together and to supplement the ancient texts and to get at least an idea of ancient mining technique.

The earliest traces of mining date from Palaeolithic times, though we can not speak of a mining industry before the Neolithic period. The rise of this industry belongs to the earlier phase of the "urban revolution" which we discussed in the preceding chapter and its foundations were firmly established by the end of the fourth millennium B.C.

The object of the earliest mining was twofold, firstly the mining of *stones for tools*, such as quartzite, flint, jadeit and nephrite and *precious and semi-precious stones, earth colours, eatable earth, etc.*, the latter aspect of mining being prompted by the beliefs and habits of primitive man.

Among the second category of stones there were certain glittering, malleable stones, the native metals, which after man had been attracted by their outward appearance only gradually grew important for other characteristics. When their special nature was recognised and metallurgy slowly grew to be a new art, the gathering of these native metals and their "parents", the rocks and stones from which they

could be isolated with the help of fire and charcoal, was the beginning of a new branch of mining, the *mining of ores*. Though later than the other branches of mining it quickly grew to achieve at least the

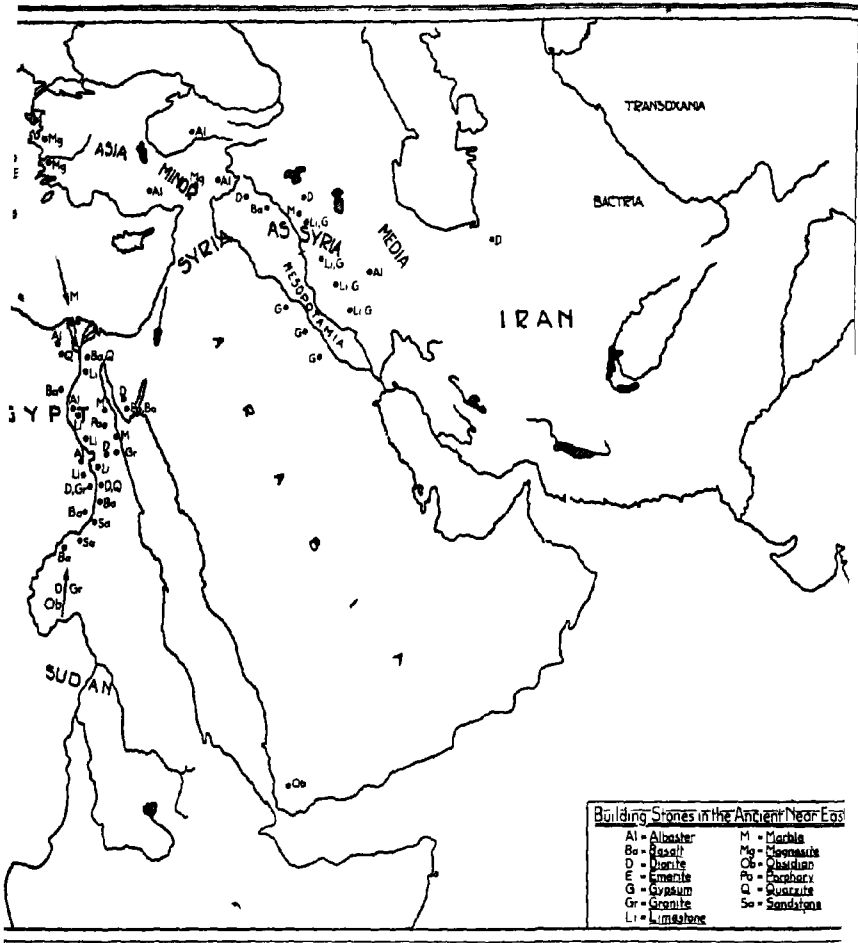


Fig. 11. Map of the deposits of building stones in the Near East

same importance as the older ones stimulated as it was by the achievements and methods of these two.

For the mining of stones for tools had already gone a long way. These stones such as flint and quartzite had originally been selected for their hardness, or their flaking and polishing properties as the best materials for the production of tools and implements. Already

in Palaeolithic times certain centres produced flint and exported it over wide areas, a trade which materially increased in Neolithic times and abrasives for use with these stones were an object of trade too. It would seem that the erection of megalithic monuments in different part of the world had a profound influence on the choice of building materials of mankind in general. He learnt to apply the lessons learnt in fashioning stone tools to the production of stones from quarries. His technique of flaking and boring and the use of wedges was now applied to the production of stones for graves, hearths and offering tables. With these seemingly primitive means and the use of abrasives the Egyptians had already produced well before 3000 B.C. wonderful art objects in natural stone such as vases and monuments in hard materials such as granite and alabaster. As the technique of producing quarried stone improved it was applied more and more in the construction of the mastaba's or bankgraves of the early dynasties of Egypt until the Egyptians took the initiative to build monuments entirely of natural stone. This was probably due to the pharaoh Zoser or more probably to his vizier and chief architect Imhotep, worshipped many centuries later as the god of medicine and identified with Asklepios by the Greeks. In the temple-complex round the step-pyramid of Sakkarah we see the first wavering efforts to use the natural stone to imitate the ancient architecture which knew only wood, reedbundles and sun-dried bricks as materials and natural stone as a facing or floor material only. Gradually the architect finds his way to the forms that are inherent to natural stone and achieves colonnades and other building which might be mistaken for classical Greek forms at first sight. The Egyptians had a lead in this matter over the Sumerians who did not possess such magnificent materials in their alluvial plain and who never did become prominent architects in natural stone. But the Egyptians used their quarries in the desert-valleys along the Nile to erect the many monuments which we still admire.

It is wrong to suppose that the coming of metal did stop the evolution of the stone tool. Far from this the stone implements continued to be used side by side with metal tools for many centuries. For the stone tool had a long history behind it, the technique of its production was far advanced and HERIG and KRAFT have proved that there existed quite a lore of selection of proper material for every type of tool. For each implement requires a stone of certain properties well adapted to the morphology of the tool and its handling. The earlier metal tool

had not yet found its true "metal" form and for many centuries stone tools were both better and cheaper for many purposes. Even as late as the seventh century B.C. stone arrow-tips were still in general use in the ancient Egyptian army and practical tests have shown that they penetrated the defensive armour of those times as well and often better than metal tips, made of bronze. Then again for other reasons stone implements continued to be used in many religious ceremonies, where the use of "later" materials was often strictly forbidden (circumcision). The search for and the mining of precious stones may have had less influence on the mining technique or ores but it was certainly important for the development of theoretical petrology. Of course the precious and semi-precious stones were collected from surface deposits in the earliest phases, then perhaps from quarries or mines. But at the earliest stage there was no knowledge of the genesis of the stones or the morphology of the strata in which they occur to guide the primitive prospector. Still this search played a large part in his life as most of these stones were not sought for their aesthetical charms but because of their supposed magical properties. It is well known that this belief is far from dead even nowadays and superstitious people will still repeat the ageless fables of the mysterious powers of the stones. Still even at the time when they were believed more fully than at present man must have noticed certain outward appearances and properties, certain characteristics of the strata in which they were found, observations which were the foundations of the later sciences of geology and mineralogy. Roman prospectors certainly knew several minerals and rocks which might lead them to the deposits of minerals they looked for.

But the precious stones were already an object of trade in Neolithic times and they were carried over enormous distances, probably handed on from tribe to tribe to distant countries where there was a demand prompted either by the needs or may be the greed of primitive man. The most important of these precious stones were lapis lazuli, callais, turquoise and amber. There was of course a large difference between our knowledge of precious stones and those known to the ancients. At present the diamond accounts for 95 % of the money value of the gems produced, but even in the last half of the eighteenth century this percentage was only 50 % and before our era it was nil. In the history of the production of precious stones Hellenism was a very important era for by establishing direct trade with India the classical world came into contact with the very important

deposits of gems in North-Eastern Iran, Afghanistan, India and Ceylon, which meant that its sources of supplies were doubled or trebled! This does not mean, however, that the knowledge of gems in earlier times was not considerable. It is certain, for instance, that the gem

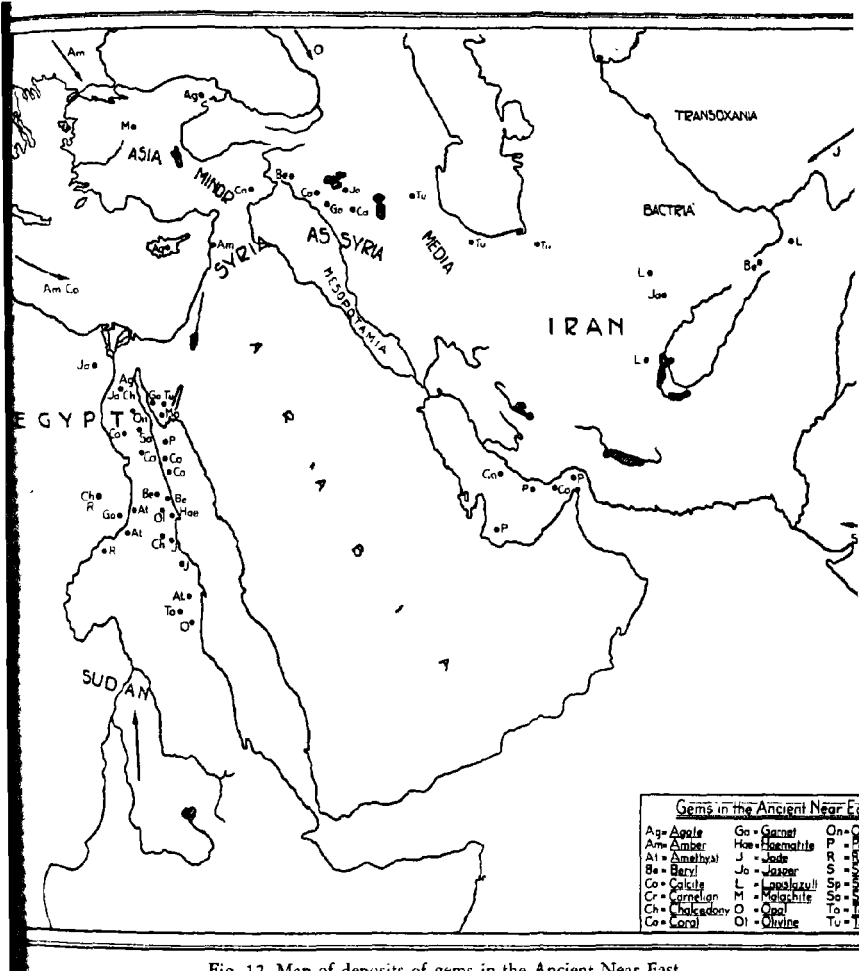


Fig. 12. Map of deposits of gems in the Ancient Near East

trade had a profound influence on the mineralogical knowledge of Sumerians and Assyrians. It will be one of the important tasks of future research to pursue the researches which BECK and BOLMAN have started, to re-determine the objects now resting in our museums and to reconstruct the history of gems in Antiquity.

Their mining had little influence on the development of mining

technique as most of them were collected from placers or surface deposits and as far as we know turquoise and a few others were the only gems to be mined or to be collected in copper-mines and the like.

As we have stated the most important achievement on scientific lines started by the collecting of gems was the study of minerals. We know from the writings of the ancient Sumerians that they attempted to classify the minerals and stones which they mined or imported from the mountain regions far outside their river valley. It is certainly not true that pre-classical science is nothing but a mess and a medley of phantasy and defective observations. The more we get to know of it the better we observe that it was a model of precision and practical classification as far as the means of those days went. Pre-classical science was a-logical, it did not want to explain things or to understand their structure and mechanism. A careful description and nomenclature was sufficient, it would clearly define the place of everything in the cosmos and the rôle it was to play. This was the aim of pre-classical scientist: to place everything in its proper place in the web of life and thereby to perceive its meaning in the cosmos. Logic was first applied to science by the Greeks and thenceforwards the methods of science turned away from the magico-religious systems of preclassical antiquity to the world of science that is ours. This break was not as easy as it seemed and for several centuries Neo-Platonism, Gnosticism and the philosophy of many Arabian authors seemed to revive the power of the old magico-religious science but the spirit of classical science held and conquered in the long run (R. J. FORBES, *Archives Int. d'Histoire des Sciences* No. 4, 1948, p. 570).

In the light of this pre-classical science we must read the lists of minerals, drugs, etc. which the Sumerians compiled, arranging everything they met in nature according to its outward appearance and properties such as hardness, colour or substance and the metal which it was thought to contain. Each member of such a group was named after the main characteristic of its group, but to this group-name there was added a determinative depending upon the individual characteristics of the member itself. Thus was obtained a cumulative nomenclature which is closely related to that of modern organic chemistry.

We find the word ZA (rock, stone) or another group name combined with GIN (blue), GUG (red), TU (white), SUH or SIG (yellow and green) or with IM-KAL (sublimate), AŠ (hard), AŠ-AŠ (very hard), *ZA-TU (effervescent with acid, vinegar). In the case of gems we often find determinatives which classify according to form such as

IGI (round bead), NUNUZ (oval stone), TAG-GAZ (cut stone). CAMPBELL THOMPSON to whom honour is due for having unravelled this system of nomenclature and identified many of the minerals indicated found that the Sumerians knew no less than 180 different minerals 120 of which occur in medical and magical texts too, thus permitting their closer identification because in these texts further details of these compounds are given. As an example we quote here the list of iron ores which CAMPBELL THOMPSON identified:

Sumerian	Accadian	Modern
ZID · ZID · AN · BAR AN · BAR ^a AN · BAR ^a KA	<i>parzillu</i>	powder of iron iron iron stone, iron ore iron ore, ochre (esp. red ochre)
^a KA · GÍG ^a KA · SIG ₇ ^a KA · PAR		black ochre yellow ochre white ochre, spathic iron ore
^a KA · GI · NA	<i>šadānu</i>	hard (heavy) iron ore, haematite
^a KA · GI · NA · DIB · BA ^a KA · GI · NA · TIL · LA ^a BIL	<i>šargubbu</i> <i>pindu</i> <i>šadānu balū</i>	magnetic iron ore ferrum vivum pyrites (iron), fire stone
^a ŠÁR · GUB · BA (^a ZUR · ŠÁR · GUB · BA; ^a GI · RIM · ŠÁR · GUB · BA)	<i>šadānu šabitu</i> <i>amarliāši</i>	iron pyrites and its decom- position products marcasite

When centuries later the Semitic Assyrians and Babylonians reigned the old Sumerian substratum they translated these lists in their own Semitic language, the Accadian, and these bilingual lists often with a third column giving the correct pronunciation of the Sumerian word or notes on its use form dictionaries which are immensely valuable to us. Of the 25,000 tablets of the Royal Library of Nineveh now mainly in the possession of the British Museum no less than 8 % consist of these sign-lists, thus classifying the Sumerian knowledge of natural phenomena for us. Many of these ancient terms survived in our modern languages as there was contact between the Greeks and the Mesopotamian world between 750 and 300 B.C. and after the conquests of Alexander the Great the library of Alexandria and the foundation of the university of Seleucia in Syria by Seleucus Nicator were centres of the revival and study of the ancient Sumerian and

Assyrian knowledge. We should also remember that the last cuneiform tablets were written in the last decade of the first century B.C. and that the Neo-Babylonian civilisation stood in close contact with Hellenistic centres. Thus it was possible that the old term *kibaltu* survives in our *cobalt*, *marhašū* in our *marcasite*, etc. CAMPBELL THOMPSON gives many more examples of this kind.

But however matter of fact and logical these classifications may seem at first sight, we never should forget that they had magico-religious meaning for the user. This is obvious in the case of colours, but even such terms as "male" and "female" kinds of a certain mineral, though they may have indicated a hard and a soft quality only in later times, certainly had a magical meaning earlier. For a time, however, the Greek mineralogists applied strict logic to their observations, especially ARISTOTLE's pupil THEOPHRASTUS (371-300? B.C.) who left us an essay *On the Stones*. Here he groups the stones according to colour, lustre, hardness and fracture, mentioning such groups as "stones of a metal nature", "stones that burn by themselves", "natural earths", "stones that colour water". His descriptions are mostly clear and comprehensive, but it is strange that however good mathematicians the Greeks were, they never used the crystalline form of the minerals to group them scientifically. To other Greek philosophers the stones and minerals or the metals were not objects for clear and cool observation but they were more or less considered to be the bearers of certain inner, abstract ideas which were fitted into the theories which they enunciated. In the science of later Hellenism there was a strong current of magico-religious speculation which came to overlay these foundations of observation and enquiry into nature. The Romans took no part in the development of geological science, their authors compiled from Greek works, but theirs was the practical work of surveyors, prospectors and mining engineers. Most of the Arabic commentators of THEOPHRASTUS were not able to improve on his observations and the field that had been conquered would have been lost had it not been for men like LEONARDO DA VINCI and above all the bishop STENO (1631-1687). The magical trend of Byzantine and Medieval lapidaries therefore is due to the examples from later Hellenism, though a few examples of the kind could be found in late Babylonian texts. In the older texts there seems to have existed a clear distinction between the observational facts and the magical speculations which theorists attached to them and which are not mentioned in the lists we quoted but which are to be found in quite distinct texts.

Before we proceed in giving a few glimpses of ancient mining technique we must first define the words rock, mineral and ore which have cropped up frequently in our story and which are so often used in a very loose way in books on our subject.

A *rock* or stone is strictly speaking any naturally formed aggregate or mass of mineral matter, whether coherent or not, constituting an essential and appreciable part of the earth's crust. The vast majority of rocks consist of two or more minerals. Such a *mineral* is a body produced by the processes of inorganic nature and, if formed under favourable conditions, a certain characteristic molecular structure is exhibited in its crystalline form and other physical properties. A mineral must be a homogeneous substance, even when subjected to minute examination by the microscope; further it must have a definite chemical composition, capable of being expressed by a chemical formula (DANA).

Not all minerals are ores, though all ores are minerals. For an *ore* is a mineral (or a mineral aggregate) containing precious or useful metals or metalloids (such as antimony, sulphur) and which occurs in such quantity, grade, and chemical combination as to make extraction commercially profitable. Seeing that profitable extraction is the main point in the definition of an ore, it will be clear that it depends on the refining technique of a certain period whether some mineral will be considered to be an ore or not. There were certain minerals like zinc ores which were not ores to the ancients as they did not possess the means of extracting the zinc from it, in other cases such as iron pyrites, neither in Antiquity nor now it is profitable to extract the iron from them and they are not iron ores in the strict sense of the word.

From the definitions given above it will be clear that the cupriforous sandstone mined by the ancient Egyptians in Sinai is a rock containing several minerals such as the nodules of malachite, chrysocolla and turquoise which they extracted. The malachite and the chrysocolla which were used to produce the copper were the copper ores; the turquoise used as a precious stone was simply a mineral to the Egyptians.

The first step in mining is *prospecting*. Guided by his knowledge of the ores and minerals, perhaps also by some knowledge of the morphology of the strata in which they occur or some theory of their genesis the prospector has to locate deposits of the ores. It is certain that from the earliest times prospectors have searched distant countries

for flint, precious stones or ores. But we have no clear record of their guiding principles. We are fairly certain that much observational lore was lost if we look at details of ancient mines. A few examples can be found in classical texts. PLINY speaks of the red colour that leads to iron ores and he knows of the concentration of precious metals in the oxidised outcrops of copper ores in Spain (*Nat. Hist.* 33. 98). AETHICUS (*Cosmog.* XXVI) mentions white pebbles (probably vein material) which are sure guides for gold placers at least in Britain.

It is certain that the Roman prospector did not leave the field until after a careful field survey and the taking of samples. We possess part of a Egyptian map of goldmines in the eastern desert on which the deposits are clearly marked. Trenching and stripping the rocks and in later Republican times driving adits into the rocky formation were part of the prospector's work. Both Romans and Etruscans had clear notions of the structure of certain mines and could follow up the local strata quite well, though such complications as faulting often left them dumb-founded. Still at Laurium they looked with prospecting shafts for certain contacts and in Italy the boundaries of the underground copper deposits were thus fixed in many places.

After this preliminary work the actual mining could be started. We can divide mines in two types:

- A. Open-cut mining (with or without stripping) which embraced a) quarrying and b) placer mining with such methods as panning, washing, hand sluicing, dredging and hydraulicking.
- B. Underground mining embracing a) breast stoping (tabular deposits), b) underhand stoping (veins and larger masses), c) overhand stoping (steep dipping veins), d) top slicing (wide veins and masses) and e) caving (large masses).

In modern mines both categories of mining are often combined to attack very large masses, but such methods were of course unknown in Antiquity. We have not yet obtained sufficient evidence to discuss the occurrence and evolution of all the different forms of mining enumerated above, but we are sure that many of them were known to the miners of classical Antiquity.

In the case of underground mining the ore could be attacked by driving vertical shafts into the soil and tunneling the horizontal levels, drifts and galleries into the strata bearing the ore. The ancient preferred to drive horizontal adits into the rocky slopes of a valley over the digging of shafts, it made drainage and haulage much easier.

The earliest method of underground mining was *pitting*, exploration

of the ore-bodies with shafts at intervals which were abandoned one after the other as the ore was extracted from the bottom of the shaft. Such was the method of the early flint miners, but the Romans generally avoided pitting and preferred regular workings. *Placer-mining* in its different forms was quite familiar to the ancients and the Romans even attacked large ore-bodies by hushing that is by breaking down the softer beds by a strong current of water directed upon it, leading the water and the debris into settling tanks. Such was the method in the case of the gold mines of Spain, the *arrugiae*, described so graphically by PLINY (*Nat. Hist.* 33.70). Harder stones and rocks were certainly washed and worked at the pit head to avoid transport difficulties.



Fig 13 Entrance of the copper mine at Umm el 'Amad (after N. GLUECK, *Explorations in Eastern Palestine*)

It is not yet possible to write the story of underground mining as too many links fail us, mostly because of the lack of reports on these mines by proper experts. It seems, however, certain that the exploitation of ore deposits by different levels did not occur until the classical period. In Roman mines two to four levels are quite common, though we should not expect the careful vertical-horizontal arrangement of shafts and levels as we meet in modern mines. This arrangement seems first found in the writings of AGRICOLA and his contemporaries. Ancient mines had no wheeled haulage and only drainage adits required to be level.

Descriptions of different forms of underground mining can be gleaned from PLINY's *Natural History* (33.66-77).

The section of ancient *shafts* has been the subject of speculation. Quiring thought that he could distinguish some historical sequence in the different forms and he correlates each with architectural details

of the period such as the current form of houses, etc. He claimed that low and broad galleries were Neolithic forms, that high and narrow forms come in at the beginning of the Iron Age and that the classical form is square. It is certain that the common Roman section of levels is square, but the form of level and shaft does depend on the type of rocks they cut, on the casing material available (rectangular forms in the case of wood and round forms for stone) and no dating can be taken from their section at all. On the other hand Egyptian and Greek shafts were usually rectangular, Etruscan and Roman shafts square, but the Romans also built trapezoidal levels! The shafts at Laurium vary from 1.25-1.4 m by 1.5-1.9 m but on the other hand



Fig. 14. Firesetting in a mine
(after G. AGRICOLA, *de Re Metallica*)

shafts of 1.9 to 2 m diameter occur too. The depth of these shafts is usually no greater than 50 m though depths of 100 m and more are known to occur. Levels branch from this shaft at depths usually varying from 10 to 25 m. The galleries of Laurium are mostly 2-3' by 2.2-2.5' or smaller, the Roman galleries were generally wider 4' by 8' but smaller ones of the ancient Greek dimensions occur too. The shafts usually show beam-holes with wooden baulks used for ladders, sometimes fixed at one side of the shaft to leave the rest of the space clear for the buckets with ore. Windlasses and other hauling apparatus were used. Sometimes there are no ladders but simply grooves used as foot-rests when climbing up and down the shaft by the aid of a rope.

The number of shafts dug in a certain mine is often considerable, at Laurion no less than 2000 shafts have been counted and the total length of the combined levels amounts to 140,000 m.!

The rock was attacked by cutting grooves with iron tools and hacking away the stone, wedges, perhaps often wooden wedges, being used to split them. There were of course other methods of breaking rocks such as *fire-setting* and chipping which were much cheaper. There are traces of fires in many old mines, the adits being often so shaped as to draw away the smoke. If there was no draught this method could hardly be used, also fuel should be abundant. And again "the miners meet with flinty rocks which they break up by heating them and pouring vinegar on them or more often (for the



Fig. 15. Egyptian stonecutters at work
(after QUIBELL, *Hierakonpolis*)

steam and smoke make the air in the galleries unbreathable) they hew them out with shattering-machines fitted with iron rams weighing one hundred and fifty pounds and they bear out the debris on their shoulders" (PLINY, *Nat. Hist.* 33.71). Often the effect of the fire was enhanced by cooling the heated rock with water. Waterpipes are already existent in the prehistoric galleries at Mitterberg. The vinegar was added probably in the belief that a substance that itself cooled (by evaporation!) would enhance the cold of the water.

As PLINY indicates in the passage cited, *ventilation* was a serious problem of the ancient miner. Sometimes it was possible to obtain proper ventilation by driving adits at different levels, and another possibility was the cutting of parallel shafts, with a fire in one of which a good draught could be obtained. VITRUV (VIII.6.13) devotes

a chapter to the testing of air in shafts and the construction of ventilation shafts. Then again "if the air at great depth begins to act injuriously, they try to improve it by the constant waving of cloth flaps" (PLINY, *Nat. Hist.* 31.28) and indeed even machines working on this principle seem to have been constructed by the Romans, but only too often as in the case of the arsenic mines not far from Pinolisa in Pontus "the air in the mines is both deadly and hard to endure on account of the grievous odour of the ore, so that the workmen are doomed to a quick death" (STRABO 12.3.40).

But the most important problem of ancient mining was the *drainage* as the inefficiency of drainage machinery made it costly for the

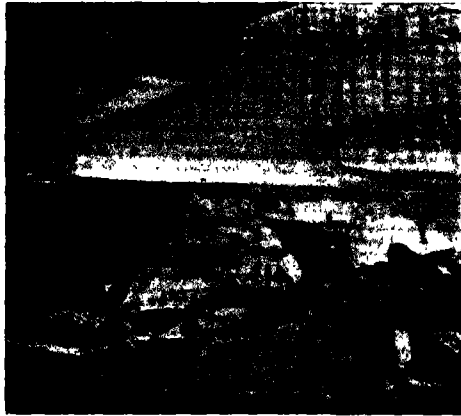


Fig. 16. View of the Aswan Obelisk, showing the drilled holes made to separate this block of stone (after ENGELBACH, *The problem of the obelisks*)

ancients to work below the ground-water line and they generally avoided this if possible. This meant that their mines were never deeper than about 100 m with a maximum of 300 m. Though unnecessary in Egypt and at Laurion drainage adits were a common feature of Roman mines, sometimes a special cross-cut at a deep level (Rio Tinto) served for this purpose. The water was collected in the shaft.

The machinery available to the ancient miner was manifold. Pails of different materials have been found ranging from esparto buckets soaked in tar as used at Cartagena to copper pails. Then there was the Archimedian screw or cochlea described in detail by Vitruv (X.6. 1-4) which did not raise the water but a few feet. They had been used for many centuries in Egyptian irrigation and many specimen

were found in Spain. They are still in use in some Japanese mines.

There were still other machines to be adapted from irrigation to drainage purposes (R. J. FORBES, *Over bevoeiing in de Oudheid*, JEOL, vol. I, 1933-1937, p. 443). There was not only the shadoof, but also the different types of water-wheels. The tympanum of VITRUV (X.4.1-2) is nothing but the ancient compartment wheel or tâbût of the Egyptians and the other wheel described by him (X.4.3-4) is the Persian wheel or sâqija. It is not certain whether waterdriven wheels were used in mines, VITRUV gives some details on their construction (X. 5). But many examples of the other types have been found in Roman mines especially in Spain, their diameter varies from 3.65 m to 4.90 m. They are often arranged to raise the water by degrees to the pit head or to a drainage adit. The section of the levels did not allow them to be animaldriven and most of them were worked as treadmills or they were moved by man-power in some other way.

Something more like our modern pumping machinery was available to the Romans. They knew bellow-pumps and the Heron fountain method was certainly used in some cases according to Sagui.

Finally there was the "water-machine of Ctesibius", a double-acting pump described by VITRUV (X.7) which could have been applied and examples of which have been found Bolsena, etc.) though not in mines. *Propping* was used in dangerous ground only. Mostly "on account of these dangers (the roof caving in) arched supports are left at frequent intervals to bear the weight of the mountain" (PLINY, *Nat. Hist.* 33.70). These natural pillars called hormoi or mesokrineis by the Greeks were mined last starting from those farthest from the entrance and the rock was left to subside. However, filling was often resorted to and this was often necessary as sometimes areas of 70-80 m by 2000 m were entirely emptied! Therefore, as STRABO says (5.2.6), "diggings in Paros, Rhodes and in India which have been mined are in time filled up again". Supports were often of a more simple nature, baulks between the hanging wall and the foot ground are fairly common and mortised olive-wood props are found occasionally at Laurium.

Haulage was usually fairly simple, wooden or wicker trays drawn along the gallery floor to the shaft served for underground transport and baskets or leather sacks were used to haul the ores up to the pit-head. Sometimes porters carried leather sacks with a strap to be fastened over the forehead. Esparto buckets have also been found and in many mines relays of porters handed their baskets with ore onwards

towards the daylight. In some cases such as mines at Paros remains of hoisting machinery have been found. As to the lighting problem "lamps serve to measure the spells of work and for many months together the toilers are without the light of day (PLINY, *Nat. Hist.* 33.70)". Earlier resinous torches or pieces of skin soaked in fat may have been used. Later earthenware or metal lamps were placed in lamp-niches cut in the rock. Their forms can be studied in F. W. ROBINS' interesting book on the *Story of the Lamp* (London, 1939), who does not show the lamps fastened to the fore-head so common in modern mining which have also been claimed for Egyptian miners. There is now evidence that lamps were hung from the roof of the gallery.



Fig. 17 Greek miners at work, from a vase
(after RICKARD, *Man and Metal*)

Underground *surveying* was a difficult job even for the Roman experts. They never achieved anything like the accurate tunneling or piercing a mountain for the course of an aquaduct, an art in which the Greeks as well as the Romans excelled even with their simple instruments like the dioptra, etc. Even the ingenious surveying table which Sagui pieced together from finds at the mines of Pangaeum seems to have availed them little. Though the results in deeper levels are fairly accurate sometimes the ends of tunnels failed to meet and caused great extra work. In higher levels the tunneling was often guided by shafts let down at intervals of 30 M. following the valley and the probable course of the vein to be mined.

Little exact information is available on the evolution of mining *tools*. In general the Greeks and the Romans used iron tools and earlier miners stone ones. Bronze tools were hardly better in mining

than stone ones. The single bladed pick generally used is hardly larger than the modern geological hammer. Harder rocks were attacked with gad and hammer, the gad usually having a square cross-section. The earlier hammers are either pounding stones or stones drilled to receive a shaft, but the most common form is the ancient rilled stone hammer, which was used not only in extracting the ore but also in pounding. This stone tool was so efficient that it continued to be used at least up to the first century B.C. in Spain, some 200 years longer in the Danube region and it survived still longer in Northern Europe. Flint tools disappeared in the Iron Age just as stone picks, but picks and rakes of horn continued in use very long. The shovels and rakes for the collection of the ores were generally made of wood like the notched trunks often used as ladders. Stone wedges formed like neolithic celts were used simultaneously with metal and wooden ones, and it seems that the boring and wedging methods used in the Egyptian quarries (R. ENGELBACH, *The Problem of the Obelisks*, London, 1923) had a profound influence on later mining technique. Another important tool was the saw with a blade of copper or iron without teeth, which was used with abrasive materials.

These few facts and definitions will help us to discuss the problems of early metallurgy. We will have occasion to discuss in the relevant chapters further details as well as the methods of crushing, washing and pulverising the ores.

A few words remain to be said on the organisation and economics of ancient mining, more details of which will be found in the works of Davies and Täckholm. Ancient mines were seldom private enterprises or perhaps controlled by rings of bankers as in the early Roman occupation of Spain. In most Hellenistic states and in the Roman Empire the mines were state owned though often complicated questions of ownership arose when new deposits were discovered. Such stories as the gold rush to Hymettus (SUIDAS, s.v. *chrysochoein*) are rare. By the third century A.D. when many state-owned Roman mines failed, more initiative was given to private persons. In medieval times mineral mines were mostly state-owned but quarries and iron-deposits generally belong to the proprietor of the soil, the latter custom probably a reminiscence of the old German private exploitation of bog ores. But ancient economy did not favour private enterprise in mining as the markets were far more limited than at present and the working of veins or lodes required machinery, centralisation and capital, factors not only inconsistent with free miners but also beyond the control of practically every private Roman or Greek banker.

Period	Mining methods	Mining tools
Palaeolithic Age	Search for boulders, etc. Open workings, conical pits	Wooden or bone digging stick, horn pick First stone tools such as hand-axe, etc.
Neolithic Age (-3500 B.C.)	Quarries, stone slabs Open workings, sloping shafts Gradually galleries	Stone picks and hammers, chisels and celts
Predynastic Age (3500-3000 B.C.)	Development of square and round shafts with galleries Ventilation and chimneys Proping	Stone picks and first copper tools
Metal Age I (3000-2200 B.C.)	Systematic stripping of outcrops Shafts with staircase (?) Filling of old galleries with gangue	General use of fire-setting
Metal Age II (2200-1200 B.C.)	Timbering of shafts(?) Drainage with pails, etc. Wider galleries	Copper tools become more general
Early Iron Age (1200-500 B.C.)	Drainage adits Large quarries	
Late Iron Age (500-50 B.C.)	Mechanical drainage, transport and ventilation	Iron tools gradually supersede stone and copper tools
Roman Empire (50 B.C.-300 A.D.)	Water-wheels, waterscrews, etc. more common, deeper mines and large open workings	

Fig. 18. Outline of the evolution of mining,

Stones, Precious and semi-precious	Ores and natural stone	Metallurgical methods
Chalcedon, quartz, rock-crystal, serpentine, obsidian, jaspis, steatite, amber, jadeite, calcite	Flint and obsidian later ochre and other natural pigments, emery	
Amethyst, fluorspar, nephrite, jet, turquoise, lapis laz., jade, agate	Granite, diorite Limestone Sandstone	
Haematite, alabaster, carneol, chrysocolla, malachite, beryl, feldspar	Native metals (gold, silver, iron (meteoric), copper) Copper ores from outcrops Alabaster, marble, rocksalt	Hammering native metals Melting and casting of metals, first reduction of copper oxides.
Onyx, sardonyx, amazonite, azurite, callais	Oxydic and carbonatic copper ores Galena, stibnite, cassiterite Obsidian, emery	Silver from galena Oxidation and reduction with natural blast Wrought iron from magnetite Copper alloyed with lead, antimony and tin.
Bloodstone, emerald, magnetite, topaze, chrysochase.	Gold-bearing quartz Oxydic iron ores Copper sulphides	Short shaft-furnaces Use of bellows Roasting of sulphidic ores more general
Sapphire, blue chalcedony, rose quartz, spinels	Limonite, haematite Copper pyrites	Wrought iron "steeled" by case-hardening and quenching and tempering
Ruby, moss-agate, zircon, opal, aquamarine, meerschaum, diamond(?)	Magnetite and spathic iron Iron pyrites(?)	Brass from copper and calamine Higher shaft-furnaces
Aventurine, moon-stone, blue spinel, spinel-ruby, pearl.		"Stückofen" Mercury produced

tools, its methods and its products

On the other hand the cost of mining was considerably less in Antiquity. At present labour forms no less than 65 % of the total costs of a mine, but ancient mines were worked with slaves and criminals and the overhead costs were few as the mines were smaller. Though many ores could not be worked by the ancients which are now considered to be rich and though they rejected many ores now worked profitably, they could on the other hand work small deposits which we could not work with any profit. The unfree miners were not only controlled by state officials but sometimes the military authorities seem to have been in control which does not mean that the soldiers were ever used as miners.

We still know little on the evolution of many aspects of the economy and organisation of ancient mining such as claims, ownership of mining rights, etc. Still less is known about the earlier stages, about the Egyptian and Hittite mines and their organisation and the same holds true of the mining technique of pre-classical days. A comparative study of the details so far available would at least clear the way for further research, and show us how the gradual mechanization and specialisation which we begin to discern took place.

Another great story that still remains to be written is the part which ancient mines and deposits of ores played in the political history of their times. It is clear that their rôle was as important then as it is nowadays and the ancients knew it, for is it not written. (I. Maccabees 8.3) "Now Judas had heard what the Romans had done in the country of Spain for the winning of the silver and gold which is there?"

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CHAPTER FOUR

THE EVOLUTION OF THE SMITH, HIS SOCIAL AND SACRED STATUS

"God gave them no sheep but cleverness instead
If they were rich, they would but lie a-bed"
(Suk saying)

Before turning to the tools of the metal-worker and the history of the separate metals we must pause a few moments on the figure of the smith. For since the first smiths started their craft in the Late Stone Age and since the first metals were used by mankind, this mysterious trade, which was so different from the other Neolithic arts and crafts, formed the centre of a wealth of myths and legends and the smith grew to form a special social type encumbered with religious rites and taboos, endowed by popular feeling with magical potencies in many directions.

The story of the smith and his religious and social aspects has never been written. ANDRÉE (4) has collected a lot of valuable ethnographical material but the archaeological and historical evidence was never published. May be the interlocking of technical, archaeological and philological factors has discouraged work in this line, but the few notes collected below will show the reader that a rich harvest awaits him, who will dare to attack the complicated question, which could easily form the subject of a separate monograph. We can do no more than glance over the "Promised Land", and while spying the land we hope to be as lucky as the smith's dog "so well used to the sparks that he'll not burn".

I

Before discussing some of the factors that made the smith the important figure he is in primitive societies, let us survey the *status of the smith with some tribes in Africa, Asia and Europe*.

As great differences are obvious in Africa, it is difficult to group the different complexes of social favours and taboos geographically. In the grass-lands of North-East Africa the caste of the smiths is generally despised, their work is not attended by any ritual. Guilds, magic, bonds with the secret societies and club-houses are features of the West African smith. In the Congo region and surrounding countries to the East and the South the smiths form no clans but guilds, they are considered the equals or sometimes identified with priests

and chiefs, their work is regulated by a ponderous ceremonial, in which "medicines" and "spirits" play a large part. But on the other hand such features as trade-secrets, taboos, personification of the tools, transmission of the crafts from father to son are spread all over Africa and it is difficult to find their country of origin or even the way along which they penetrated Africa. Let us therefore take a few examples at random.

In North-East Africa the smiths of the Masai and the Bari are slaves and pariahs (37), often remnants of subjugated aboriginals. Thus the Tumulods are the slaves of the Somalis and the Watta are subjects of the Galla. Their status with the Nandi is somewhat better, here they are not forced to intermarry. But the Somali will never enter a smithy, does not shake hands with a smith or marries his daughter (35). Among the Tibbu (51) they form a pariah-caste with rigid taboos, their craft is handed from father to son, though they do not differ anthropologically from their tribesmen! The word "smith" is considered to be a term of abuse, though it is also unwise to curse or insult a smith. Even the fellahin of Eastern Egypt and the Oases hold the smith in awe, he is a tramp whom one respects but avoids (45).

Among the WaChagga (33) the smiths form a separate clan, which seems to have been adopted long ago by the tribe. The smith is honoured as the maker of deadly weapons, because he knows how to join iron and iron and because he possesses tools of great power. Though he is not considered to be a magician, it is dangerous to bleed him and it is unusual to marry his daughters. The smiths do not join the warriors, they make their weapons using iron, which is, however, taboo in many ceremonies.

Among other tribes in West Africa every familygroup has a smith, for whom corn and other agricultural products are cultivated and for whom the community builds a smithy. The tools of this smith have great power, they are considered to do the work, not the smith and they would kill the smith, who gave up his craft, or they would at least smite him with a fever lasting a year (75). The Fans make no difference between the chief, the medicineman and the smith, because the smithcraft is so highly honoured that only chiefs and their kin are allowed ply it (28). In Benin a smith can be enobled, he is generally considered to be a magician (81). On the Loango coast the ritual nails are forged by a priest-smith (44). In the Congo or Ogowe regions, where there is no smith, bellows or smith-tools

hang in the fetish-houses. In the Congo region and in West Africa the smith is generally a honoured and rich man, who inherits his craft. He is potent magician, his fire is holy, his social position is high in proportion (27). This is in great contrast to the pariah-smiths of the Masai, though this tribe acknowledges some magical power to the smith's products. Swords will spill blood, therefore they shall be cleaned before use with butter or fat. Among the Baghirmi Arabs of Lake Tchad (8) there are many groups and sub-groups, but the Had-dâdîn, the smiths, form an undivided clan and a separate caste as with so many other African tribes. Neither are they Arabs, but probably of Hamitic-Negritic stock.

CLINE (15) gives many other examples in detail and finally he draws this conclusion: "Hunting is ritualized as much as metal-working, both require considerable skill and occupation excluding most of the cattle-raising or agricultural population. The smith provides weapons and tools necessary for life but his trade asks for a long and arduous practice, tending to isolate him seasonally or throughout the year. It may effect his position with people who identify cattle-raising or agriculture with everything that is noble or with people who despise manual labour. The smith has the most elevated position in the Congo and West Africa where the arts and crafts were well developed. Both ritual and caste are conditioned by the cultural frame rather than by the wonderment of primitive man at processes which he failed to understand."

And we must add, that the present situation has of course been changed and often very drastically by imports of cheap European industrial products. For the Negro smiths are very ingenious craftsmen in inventing and using new tools, types of bellows but now they often work with imported iron (46).

Apart from the guilds or clans of smiths we find many itinerant smiths or tinkers, who are very special considered to be powerful magicians (58). Africa is still a field in which the primitive smith can be studied from many aspects, as there is hardly another region in the world where we find a so well developed smithcraft, which reached such a height before the advent of modern industrial products and here types and forms are far better developed here than in Oceania or America.

In Asia the situation is far less clear, because many strata of higher civilisation overlay the more primitive strata and the archaetypes break through only now and then.

The position of the smith in Java or Bali is most interesting. Under the empire of Modjopahit Java counted no less than 800 smith-families in the eleventh century. When this empire was dissolved four centuries later many of them flew to Bali. The ironsmith was honoured as a wise expert, but only he, for the Cheribon lawbook ruled the copper-, gold- and silver-smiths out of court and admits only the *pande* or iron-smith.

The armourer or *empu* is greatly honoured in Bali. He fulfils a very special duty in the kampong, for is not all metal 'charged' and

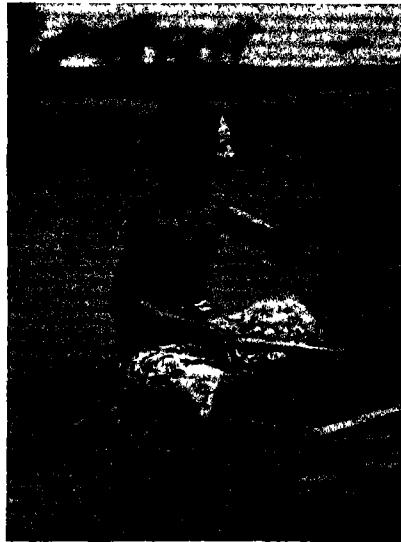


Fig 19 Making the holy kris (Java) (courtesy of the Indisch Instituut)

therefore dangerous to everyone but to him who knows how to handle it? He has the magical power to work the dangerous metal. But the close bond between the smith is not only formed by their trade-secrets, but also by the magical rites of their craft and the initiation of their pupils. Special mantra's are recited before the use of every tool. These *pande-wési* (ironsmiths or foremen) have a written tradition which claims their creation through the intercession of Brahma (who takes the place of the fire-god Agni!), who gave them their sakti or magical power. This guild embraces not only the iron-smiths but also the tinkers, gold- and silver-smiths, carpenters, draughtsmen and painters, it allows them certain rights, they are freed for certain imposts and

communal tasks. This written tradition would make them form part of the Triwangsa and therefore elevate them above the common people though the members of the Triwangsa doubt this (30) (39). We shall revert to some aspects of the Javanese smith later on.

In other parts of the Dutch East Indies we find the same peculiar position of the smith. The Batak smith worships his tools in particular and gives them mysterious names (56). For the tools are supposed to do the work and the spirits of these tools protect the smith and his family. The smith himself is a priest, by whose power the weapons are imbued with a mighty spirit, but then this applies to the armourer or ironsmith only. The son shall take up the trade of his father lest "the



Fig. 20. Javanese court goldsmith (Jokjakarta) (courtesy of the Indisch Instituut; photograph J. HUYSER)

tools lay snares for him'. Most operations are preceded by an offering, whilst the tribesmen pour out libations in the smithy in case of illness thus using it as a temple! In general it seems that the smithy is regarded as a temple of the spirits of the earth, whose power resides in the tools and products of the smith. Among the Bahau and Kenya Dajaks every village has a smith or two, whose smithy stands near the "long house" (53). This professional smith is imbued by a special spirit called *to temne* (smith-spirit) without whom he would lack his expert knowledge. But a civilian can also call upon this spirit to possess him and to deliver him of his ailments. The smith must propitiate this spirit by regular offerings in the smithy. Many of these old customs have disappeared because the Dajak smiths now work import iron and no longer smelt the ores themselves.

The smiths of Doré (New-Guinea) form a special caste, during



Fig. 21. Smthly of the Papuas at Manokwari, New Guinea (courtesy of the Indisch Instituut; Mamberamo expedition)

their initiation they swallow special "medicines" and avoid pork. The Buginese have a smith-caste, that keeps its trade secret just like the smiths of the Igorotes of Central Luzon (4). In Madagascar the smiths occupy a position like those of Java, from whom they seem to have adopted tools and bellows, which differ entirely from the types used in the African continent.

On the continent of Asia the Baris live as pariah-smiths with the agricultural and pastoral Shiaposh of the Eastern Hindu-Kush (3). In Nepal too the smiths are pariahs, but they are highly honoured by the hill-tribes of Assam, where every village has a smith, who, however, only works scrap bronze from Tibet or iron bars from Assam (19). This degeneration of the craft of the smith is striking all over Asia. The Kazak tinkers are much less skilful and self-reliant than formerly, often they are itinerant smiths.

Kalmuck smiths no longer attempt to make any complicated implement. No Siberian smith smelts iron any longer, but the Tungus smiths forge iron tools from bars and scrap iron (27). Still Tartar and Siberian smiths produced iron from local ores when the Russians occupied the country, mostly working ores from rivers and mountain streams.

Around no craftsman in Japan has mythical legend and ancient story thrown such a halo as around the smith. In remote Antiquity his ancestors are numbered among the Gods of the Divine Age and in later times his astounding feats form the themes of innumerable tales. His profession, notwithstanding the manual labour it involved, was deemed an honourable one and men of noble birth were not debarred from pursuing it (31).

In America metallurgy was introduced either by the Aztecs and Incas or by the European, except perhaps with the pre-Columbian Indians of Colombia and Peru. But here again we lack proper information as hardly anything is known about pre-Columbian metal lurgy and the position of the smith among Indian tribes. The Navajos seem to have possessed itinerant smiths, who not only worked iron, but also copper, silver, etc. (MATTHEWS, Sec. Ann. Rep. Bur. of Ethnol. Washington, 1883, pp. 171-178).

The smith of prehistoric Europe occupied an honoured position. Had not the gods themselves forged metals according to the Voluspä? In Scandinavia and England the smiths were considered the equals of the bards or priests and no slave could profess their craft without seeking permission to do so. The famous smiths of Wales, who made

their own iron, were by the laws of that country allowed to sit near the priest of the household in the king's presence (61). They had mysterious powers, for were not the maxims of Druids, smiths and wise women dreaded by the Celts? (71). And though we do not know much from direct tradition, the great part which the smith-craft plays in legend and myth (Wieland, Mimir), figures like the giants, dwarfs, elves and fairies, who forge metals and watch their accumulated treasures in mountain recesses, the "super-smiths" of the Kalewala, Kawelipoeg and the myths of the Esthonians, these all tell us something about the lost glory of the prehistoric smith.

Sometimes we are allowed a glimpse of the status of the prehistoric smith from archaeology. Thus, for instance in the Transcaucasia of the Middle Kuban period when local metallurgy developed strongly on Mesopotamian and Anatolian lines, smiths were admitted to the ranks of the barrowbuilders, as is proved by the moulds and tools found in their tombs from that period onwards (14).

We shall revert to the gods and heroes of the smith later on.

II

But before discussing the characteristics of the primitive smith we must follow up this somewhat dry summary of ethnological and historical examples by a discussion of the *diffusion of metallurgy from the point of view of the smith*. Still we can not pretend to be "the little smith of Nottingham who doth the work that no man can", our evidence is far too meagre for that and we can give no more than a working hypothesis.

In discussing the archaeological material on the evolution of metallurgy we saw that metallurgy came to the Near East from the East and the North. The oldest metal objects have been found along the mountain range that reaches from the Caspian Sea and the Elburz to the Hindu Kush and the T'ien Shan mountains towards Lake Baikal. In these mountains there are many places where copper and iron ores occur, while the mountain streams contain alluvial gold, magnetite and cassiterite. There is an old practically forgotten suggestion of Lenormant, who contended that the discovery of metallurgy should be ascribed to the Turanians and Ugro-Finns. ANDRÉE (4) has elaborated this thesis by saying that the northern slopes of these mountains were originally occupied by tribes akin to the Chudes or Chudaki, who had invented metallurgy and who were the ancestors of the Finns! WAITZ (81) even proposed to consider the Finns as

the aborigines of prehistoric Europe, who had brought metallurgy from their Asiatic home and transmitted this knowledge to the Indo-Europeans and other tribes inhabiting Europe later on. Of course this no longer holds true in the light of modern archaeology, however strong the evidence of metallurgy may be in the Kalewala and the myths of the Latts and Esthonians. It is highly improbable that these West-Finns came to Europe before the rise of the Danubian I civilisation which marks the rise of metallurgy in Central Europe.

Much more light could be thrown on the question by an exhaustive study of the primitive smiths of Asia, a subject that never received that same attention as the study of African metallurgy. Still here and there evidence crops up. Thus RUBEN (67) published a remarkable study of the Asûr, a primitive tribe of smiths living in the mountains of Chota Nagpur in India. Nowadays they no longer smelt ores but forge iron bars which they buy. Originally they were half-nomads, who remained between a few months to three years on spots where there were ores and fuel until they had exhausted them. They formed a community of specialists, divided in totemclans, who hunted a little and kept cattle, though they did not raise them. They did not know agriculture and gathered fruits and nuts. The single smith was honoured by the surrounding tribes, though he be from a totally different anthropological stock, but as a mass the smiths were despised and hated though feared. RUBEN has proved that we have to do with a tribe that originally belonged to a cattle-raising culture, which tribe specialised in metallurgy and which was driven by the Aryan invaders from their original homes to the hinterlands of Dekhan. The Asûr originally lived north of the mountains of the Punjab, where the cattleraising culture is at home and where the earliest metal objects were found. This culture is certainly connected with early metallurgy also by the fact that they were the first to possess good pottery. We have already pointed out that metallurgy and the possession of proper furnaces are intimately linked and that it is impossible to smelt ores in a camp fire. COGHLAN in his interesting experiments at the Royal School of Mines (London) in 1938 proved beyond doubt that the only primitive furnace that would smelt ores was the pottery kiln, which later on led to special metallurgical furnaces as metal technique improved. But reverting to the ethnological evidence there are many signs that the iron workers of many jungle tribes of southern India are immigrants and form a sort of alien guild or craft, just as much of the practice of iron working in Africa has been spread by the guild

of artisans (68). It would then seem from archaeological, mineralogical and ethnological evidence that the cattle-raising cultures of the northern slopes of the Altaï and Paropamisos discovered metallurgy after evolving the art of the potter, probably discovering native metals (gold, copper and meteoric iron) when tending their herds in their summerquarters on the mountain-slopes both in the hills and the mountain-streams. Possibly they had even discovered the working of some ores, for the smelting of copper is already in possession of the prehistoric peasant culture when it spreads from these quarters over the whole of the Near East and North-Africa. The oldest settlements of Anau yield quite good copper instruments made from copper ores! From this home of metallurgy the craft spread with the peasants to secondary centres like Caucasia, Elam, Armenia and Pontus, whence is migrated to tertiary centres like Phrygia, Lydia, Cyprus, the Balkans and the Danube valley to spread beyond.

With the coming of these primitive smiths there arose among the non-metalworking tribes around them the many legends and myths about gnomes, dwarfs, kobolds, Dactyloi, Kuretes, Korybantes, Telchines, Hephaistos and others that tell us of the smiths and their fire-god, their mysterious rites and their craft.

Even the history of iron, that late-comer among the metals, seems to point to the original working of magnetite and other iron ores of the mountain streams. The civilisations of the alluvial river-valleys, which possessed no ores worth mentioning always regarded metalcraft as a highly mysterious job, though the smiths living amongst them gradually lost their original traits and we find only smith-guilds with little or no special traditions or rites to remind us of their ancestors.

But "often a full dexterous smith forges a very weak knife" and the suggestions given above remain to be proved by excavations both in the Armenian highlands and the regions of Afghanistan and Baluchistan which are so desirable from many another point of view.

But whatever future excavations may tell, it has been proved beyond doubt that the smith occupied a special position in primitive society. He can but exercise his own craft, whereas the primitive potter would not be hindered in his agricultural occupations and many other crafts of prehistoric man simply filled up his spare time. We must admit that the smith must dispose of a formidable body of industrial lore. Craft traditions embodied the results of long experience and of many deliberate experiments. It may seem to us no more than applied science with a tangle of magic, but science it was that was handed down from generation to generation of smiths. *

It is certain that the effective utilisation of metal discoveries involved the elaboration of a highly complicated technique through series of inventions. These form a range of discoveries and inventions so abstruse and complex that independent origin in parts of the Old World must be considered fantastically improbable, at least in the early millennia of the history of mankind. As to the links between Old and New World metallurgy no discussion is possible at the present stage as we possess insufficient data and analyses from the American continent. From what we know it seems that the foundations of metallurgy penetrated into the New World and there were developed on original lines best suited to local circumstances.

In the Old World mining and metallurgy were originally practised by a caste or clan of few members, the membership of which implied initiation in the tangle of technical traditions, but which conferred upon the members some degree of immunity from the bondage of tribal customs and duties. We must never forget that the number of smiths in primitive society was small. A tribe of a few thousand members would not use more than 1 Ton of metal a year, that is less than the production of ten smiths, who even now produce with ease three to five Kgrs. of metal a day with very primitive means (15).

The diffusion of the special lore of these craftsmen is of course associated with the spread of the craftsmen themselves, for instance prospecting, sometimes not only in quest of ore but as perambulating smiths seeking fortunes by plying their trade among barbarians, sometimes as slaves captured in warfare, often as smiths who had secured initiation and returned home.

Naturally the pupils were not always as clever as the masters, those who had learnt a new technique were apt to apply it very clumsily, the proficiency of the trade was only acquired by generations of practice and discipline. Thus the early Minoan and Cyprian metal tools are much more clumsy than the Sumerian originals.

However, a true Metal Age arises only when there are permanent settlements of smiths in a certain region. Itinerant smiths or prospectors in quest of ore may produce a "Chalcolithic Age" by importing a few metal objects which are used side by side with the aboriginal stone and bone tools, or they may give instructions as to the shaping of metal objects. But a true Metal Age can only arise with the settling of the smith. The diffusion of metallurgy need not differ from that of the potter's lore, where new types often herald the settling of new inhabitants. Archaeology affords us definite proof of the continuity of dif-

fusion of metallurgy from a certain centre. GORDON CHILDE pointed out that the same hammer made of a grooved stone lashed to a forked stick heralds early mining in Sinai, Caucasia, the Alps, Spain and Cornwall and that the oldest metal tools and weapons are very similar both in Mesopotamia and Egypt and tend to differentiate from protodynastic times only. Still certain common tools remain identical for a very long time over vast areas.

It would appear from archaeological data that the oldest smiths moved about quite freely in prehistoric Europe. But this is not strange as we have many historical examples to prove the same. Thus we remind the reader of the stimulating influence of Bohemian and Bavarian coppersmiths on the bronze-craft of Benin. Manipuri workers were carried off to Burma in 1760 where they became responsible for many crafts (68). For Chingiz Khan's successors worked Chinese, Persian and even German miners and a French jeweller!

Of course the itinerant specialist occurs less frequently among primitive peoples and tends to be restricted by the deposits of ore and fuel to the country of his tribe. But their wanderings may be prompted by pressing needs or social conditions and warfare. There seems no reason to doubt the diffusion of metallurgy at least in its primitive stage. Later and especially in developing the metallurgy of iron there are indications that we must be careful in applying the diffusion principle. We must not fall into the mistakes of de Mortillet who contended that iron metallurgy was discovered in Africa, or Bataillard who thought that the gypsies were the initiators of the Bronze Age.

III

Before discussing the characteristics of the primitive smith another problem must needs occupy us for some time. We mean the *technical background of the primitive smith*.

We have already discussed the difficulty of applying the well-known series of Copper-, Bronze and Iron-Ages to certain tertiary and fourthly centres of metallurgy, but the sequence propagated of old holds true for the Near East. However, these Ages can hardly be said to characterize true stages of metallurgy, these stages are far better characterised by modifications of metal technique.

The study of material things has helped to illustrate man's efforts to utilize his environment, but not only this, his tools and implements are the outward signs of peculiar ideas in his mind. Materially speaking there is a close interrelation between tools, processes, raw materials

and finished products, but above these there is the presence of motive and insight of the creator (68). In his gradual conquest of the metals man has not proceeded by small variations to a gradual change of metal technique, but there are certain periods in which inventions have created new paths and technique advances in leaps along lines drawn by experiment and practical science. Each of these stages creates its own means and processes. Thus the Bronze Ages smiths elaborate casting methods, the Iron Age smiths of La Tène develop rivetting. We have already sketched the three stages of metallurgy.

The earliest stage, the "native metal stage" is the transition from Stone Age to the Metal Age. Man had already learnt to use the native metals gold and copper (and also silver and meteoric iron), but he had only treated them as he worked bone, stone and wood. But now he learnt to appreciate their true metal character by heat-treatment and discovered that the "mysterious stone" could be shaped by tempering, hammering, cutting and grinding. Soon, and this phase of the use of native metals already falls within the second stage of metallurgy, casting and shaping the metal when hot, joins these treatment to complete the cycle of operations. The new possibilities of casting and heat-treatment have impressed themselves so deeply in the mind of early mankind, that some of the stone objects of the Late Stone Age take the form of metal objects in regions that border upon others where metallurgy has already become a regular trade (19).

But true metallurgy begins with the "ore stage", with the discovery that certain stones, which we call ores, could be reduced to metals (first copper, then lead and silver, etc.) and that metals could be beaten until they could be cast when molten. Here again we have another, but completely different cycle of operations and processes, of discoveries and inventions. Here the smiths have struck an entirely new line and several generations of experimenting and trials must have preceded a long line of masters in the "new art" and their pupils. It is practically certain that this new stage of metallurgy brought along specialisation. Especially when the surface deposits of certain ores grew rare and the smith had to work deeper strata and start vein mining, he could no longer dig the ore and produce the metal object from it. There arose the craft of the *miner* who did the prospecting and mining side of the job and the *metallurgist* who reduced the ore and worked the metal. The new element in this stage of metallurgy is not so much the metal as the processes, the many phases of working and reducing the ores, the preparation of new

metals and of alloys (bronze) and the gradual insight in the proper field of application for which each of these metals and alloys were destined by their nature.

The preparation of alloys was no mean task. They could be prepared by the smelting of two different ores, by smelting a metal with another ore or by melting certain metals in the appropriate proportions. The first two methods were the oldest, the last was not used until the end of the Bronze Age. Therefore alloys vary greatly in composition in the Early Bronze Age and only late their composition could be kept within

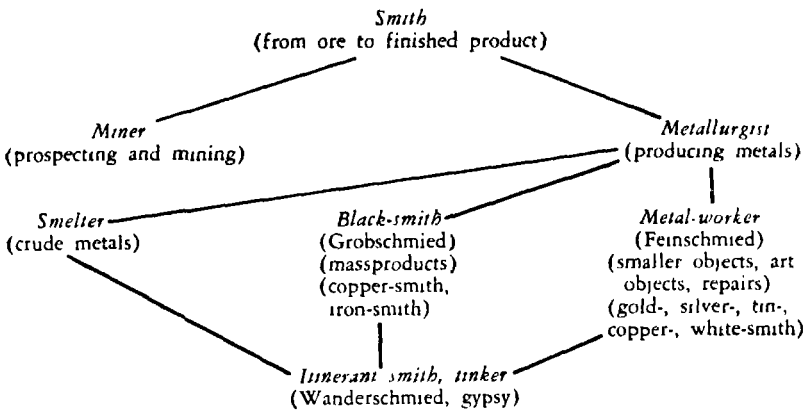


Fig. 22 The evolution of the smith

a close range. But this meant no disadvantage for the alloys in their early stage were far less differentiated for their applications than they are nowadays and their composition could vary within wide limits without decreasing their usefulness to the early metallurgist. Neither was the purity of the metals of great importance at this stage, though the practical and unscientific (and therefore uneconomical) preparation with primitive apparatus and methods often yielded remarkably pure products.

The formidable growth of the mysteries connected with the extraction of metals led to further specialisation. Gradually three different types of metallurgists are evolved. The first of these is the *smelter*, whose task it was to produce the crude metal or the alloy from the ores. Then there arose the *blacksmith*, who manufactured mass products from crude metals, first copper objects (copper-smith) then

mostly those of iron, a task which we have come to identify with the name "blacksmith" though the metal-workers of the early Assyrian and Babylonian texts were certainly copper- and bronze-smiths of mass products. Finally there were the *metal-workers*, who produced the smaller objects, art objects and who repaired or decorated metal objects. As such we find gold-, silver-, tin-, white- and copper-smiths. It is quite probable that the earliest specialists of this type were the gold- and silver-smiths, who very early in the history of metallurgy reached a skill that is hardly less than that of his modern colleague. Thus for instance the gold objects from Dashur in Egypt show us that the Egyptian goldsmith was a master of many a technique which is still practised in the same form (at least in principle) as so many centuries ago. The value of his experiments for the development of copper metallurgy remains to be studied.

A third and most important step was the discovery of iron metallurgy and the preparation of iron from its ores. The "iron stage" meant a new series of discoveries and inventions again. For here the composition of the metal or alloy is of secondary importance. The ancients could prepare wrought iron and steel, though cast iron was probably beyond their pale and produced incidentally now and then. The different forms of iron which we know are essentially alloys of iron and carbon. By introducing a small percentage of carbon in the practically pure wrought iron we obtain an alloy which by appropriate heat-treatment can be transformed into steel. This introduction of a small percentage of carbon was achieved in Antiquity by frequent re-heating of the wrought iron in a charcoal fire between the hammerings. But the essential factors for the properties of the resultant iron or steel lay in the quenching, tempering, forging and re-heating, in short in the working of the material. The iron stage therefore means a completely new cycle of processes and operations, mainly centered on the working of the metal. The new smith of this iron stage is the smith whom the word always evokes in our mind. His stock of trade is different from that of the older smith of the "ore stage" though he has of course built up his world of knowledge on the foundations of practice and experience of the earlier type. In the Iron Age the specialisation at which we have already hinted was completed. In classical times there is a fairly complete differentiation between the miner and prospector, the smelter, who prepared the crude metal and the alloys, the work of the blacksmith (*Grobschmied*), which consisted in the making of large pieces and mass-products and the metal-

worker (Feinschmied) who shapes the crude metal to small objects, art objects and who effects small repairs.

In Homeric and classical Greece the *metalleus*, *chalkeus* or *sidereus* was still one who worked his own ores and produced finished metal objects. But in Roman times the differentiation had already proceeded very far. Mining is conducted on truly industrial scale, metallurgy is a real industry, that produces metal in bars and blocks; the blacksmith and the different types of metalworkers are common figures in Roman public life.

Apart from the different types of smiths already mentioned we meet the itinerant smith or tinker (Wanderschmied). He is sometimes a blacksmith, but more often shows the characteristics of the metalworker and is either a copper-smith or a white-smith or both. The few examples of tinkers or smith-tribes, that are nomads and who still work their own ore, may go to show that this type of smith existed before the Iron Age. That the type became general with the coming of the Iron Age is clear from many data. The typical tinker is the gypsy, whose history is full of curious sidelights on the history of metals. The Hungarians say "there are as many smiths as there are gypsies". They seem to have come from India and indeed their language is intimately related with Sanskrit. Their word for metal or iron is *saster* (compare the Sanskrit *sastra!*), copper is called *lolo* (red) *saster*, brass *dscheldo saster* (yellow iron), a typical nomenclature of a people that was originally a tribe of iron-smiths, now the typical tinker and copper-smith! We remind the reader of a similar feature in Negro nomenclature, which also shows the precedence of iron to copper in Africa! The gypsy is the typical tinker who carries his smithy, anvil, firehearth and tools along and who works sitting, a position quite impossible for a black-smith. At the same time he is the fortune-teller and the musician, a combination that is a regular feature of itinerant smiths in other regions. The Roumanians call him *calderari* or tinker, and *spoitori* or white-smith and this again illustrates the evolution of a people that left India as a tribe of iron-smiths. Still this original occupation is extremely useful for the explanation of many of the features of gypsy technique and this again shows the extreme importance of the technical background of the smith.

SCHRADER had pointed out, that there is no general Indo-European term for smith (71), but that terms were formed in the languages belonging to this family after their separation and that the introduction of metallurgy among several of these peoples occurred at a stage

when differentiation of the smith's craft had already proceeded quite far. Some of the terms for smith are connected with certain metals (*chalkeus, sidereus, smith* (from *smida*: metal?)), others point to certain operations (*kovaci*, compare the Latin *cutere*: cutting, a word that was taken over by the Magyar, the Latts and the Ethonians) and finally some which simply mean a worker, one who *fashions* (Lat. *faber*). The same holds true for the names of the smith's tools. The identity formerly claimed for the Negro terms for smith and shaman seems incorrect (15). Thus for instance the Bantu word *ngangu* means skill, cunning, art, and applies to the smith as the shaman as well!

The material given above will have convinced the reader that even the most primitive smith must have been a very skilled person and therefore CHILDE is quite correct in calling him the first expert (11) whose work was a "full time job". Though he works for the community of his tribesmen, he is unable to help them in producing food, but they have to feed him in return for the goods produced by him. The coming of the smith is therefore a social revolution, the effect of which is still visible in the regard which both parties have for each other among primitive people. It is true that the technical background on which his trade was built up has changed considerably in the course of many centuries, but it remained a factor which cannot be disregarded if we want to discuss the social and religious status of the primitive smith. There may be something in the saying that "the smith has always a spark in his throat", but his thirst was not always materialistic and he acquired a wealth of knowledge and applied science which were of the greatest importance to the evolution of mankind.

IV

Apart from the materialistic factors and the technical background of the smith, which emerge clearly from the archaeological data, there is little to help us in describing the *social and religious status of the primitive smith*. Still the ethnographical material of which we gave a summary will help us to determine the main characteristics.

1—First of all the place of the smith in primitive society wavers between extremes. He is either *honoured or despised*, but always held in awe. We cited CLINE's opinion which is essentially true. The smith is bound to the place where he finds his ore and fuel (wood or charcoal), often for long, though he may wander away after a short time, when the surface ores are exhausted as in the case of the Asûr.

Among nomads or pastoralists he is a social outcast, there he is despised most because of his manual labour and the nomad treats him with contempt and fear, because he does not understand his trade and never will. There he belongs to the lowest castes or is simply a pariah, his name is a term of abuse. Still they suffer him, for he is useful, he forges the weapons which they use in warfare, which he is not allowed to join. If his wives and daughters practice a little agriculture or collect fruits, berries and the like, they despise them the more. But his share is a honourable one with the agriculturalists, who as a matter of course lead a sedentary life too. He forges their implements and he is the wise friend of his villagers, who come to his smithy to study him at work: he is their councillor, because he is clever, an expert who often is an important trader and go-between, often chief, village-head or councillor of kings, often priest or even a prince of the blood. Here where social life is differentiated in the extreme he is at home and the can display his influence to its limits.

This of course holds true for the sedentary smith only, for the tinker is truly despised everywhere though feared, just as the modern peasant still identifies every gipsy with a thief.

Before proceeding let us survey the interesting details of the Javanese smith given in two publications by RASSERS (62) (63).

Nowadays the smith in Java is a poor-humble man, but all the same he is still a special and honoured person. From the way in which he is treated and also from his own behaviour it is clear that the belief that his profession brings him into contact with supernatural powers has not yet entirely disappeared. The word for smith is *pande* (expert), a word used especially for the black-smith, and *empu* or *kyai* (Lord, master) as used for the armourer.

Gold-, silver- nor copper-smiths were called *empu*, but this term was formerly used in Java to denote the iron-smith in general though it came to mean armourer later. In Bali not every armourer is called *empu* but only those who forge superior weapons of magical power or those destined to be used by princes.

In ancient Java forging was veiled in mystery and since the introduction of the Javanese kris, the dirk of ancient Java, in the Iron Age (between the fourth and seventh century A.D.) a whole literature arose around the mysterious figure of the kris-smith, who often was honoured like a prince of the blood. Under the government of the princes they are said to occupy honoured positions at the court. The smith could under certain circumstances represent the entire community.

In ancient Java the rôles of smith and prince more or less overlap, sometimes their relationship is compared to that of brothers. Their genealogy like that of the princes goes back to the gods. In Bali the *ban.gsa pande* or guild of the smiths was originally a clan or genealogical group.

Even nowadays when a kris will be manufactured the shabby smithy is decorated to become a *kayon*, the stage for the performance of a masked play or sacred ground. The smith is obliged to hand the small model of a tent (*taroeb*) under the eaves outside, thereby making his smithy a *taroeb* or sacral ground and a meeting place of the community. Originally the *taroeb* was the primitive tribal temple dedicated to Banispati, the cannibalistic Lord-of-the-Forest who is also Panji, the tribal hero.

The *pandjaq* is not only the smith's assistant, but the assistant of the gamelan or sacred band is also called *pandjaq*!

The sacred offerings before starting the work on a kris are exactly the same as those of other "rites de passage", such as circumcision and wedding ceremonies. Not only are the regulations of the decoration of the smithy very strict, but the details of the fashioning of the kris and the ornamentation of the weapon are carefully fixed in tradition. The smithy is more or less the space in which the adventures of the tribal hero Panji are enacted and the decoration of the kris inevitably recalls the picture of the *kayon*, the triangular screen used in *wayang*, which represents Panji or Banispati. Shape and motifs used for damascening the weapon have acquired special significance and so every wearer of a kris has chosen his weapon a shape and *pamor* most suitable and auspicious!

2—It is clear that the early smiths were organized either in *castes* or *guilds*. Among nomads and pastoralists we mostly find smith-castes which are always endogamous. The smith-caste lives apart in seminomad tribes in a special quarter. They are often members of aboriginal subjects or strangers without rights but often members of the same tribes without any anthropological or ethnological distinction. Among the agriculturalists the stress lies on the guild-form of organization, but the smiths often retain traits of their original clan organization. Even here they often form a proud endogamous line of families with long genealogies who ply their trade from father to son. The pupils are initiated, a rite sometimes even applied to strangers and strong links bind masters and pupils. Their pride often culminates in their claim of royal blood. The trade secrets are jealously guarded,

ethics are very strict among the guild-brethren and their number is often limited. Gradually the guilds of gold- and silver-smiths, copper- and bronze-smiths separate from the iron-smiths, who are generally held in higher esteem as they forge the weapons and implements. Even here the iron-smith is seldom at the same time a warrior, he remains at home to look after the supply and repair of arms. Sometimes the smith-clan also embraces members who are leather-workers, wood-carvers or who ply any other trade.

3—The smith is always a mysterious figure, whose work apart from being a continuous source of wonderment to the primitive tribesman, is generally bound by traditional rites and ceremonies. The *ritual of the smith's craft* is generally determined by the religious systems of their fellowtribesmen. The primitive societies hold that many processes can not be carried out by anyone, at any time or in any circumstance. The operatives should be in a state of ritual purity and as it is essential to ensure this various ceremonies and abstinences may be necessary. The Bambala iron workers consider it impossible to smelt iron without the medicine which they say transforms iron ore into iron. The principal person therefore is the "iron doctor", who has jealously guarded knowledge of the different medicines. The work is carried out in spring only! During the work the smelters live in temporary shelters in a state of strict taboos. They may not enter their own home, nor shall their wives wash, anoint themselves or put on ornaments that would attract the attention of men, e.g. they are to remain in the same state as bereaved widows. The men moulding the kiln for smelting the ores are not allowed to drink any water (68)! This example is typical for many other taboos and rites. Practically every operation such as the lighting of a kiln, the starting of a new piece of smithing, etc are carefully regulated and they should be accompanied by certain offerings or ceremonies. This even covers the digging of the ores. Especially sexual taboos are prescribed all over the world. The smith has to avoid the company of women; no woman, more particularly pregnant woman shall enter the smithy; the workers often work naked. The fire shall be kept pure, for does not the god who gives the smith power reside in it? The earth-fire is his assistant and the invisible power that helps him to smelt the stones and transform them into metals. The fire shall always be kept burning and shall be purified by regular offerings. Religious hymns are sung during the work, and the connection between the smith and music is one of the most interesting themes of the many legends and myths.

4—The smith is often identified with the magician or priest as is evident from the examples which we have cited; even the nomad who despises and fears the smith always considers *the power of the smith* awe-inspiring. Does he not possess the power of the medicine-man as he transforms the ores into metals? He must possess “strong medicines”, often he is considered to be the only one, who should be allowed to touch and work the “dangerous stones”. The power of the expert is soon expanded in different directions in the mind of the primitive tribesman. He is often depicted as a great warrior, a magician, a robber, a merchant and he acquires important social functions such as magician, master of the ceremonies in secret societies, etc. His power is derived from the spirit-world with which he is in constant contact. In European legends he learns his craft from higher beings, dwarfs help him, the gods visit him or his power comes from the “swarze Meister”, the devil, and he takes part in the “wild hunt” of the spirits of the dead!

His power is also evident outside his craft. According to Philon of Byblos the ancient Phoenician author Sanchuniaton says that his countrymen called the iron-smith *chorosh* which also meant “magician”, probably because of the intricacies of iron metallurgy and his knowledge of the secret manipulations and necessary rites to purify the “new, unclean metal”. In ancient Java (10) the smith bears the same title as a priest. One of the most renowned magicians of ancient Java, who floated on a leaf from India to Java and who understood the art of making gold, was called Loh-Gawé, that is the Sanskrit *lobakara* (metal-worker) rendered in Javanese. And nowadays the Protestant minister is often honoured with a title closely related etymologically to the Javanese word for smith. Javanese literature abounds with wonder-tales of the smith, whose sakti (mana) is considered to be enormous.

His curse is very effective and biting. “It is expensive to buy off the curse of a smith” as the Negro saying goes. He has special powers to detect thieves and to ban the devil. Because of his relations with the spirit world he can see into the future and he often prophesies from the slags of his furnace or the charcoal. He has healing powers, especially if his line has practised the craft for generations, he can prevent illness by hardening men like his iron! A special trait is the power of the blood of the smith. This plays a large part in several rites, for instance in the special ablutions necessary when one marries the daughter of a smith. Spilling the blood of a smith is a dangerous

thing, it is followed by a curse which only blood can wipe out, and killing a smith can only be attempted by one who possesses considerable *mana*.

But often his personal power is not considered sufficient for the work. The Ba-Ila say that the efficiency of smelting operations depends on the ritual purity of the smith, the power of the fore-man of he smith or iron doctor and his medicines; the Pangwe ascribe the success of these operation to the power of the ancestors, the spirits of the fire, the magic of the plants and herbs, that are often added to the furnace for reasons of the "sympathetic magic" type and the strictness with which the sexual taboos have been observed. The smith is also considered to be dependent on the power of the metal and his tools.



Fig. 23. Smithy in ancient Egypt. Simple furnaces heated with bellows, with baskets of charcoal. Removing crucibles with molten metal. Part of a casting mould in the righthand corner, 1400 B C (from the grave of Rehmire; WRZESZINSKY, *Atlas*, I, 316)

5—*The power ascribed to the smith's tools is considerable.* An old Dutch rhyme says that "to touch something in the smithy, to taste something in the chemist's shop, and to read in a book of legends and ghost stories, can be dangerous". As we saw, it is often said that the tools do the work, not the smith. This applies especially to the smith's hammer, which is often "loosened" by special rites. When making the hammer, it should not be touched before it is ready. In Angola the hammer is worshipped because it is connected with the earth-spirit, as it forges the adze and other agricultural implements. It is treated as a prince and fondled like a baby. The hammer is worshipped all over the world, it is the symbol or implement "par excellence" of the thunder- or fire-god, viz. Thor's hammer. The Evhe smith of Togo talks of his tools as "the hammer and his family". The bellows are often worshipped, even by tribes who have no smiths, and hung in the fetish-house. The anvil plays a large part too, for are not

powerful medicine and curative mixtures "forged" on the anvil? An oath on the anvil is considered to be particularly binding and many a magical rite of the smith is connected with the anvil. The furnace also plays a part. The building is often accompanied by imitative rites. Two children are placed in the new furnace and crack beans to imitate the crackling fire, so that the furnace shall burn well later on. When building it special taboos are observed.

Below it are buried medicine or some sacrifice (often an embryo!) to make it more efficient. The smith shall never give his tools away, lest he die!

6—Still more *powerful is the metal* itself. This belief dates back to the period before the smith when mankind learnt to know the native metals gold, copper and meteoric iron. The awe for these "special stones" only grew when the smith learnt to smelt, melt and cast them.



Fig. 24. Metalworkers at work in the grave of Ipu-im-re, 1400 B.C.
Note the use of the blowpipe (WRESZINSKY, *Atlas*, I, 153)

In this respect we consider the awe for the power of the metal primary and the belief, that metals were endowed with a particular power because of the miraculous transformations that attended their manufacture, as a secondary factor in the wealth of beliefs.

The Negroes thought that the metals possess inherent mysterious qualities either by virtue of their hardness and brightness when found native or by the effects of the smelting operations. This latter belief in the power of the metal as a "condensate" of the power of the smith is later. A very general belief is that fashioning a new metal may bring along an epidemic to man and beast or a failure of crops (15).

The power of the metal is ascribed to its connection with the earth, it is produced from a stone by fire. The metal is no less than a piece of earth purified by fire, a piece of earth charged with *mana*, earth of great potency. They who produce or handle these stones charged with *mana* should possess *mana* themselves lest they incur all kinds of dangers. The spirits of the earth and protectors of the metals should be propitiated when digging the ores, a belief that is still strong in fifteenth century mining and later. These charged stones

from heaven (meteorites) and earth carry along part of the power of the element from which they sprang. This is why both mining and metallurgy have always had strong religious traits until very recently. The fire plays a large part in these beliefs, especially the earth-fire, that brings forth the metal in the womb of the earth. These charged stones have the regenerating powers of the earth, they are less transitory than other stones. They are born from the earth and are still born everyday! The legend of the growing metal is a very persistent one, which lived until recently and played a large part in the world of the alchemists. Just like everything that came forth from the earth the metals possess the qualities of regeneration, growth and propagation. The sexuality of the metals is a very early belief that is not yet dead. By "marrying" male and female ores metals are born, these too have a gender and the "marriage of the metals" is a special feature of medieval alchemy. This belief in the gender of ore and metal reaches back to Babylonian times and possibly earlier, it created an organic cosmos, which was generally reshaped by the reasoning of modern science into a world of laws and mechanical processes.

Metals like the earth from which they sprang were subject to the cosmic laws of birth, growth and death. We read in a Chinese book, that when the people were ordered to dig for gold in the T'ung-t'ing mountains, the metal assumed the shape of a cow which fled over the crest of the range (32). Death and resurrection was their fate and the smith, who worked these "charged stones", performed a rite full of secret dangers. As he conjured the metal out of its ore with the help of the fire-god, his patron, he interfered with the harmonious growth of the metals in the earth. Perhaps the sacrifice of an embryo when building a furnace has the meaning of an expiatory offering, giving one life for the other, or should we read in it the "charging" of the metal with the budding life of the embryo? Purification and sacrifice were necessary when interfering with the processes of Mother Earth, abstinences and purity of the officiant necessary. The smithy was a temple of the spirits of the earth and the fire; the smith a priest who by certain rites could accelerate or cause the birth of the metals, the furnace an altar on which the rite was enacted. The belief in the growth of the metals led to the idea of their transmutation, inherent in our mind to the doctrines of alchemy. Every metal was gradually transferred to the highest state of perfection, gold, by the care of its mother, the earth. Men could accelerate this process under certain circumstances. But the idea of transmutation is a late one and even

the doctrines of the gender and growth of ores and metals may not be as old as they are sometimes believed to be. But it is certain that the belief that metals were bearers of power, earth charged with mana, was very old. The rarer the metals were the more powerful (43)!

Later these doctrines were extended by connecting certain metals with planets and gods and colour symbolism was introduced into the theories. The astrological theory of metals is probably not older than Neo-Babylonian times, though the connection of certain metals with gods may be older. The theories about colours connected with certain metals are older too, at least in part. This may be due to the fact that ancient nomenclature was often devised on the colour of the metal or alloy as we shall have occasion to point out. Gold for instance is of old the metal of the sun, it has the power and life-giving properties of the sun. Masks for the dead are made of gold and the Egyptian king rewards his faithful subjects with the "gold of victory".



Fig. 25. Smiths in the grave of Ipu-im-re, 1400 B.C. Use of the blow-pipe and the bellows. A crucible of molten metal is lifted from the fire (WRESZINSKY, *Atlas*, I, 153)

But the field of study of this subject still lies fallow, at least for the objective student. A mass of literature exists on the subject that is written in a spirit of enthusiasm, bias and ignorance rather than in a cool and critical state of mind. These questions of symbolism especially the interpretation of pre-Hellenistic texts belong to the most intricate problems of the history of religion and only a thorough knowledge of the texts and the world in which they were written, in which these beliefs grew and flourished, will really help us. It will be seen, that many of these magical beliefs and rites go back to the times when primeval man believed that by following the example of the cosmos he could attain more power and become perfect. But there are also traits that go back to the technical facts behind the craft of the primitive smith. In different beliefs in the power of smith and metal we retrace the struggle between the world of the Stone Age and the new world of the Metal Age. We think of the part played by the different metals in magic, especially in the taboo of

several metals in certain rites and ceremonies (for instance the unhewn altar of Jos. 8 : 31 or the circumcision rite). We also see the struggle between the worlds of bronze and iron, especially in the strange rôle of iron in certain rites. It should not be used for certain magical ceremonies, or it is expressly mentioned to give protection over other metals. It bans devil and witch, horse-shoes are used against evil spirits, a knife thrown into a whirlwind will strike the demon who inhabits it; iron may give protection or even invulnerability against rain, illness or even abortion. In short, iron protects against the demons and spirits of the Bronze Age, but it should never be used when evoking these powers.

Thus the use of certain metals in magical rites is a sure proof of their antiquity, the frequency with which a metal occurs in these rites an indication of their relative age. "Late" metals like tin and zinc are practically absent from magical precepts. But this leads us from our subject and lest the reader becomes like "the smith's dog that sleeps at the noise of the hammer and wakes at the crunching of teeth" we must revert to our original theme.

v

This survey of the powers of the smith should be completed by a summary of the *gods and heroes of the smith* though it belongs rather to the domain of the history of religion. Many decades ago ROSIGNOL (66) collected much evidence in a rather forgotten but excellent book which gives much information on semi-mythical smiths-tribes, demi-gods and gods of the smith and though much of his interpretation will no longer stand in the light of modern evidence, we at least owe it to him to have pointed out and studied this very important material which is not yet exhausted by far!

Among the historical smith-tribes the *Chalybes*, the classical smiths of Pontus are prominent. The discovery of iron is ascribed to them (AISCH. *Prometheus* 714; STRABO XII c. 549; PSEUDO ARIST. *De mirab. auscul.* 481). They are said to descend from Ares (HEROD. I. 28) and live in the region south of Trebizond, Sinope and Amisus, in the country of the iron-ores. Probably they are the tribes that make iron for their Hittite masters and later for their new masters the Mossynoeci and Chaldaioi (XENOPHON *Anab.* IV. 3. 4; V. 5. 17; CYROP. III. 2. 7).

The *Tibareni* (Tabareni) are probably identical with the Tubal of the Bible (69). This people comes together with the Mossynoeci as

a Thacian-Phrygian tribe from the Balkans, but whether there is any historical evidence to prove that they were smiths is still an open question. Probably their fame was partly due to the Chalybes who were their subjects. This is certainly the case with the *Mossynoeci* (Muški), the later masters of the Chalybes. There is nothing of the smith about the Tibareni as the classical authors describe them, on the contrary they are said to be a care-free and gay people (HEROD. III. 94; XENOPHON *Anab.* V. 5. 2; DIODOR 14. 30. 7) that lived partly in the Pontic plain, partly remained like the Muški, their kinsmen, in Cilicia after the Cimmerian migrations, which broke their power as the hereditary enemy of the Assyrian kings.

Semi-mythical and partly historical are the legends about the *Telchines*. They consist of seemingly historical traditions of smiths that peopled Crete, Rhodos and Cyprus (from the continent of Asia Minor?), but these traditions have been greatly overgrown by traits of demon-smiths, powerful magicians with the "evil eye", who could change their shape at will and who were not always the friends of mankind. They were often connected with the sea in later time. Four namen are often given, Aktaios, Megalesios, Hormenos and Lykos, who are said to have been born from the blood of Uranos. They belong to the sphere of Rhea, the mother of the Cretan Zeus. Crete is often called Telchinia! But it is very doubtful whether these pre-Greek figures belonging to the sphere of Rhea and Zeus, really hail from Crete; it is more probable that their original home was Phrygia or at least the continent of Asia Minor. For the historical part played by Crete in the evolution of metallurgy is far less important than the legends of Greece would have us believe, they may be founded on the fact that many metallurgical achievements may have come to that country from Crete. According to WISSOWA the words "chalkos" and "telchein" go back to the same root, that is probably of Asiatic origin (50) and connected with the Old Norse *dfelch*, dwarf. It may be that the Telchines represent old gods or spirits of the Bronze Age pushed back from prominence by the Olympians.

Prominent among the mythical figures are the *Dactyloi* who were the first discover and forge the iron of the mountain-valleys. They too seem to belong to the sphere of the Cretan Rhea (DIODOR V. 64-65), though there are other traditions that bring them from Phrygia (PLIN. *Nat. Hist.* 7. 57). Mostly five male and five female figures are mentioned. They come from Crete to Samothrace and Olympia, in which latter place they are worshipped together with

Heracles. They are not only skilful smiths but also musicians (PLUT. *de musica* c. 5, 8. 3). They have many traits of the European dwarfs and elves, who protect and watch their treasures in the mountain-caves, work gold and silver and forge iron into steel. They serve mankind by forging implements for house and field. But the European dwarfs seem more than the Dactyloi, for are they not imbued of the characteristics of the old nature-, earth- and death-demons and at the same time half-buried memories of older cavedwellers who forged and raised cattle, of aborigines, nomads, Finns, Celts and Gypsies?

The *Curetes* are their kinsmen, whom HOMER described as a tribe of Aetolia. Later they are said to be the children of the Dactyloi. They belong to the followers of the young Zeus and are also said to have accompanied the child Dionysos in Phrygia. The myth of their shield-dance which saved the life of the child Zeus is well-known. Later they are said to have discovered the manufacture of arms, especially in Euboeia. They were also worshipped in Ephesos and Priene, but they are soon absorbed by the Corybantes, who came from Eastern Asia Minor as their orgiastic traits show.

In close connection with the smith stand the *Cyclopes*, thunder-storm- and fire-demons, often connected with volcanoes, smiths and metalworkers of great skill. They were worshipped in the Peleponese, Corinth, Argos, Thrace, Rhodos and Asia Minor, some legends tell that they were killed by Apollo who is also said to have killed the Telchines. They are the smithing assistants of Hephaistos, who are afterwards located with him in the Etna. They are often pictured with traits of satyrs (pointed ears, etc.).

As in primitive times all craft is sacred, the evolution of smithcraft had great influence on creation myths and we find smith-gods or fire-gods among all peoples of Antiquity. Everyone will recall Agni, Vulcan and Hephaistos and perhaps also the Babylonian Girru. Brahma as a blacksmith creates man and the Michoacans of Mexico believed that they were created from metal by a smith-god. The Toradja's of Celebes have a subterranean smith-god, called Langkoda ("the Lame"), who tests the souls of the Toradjas as to their "quality" and the Smith of the Upper World (*Proeë m Palaburu*, the Lord Creator and at the same time the Great Physician) reforges the souls that have failed (7)! In the R̥gveda Indra is the smith of the gods and the Avesta recognizes the Amēneshpēt Kshatra Vairya as the genius of the metals. But the god of the smith, often the god of the earth-fire is a typical example of an ambivalent god, both a saviour

and a demon. Loki guides the hand of the blind Hodur when he kills Baldur, just as the smith Kedalion guides the blind Orion and a Jewish legend says that Tubal-Cain guided the hand of the blind Lamech when he murdered Cain, Adam's son.

Vulcan is the most debated of the two classical smith-gods (2) (65) (78). The French school of CARCOPINO and TOUTAIN make him the god of the Tiber who later on inherits traits of Hephaistos, others see him as an old Roman god of the fire as the destroying and purifying element, who later on becomes the god of the smith-fire. But he is also the god of the earth-fire (PLINY *Nat. Hist.* 2.240) and he is worshipped with the vegetation and earth goddess Maia, perhaps because of the fertility of the volcanic ashes. The arms of the conquered enemy are burnt in his honour. Then he appears as the divine smith of the tubae for the Tubilustrum and he adopts the attributes of Hephaistos, felt cap, hammer, tongs and apron. His cult in Ostia is very old, but he has been coupled in vain with the Etruscan Séthlans who is far more like Hephaistos and works at Populonia like Hephaistos at Lemnos. His son Cacus is nursed at Praeneste by the Digidii (Dactyloi!) and the Etruscans tell that he forged the lightning.

One does not find these traits in the oldest texts on Vulcan and ROSE (65) therefore is inclined to believe him to be a god that came from the eastern part of the Mediterranean, a god of the earth-fire, who has similar traits as Hephaistos, who also hails from these regions. But Vulcan must have come to Ostia at a very early date.

The figure of *Hephaistos* is better understood. His home country seems to have been the Phrygian-Carian region, more specifically the region of Phaselis and the Lycian Olympos (PLIN. 2.106) where he manifests himself as a god of the earth-fire in the many burning gases and where he was worshipped of old. He was also at home in Lemnos, Naxos and Samos and came to Athens with the Carians or the Pelasges where he was "married" to Athene. He is often pictured on the coins of Asia Minor, but he is hardly ever shown as a crippled man, which he is according to every legend. His assistants are the Dactyloi and other dwarf-like figures who forge steel in the fires of the mountains. Hephaistos is not the smith who forges the sun at dawn as MANNHARDT claimed, but a fertility god of volcanic nature, the god of the earth-fire. The Hephaistos of Lemnos was originally the lover of Kabiro, the earthgoddess, who had accompanied him from the East. KINATHON calls him a cousin of Daedalos and HESIOD marries him off to Charis or Aglaia (both earthgoddesses) but it was HOMER who claimed his marriage with Aphrodite. The wild, elemental side

of his nature remains much longer with than with other gods. Still in the Iliad (18.369) he is entirely the divine smith. Sometimes, for instance when the fire is carried out into the world during the Hephaistia he shows some traits in common with Prometheus.

He has also much in common with some of the *supersmiths* of the legends like Wieland or Vönundr, Mimir, Ilmarinen and many others. Wieland is lamed to keep him, Hephaistos limps like Vulcan. But the Amazones used cripples as leather workers and copper-smiths and many craftsmen are said to be cripples in Antiquity. Just as Jacob is lamed in his struggle with God, Hephaistos is lamed by Zeus. But he is generally represented (if so) as having only one lame foot, though the legends say that he is lame on both. The most beautiful of all the legends of supersmiths is that of Ilmarinen who forges the metal vault of the high sky and the magic weapon *sampo* in the Kalewala (runes 8 & 9). Much remains to be done in further studies of this chapter of the history of metalworking.

VI

The discussion of Vulcan and Hephaistos have led us back to our original plan of describing at least in outline the gradual social evolution of the smith from clan to caste and guild. Having surveyed his early status in primitive societies and the characteristics of the early smith we must now discuss the meagre data on the story of *the smith in the civilisations of Antiquity*.

We shall start with Egypt because Greek writers always stress their identification of Hephaistos and Ptah, the creator-god of Memphis. The first to do so was HERODOTUS (II. 3) and many followed. He was said to be the son of Nilus, to have reigned Egypt and some authors like JOANNES MALALAS and JOANNES ANTIOCHENUS even contend that he learnt the Egyptians to forge iron weapons. But Egypt did not come to use iron generally before 1200 B.C.! DIODOR (I. 12-13) even calls him a fire-god. Sometimes the name Hephaistia is used for Egypt (HOPFNER, *Fontes...*, pp. 301, 673).

This identification is made on very loose grounds. Ptah is first of all the divine creator and earthgod, later on he becomes the patron-god of all craftsmen, more specially of the carpenters and smiths. But all the important texts such as the famous Shabaka-text represent him in his creative function only.

Now and then Ptah is called the "creator of all handcraft" (AR III. 28) and he is said to have formed "the mountains, the beautiful precious stones and great mighty monuments". There is also the ex-

pression "electrum from the mountains and native gold from ... the workshop of Ptah", but this does not help us very much to understand the Greek point of view. A very curious text is HERODOTUS III. 37, where we hear of an image of Ptah in the temple of Memphis which is "a figure resembling that of a pigmy". Usually he is represented in mummy form. Perhaps we have a similar image on a cippus of the British Museum of the Ptolemaic period (B.M. 36250) where Ptah is shown as a dwarf on top of a staircase! Perhaps we must see here as well as in the Herodotus text some foreign influence that worked under the impression of the Hephaistos legends.

In the same passage HERODOTUS mentions a temple of the Kabeiri at Memphis, where there were images of the "sons of Ptah", the Knumu (*hnmw*) dwarfs with short legs and long arms. The *hnmw*

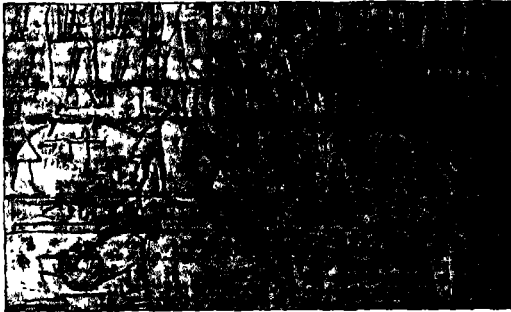


Fig 26 Goldsmiths in the grave of Ti, about 2800 B.C. Heating the metal in a furnace with blowpipes. Beating gold leaf. The undermost row shows dwarfs at work (WRESZINSKY, *Atlas*, III, 34)

are sometimes called the children of Ptah but more often the children of Re, they are said to have helped Ptah to fashion the world. We do not know much more about them. When talking of the *hnmw* one thinks of the representations of dwarfs on Egyptian reliefs, where they work as gold-smiths. As long as they are represented with long arms and crippled legs we have to do with crippled workmen, but in the case of pictures of real dwarfs there is no reason to think that the Egyptians used dwarfs as smiths to prevent them from running away or because they had especially strong arms! The combination smith-dwarf is known in many countries and may be a reminiscence of the earliest smith who may have had short stature as a mountain people working in the mines.

Metallurgy was an early art in Egypt and the silver- and goldsmiths

were exceptionally clever. Perhaps when we read in WEILL's study on the word *bi3* which originally meant "copper" but also came to mean "something rare, curious or wonderful". we may infer that we find here something of the astonishment of the primitive man for the products of the first smiths (82).

It was formerly often stated that one of the invasions in prehistoric Egypt was that of "the smiths of Horus", but this thesis of MASPÉRO rested on the wrong translation of the word *mšntyw* which has nothing to do with smiths but means "harpooners". But unfortunately this story is still found in many a handbook where it serves to prove the originality of Egyptian metallurgy!

It is strange that we know practically nothing of the metal-workers of ancient Egypt themselves. Whereas the ordinary metal-worker does not seem to have been respected any more than his fellow craftsman (24), the goldsmith seems to have formed an exception. Though he is as little his own master as any other craftsman and though even the goldsmith of the vice-roy (in the New Kingdom period) has to ask his master for leave to attend a feast for Amon, they seem to have enjoyed more respect from the higher classes. Generally speaking, the goldsmiths and chiefs of the gold smiths have fathers and brothers exercising the same trade, in the same way as the craft of the painter or sculptor seems to have been handed down from generation to generation in the same line. Under the Old Kingdom the smiths (or perhaps only the gold- and silver-smiths) formed a guild that worked under the supervision of the temple. It was thought until recently that this guild was presided by a priest with the title "high inspector of the artists" (*wr hrp . w hmw . t*) but this is now doubted as JUNKER has argued very plausibly (APAW, 1939, No. 23, p. 29) that we should read this title *hrp hmw . t Wr* (Atum!) and that therefore the high-priest of Ptah in Memphis bore the title of "inspector of the artists of Atum" and was not the chief of all the smiths in Egypt. Though there is no sign of centralisation of the smiths, many priestly titles show their importance.

We also read of metal-workers (ERMAN-GRAPOW's dictionary has *bi3 . ti*: Erz-arbeiter) but apart from a few texts without much information this word is not used. It seems to form part of a surname sometimes, thus in the papyrus Abbott someone bears this name with the suffix *p3 h3rw* (the Syrian). But EERDMANS is not right in saying (20) that we see only pictures of gold- and silver-smiths on Egyptian reliefs, for though they are rarer we know of pictures of copper-smiths, the casting of copper and furnaces!

We do not know neither what the esteem was in which the smith was held in ancient Egypt. One should not believe the words of the papyrus Sallier (2.4.6): "Never did I see a smith as an envoy or a gold smith with a mission, but I saw the smith at work in front of the hole of his furnace. His fingers were like the hide of a crocodile and he stank of the spawn of fishes", for we read here a song of praise of the trade of the scribe. It reminds us of Eccl. 38.28: "The smith sitting by the anvil and considering the ironwork, the vapour of the fire wasteth his flesh and he fighteth with the heat of the furnace: the noise of the hammer and the anvil is ever upon his ears, and his eyes look still upon the pattern of the thing he maketh" or of Is. 44.12: "The smith with his tongs both worketh in the coals and fashioneth it with hammers and worketh it with the strength of his arms; yea, he is hungry, and his strength faileth, he drinketh and is faint". But here too the prophet is apt to exaggerate the fatigues of the smith's work.

Nor is there known very much about the smith in ancient Mesopotamia. A Sumerian term for smith, SIMUG, is written with a complex sign that is made up of two others, viz. that for "smith's fire" (FALKENSTEIN No. 325, which author calls it a smelting furnace, though the pictograms very clearly show the picture of a basin with burning charcoal as used by the smith) and that for "foreman". It seems certain that the word smith meant "foreman of the smith's fire", which we can compare with the later Accadian *nappâlu*, which literally means "one who blows the (smith's) fire".

The smith in ancient Sumer was not a free craftsman; he was linked closely to the temple-state economy that characterizes this ancient civilisation. He belonged to the GIŠ-KIN-TI (craftsmen), who were controlled by a priest-smith called SANGU. During Urukaginna's reign he was even elevated to the higher rank of SANGU-GAR. So he was a bondman and remained so for many a century. Even the Codex Hammurabi (par. 274) ordains that the smith shall receive a lower pay than the peasant, because he is only a *muškênu*, a bondman, controlled and fed by the temple. This does not mean, however, that he was a slave. He was only controlled by the temple authorities and received his raw materials from them to obtain his wages in return for the finished goods. We hear that the temple-state had central storehouses called AZAG-AN distinguished by a suffix running "place where ... is kept" where the imported metal and other goods were stored. Here the smith came to receive his assignments and the necessary raw materials (70) to work them at home in his smithy. In return of the

finished goods he received his pay. Several contracts between the store-house keepers and the individual smiths have been found. As we shall see this system persisted even after the smith had become a free man again. We hear about a town called Dûr-gurgurri (BAD-TIBIRAKI) that was founded by Sin-iddinam of Larsa and which seems to have been an old Sumerian metallurgical centre as the name means "fortress of the copper-smiths". Its location is unknown but it flourished for many centuries as it still figures in the correspondence of king Hammurabi, when transports of wood-blocks for the metal-workers are mentioned (VAB VI, No. 54) and when it is the scene of an inquiry of bribes taken by officials (VAB VI, No. 17) from the tribute of silver. Unfortunately its exact location is unknown, but its excavation might yield interesting results.

In the reign of king Hammurabi and his successors the old temple-economy of the Sumerians broke up. The temple-guilds seem to have declined and though they still have a certain religious prestige they have a difficult time which grows worse in the Cassite period when the guilds break up into guilds of free craftsmen. A great change is wrought by the dissolution of the Hittite Empire about 1200 B.C. under the pressure of migrations of peoples from the Balkans. The monopoly of iron manufacture which this empire had for several centuries was broken and many a craftsman and iron-smith was driven from his home in Asia Minor. Already in the days of Hammurabi we read of " $\frac{1}{3}$ mina of copper-ore(?) (*erêm*) which they have added for the Subartan" (CT VI, 25), which probably means that there was a smith or metal-worker from Subartu, the mountain region to the north working in Mesopotamia at that time. In Assyria Tiglath Pileser already possesses large quantities of iron which becomes quite common in the eighth century for the manufacture of weapons and clamps for architectural purposes. Then of course Mesopotamia must have possessed its own iron smiths, though we can not expect any smelting on a large scale in these river-valleys without sufficient fuel and ores, but there seem to have been blacksmiths and metal-workers (79). They remained valuable craftsmen and Sennacherib mentions expressly that he carried off the smiths of Babylon and Nebuchadnezzar did the same with those of Jerusalem (II Ki. 24 : 14; Jes. 24 : 1; 29 : 2).

There was already much specialisation by those times. We hear of the *nappâhu* or black-smith and the *gur-gurru* or metal-worker, the latter executing more delicate work like casting, chasing and embossing; while the jeweller or gold-smith is called *nappâhû hurâsi* (KUG DIM).

We know little of the religious status of the smith in Mesopotamia. His patron-god was Ea, who is the patron-god of all craftsmen, later on special patrons of every craft were created and the fire-god Girru became patron of the smiths, and the goldsmiths. Some time ago HROZNY pointed out that the oldest Fara texts (27th century B.C.) gave the following version of the name of the hero Gilgames: "(dingir)gišGIBIL.GÍM.MES" which means "the man of the fire and the axe". This might stamp the national Sumerian hero as the patron of all those who work metals and wood, e.g. smiths, goldsmiths, carpenters, etc. (36). This interesting suggestion, however, remains to be proved.

The later dynasties have kept the old system of central stores of raw materials which were given out to the smiths for refining and working. If we take for instance Assyrian letters of the Sargonid era (722-626 B.C.) we read (HARPER, 1194): "We have seen, we have examined what was placed in the house of the scribe. We have smelted 23 minas of aššapi gold together with the alloys, it has been worked up into foil, according to the measure which the king commanded, Then it was locked up." Another letter runs (HARPER, 114) "During the month of Tishri the gold that the abarakku official, the court secretary and I examined, viz.: 3 talents of refined gold, 4 talents of unrefined gold, was placed in the store house of the chief of the danibe-workers (metal-workers); he has sealed it. May the king issue orders to the abarakku chief and the court secretary to open up the gold, the beginning of the month being favourable, let them give it to the artisans, so that they may proceed with the work". But there is always some danger in this system, for (HARPER, 1317, K. 5397) "The iron which the king my lord gave to the smith for the work was sold by him to certain merchants of Caleh... they are not willing... five minas they are giving. Having taken courage they will bring it down below", so after all there seemed some chance of recovering the stolen iron. But even at that time there was a lot of red-tape for (HARPER, 91, K. 620): "In regard to the wooden building wherein the iron is stored which is in the palace of Aššur and about which the king my lord wrote. I have interviewed prefects, city magistrates and elders. (They say) "the district chief tears down and rebuilds. In as much as he manages the affairs of the palace he is bound to repair the cracks and should roof the building. But if a rafter decays the city magistrate of Aššur should repair the damage." Now (I am telling) the district chief to gather my helpers, he is willing. I shall replace

those rafters which are weak. This year is far advanced but by the month Shebat the king my lord can come and give orders."

We have already seen that the dissolution of the Hittite Empire accounted for the wandering of many Pontic smiths over the Near East. Otherwise the quick spread of the working and use of iron at that time would be much less intelligible. It is logical that these groups or clans of iron-smiths were not allowed to immigrate everywhere. As far as we can judge from the meagre data the frontiers of the bigger states like Egypt, Assyria and Babylonia were officially closed against these immigrants, whom the inhabitants of these civilised countries would hardly have distinguished from the wandering bands of marauders in these troubled times. Therefore the earliest signs of these iron-smiths are found with the nomads of the Syrian and Arabian desert, where they were the ancestors of the typical tinkers which we find at the present time in Arabia. These iron-smiths possessed a mass of lore and knowledge quite different from that the copper- and bronze-smiths who were already at home in the towns of Syria and Mesopotamia for many a century.

The Kenites of the Bible must have formed a group of these ironsmiths driven from their homesteads, though we would not contend that there were no Kenites before 1200 B.C. or perhaps other bands of tinkers outside the Hittite Empire, but the majority will have spread over this region after the fall of the empire. EERDMANS has published two studies on the Kenites (20) (21), these despised and feared smiths and tinkers of the desert.

The nomads of the desert were those who despised them most, for the Hebrews treated them with much more sympathy. EERDMANS proved beyond doubt that they were tinkers, who did not belong to the nomads but who were originally at home in towns, who lived in the oases at that period and only took to nomad life much later. In the Old Testament they live in the North (Judges 4 : 11) and in Amalek (I Sam. 15 : 6), the Rechabites were their kinsmen (I. Chron. 2 : 55). Their name is derived from Qain, which means "smith" (Gen. 4 : 22). In this passage the original Hebrew text reads "a hammerer, an artificer in copper and iron". Then we saw that Tubal has some connection with the Tibareni of Pontus but not with the Persian *tûbâl*(slag) (GESENIUS) or with the name of the god GIBIL (now read Girru) (PARTINGTON). They were mainly iron-smiths, who worshipped a thunder- and fire-god in Sinai and EERDMANS suggests that the sympathy between Hebrews and Kenites was caused not in

the last place by their god, who showed some traits of the God who gave the Israelites the stone tablets. Moses takes the daughter of Hobab the Kenite as his wife in the land of Midian that was rich in ore, so that here again the Kenites live in a country where they could get the ores which they required as good smiths. They seem to have worn a tribal "sign of Qain" by which their god protected them against evil spirits, in the same way as modern Arabs use such signs. The despise in which these "townsmen" were held by the true nomads is well expressed in the story of the shepherds and the daughter of Ruel the Kenite (Exod. 2 : 17). But the Hebrews were not their enemies, the tribes seem to have intermarried freely. Even the later Rechabites who lived in tents were looked upon with friendship as a tribe who lived in a way that was not quite according to the Law, as a type of Nazirites, who prohibited strong drink and wine and who did not practise agriculture. By then the Kenites have already become the wandering desert-smiths which DOUGHTY described so lively (*Travels in Arabia Deserta*, I, pp. 137, 278). If they are said to raise cattle even in the older periods, this can of course not be taken as a proof that they were nomads.

But these smiths were of the greatest importance to the nomads, for they alone forged the iron weapons, which helped the nomads to attain that superiority over the bronze-using troops of the civilised states into which they carried their raids. The superiority of the Hittites, which seems to have been due largely to the possession of iron and other superior weapons, and also the domination of Palestine by a handful of Philistines seem to have been due to their excellent smiths. For "there was no smith found in all the land of Israel, for the Philistines said, lest the Hebrews make them swords and spears!" (I. Sam. 13 : 19).

The gradual evolution of the tinker to the state of a true nomad, did not heighten the respect of the desert tribes for him, he remained despised as the smith of the Somali or Masai or the Jewish smiths of the Faladshas of Abyssinia. But he had become a necessary part of the tribe, may be despised but suffered and even held in awe. His status is a strange one. In every camp (25) there are one or more families of smiths, who stand outside the Bedâwîn community. They are generally "strangers from the Euphrates country or Iran". They marry among themselves or very occasionally with slaves, but they are never permitted to take a bedu woman. These smiths work for the camp as a whole, shoeing horses, making swords and repairing rifles.

In summer they receive their fee based on the number of horses to buy clothing, grain and other supplies for the ensuing year. They take not part in raiding and are not attacked by raiders. Their losses during raids are recovered by their fellow-smiths in the enemy tribe and usually they get some of the profits of raiding.

Nothing is known of the smith of the Indus civilisation, but in Hellenistic India we find that the craftsmen and tradesmen are mostly associated in guilds. Some crafts like mining, gold- and silver-working and the manufacture of arms were government undertakings (76).

The manufacture of arms and agricultural implements were probably wholly in the hands of the state, and the craftsmen employed by these government factories received food and wages for their labour.

The factories for the working of base metals were supervised by the "inspector of the base metals" (*Lobâdhyakṣa*), a central authority for urban workshops and those in the country. But on the royal domains the *śitâdyakṣa* supervised the smiths who worked there and saw to it that their work was properly done. Therefore, there does not seem to have existed a strict centralisation, but the situation that most of the country smiths obeyed another authority than the urban smiths is wholly in the line of the Arthacâstra, the leading manual of state-craft of the times.

Still from Buddhist texts we learn that not all the smiths were employed by the state, as they seem to have lived in villages too and to have fashioned agricultural implements freely for their brethren. These smiths seem to have been placed under the supervision of the local authorities.

In Homeric society (77) metals still take an important place in private fortunes (*Odysse* XIV. 321) and the smith was an important person, but in classical Greece we already find specialisation of different branches of metallurgy even going as far as specialisation in different types of arms. Between the sixth and fourth century B.C. hours and markets were fixed for metal products in the different Greek towns and in the course of our discussions we will be able to mention many important metallurgical centres of Hellenism.

In Republican Rome different types of independent smiths are known to exist, for instance they buy the crude metal of the Elban mines and work them up to products which they sell again to merchants. They seem to have been organised in guilds, for PLINY says (*Nat. Hist.* 34.1): "In the distant past, a guild of copper smiths was third among

those established by Numa" and PLUTARCH mentions this guild as the seventh of ancient Rome. Every large city in the Roman Empire had its smiths that worked the blooms of iron into tools and implements for some of the local needs. Rome, for instance had a local guild of smiths (*fabri ferrarii*), but also several individual ferrarii and the guilds contained a lot of specialists apart from the ordinary iron-smiths. At Milan there was a very large *Collegium Aerariorum* of twelve centuries of members and that of Brixia (*Brescia*) had an unusually large number of members too! Aquilea too counted many smiths among its inhabitants for it was deeply interested in the mines of Noricum, where Roman state contractors lived, but only few fabri.



Fig 27 In the workshop of Hephaistos, after a Greek vase (after BLUMNER, *Technologie* etc)

But at various centers large production with slaves must have prevailed if we look at the few inscriptions of individual ferrarii.

In the Imperial period Italian metal industry shows a generous investment of capital and far-reaching division of labour.

At Puteoli it would be incorrect to speak of iron factories. Undoubtedly there were establishments of slave-worked forges under one roof which specialised in certain articles for a wide market, but the products carried no trade-marks! A dealer and wholesale merchant is mentioned in an inscription. At the iron mines of Noricum it is more likely that there was something approaching a factory system prevailing. Noric iron had a good name all over the Roman world, but always as a blade or tool, not as the ore or unworked wrought iron.

But again plain kitchen utensils and farm implements require the service of many individual shops. These copper- and iron-smiths combine the functions of craftsmen and salesmen, often melting down

articles of stock to supply material for immediate need. Even at Capua where silverplate manufacture was more or less a factory system, the production of iron implements was often conducted in small shops and in Rome we found many individual iron workers. Terra-cotta tablets of the oldest tombs at Ostia mention ironmongers, cutlers, etc. At Pompeii there were many retailshops or iron-ware probably supplied from the factories of Puteoli and Capua.

Thus in our survey we found that the characteristics of the primitive smiths have disappeared in the civilisations of the Ancient East and that later on, we find guilds of smiths with little to distinguish them from other craftsmen and little of the original peculiar social and religious status. Only the tinkers of Arabia and their ancestors, the Kenites and other itinerant smiths of Antiquity descended from the Pontic smiths still have some of these characteristics. The other smiths have evolved from clan and caste to guild and the individual smith would have disappeared in the factory system of the Later Empire had not the Dark Ages and the Middle Ages put a stop to this process and returned to the smith some of his original individuality and craftsmanship!

What the smith gained in individuality and craftsmanship in the Middle Ages and after was largely lost again in the Industrial Revolution and the great social revolution that accompanied it. We all know what happened after that and how the old rhyme:

"I heard that Smug the smith for ale and spyce
Sold all his tools and yet kept his vice"

has come to be only too true! If to pursue the study of the ancient smith further would mean understanding the factors which determined this great change better, this alone would already make it worth while to amplify and to go more deeply into the outlines of his craft and his social and religious status sketched above. But even without such an important return "a good peice steil is worth a pennie".

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SOME IMPORTANT CLASSICAL PASSAGES

- STRABO VIII, c. 355; X, c. 462-474; XII, c. 549; XIV, c. 654.
 DIODORUS SICULUS V, 49, 55, 65, 70.
 PLINY, *Natural History* VII, 57; XXXVII, 170.
 PLUTARCH, *de musica* c.V, p. 8. 3.
 PS. ARISTOTLE, *de mirab. auscult.* 481.
 XENOPHON, *Anabasis* V. 3. 4; V. 5. 17; *Cyropaedia* III. 2. 7.

CHAPTER FIVE

TOOLS AND METHODS OF EARLY METALLURGY

Behold, I have created the smith that bloweth the coals
in the fire and that bringeth forth an instrument for
his work. (Is. 54 : 16)

Four things are essential to the early metallurgist, viz. ores, fuel, blast air and tools, furnaces and crucibles.

The *ores* were mostly plentiful and of good quality in the Ancient Near East; we will have occasion to discuss them and their deposits when we deal with the different metals known in Antiquity.

But the *fuel* was often rather a problem. For the quantity and above all the quality of the fuel determine to a large extent the temperature attained in the furnace and this again is largely responsible for the possibility of working certain ores and of using certain processes. In other words the fuel determines to a certain degree the melting and smelting activities of the early smith.

In this respect ancient metallurgy was seriously handicapped for the production of coke from coal which gave an excellent hard and well-burning fuel for the reduction of ores in large quantities is a recent invention. Coke was not used for metallurgical purposes before the end of the eighteenth century, at least on a large scale. However, charcoal was an excellent though relatively expensive fuel which burned well and was capable of reducing ores, though it was not hard enough to bear heavy loads of ore and therefore charcoal-burning furnaces could never attain the size of modern smelting appliances.

In ancient Egypt charcoal was available to the smith. It was extensively burned in the eastern desert and the Sinai peninsula which accounts for much deforestation in these parts. Samples of charcoal have been found in Early Dynastic tombs at Naga el-Deir, in a First Dynasty tomb at Saqqara and in the storerooms of the pyramid temple of Menkaure. Though charcoal was found in Sinai too, this may be charred wood, the latter being the original fuel. The "charcoal furnace" found by PETRIE at Tell El-Amarna (*El-Amarna*, London, 1894, p. 26) is rather unconvincing, its construction is loosely described and it belonged to a glass factory, while the author later said that straw was used in this factory.

But the existence of charcoal, the Egyptian *d'b.t* (Coptic *djèbbes*, *djèbes*) is well attested and a special measure for this fuel was used, the *g'ir* (ERMAN-GRAPOW, *Wörterbuch*, V, 206).

On the other hand it is also certain that wood was used in ancient Egypt as the texts mention *ht.n.sdt*, literally fire-wood (ERMAN-GRAPOW, *Wörterbuch*, III, 340). BAUERMANN found remains of mimosa wood as still in use in modern iron smelting of the natives of Cordofan and tamarisk wood makes excellent fires, as does accacia wood and that of the nabak tree.



Fig. 28 Gathering brushwood for charcoal manufacture in Palestine
(after DALMAN, *Arbeit und Sitte*)

THEOPHRASTUS tells us that the Egyptians "use the roots of the papyrus plant instead of wood for burning, for the wood is abundant and good" (*Hist. Plant.* IV. 8.4.) and their "smiths use the root of the sari grass, for it makes excellent charcoal because the wood is hard" (*Hist. Plant.* IV. 8. 5). This root of the sari grass is a producer of good hard charcoal which burns with an intense heat, as does accacia charcoal.

Other fuels available to the Egyptians were straw, chaff, animal dung, reeds, rushes and sedges. Though most of these were used by the potter and other craftsmen, the metallurgist used chaff for certain smelting operations, for, as STRABO remarks (III. 2.8. c. 146): "gold is preferably melted with chaff-fire, because the flame, on account of its softness, is suitable to a substance that yields and fuses easily; but the charcoal fire consumes much of it, it overmelts the gold and carries it off as vapour". STRABO's theory looks rather fishy!

Grass and camel dung are used by the modern fellahin, they are collected by children and dried in the sun to flat cakes, which form an inferior fuel, that was certainly known in Antiquity too.

Portable charcoal fires are depicted on ancient Egyptian reliefs. The use of olive wood and charcoal made from it is mentioned in late Hellenistic Gnostic papyri. These charcoal fires easily attain a temperature of 900° C., and the temperature can be raised by the application of blast air, it was therefore eminently suitable for the production of small quantities of metal and it served the skilled Egyptian goldsmiths well.

In ancient Mesopotamia charcoal was known from times immemorial, as powdered charcoal was even used as a pigment in prehistoric pottery. The charcoal called *pêntu*, though used early always remained expensive in a treeless country like Mesopotamia. The most common wood used for the manufacture of charcoal was *šarbatu*-wood, which is almost certainly either styrax wood or a similar gummy wood. It was cut up into logs (*kurû*) in the hot month of Api and the logs were not bound up in bundles but stored under hides, if they were not used for the manufacture of charcoal immediately.

There is an interesting letter in the correspondence between Hammurabi the king and his servant Sin-idinnam on the fuel supply, reading (BM 26.234): "... Wood for ... the metal workers they shall seek for you in Dûr-gurgurri and there where there are more (metal workers); then they shall cut for you 7200 logs of ... wood of a volume of 10,20 and 40 cubic centimetres (?) and of a length of 1 m, 1.50 m and 2 m. Every lot of 300 logs shall be loaded into a freighter and ... brought to Babylon. Among the fire-wood that will be cut, there shall be no wood that died in the forest. They shall cut green wood only. This fire-wood shall be brought quickly lest the metal workers sit down with empty hands."

On the other hands date-kernels were used by the smiths as a substitute for charcoal, for STRABO says (XVI. 1.14): "The bronze-smiths use the stones of the fruit (of the date-palm) instead of charcoal." Thorny shrubs called *asâgy*, which were found in large masses in the desert were also used and probably the chopped straw or reeds and the camel dung still used as a cheap fuel when burning lime or making pots nowadays in Mosul served just as well in Antiquity. Neither was the fuel-supply plentiful in ancient Palestine.

At present the storax tree and wild almond tree are no longer cut for fuel but other wood is cut freely. In the Old Testament fire-wood

'êšîm is often mentioned, though it seems to have been scarce on occasions (II Sam. 24 : 22; I Ki. 19 : 21), and the glowing embers (*gahêlet*) are often mentioned as equal to charcoal. This live ember (Prov. 25 : 22, 26 : 21; II Sam. 22 : 9, 13) is different from the charcoal called *pehâm* (Prov. 26 : 21) which is prepared in heaps and is used by the smith. Only the fire transforms it into live ember. Then dung and hay or chopped straw (*kaš*) (Ez. 4 : 15, Matth. 6 : 30) were used, the remnants of olivepressing (*gêphet*), kernels (*gal'inîn*), thistles and shrubs (*sîrîm*, *hamâsîm*) also served for burning.

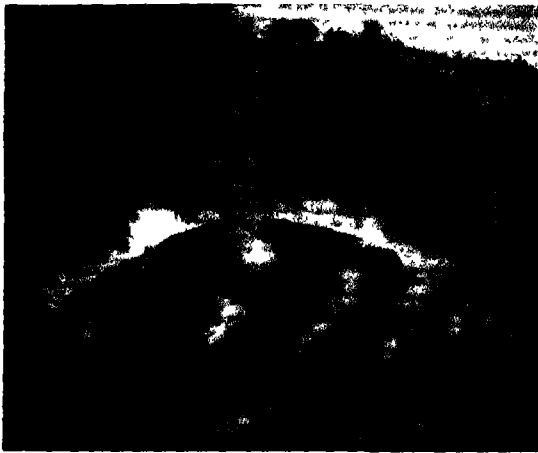


Fig 29 Burning charcoal-heap in Palestine
(after DALMAN, *Arbeit und Sitte*)

In the classical period charcoal remained the principal metallurgical fuel. We have several reports on its manufacture from classical authors, such as PLINY (*Nat. Hist.* 14.122, 127; 16, 38, 52) but none is so well-informed as THEOPHRASTUS whose description is not only correct even for present conditions but his arguments on the properties which a good metallurgical charcoal should have are quite sound and could hardly be improved. We will therefore quote the relevant passage from his *Enquiry into plants* (V. 9) in full.

"The best charcoal is made from the closest wood such as the holm oak, for these are the most solid, so that they last longest and are the strongest; wherefore these are used in the silver-mines for the first smelting of the ore. Worst of the woods mentioned is oak, since it contains most mineral matter (ash!) and the wood of older trees is inferior to that of younger, and for the same reason that of really old

trees is especially bad. For it is very dry, wherefore it sputters as it burns; whereas wood for charcoal should contain sap. The best charcoal comes from trees in their prime and especially from trees which have been topped, for these contain in the right proportions the qualities of closeness, admixture of mineral matter and moisture. Again better charcoal comes from trees in a sunny dry position with a northern aspect from those grown in a shady damp position facing south. Or if the wood used contains a good deal of moisture, it should be of close texture; for such wood contains more sap. And, for the same reason, that which is of close texture either from its own natural character or because it was grown on a dry spot, is, whatever the kind of tree, better. But the different kinds of charcoal are used for different purposes; for some uses men require it to be soft; thus in the iron-mines they use that which is made of sweet chesnut when the iron has already been smelted, and in silver-mines they use charcoal of pine-wood; and these kinds are also used by the crafts. Smiths require charcoal of fir rather than of oak; it is indeed not so strong, but it blows better into a flame as it is apt to smoulder less: and the flame from these woods is fiercer. In general the flame is fiercer not only from these but from any wood which is of open texture and light, or which is dry; while that from wood which is of close texture or green is more sluggish and dull. The fiercest flame of all is given by brush-wood; but charcoal can not be made from it at all, since it has not the necessary substance."

"They cut and require for the charcoal-heap straight smooth billets for they must be laid as close as possible for the smouldering process. When they have covered the kiln, they kindle the heap by degrees stirring it with poles. Such is the wood required for the charcoal-heap."

"For the crafts requiring a furnace and for other crafts various woods are servicable according to circumstances. For kindling fig and olive are best, fig, because it is tough and of open texture, so that it easily catches fire and does not let it through, olive, because it is of close texture and oily."

In another passage he adds (III. 8, 5, 7): "The scrub oak gives poor wood for burning charcoal as does the sea-bark oak ... The wood of the Turkey oak is even more wretched for burning and for making charcoal for the charcoal is entirely useless except to the smith, because it springs about and emits sparks."

Furthermore he discusses the manufacture of tar as a by-product of the production of charcoal (IX. 2. 1).

PLINY recommends the use of wood from coniferous trees, cypresses of terebinths for the manufacture of charcoal in the passages mentioned above, but he is mainly concerned with the manufacture of tar and similar products.

In Populonia SIMONIN found the remnants of oak and chesnut charcoal. STRAKER found birch, oak, hazel and maple charcoal on Roman smelting sites in the Weald, and he gives further information on the fuel of post-Roman metallurgy.

The charcoal-heap or pile (pit) is called *Meiler* in German and *myt* in Dutch, words both derived from the Latin *meta* (a cone-shaped heap) and thus here is another proof that little has changed in the method of charcoal-burning. Charcoal and wood were the two popular types of fuel in the classical world and charcoal had the advantage of being more concentrated "heat". As PLINY expresses it (*Nat. Hist.* 36, 201): "It is only when ignited and quenched that charcoal itself acquires its characteristic powers, and only when it seems to have perished that it becomes endowed with greater virtue." It was exported from production centres like Magna Graecia and Macedonia, Mt. Ida and Gaul to many other quarters of the Roman world, where the price was usually carefully regulated as was the sale of fuel. We have a good example of the regulations from Delos (*Inscr. Délos*, 509).

It is often said that many regions of the Ancient Near East were deforested by the cutting of the trees for the burning of charcoal, but this is largely exaggerated. Of course the fuel supply for the metallurgical centres was an important factor in this process, and as STRABO says (XIV. 6.5): "In ancient times the plains of Cyprus were thickly overgrown with forests, and therefore covered with woods and not cultivated. The mines helped a little against this since the people would cut down the trees to burn the copper and the silver and the building of the fleets has further helped...." But there are certainly other and more important factors that stimulated deforestation and one of these was formed by the numerous goat-herds kept in the Mediterranean region since Antiquity. It can be said without exaggeration that the goats have denuded many a fertile region in Greece, Malta and other parts of the Ancient World. Still in the neighbourhood of mines charcoal burning must have done much damage. On the island of Elba the best iron ore of the Roman world was found, but the local wood and charcoal had apparently already given out before the Empire and the ore had to be transported after roasting to Populonia to be

smelted there, where wood and charcoal could be easily obtained from the Ligurian mountains. PLINY complains that "the effect of the shortage of fuel on the roasting operation is particularly noticeable in Gaul, where the second roasting is carried out with charcoal instead of wood" (*Nat. Hist.* 34, 96) and he also comments on the shortage of fuel in Campanian metallurgy (*Nat. Hist.* 34, 67) and therefore there is some truth in the statement of the effect of metallurgy on deforestation. But the supplies of wood and charcoal remained plentiful in Antiquity even if cheap local resources may have given out and smelting continued to use these fuels for many centuries without difficulties except perhaps somewhat higher charges on the fuel bill.

According to THEOPHRASTUS (*de ign.* 37) briquettes were also made in Antiquity by pressing together charcoal, pitch and tar, the latter serving as the cementing medium. It is not known whether these briquettes were ever used in metallurgy, but this is improbable.

A similar exceptional case is the furnace mentioned in the apocryphal "Prayer of Azaniah" (written after 170 B.C.) which is said to be heated with naphtha, a fuel which was also used in certain baths of Byzantium, but which is not known to have been used in metallurgy until very recently, for special metallurgical furnaces.

There are, however, different members of the coal family which are mentioned as fuels by the Ancients. BAILEY in his note on the gagates mentioned by PLINY (*Nat. Hist.* 36.141) says that "Theophrastus (*Lap.* 23-28) gives an account of quite a variety of minerals from Thrace, the Lipari islands, Sicily and Liguria, all of which burn, an account which leaves the writer in no doubt that, in addition to asphaltic materials, some varieties of coal were known to the ancients" though their inflammability when moistened with water and the subsequent quenching with olive oil is a fable of course.

There are some references to lignite such as the passage in THEOPHRASTUS' *Lapidary* (16): "Those products of mining which are called carbo (anthrax) are found as earthy stones, they can be kindled and burn up wholly like charcoal. They occur in Liguria and in Elis on the road over the mountains to Olympia. These coals are used by the smith" and DIONYSIOS APHRUS refers to "an earthy and sulphurous mass, like coals, which the smiths and inhabitants of Britain use to a large extent as fuel". They do not seem to be true coal as DAVIES supposed. At Velem St. Vid there is certain proof that lignite was used in the metallurgical processes.

There is, however, no proof that peat was ever used, though it is

mentioned by TACITUS (*Annals* 13.57) and PLINY says (*Nat. Hist.* XVI. 1): "The Chaucians collected mud with their hands dried more by means of the wind than by means of the sun and therewith warm their limbs which are stiff because of the northern colds." It would have been of little use. But in the case of true coals we have certain proof that they were used by the metallurgists of the classical world. Its value was not appreciated quite fully by the Romans and they neglected such coal-fields as Esterel and Clermont-Ferrand in Gaul. Owing to its impurities (especially sulphur!) it was always a bad substitute for charcoal until coking was discovered in the eighteenth century and the noxious substances could be removed to obtain a fine, hard fuel. But coal was used for domestic purposes in provinces where it occurred in surface outcrops especially in Britain. CUNNINGTON gave quite a list of references of finds of coal in the remains of Romano-British villas which go to show that in Roman times coal was certainly used and even transported over rather large distances probably by means of packhorses. This coal was often found in association with iron slags and it was apparently used for smelting lead at Pentre.

After surveying all the archaeological evidence obtained in Roman Britain we can say that in most places where coal crops out within the Roman area it was worked more or less systematically in Roman times. This exploitation was most systematic in the civilised south-west, where Somerset coal came into extensive use even among the poor and secondly in the military north where Tyne-valley, Cumberland and Scottish coal were regularly used in the frontier-forts. The coleries of the Wall districts were no doubt under military control, but we have no evidence as to the control and management of the others. From the association of coal and iron slags it would seem that coal was used in smelting iron though not frequently.

Summing up our evidence we must conclude that charcoal was and remained the principal metallurgical fuel in Antiquity and that wood was also used extensively. In the Near East certain local fuels were certainly used as they are nowadays and in some Roman provinces coal seems to have been used to some extent. Once the different types of furnaces are known in detail it will be interesting to measure the temperatures obtained with these fuels in the ancient kilns, as such figures would go far to help us to understand the metallurgical processes, usually described so loosely by the ancient authors.

The third important factor in ancient metallurgy, the production of

blast air, still is more or less a mystery. Blast air was not necessary for all metallurgical processes, but only for those that required high temperatures or when larger quantities of ores were smelted. There is no doubt that the simple means of raising the temperature of glowing charcoal such as the fan and the blowpipe belong to the oldest tools of the smith. Both are still widely used with charcoal fires all over the world.

The fan is known in different forms and it has gradually been mechanised. But however elaborate mechanical types of fans or fan-

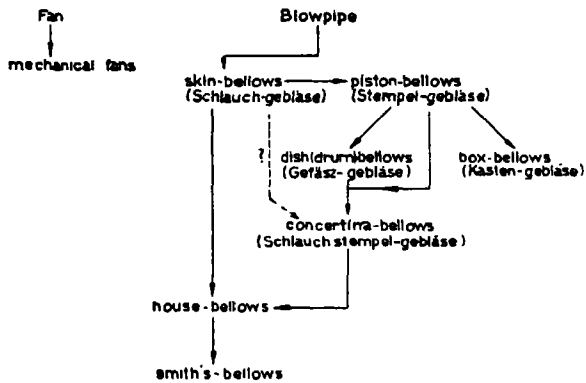


Fig 30. Evolution of the means of producing blast air

like apparatus were developed, none of them would have more effect than a good natural draught and for many metallurgical purpose it would be of no use. The fan was, therefore, more and more used for air-conditioning and similar applications for which work it was better suited. We find it in use in primitive mines, etc. but less and less in metallurgy.

The blowpipe was far better suited for the work of the smith. It gave a stronger air-blast which could be directed on the exact point of the fire where it was wanted. It raised the temperature of the glowing charcoal far better and it was eminently suited for the work of the goldsmith and the jeweller, for which purpose (granulation-work, etc.) it must have been used very early, for the oldest Egyptian pictures of blowpipes often occur in scenes depicting the work of

goldsmiths. BERGSØE's studies have shown what primitive South-American Indians were able to do with this simple instrument. In Egypt the blowpipe is depicted on Old Kingdom reliefs, one of the best known pictures of this instrument is found in the Fifth Dynasty tomb of Ti at Sakkarah (G. STEINDORFF, *Grab des Ti*, pl. 134). The Egyptians probably used metal pipes with clay tips, possibly also reeds like the Sumerians and Babylonians. The New World seems to have known the blowpipe only, Mexican and Inca smiths never seem to have developed any form of bellows. For the evolution of the blowpipe, which is too small and too clumsy for larger fires, led to the invention of bellows. The clay-nozzle or tuyère at the end of the older types of bellows conducting the concentrated air-blast into the fire. can be more or less regarded as the condensed survival of the old blow-pipe, the rest of the bellows merely forming an evolved form of better and larger form for producing the necessary volume of air. These tuyères have often been found in ancient smelting furnaces or on smelting sites, and though they have often been disregarded they form certain evidence that blast air has been used (12). The ethnological evidence and theories on the evolution of the bellows have been neglected by the archaeologists, but we must necessarily draw on them to supplement the very meagre archaeological data.

Several authors, especially FOY (8) and KLOSEMANN (15), have traced the evolution of the bellows. By general consensus the earliest form of bellows was the *skin-bellows* (Schlauchgebläse) formed by sewing together the skin of an animal (often a goats' skin), attaching the pipe and tuyère to one of the leg and using a slit with two wooden rims as the opening for introducing fresh air into the bag. This is, according to all authorities, a very old form evolved in the Near East, but more probably in Western or Central Asia. It is the form described by the ancients (Iliad XVIII, 468) (VIRGIL, *Georg.* IV. 171) (LIVY 38.7) (HORACE, *Sat.* I. 4.19) (THEOPHILUS III. 82-84). For though CLINE says that the skin- or bag-bellows admits little variation it is certainly the parent of all modern forms of bellows. FROBENIUS was of the opinion that two categories of bellows were evolved from these primitive forms, viz. the wooden forms of Asia (pump-bellows, box-bellows, and drum-bellows) and the typical African drum-bellows, in the latter case because the climate of Africa is not suitable for a long life of leather or skin forms (11). He regards the pump-bellows as the typical Malayan form, the box-bellows as the Far-Eastern form and the wooden dish- or drum-bellows as the East-African form,

possibly introduced under Malayan influence. But his theory is sketched rather rapidly and without due attention to the facts and we think that FOY, who studied the problem in detail, gave a more consistent story (8) (17).

The skin- or bag-bellows was according to FOY the oldest form, evolved in Central Asia and the Near East. As practice demanded a constant supply of air, two or more pairs of bellows were used, each smith working one pair. Are we not told about Hephaistos' forge that "through twenty pipes at once forwith they poured their diverse-



Fig 31 Primitive skin bellows of the Gypsy-smiths according to KOPERNICKI

tempered blasts" (*Iliad* XVIII. 468)? And does not the Pythian priestess describe the smithy at Tegea with the lines:

"There is a place, Tegeë, in the level plain of Arcadia,
Where by stark stress driven twain winds are ever a-blowing,
Shock makes answer to shock and anguish is laid upon anguish."

(HERODOTUS I. 67)?

These old skin-bellows came to Africa and Europe from the Near East, not as LUSCHAN contended from Africa to the rest of the world. They are depicted on ancient Greek vases and they are still used by primitive tribes in Africa and India. They are the typical bellows of the Gypsies.

A second group of formes was evolved from the *pump-bellows* (Stempelgebläse), a type akin to the bag-bellows and probably evolved in Southern or Eastern Asia. The blast air is forced into the tuyère from a wooden or bamboo cylinder in which a piston is moved up and down. Here again, two cylinders are worked alternately to maintain a constant stream of air. It is found in the Far East, Farther India, Malaya and Indonesia and in East-Africa as far as the Islam penetrated from the coast, for instance up the Zambesi river. One form with *horizontal pistons* belongs to the Far East and was elaborated and mechanised to form the *box-bellows* or "tatara" of the Japanese and Chinese. The second type with *vertical pistons* is still

characteristic of Farther India and Indonesia, but it occurs in Burma, India and Madagascar too.

The *dish- or drum-bellows* form an intermediate form between the bag- and the piston-bellows. This form, probably developed in Central Asia or India on the border of the region covered by the two primary types, spread over the Near East to Africa, where it is still the domi-

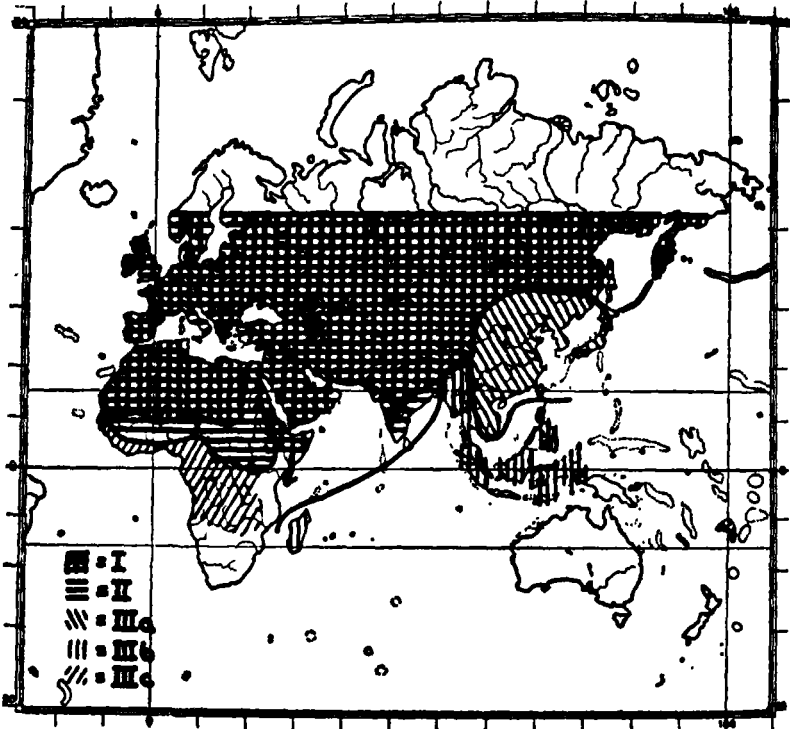


Fig. 32 Types of bellows and their distribution according to KLOSEMANN I: Original skin-bellows, leather. II. Dish-bellows, intermediary form, partly in clay IIIa: Far Eastern box bellows (late wooden form) IIIb: Malayan piston bellows (late wooden form). IIIc. African dish-bellows (late wooden form)

nant type in the region of South and Middle Africa between Liberia and the Upper Nile. It consists of a loose diaphragm fitted over a solid chamber. The air is inhaled either through a slit in the diaphragm which is closed when depressing the diaphragm or else through a flue leading into the chamber. In the latter case the spout of the bellows is inserted far enough into the broad end of the tuyère to direct the blast straight into the fire, but not far enough to prevent

the intake of fresh air when the diaphragm is raised. The dish-bellows (*Gefäßzblasebalg*) is moved by a set of sticks (Africa) or with a pair of strings (Near East, India and Malaya), but in other forms the diaphragms are moved with the hands, are at the same time used to shut the slits through which the air is sucked in, which are found especially in these sub-forms.

A hybrid form that came originally from Eastern Asia (as parallels are found in Siberia!) are the *concertina bellows*, a cross between the piston- and dish-bellows. They resemble the double-bodied dish-bellows except for the larger size of the body and the voluminous skin, which encloses a large stack of rings which are drawn apart by short pistons and allowed to fall as the bellows is raised and lowered. They are found in Africa, being probably introduced from the Mediterranean lands (3). For they were introduced into Europe from Asia and there crossed with the skin bellows to form our leather *house-bellows* with an accordion-like bag expanded and collapsed between to wooden boards. Others have suggested, that the house-bellows were evolved in Europe from forms of dish- or drum-bellows. The earliest reference to these forms of bellows can be found in AUSONIUS' *Mosella* (V. 267), a poem of the fourth century A.D. THEOPHILUS (29) gives an adequate description of their construction and manufacture (III. 82-84). The dish-bellows with their wooden or earthenware chambers are now more or less African forms, showing the great ingenuity of the native smith; but they have disappeared from Europe.

The house-bellows grew larger as the volume of air necessary for smelting was increased by the evolution of iron metallurgy. In general we can say that the evolution of the bellows is intimately linked with the development of iron metallurgy. As in the Middle Ages and perhaps even in Roman times water-power was used to produce blast air, the typical *smith's bellows* were evolved. The dish bellows survived especially in those countries where leather was less common or where the climate was not suited to this material (Africa), for the same reasons the piston bellows maintained themselves in Indonesia, etc.

It might seem from these lines that the evolution of the bellows is quite clear, but only the outline can be barely traced as we possess very few details on the bellows of Antiquity. Probably much material is still buried in texts and in the pictures of reliefs, vases, etc. but no adequate study of the subject has yet been made. Most authors mention that bellows were known in Egypt in the XVIIIth dynasty but

they leave it at that or they simply take the date of that dynasty as the date of the invention of these apparatus without ever looking at the details of its construction which undoubtedly point to a much earlier date for its conception. For it may be true that the earliest pictures of bellows are found on the walls of XVIIIth dynasty tombs, such as those of Rehmire (P. E. NEWBERRY, *The Life of Rehmire*, pl. XVIII) and Menkhepherrasonb (N. and N. DE G. DAVIES, *The Tomb of M.*, pl. XII), but these are dish-bellows, probably with earthenware chambers and a skin moved by strings. The assistants of the smith stand upon the top of the chamber and seem to have closed the slits in the diaphragms with their feet when pushing it down. However, the details are not clearly visible and we might also suppose that the blast air is blown into the tuyère from some short distance leaving a space through which the fresh air can be sucked into the body of the bellows by lifting the diaphragm by the string, a method which we have already described as still used in Africa. Anyhow, the forms of bellows shown here are far from primitive forms and they must have had quite a long history behind them. How long, we do not know, for there are no other pictures to guide us at present neither from Egypt nor from Mesopotamia. The blow-pipe is certainly used in the earliest historic times in Egypt and the Old Kingdom texts have the expression *rkḥ šdt* (fanning, blowing the fire) (ERMAN-GRAPOW II, 458) (compare the Coptic *rokḥ*, *rakhe* and the Greek *anthrakia*, a coal-fire). Another very old Egyptian word *hwt* (fireglow, blaze) (ERMAN-GRAPOW II, 485) is related to the Coptic *hôt* (blow-pipe, bellows, but also vent, see the Greek *physetér* in Job. 32 : 19 and HERODOTUS IV. 2) or the Coptic *hoi n. nift* (bellows) (the Coptic *nife*, *nift* being the Egyptian *njj*, *nf*, wind, air). But no Egyptian term for blow-pipe or bellows is known notwithstanding the pictures we possess of these apparatus!

Bellows are mentioned in the Bible, once directly in connection with lead-smelting (Jer. VI. 29) and twice indirect (Isa. LIV. 16, Ezech. XXII. 21), but the smith is traditionally called *nappah*, that is the "user of bellows". But these passages do not allow us to draw conclusions on the date of their introduction in Palestine. But in Mesopotamia where the blow-pipe is certainly very old and perhaps depicted on a sign of the Uruk-period from Susa (LEGRAIN, DP, vol. XVI, p. 31), both blow-pipe and bellows are represented by terms which occur in fairly old texts. Both Accadian words are derived from the same root *nph* which means "to blow, fan(a fire), set ablaze". The blow-

pipe is called *nappahu* and we know a Sumerian ideogram for this apparatus written GI plus KA · IM (ŠL No. 85 plus ŠL No. 30) (BR. MEISSNER, *Seltene Assyrische Ideogramme*, No. 1470) which occurs in a text going back to the Kassite period (seventeenth century B.C.) at least if not earlier. This shows us that at the earliest time a reed, tipped with clay was probably used (CT XI. 47, iii.26).

The bellows were called *nappahtu* and the metallurgist and more particularly the smith was called *nappahu*, the "user of bellows" as in Hebrew. As no Assyrian or Sumerian picture of a complete bellows is known nor one found in the excavations probably as no attention was given to the remains of dish-bellows or other forms (consisting for a large part of easily corrodable materials) we must rely at the present on the philological evidence which shows that these words belong to the earliest Accadian stratum that is at least to the beginning of the second millennium B.C.

Probably a patient search on philological and archaeological lines will throw more light in near future on the history of the bellows in the ancient Near East. This is of the greatest importance to the historian of metallurgy as several techniques and especially iron metallurgy are closely related to the evolution of the bellows, without which we can not picture the smith. Of course many other techniques such as the smelting of certain copper and lead-ores were wholly or partly possibly without blast air, but the most economical processes wanted it badly and on the evidence of their development we must guess that the evolution of the bellows from the blow-pipe dates from the third millennium B.C. The evidence of tuyères found in early smelting sites had often been disregarded, but they were found near a furnace at Telloh (Ur III period, 2300 B.C.) and other early sites in the ancient Near East and Bronze Age Europe. As they either represent the clay nozzle of the bellows themselves or the clay pipes let into the wall of the furnace into which the nozzles of the bellows were introduced, they may prove that bellows were used at those periods, for at least in the latter case the use of blow-pipes is impossible.

Bellows are quite indispensable to certain metallurgical processes, thus the discovery of the production of cast-iron was the result of better and larger bellows, whereby the temperature in the furnace could be raised above the melting point of iron.

Even the primitive smith could not work without tools, but they need not be very sophisticated, for the ancient smiths produced their best work with very simple tools. When discussing the story of gold

we will have occasion to point to the interesting studies by BERGSØE on pre-Columbian Indian metallurgy and a quotation from the native author GARCILLASSO DE LA VEGA will show how in the New World too the smiths often worked with very primitive tools. In his chapter on the arts and crafts of the Incas he says: "The gold- and silversmiths had no anvils made of iron or any other metal. This was because they could not produce iron, though they had iron-mines (sic!). In their language iron is called "quillay". They use hard stones of a yellow-green colour as anvils, they polish them on each other and regard as one of their most treasured possessions.

"Neither did they possess handled hammers. They use tools of copper or bronze in the form of dice with rounded corners and of different sizes. Files or engraving needles were unknown, neither had they bellows, but they blew the fire with copper tubes of half an ell or less in length, which had a small opening at the end, through which the air was forced out with great speed. Sometimes eight, ten or twelve men were blowing the fire as required. Neither were they able to make tongs to pick the metal out of the fire. This they did with two pieces of wood and then they placed the hot metal on wet sand, which lay before them; there they turned it round and round before they dared to touch it. Notwithstanding these difficulties they produced beautiful metal-work and even objects, that were hollow inside (hollow castings!). They also knew that the vapours of metals were unhealthy and therefore they never had their smithies or smelting sites indoors but always on an open space in the courtyard."

Now the history of tools has been gravely neglected. Though FLINDERS PETRIE's *Tools and Weapons* has a large number of outlines of tools from Egypt, the Near East and Prehistoric Europe, this book suffers from the same defects as many other volumes written by this author, the survey is too general, though interesting and contains too little details to make further work possible. Only careful studies of the available data and museum pieces, such as embodied in OHLHAVER's recent work on European prehistoric tools (22) would be of any use. Here again CLINE has set an example in his book on African metallurgy (3).

The only attempt at a history of the tools in the Ancient Near East can be found in a few chapters of GOMPERTZ' *The Master Craftsmen* (London, 1933) as the data given in the works by FELDHAUS or NEUBURGER are generally untrustworthy, or no longer up to date.

Leaving aside such well known instruments as the saw, the chisel

and the adze or axe, we will give a few details on some other implements such as hammer, tongs and files.

Though the mallet was used very early in the carpenter's trade, no longhandled hammer was used in metallurgy in early Egypt. Practically all the copper and bronze objects were shaped with stone hammers without a handle. These polished stone hammers held in the fist were also used to beat gold-leaf and similar thin sheets of metal. The hammer-stone developed into the long-handled hammer, the ancestor of our sledgehammer, in the Iron Age only, when the head was also made of iron and no longer of stone. In Mesopotamia stone hammers were used originally, some beautiful small haematite hammers have been found. Later, however, copper and bronze hammer-heads were used, and as soon as commercial iron appeared iron hammers. Several objects resembling the heads of sledge hammers were found in Assur-nasir-pal's palace at Nimrud. The same sequence of stone and iron hammers is found in Palestine, Malta and Crete, but in Cyprus bronze hammers were found in a bronze factory at Enkomi.

Anvils are usually made of stone and later on of iron. Some anvils are hardly distinguishable from hammers and the nail-like anvils of Africa probably find their proto-types in the Near East. The Greeks had small hammers and large sledge-hammers, while the Romans possessed different types each specially adapted to the farriers, coopers, carpenters, and other trades, and knew several forms of adze-hammers. Many tools were adapted from the Celtic smiths.

Other important metallurgical implements are tongs and forceps. Tongs work on the hinge-principle, forceps are made by bending a piece of flexible metal until the ends can be forced to touch. Different types of tongs, forceps and tweezers were found in Egypt and they still retain their spring perfectly. Some New Kingdom examples are in the British Museum. The forceps are undoubtedly the older type, they are depicted on Old Kingdom reliefs. Round-tipped copper tongs have been found in a glass-factory at El-Amarna. In the Iron Age both types are made of iron and they become fairly common, examples from the classical world and from prehistoric Europe are well-known. Still the early metallurgist was able to work without them using green twigs or pieces of wood as the African smiths still do. Both the jointed tongs with two jaws and the one-piece pincers or forceps seem to be foreign imports in Negro Africa, even of late date (8), simple wooden forms are used very frequently as they are in primitive Indian metallurgy.

Bronze files were known in Old Kingdom Egypt, but the first iron file is that belonging to the Assyrian set of tools found at Thebes and dated 666 B.C. Bronze files were common in Antiquity but later they were quickly replaced by iron and steel files.

These few lines may serve to show that rich material is still awaiting a future student though the evidence is of more importance to the history of metal-work than to the evolution of metallurgy itself.

It is difficult to write the story of the *metallurgical furnace* for not only are data in certain regions as the Near East practically absent, but on the other hand the abundant data from other regions such as prehistoric Europe show such a welter of types and are so lacking in correct observation and detail, that one can not but wish, that many of these excavated furnaces should be studied and described again by specialists and that in such important regions as the Near East more attention should be given to furnaces and other details of smelting sites. Excavators should call in experts to review these finds, for is it not strange that we know next to nothing about these things from the actual centre of ancient metallurgy and should depend on descriptions by laymen who more than often use wrong or misleading terms for what they believe to have found. Thus for instance FLINDERS PETRIE's description of the important Gerar furnaces is not only lacking in detail, but as far as one can judge from the scant data and photographs entirely wrong. No piece of ore was ever smelted in these "smelting furnaces" and they seem to represent a "military forge" in which blooms of iron (or perhaps bars) were reheated for further forging. Now in this case WYNDHAM HULME gave the correct interpretation, but many other descriptions of other furnaces remain uncriticised by experts and their "evidence" is used in building up theories on the story of metallurgy. What we want at present is a re-examination of the existing data by experts and more expert attention to new finds.

In view of this situation we need not wonder that few have ever tried to find the threads of the story of the furnace as most writers have shunned this labyrinth and skipped over this subject with a few paragraphs of generalities. The only one who to the knowledge of the writer has tried to systematize the data on primitive furnaces is KLOSEMANN (15) but this author was misled by his theory of the African origin of iron metallurgy. Recently WEIERSHAUSEN (33) and DEICHMÜLLER (6) have summed up the data on furnaces in prehistoric Europe, but more essays of this type are needed before an adequate picture can be formed.

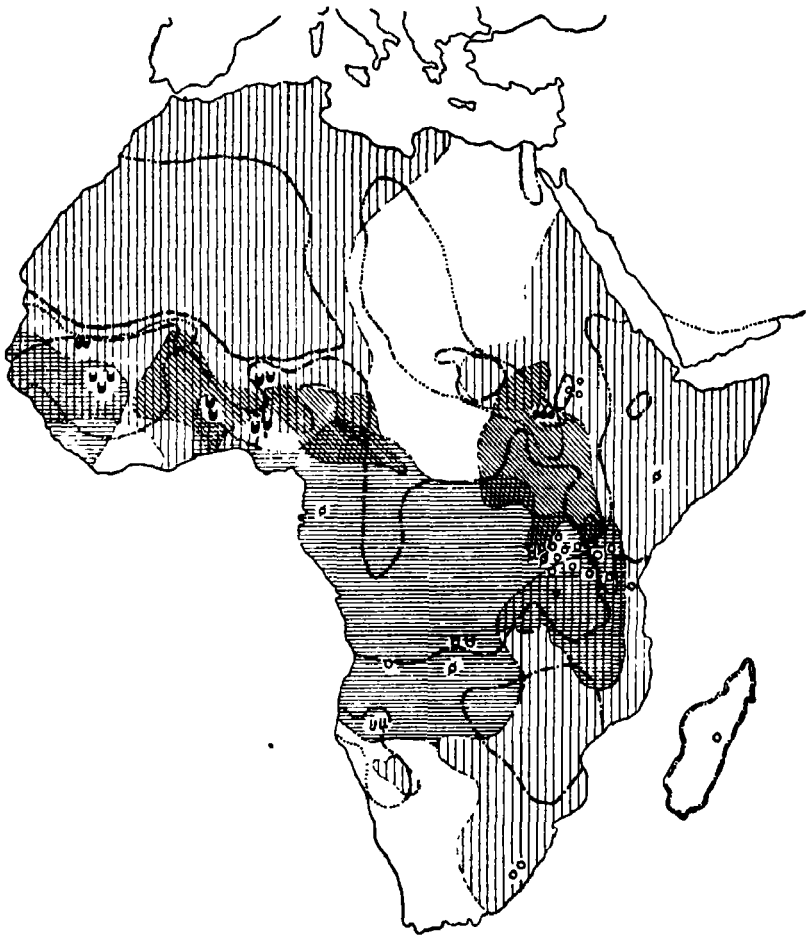


Fig. 33. Distribution of the types of bellows and furnaces in Africa according to FROBENIUS (*Das Unbekannte Afrika*)

- | | | | |
|---|-----------------------------|-----|---|
| ○ | simple hole in the ground | ▨ | skin-bellows |
| ♣ | built-up furnace | ▨ | dish-bellows (wooden) |
| ♣ | blast furnace type | ▨ | claydrum-bellows |
| ♣ | blast furnace (cylindrical) | — | smith honoured |
| ♣ | blast furnace with crucible | ⋯ | smith hated |
| u | crucible only | — } | smith honoured as an artist but outcast |

What we will give in the following lines is a very tentative picture, more or less a discussion, of some of the principles underlying the different types of furnaces with a few details on ancient types.

A furnace is a contrivance in which the metallurgical operations are carried out under the influence of heat derived from either the combustion of some kind of fuel or in modern types from the heating effect of electrical current. The temperature of such a furnace varies according to its size and purpose. A furnace consists of two essential parts: a) the fire-box in which the fuel is burnt, and b) the hearth in which the actual operation is carried out. In many primitive furnaces these two parts are actually one. Many furnaces are now built with chimneys and they are also provided with some contrivance for the production of blast air if they work under "forced draught".

We can distinguish three types of metallurgical furnaces, viz. 1) those in which the fuel and the substance to be heated are in contact, 2) those in which the ore is heated by the products of combustion, and 3) those in which neither fuel nor products of combustion come into contact with the substance to be heated.

If fuel and ore or metal come into contact we speak of shaft-furnaces or hearth-furnaces. In the case of *shaft-furnaces* the height is considerably more than the diameter and two types can be distinguished. The *shaft-furnaces* worked with natural draught do not generally yield a very high temperature, but they are used for calcining ores, burning lime, etc. They can be used for continuous work, being fed at the top while the end-product is withdrawn from the bottom. They are also called *kilns*. Similar furnaces but used with blast air or forced draught are called *blast-furnaces*. These blast-furnaces are used for the smelting of iron, copper and lead. The ancient type had a square section, but now these furnaces, especially those used for producing iron are round. The bottom is generally conical to form a well in which the metal collects. Both kilns and blast-furnaces show a great variety of types, each appropriate to some specific purpose, each of these has some special name like "rapid cupola, fire-hearth furnace" etc..

In the case of *hearth furnaces* the height is the same or less than the diameter. They can also be worked with forced draught. Here too there is direct contact between fuel and ore and the process can be guided towards an oxidising or reducing reaction. These furnaces comprise liquation hearths, finery fires, etc. They are used for the production of lead from galena, for the production of wrought iron directly from iron ore (Catalan forge, etc.) and as a smith's hearth.

The second category of furnaces, in which the products of combustion heat the ore or metal are called *reverberatory furnaces*. They are quite modern apparatus and entirely unknown in Antiquity. They are now used for many roasting, calcining and melting processes.

The third family of furnaces protects the ore or metal from contact either with the fuel or with the products of its combustion. They are all derived from the crucible. In the case of the *crucible furnace*, the heating chamber (which may be a simple crucible!) is movable. Such a process is used in Antiquity for refining gold, for producing "wootz" steel, etc. In other, so-called *muffle furnaces*, the heating chamber is a fixed part of the structure, which may for instance be used to store crucibles during the heating period. Small models are used for testing ores and metals in the laboratory since the sixteenth century A.D. Some kinds of furnaces are built to volatilize and condense certain compounds or metals recovered from the ore. These retort furnaces are especially used in modern zinc manufacture.

In most furnaces there is a certain zone in which the essential reactions take place or where the temperature is such that corrosive compounds are formed (which may again be destroyed or bound in other parts of the furnace). Such conditions determine the life of the furnace and many of the most primitive furnaces served only once. That is why we often find the remains of thousands of ancient furnaces on these smelting sites. Once, however, the furnace is built up of stone (on the inside at least) its life is considerably longer and the way is paved for the evolution of furnaces which can produce continuously. The type of stone used in building these furnaces should be carefully selected and adjusted to the peculiarities of the ore treated. We distinguish *acid* materials such as flint, ganister, sand and fireclays, *neutral* materials such as graphite and chromite and *basic* materials such as limestone, dolomite, magnesite and bauxite.

The choice of these materials depends on the gangue of the ore and it will aid the flux in destroying the effect of the gangue on the process. In the case of acid, siliceous gangue a basic lining of the furnace will be chosen and renewed after the furnace has worked for some time.

When we turn to ancient furnaces we find that this truth has been realised quite early and that their construction ranges from the very simple open-hearth-furnaces to the precursor of the blast-furnace, the Stückofen. Simple types often had a very long life if they were suited to the particular use and the rather mild demands of the early metallurgist (154), but it was realised that furnace lining lengthens their

life. Thus certain types of furnaces were developed by Illyrians and Celts and taken over by the Romans, whose simple "lip-fires" survived until the puddling process was invented in the XVIIIth century. The Romans merely increased number and size of the furnaces but they were singularly uninventive as to new types. The original bloomery fire of the Celtic iron-smiths was long in use side by side with the larger and better Stückofen or shaft-furnace, which latter type survived until the thirteenth and fourteenth century A.D. in Central Europe and even later in the North.

It is yet impossible to trace many of the older types, as we possess

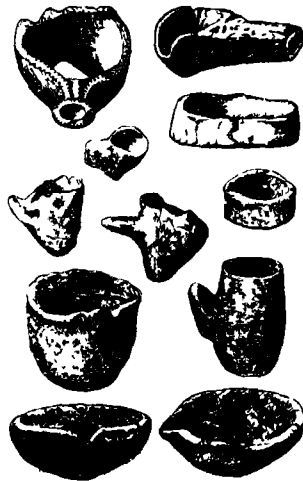


Fig. 34 Clay crucibles found in El Agrar, Spain
(after GOWLAND, JRAI, XLII, 1912)

so few data on furnaces in the Ancient Near East. GOWLAND held that two centres were responsible for the evolution of different furnace types, viz. the Sudan and Nubia and the Near East (Asia Minor). He was wrong about the former centre, the date of which is no longer believed to be much earlier than 700 B.C., but he is probably quite right about Asia Minor, which played so important a part in the technique of many metals and the mountain region between Mediterranean and Caspian Sea was probably responsible for the development of many furnace types. If we see among the scanty data such specialised furnaces at Gerar in the fourteenth Century B.C. far earlier than the development for iron metallurgy in Europe, we may regard these as a proof for GOWLAND's theory.

* The early development of copper, gold, silver and lead metallurgy

in the Near East undoubtedly led to a vast amount of experience in smelting and furnace building, so that it was comparatively easy to adapt certain types to the new smelting technique of iron. Further analysis of metal remains and slags will no doubt cast further light on the temperature and efficiency of these early furnaces, as well as on the connection between the furnaces of the Near East and those of prehistoric Europe. There are certain signs that the gradual evolution of iron smelting furnaces from prototypes destined for the treatment of copper ores took place in different regions locally. Thus there seems to be a link between the older Schmalzgraben copper furnace and the later Tarxdorff iron furnace. But the existence of pre-Roman specialised furnaces in the Near East gives support to GOWLAND'S theory of a development of the furnace in these regions and spread of its construction with the metal techniques.

A type of furnaces quite common in Antiquity is the *roasting furnace*, which was used in the case of iron ores to drive off the water and make the ore more porous and in the case of galena and pyrites to expell the larger part of the sulphur and arsenic from the ore. The most primitive roasting furnaces were just heaps of ore on fuel (wood), but in prehistoric Mitterberg long narrow buildings were used for the roasting of the copper ore, in which a bed of slag carried the charcoal on which the ore was heaped. The Romans used either large bowl-shaped hearths (sometimes even equipped with tapping channels!) and also round open-hearths. In Hüttenberg roasting furnaces and smelting furnaces were built in pairs, both being of the bowl-furnace type. Generally speaking we can say that the most suitable types of smelting furnaces were selected and used for roasting.

The most primitive and probably the original "smelting furnace" is the *bon-fire* or open hearth fire, as this was only suitable for some very readily reducible ores, we do not often find their remains, though they were long used for the reheating of blooms, etc. in the smithy. The most primitive type generally found, because it had such a long life, is the bowl-furnace, a clay-lined hole in the ground which, when blast air was used was provided with a tuyère blowing over the rim on the contents. The furnaces of Hüttenberg consisting of pairs of bowl-furnaces seem to have combined roasting and smelting in one pair of furnaces, the latter operation being conducted in the larger one. This type of furnace was very common in the Ancient Near East as it still is with many primitive smiths. It is mentioned by HESIOD (*Theogony*, 864) and it was used by the Romans side by side with,

more sophisticated types. The German bog-ore smelting continued to use it for many centuries

The bowl-furnace was the ancestor of many new types, one of which was the figure-of-eight furnace, consisting of two bowl-furnaces sunk in the ground, of which the front one seemed to have received the slag from the other. This furnace was fitted with a hood-chimney and probably the blast was not introduced at the base but continued to be applied over the rim. This type of furnace, possibly a Roman invention, was not much used afterwards

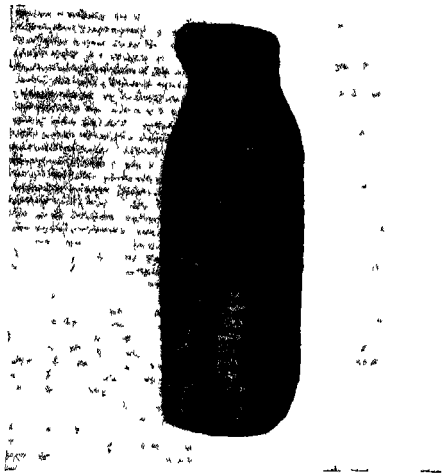


Fig 35 Bronze Age anvil found in Augsdorf near the Worthersee, Austria (from a photograph of the Museum at Klagenfurt)

The bowl-furnace was not very efficient, the chief waste arises from the total loss of the heat escaping from the zone of combustion and from the great loss of metal in the slag. Therefore, the *pot-furnace* is an improvement. The neck of the bowl-furnace was contracted so as to form a dug-in pot, blast and tapping hole were built in at the base, but the walls remained of clay, the furnace did not yet rise above the ground. This development can be traced in its different stages in Central Europe quite clearly, for instance in the earlier furnaces at Lausitz and in Silesia. In Tarxdorff a special hour-glass type is found, consisting of two chambers above each other, of which the top chamber serves to hold the bloom, the lower chamber collects the slag. Other varieties of this Tarxdorff furnaces were found at other sites. The pot-furnace seems to have been in general use in England, and possibly in Bavaria too, in Roman times

A further development of the pot-furnace is the Jura-type, built in the hill-side, which is also found in Carinthia. They are mostly vertical holes in the hill close to the face of a steep bank, with lateral apertures near the base, to which wind is admitted through a horizontal channel lined with stones. They seem to have been worked with natural draught, though free-standing furnaces of this type would be more suitable for natural blast.

Another development of the bowl-furnace is the *ditch-furnace*, of which the sloping types seem to be the earlier, the horizontal form the later one. They were mostly used for roasting and they are the ancestors the *roasting-hearth*.

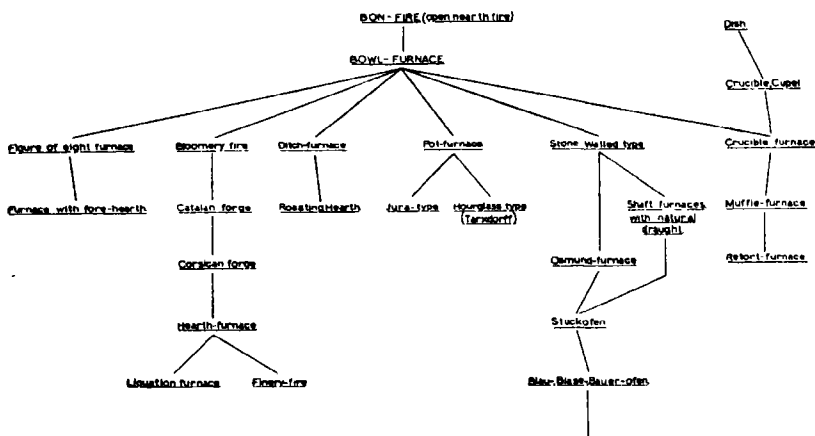


Fig. 36. The evolution of the metallurgical furnace

Further types of the bowl-furnace were lined with stones and the walls were raised above the ground. Some of these stone-walled bowl-furnaces were covered up after filling them with ore and fuel, such covered types are still in use in Madagascar and may be the ancestors of the cupola-furnaces of much later date, which at the same remind us of the old type of baking furnace in use in the Near East.

If the bowl was simply lined with stone, we get the *bloomery fire* from which the later *Catalan forge* and *Corsican forge* descend and the *hearth-furnace* to which class the liquation hearth and the finery fire belong. Furnaces with a fore-hearth also seem to descend from the bloomery-fire, possibly combined with the figure-of-eight furnace.

Most of these types have separate chimneys built over or next to them. But by raising the walls over the bowl a structure containing

both furnace and chimney was obtained which could be worked with natural or artificial blast like the bloomery fire and its descendants. This is the *shaft-furnace*, which in its primitive forms is called *Osmund furnace*, or if double the latter's size *Stückofen*, from which type through such varieties as the Bauer-, Blau- and Blase-öfen the *blast furnace* was evolved. The blast furnace is now the most typical iron smelting apparatus, but many types such as cupola-furnaces, the rapid cupola or the fire-hearth furnace are used for preparing other metals as well and more primitive forms were applied to the same use in Antiquity, though generally with natural draught if such easily smelted metals as copper or lead were prepared. It is, however, very difficult to generalise, as ancient metallurgy was still trying out types of furnaces and many combinations are known which were dropped in later ages.

Transitional types from bowl-furnaces to shaft-furnace can be observed in prehistoric Europe in Carinthia, Epernay and the Jura. Types partly built into the hill-side and not yet free-standing, more or less constructed round the charge, were found at Eisenberg. These shaft-furnaces usually built of stones and lined with refractory clay seem to come to central Europe from the Eastern Mediterranean at the end of the Bronze Age. They are found in very early remains at Mitterberg and Velem St. Vid, though the old bowl-furnaces remain supreme in the Eastern Alps. Shaft-furnaces at Hüttenberg and Lölling were used with artificial blast quite early, but as often old furnaces were torn down to build new ones, the dating of these remains is often very difficult. At Laurion the lead furnaces are shaft-furnaces, and the type is common in Siphnos in the sixth century. Gradually they are improved especially the *Stückofen* used for the production of iron. This is clear when the Hallstatt furnaces of Neuwied are compared with the La Tène types from Siegerland. The Celts developed a type with a chimney and tapping hole. Other types have been found at Bibracte, Cartagena and in Etruria and they grow very common in Roman times. These Roman types are usually small cylindrical shafts of 3'-4' high and working with artificial blast through tuyères. In Populonia both natural and artificial blast is used and some types with 6 blast-holes have been found. In Moravia the type is used continuously from Hallstatt times upto the tenth century A.D.

As water-driven bellows increase the quantity of blast-air, the height of the furnace can be increased and the blast-furnace is evolved which is able to produce cast-iron, a substance unknown to Antiquity.

In Roman times such special furnaces as welding furnaces, examples of which were found so much earlier at Gerar, Palestine, now spread over the Empire (Corstipitum, etc.).

The future student of this problem will do well to remember that we have pointed out the profound influence of the potter's furnace on early metallurgy. Early Susan pottery was burnt at temperatures ranging from 900 to 1200° C. though temperatures as high as 1400° C. do not seem to have been reached in these early times. We must also remember that baking furnaces (for bread, etc.) and glazing-furnaces were well known in these early times and that there is almost certainly a bond between these types and their evolution.



Fig. 37. Smith's fire of the primitive metalworkers of Bijapath, India. Note the dish-bellows and the combination of modern and primitive tools

From reliefs of the Old Kingdom period we know that a small portable (charcoal) fire with checks was in use in Egypt, especially by goldsmiths. This is probably the brazier called *'h* (ERMAN-GRAPOW I, 223) which corresponds with the Coptic *âsh*, which is often translated with *kaminos* (furnace). Apart from this the Egyptians had different kinds of furnaces, the potter's kiln *t3* (ERMAN-GRAPOW V, 228) mentioned in very old texts the baking furnace *trr* (ERMAN-GRAPOW V, 318) (Coptic *trir*) and the furnace of the metallurgists *brj.t* (ERMAN-GRAPOW III, 148) (Coptic *bro*) are both late terms which occur only at the end of the New Kingdom, though the appliances were certainly known earlier. A general Coptic term for furnace, *intok*, seems to have been derived from an Egyptian *pr(n)tk3*, literally "house of the burning".

The ancient Sumerian sign for "smith" is nothing but a brazier (SIMUG) which is exactly the same as the modern *manqal* still used in Iraq. The smelting furnace was called GIR₄ in Sumerian, *kêru*, *kûru* in Accadian though the term UDUN or Accadian *utunu* is also used. The latter term, which is related to the Hebrew *attûn*, seems to denote more especially a kiln such as is used for burning lime or bricks (Dan. 3 : 6). The Bible uses the word *kûr* in several passages (Deut. 4 : 20; Isa. 48 : 10; Prov. 27 : 21) or *kibîân* which seems to denote the smelting furnace (Gen. 19 : 28), while *kûr* is the refining furnace. Apart from these the Bible also mentions the baker's oven (*tannûr*) (Gen. 15 : 17; Isa. 31; 9; etc.), the potter's furnace (Eccles. 27; 5; 28; 30) and the blacksmith's furnace (Deut. 4 : 20; Jer. 11 : 4). The Mesopotamian texts mention furnaces for smelting gold but they give no details of their construction, at least in the case of metallurgical furnaces and therefore we depend entirely on the finds of such furnaces in Ur, etc. None of these have been described in sufficient detail to enable us to express a further opinion of their efficiency.

But apart from these different smelting furnaces we find *crucibles* in general use in Antiquity. The Egyptian sign for copper (*bi3*) is accompanied by a determinative which pictures a crucible and crucibles are shown in mural paintings and reliefs. Examples were found in Sinai and elsewhere, clay crucibles used in iron manufacture were found by Sayca at Kerma (Sudan). Eighteenth dynasty reliefs depict the casting of bronze doors from crucibles, which are about 5" high and 5" in diameter. Clay crucibles were also found in Mesopotamia (Ur, etc.). Crucibles were found among the remains of Troy II and a lump of stamped silver from Zendjirli (700 B.C.) retains the form of the bottom of a crucible. HERODOTUS mentions the smelting down of gold and silver in crucibles (*pitbos*) (III. 96) as practised by the Persian treasury. Crucibles have been found at Gezer, they are called *alîl* and the "fining pot" mentioned in different passages of the Bible (Prov. 17; 3; 27: 21; etc.) is either a crucible or a cupel.

It is quite probable that the earliest *crucible* was a smelting pan of refractory clay or sand mixed with clay used for the smelting of metals in a pottery kiln. Both crucible and cupel were developed as the smelting, melting and refining of metals came to be more known and the proper refractory ingredients were soon found in a world which had a thorough knowledge of the potter's art. Of course each of these crucibles could be heated separately in a bowl-furnace or even an open hearth fire if the required temperature was not too high, but as more

difficult operations such as the preparation of steel were carried out in crucibles, the experience gained in glass-making, in pottery and in the construction of bowl-furnaces was combined to construct *crucible-furnaces*, in which the crucible protected its contents against the fire and other possible sources of impurities. A further development was the *muffle-furnace*, in which the heating chamber is fixed but admits the introduction of one or more crucibles. This furnace was known to AGRICOLA and his generation and was already used for assaying in those days. As far as we know the Romans have not used the muffle-furnace, it was invented later.

But the Romans were well informed on the proper materials for making cupels and crucibles and the selection of the proper refractory clay. PLINY (*Nat. Hist.* 33.69) mentions "tasconium (from the Spanish *tasco*: crucible or cupel), a white earth-like potter's clay, which is the only substance which can endure the combined efforts of the blast, the heat of the fire and the glowing charge of the crucible". The term *kálatbos* (Pollux VII. 99) seems to denote the melting crucible, another term, *periodos*, said by some authors to denote the smelting crucible for the preparation of crucible steel, can not be traced.

A few words remain to be said on the working of metals. We can not enter into details on this subject, partly for the lack of proper analytical data and other evidence, partly because many of these processes do no longer belong to the production of metals, our proper subject, but to the history of metallurgical art, a chapter of the history of art in general. Still it may prove useful for our further discussions to present a general outline of the different processes and to classify them according to their technical principles.

Sometimes metals were used in their *native state*, but this practically limits their application to ornamental uses. In the overwhelming majority of cases the metal is worked by some process, the earliest group of processes being those of mechanical working and heat treatment. *Heat treatment processes* include simple heating (for instance before hammering), glowing, case-hardening (cementation or carburisation, so important in iron technology, where we shall discuss its merits and effects), hardening, tempering or annealing (used especially in the case of copper and iron) and quenching (so important for the preparation of steel). Subjecting a metal to such an amount of heat that it melts, is the first step in the important process of *casting*. The earliest form of casting was *open mould casting* using stone, loam or clay moulds. Sand casting was not practised in Antiquity, this is an

invention of the eighteenth century. The moulds were either temporary or permanent. The use of moulds of more parts, valved and closed moulds comes later. Permanent open and closed moulds made of stone (steatite, etc.) were generally used for small mass products such as votive and ornamental objects and coins. Temporary moulds were often formed over stone models. Open mould casting was soon replaced by a better process, the *cire perdue process* or wax casting process. At the same time we see a gradual tendency to replace solid casting by hollow casting, the core used often being made of oiled sand or a bitumenous mixture (especially in Mesopotamia) Temporary moulds were made of loam or clay here again sand casting came only very late. *Valve moulds*, moulds with permanent parts seem to have been used in classical Antiquity, their use was part of the everyday routine of the metallurgist of the tenth century A.D. (Theophilus III. 84) and his proficiency shows that it was already known and used for many centuries. It is, however, doubtful whether metal moulds were already used in Antiquity and it is of course quite certain that *chill casting* and *steel casting* were still unknown. Among the metals cast in Antiquity we find, gold, silver, lead, copper and its alloys such as bronze, brass, lead- and antimony-bronzes. Cast-iron was probably unknown in Antiquity as the furnace temperature for the proper carburizing and melting of crude iron was unattainable.

Apart from the heat treatment and casting processes both machining and mechanical working processes are known in Antiquity.

The *mechanical working processes* deform the metal, the *machining processes* take away parts of the metal with tools. The most important mechanical operations are hammering and forging, the latter operation embracing not only plain forging, but also forging with a mandrel, swaging, stamping and punching, the latter two operations being often used in coining. Like all mechanical operations these treatments can be executed with cold or heated metals. Other mechanical operations are bending, including the making of rims, cutting and spinning (as often used with precious metals). Akin to spinning is the modern operation of rolling. Press operations include raising (stamping out or bending in), jumping, drawing down, flattening, shearing, blanking and ironing. Drawing tubes from metal was of course unknown in Antiquity, but it may be that the drawing of wire was known at that period. However, ancient wire is very often cut from metal sheet or foil and hammered (sometimes in V-shaped stone moulds), we very often still recognize the peculiar square section of such cut wire. Gold, silver

and copper wire were used very frequently in Antiquity, often the wire is plated before use. True drawn wire is said to have been found in Troy II, but confirmation is still lacking. Multiply wire or wire coiled into spirals is very frequent in ancient jewelry and copper wire was used in Saqqarah (27th century B.C.) for attaching glazed tiles in king Zoser's pyramid. Cutting metal was of course a very common operation. Many of the *machining processes* were known to such as-reaming, boring, planing, grinding and smoothing, scraping, drilling and filing. Even turning seems to have been practised but milling seems to have been unknown.

Different *joining methods* were practised. *Riveting and caulking* were known quite early in ancient metallurgy. The plates of the statue of king Pepi of Egypt were riveted with copper bolts, tang and rivet were used in that country for axes upto the twelfth dynasty, when casting was introduced for this kind of work. Even the earlier iron objects are often rivetted with bronze nails. The pieces of larger bronze and copper objects were rivetted all over the Ancient Near East since the third millenium and often already earlier. Both *soldering and welding* are other ancient methods of joining. Though these terms are often used very loosely, soldering should be used only in the case of the use of any metal or alloy whose melting point is lower than that of the metal or alloy to be soldered, which may be run between the parts to be joined to fasten them together. Two types of solder are known, viz. soft solder and hard solder, a classification based upon the melting point of the solder. Ancient soft solders are very often lead alloys, among which alloys of lead and tin are very popular up to the present time. Hard solders may be alloys of the type of brass or alloys containing silver, etc. Solders of the latter type were often used by ancient jewellers, natural alloys such as electron being often used in Ancient Egypt. MÖTEFINDT claims that soldering was an Egyptian invention, but since very early examples have been found in Mesopotamia. Gold beads from the Royal Graves at Ur were found to be soldered, the Entemena vase is an example of the soldering of silver with copper, other objects (from AlUbaid) were soldered with lead. Soldering copper or bronze does not become general until the classical period, though a few Old Kingdom examples are known soft solder does not seem to have been used very early. Still most of the early soldering methods seem to have been methods of *fusion-welding*, that is joining metals by melting the adjacent edges or heating them and running some molten metal of the same kind into the intermediate

space. This soldering should therefore be called more properly welding. Other forms of welding such as *pressure-welding*, that is welding hot or cold without fusion by hammering and sweating together or *surface-welding* without pressure may both have been known but sure proofs have not yet been published. On the other hand when applying soft-soldering the edges may have been overfired accidentally and thus show the characteristics of fusion-welding. An ancient form of pressure-welding is the hammering-on of a thin strip of metal on the joint. Other forms of joining which really belong to casting are *casting on* and *burning on*, but very little evidence is available on ancient joining methods and more data should be forthcoming before we can decide upon the lines along which joining methods developed.

Apart from the classes of operations mentioned there are many *decorative and ornamental processes* which figure largely in art objects and the story of which forms part of the history of ancient art. There is the old process of beating, beaten copper and gold leaf being very old both in Egypt and Mesopotamia. Other beaten work includes the beating of copper leaf or sheet over a moulded bituminous core such as the famous Sumerian lion heads and others. Beating gold leaf in Egypt differed from that in Mesopotamia for in the latter country no gold-beater's skin was used but the gold was beaten between two stones, haematite hammers such as found at Ur may have served for this purpose too. Beaten bronze and copper strips figure largely in Assyrian and Egyptian decorative art. Other decorative operations are chasing (engraving), cutting (incising), drilling (punctuating), embossing (raising in relief), moulding (shaping), punching or stamping, raising, repoussé (chased relief) and many others. Some of the most important surface treatments of metals are encrusting, cloisonné or inlay-work, ornamentation, brazing, plating and enamelling. Many of these techniques were known in Antiquity. Assyrian bronze objects were embossed over clay cores and the famous treasure of the Oxus contains many embossed gold and silver objects. Repoussé work was known in ancient Egypt and Mesopotamia, the technique was used in Crete and Phoenicia and it was well known in Neolithic Europe. Punching belongs to the stock in trade of the Mesopotamian artists, actual punches have been found at Tell Halaf and are said to date of the early third millennium. It is used in Egypt, though not frequently until later periods but this technique is quite common in the Aegean. Cloisonné work was found at Ur but remains rare in these regions. It is, however, quite common in Egyptian jewelry from the XIIIth

dynasty onwards, and the art was practised in Sidon and Tyrus from 2000 B.C. onwards. Plating, if we mean applying sheet metal to wood and other materials, is a very early technique but true plating, the covering of a metal surface by another metal is not so common. Still in the Gudea period copper was plated with gold and the plating of silver and copper with gold was quite well known in Egypt and Mesopotamia at an early date.

Apart from these techniques there are the *finishing operations*. Apart from such techniques as etching, varnishing, brushing, pickling and cleaning with a sand-blast (the last two are quite modern) metal surfaces may be finished by *abrasion*, that is cleaned and polished using abrasive materials like sand and emery with leather-covered or wooden wheels (cutting down or buffing as the jeweller calls these techniques) and with covered or solid wheels (grinding).

A second class of finishing operations, *polishing*, is effected by very fine abrasives with cushioned wheels of felt, chamois, etc. These include the techniques called glazing, dollying, colouring, finishing and lapping. Finally the surface may be finished with steel or agate burnishers, an operation called *burnishing*.

It is to be hoped that soon a larger amount of objects will be examined by experts, for at present it would be extremely difficult to trace the evolution of these techniques from the scant data, partly buried in literature on the history of art and partly in excavation and museum reports. A thorough study of this subjects is sorely wanted, for it will throw much light on several outstanding questions of the history of metallurgy too. Again this re-examination of published analyses seems important as many reports are incomplete and some results seem very doubtful, terms being used very loosely indeed.

But we should not tarry long in the wilderness of these untrodden paths for as the Walrus said:

“The time has come to talk of many things”.

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CHAPTER SIX

GOLD IN THE ANCIENT NEAR EAST

Cest or auquel chacun tend, chacun vise, pour lequel
nuyt et jour ce misérable monde vit en continuelle
peine et tourment de corps et d'âme.

JACQUES GOHORY (47)

I

Probably ever since gold came into use in the Ancient Near East men have both cursed and blessed this glittering metal. Many a philosopher before PLINY will have expressed in his own tongue the words: "Gold is accursed by reason of the hunger with which it is sought, censured and reviled by all really good men, and discovered only to be a scourge to life" (*Nat. Hist.* XXXIII. 6) and many a document will have weighed the merits and disadvantages of gold for mankind with the same fairness as AGRICOLA did in *de Re metallica* Book I (1) (54).

But the speculations of moralists and philosophers have not been able to stem the stream and since the discovery of gold its production and value have been determined by the greed (PLINY, *Nat. Hist.* XXXIII, 4—52) so well expressed by the words of FERDINAND, king of Spain in his letter to the colonists of Hispanola (July 25th 1511): "Get gold, humanely if you can, but at all hazards get gold" (52). It would be futile to speculate on the name of the discoverer of gold, PLINY half-heartedly contributed a few names of mythical persons such as Cadmus, etc. (*Nat. Hist.* VII, 197). A metal like gold is not suddenly discovered by one person, but its characteristics are slowly recognized by a long series of observations. It is more profitable to enquire whether the common opinion is true that gold was the first metal discovered by man. There is probably no general answer to this question. We must remember that the first metal must have been a native metal; it is extremely improbable that man had any knowledge of metallurgy and the smelting of metals from ores before he had appreciated the specific "metallic" properties of these "shining stones" found on the earth's surface. There are only four metals (gold, copper, meteoric iron and more rarely silver) which are found in sufficient quantity in their native state to rank amongst the earliest

metals discovered. Therefore, neglecting the extreme "diffusionist" attitude it depends on the mineral wealth of a country, on the contact of its inhabitants with other metal-using people and on their own degree of civilisation which is the first metal discovered or known in that region. Generally speaking the common opinion that gold was this metal is right, but there are some striking exceptions to this rule. In Egypt copper was known much earlier than gold, if we judge from the excavations at prehistoric sites. Though copper was known in earlier periods, gold appears more generally only in the Badari period but it is worked like copper as if it were a kind of stone (41) (77). Again in Africa in general gold seems to have come after copper or other metals. Thus the Katanga negroes say that "yellow copper (gold) is easier to make into bullets than ordinary red copper", calling it thus because they knew copper before gold (17) and some Kaffir tribes call gold "yellow iron" (96). The North American Indians probably knew copper before gold. On the other hand in South America and Mexico gold seems to have been the earliest metal and in Chinese *chin*¹ (金) meant gold before it acquired the more general present meaning "metal" (20). As for Iran and Mesopotamia we have expressed the opinion that the science of metallurgy originated in the Armenian mountains or the highlands of Iran, where native gold occurs fairly frequently and we think it highly probable that in these regions gold was the first metal too (38). Archæological discoveries lead us to place this discovery of gold in the early Fourth Mill., but we can not ascribe the priority of such a discovery to any region because the evidence is still very slight. But after all the priority question is not very important.

We will not dwell on the rôle which gold played in religion, myth and magic (50) (76) (152), though we should like to point out that many authors show a tendency to overstress the available evidence (138). This glittering yellow metal was very early connected with the sun and even in the sixteenth century A.D. AGRICOLA had to protest against the idea that the native gold found in river gravels is drawn out of the earth by the sun (Book III) (1).

Its supposed mystical and philosophical (but later often its more material) qualities were the driving force of early chemistry and alchemy (53) (72) (152) from which after nineteen centuries of strenuous research our modern chemistry arose.

Our present chapter is concerned with the early history of gold technology, of the production and refining of gold in the Ancient Near

East. There is a long period between the first discovery of gold and the Egyptian texts extolling the King's virtues in such words as "the hills and the mountains pay thee impost of gold" (AR IV. 33) or "gold comes forth from the mountain at his name" (AR III. 285). Though it is very probable that in most regions gold was the first metal to be used, it must be remembered that the early use of gold falls in the Neolithic Age and that this gold was not recognized as a metal in its early days. In this early phase gold was simply a tough material, worthless for practical purposes of life (PLINY, *Nat. Hist.* XXXIII, 59) but collected for its æsthetical or supposed magical properties. It could in no way compete with wood and stone as base material for the making of tools and weapons. Still in those early days when the possibility of melting gold had not yet been discovered and only its malleability was known, it was collected in small quantities from surface deposits and fashioned as stone or wood objects would be manufactured. In the case of wood or stone the final object was formed by cutting away from a crude piece of wood or stone (64) all the unnecessary parts. The final objects was therefore contained in the spatial limits of the original stone or piece of wood. It seems that some of the earliest gold objects found in Egypt were actually fashioned on this principle but soon the malleability of gold was discovered and objects were made by hammering out gold nuggets and bending or cutting the small sheets or wires obtained.

The *melting and casting* of native metals (mostly copper) are discovered in the transitional period between the true Neolithic and the Metal Age. This Metal Age begins when the extraction of metal from the ores has been discovered. The radical transformation of the ore by means of heat, air and charcoal and the production of a (fairly pure) metal from a metallic compound (the ore) is called *smelting*, a process which archæologists should distinguish more carefully from the simple liquefaction of metals called *melting* (111). We will have occasion to discuss the fact that gold occurs always as a native metal in all of its commercial ores and deposits (PLINY, *Nat. Hist.* XXXIII, 62, 77). Gold technology therefore never contributed in the same way as copper technology to the development of metallurgy; the characteristic smelting process was only developed in the case of a metal like copper, which though it occurs in fairly large quantities as a native metal, can be obtained easily by the smelting of widely distributed copper compounds or copper ores. In this sense we agree with GARLAND that there was no connection between the technology of copper and gold (46)

but of course many metallurgical processes such as bending, beating, embossing, boring, welding, turning, raising, etc. which were developed in the Metal Age are not characteristic of one metal only but are used for all other metals after their discovery. The goldsmiths of all ages must have adapted these metallurgical processes to their craft quite freely. The early metallurgy in the Ancient Near East and indeed for many centuries after was greatly impeded by the lack of good smelting processes and apparatus, and we can safely state that the production and refining of metals up to the eighteenth century A.D. was completely limited by such apparatus as ovens, crucibles, etc. Metallic silver, for instance, occurs rarely in nature, it is mostly produced from lead ores and therefore the production of silver was limited by the development of smelting lead ores and refining lead. Gold never suffered from such a hindrance, the metal was easy to work even without the application of heat and, since only small quantities were worked at a time there was no need for large and intricate apparatus.

II

Before enumerating the different gold deposits known in the Near East in ancient and modern times we will give a survey of the *nature and characteristics of these deposits* (73, 74, 75, 79, 171).

Gold is rather widely distributed in nature, it occurs in minute quantities in almost all rocks. Even such common rocks as limestones or sandstones contain gold and so does seawater. The amount of gold in a ton of ore is usually so small that even if the ore is concentrated by washing away the gangue, it is generally impracticable to smelt the ore so as to collect the precious metal in lead or copper and to remove the base metal afterwards by some process. The present economic limit for the extraction of gold from auriferous rocks is about 2—3 grains per Ton (0.0001 %), a considerable advance on the limit given by AGRICOLA for sixteenth century gold technology (0.188 %) (1). At present a considerable percentage of the world's gold production is produced from copper or silver ores as the by-product from lead or copper mines. This production of gold as a by-product from other ores was probably started by the Romans who in the first century B.C. began to work pyrites and other sulphides for gold. Still as late as 1875 this process was not in common use and 90 % of the gold was collected from placers. We will therefore direct our attention to the production of gold from auriferous rocks only and we can, for the development in the Ancient Near East, safely disregard the extraction of gold from other ores or metals.

We can distinguish two types of gold, v.i.z. *reef gold*, irregular masses of gold occurring in quartz veins or lodes and *alluvial or placer gold*, deposits representing the detritus, gravels and sands derived from the desintergration of auriferous rocks and veins. Often this debris is washed far away from the original rocks and the gold is deposited amongst the river gravels and sands. The gold is often crystallized (filiform gold, wire gold and other dendritic forms) which fact gave rise to the legends about "growing gold", which even AGRICOLA did not succeed in weeding out (1) (54).

A century ago an author (55) deplored that "the ancient leaders sought the precious metals not by exploring the bowels of the earth but by the more summary process of conquest, tribute and plunder", but the ancient miners must have had some more scientific method of prospecting. We can not say whether the search for gold deposits (*prospecting*) (124) was conducted along certain empirical lines in early times, but we do hear that the Roman geologists looked for certain white gravels near which they expected to find gold placers (AETHICUS, Cosmog. 28) and PLINY (*Nat. Hist.* XXXIII, 67) states that the prospector has a good chance of finding gold in certain oxidized top-layers of veins of copper ores in Spain.

The ancient *mining or extraction processes* (which are still used) were very simple because *gold always occurs as a metal in all its ores* and though a few compounds of gold exist, they play no rôle in the production of gold. Even in the quartz or quartzite the gold occurs in the metallic state. Therefore after mining the gold is simply extracted and though it is never quite pure but practically always alloyed with silver, copper or traces of iron, it is practically ready for use and no special treatment of the rock containing the gold is necessary. The mining processes though differing according to the nature of the deposit and the ore, consist mainly in the freeing of the gold particles by crushing or sifting the ore and separating the gold from the rest by making use of the high density of the precious metal.

Most of the gold produced in Antiquity was placer gold (or alluvial gold). In these placers the gold is often derived from auriferous rocks whose exploitation would not have been profitable but erosion of the matrix and subsequent concentration by water have left accumulations of economic value. The gold occurs scattered as dust, grains or pellets (*nuggets*) and hand picking, dry-blowing, winnowing or sifting may suffice to collect it. We may say that nature has opened the lodes and veins. These nuggets may be of considerable size, the largest ever

found (at Ballarat) weighed 190 lbs. The sand can also be washed over smooth sloping rocks by running water, when the gold particles have a tendency to sink to the bottom of the stream owing to their high density.

The following methods are used in the case of *alluvial gold*, their principles probably date back to the earliest historical periods.

- a) *Panning or pan-washing*. The sand or gravel is agitated with water in pans, troughs, or "cradles" of various forms (usually shallow basins), the rocky matter is floated off and the gold particles collect on the bottom as gold dust or nuggets.
- b) *Placer mining*. The sand or gravel is shoveled into a "sluice", a long flume or trough with transverse cleets, riffles or obstructions along the bottom. Water streams through and sweeps along the sand, the gold collects in the crevices. The sluices may be covered with fat to retain the nuggets or the riffles may be covered with skins of certain animals. The legend of the Golden Fleece is often connected with the production of gold by washing sands containing gold over sheep skins.
- c) A later process better suited for organized gold production and probably not used before the Romans, is called *hydraulic mining (hushing)*. Softer beds were broken down by strong currents of water in Antiquity, these were the "arugiae" of the Romans in Spain (PLINY, *Nat. Hist.* XXXIII, 68—77) (STRABO III. 2. 8. cap. 146) (10) (108) (109) (110) (146). At the present time water is directed under high pressure from a reservoir through a special nozzle against the gold bearing earth. In both cases the washings are conveyed in sluices and treated as described under b).

These methods were applied very efficiently in Antiquity. English engineers exploring the Egyptian gold mines in the Nubian desert found that the ancient Egyptians were "very thorough prospectors and no workable deposits were found which they had overlooked" (77). We must remember a very important factor in these processes, the fairly large amount of water essential to the washing of the sands or gravels. This water was the determining factor for ancient gold mining and no mines could be opened up if water could not be procured (AR III, 259; III, 166—198). The more difficult extraction of gold from quartz rocks is called *vein or reef mining*. AGATHARCHIDES has given us a very exact description of the use of this method in Egypt and if we translate this passage preserved for us by DIODOR (III, 12—14) into modern technical language, it would run like this: "In

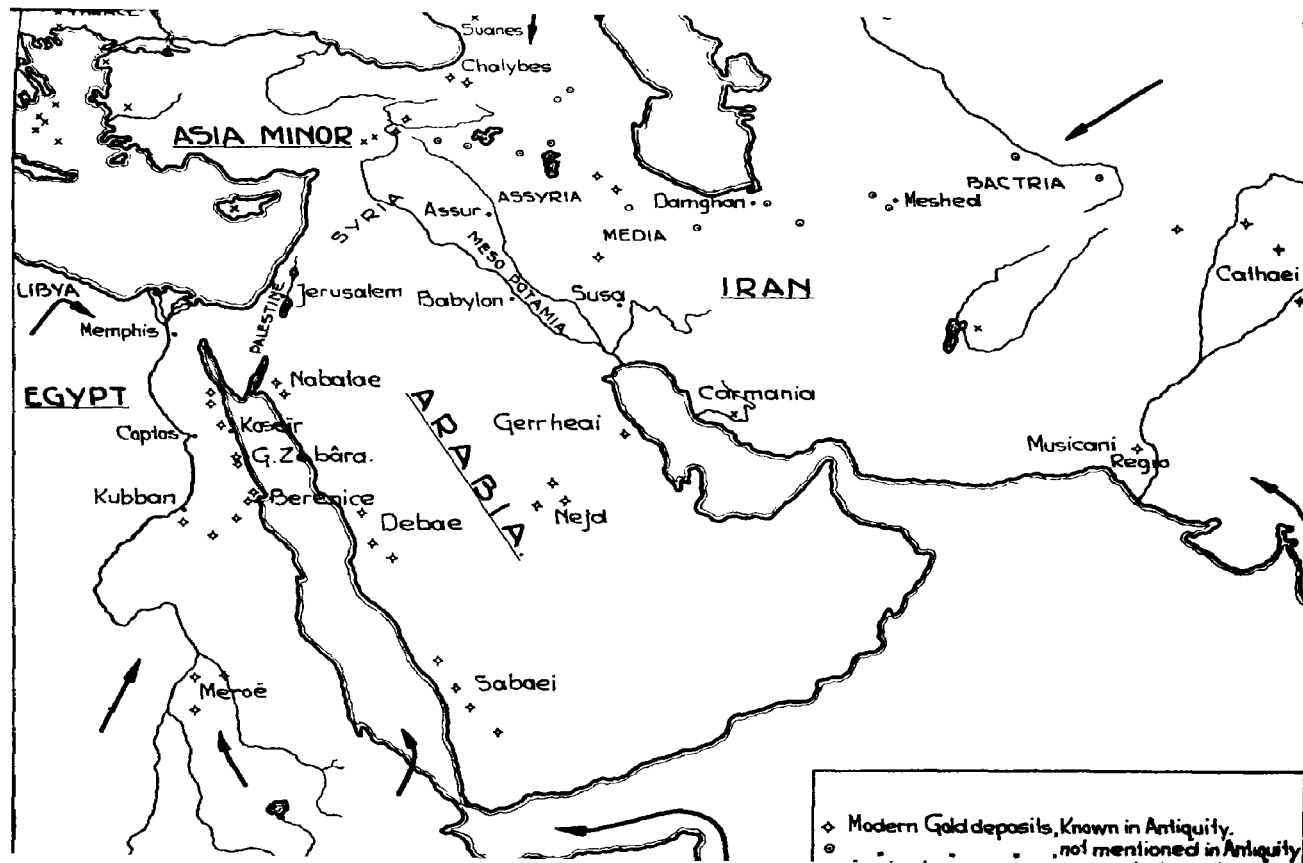
Egypt dark rocks traversed by veins of white quartz containing the native gold are exploited by means of adit-levels. The rock is broken up by the fire-setting method (because the ancients lacked proper explosives) and the pieces broken up further into small pieces by hammers. These small pieces are reduced in mortars to pea-size and these pellets are transferred to handquerns fed through the upper stone. The pulverized product is then spread over sloping boards or stones and the gold separated from the gangue by the aid of water. Clotted lumps are rubbed by hand to expedite the concentration. The gold is then collected and weighed."

Reef mining was conducted to depths of nearly 300' in Egypt and tunnels of up to 1500' followed the veins into the rocky slopes of the valleys in the desert region.

III

If we want to draw a *map of the gold deposits* (32) (42) known in Antiquity, adding as we have done in this map (Fig. 38) the deposits discovered by modern geologists and not mentioned in ancient literature, we must not forget that we must distinguish carefully between the ancient deposits mentioned as mines (which are very rare) or those regions or places from which gold is said to come as tribute, booty or by trade. The latter may be countries like Libya, where modern research has failed to find any trace of gold placers either ancient or modern, or like the Western Oases (AR I, 521, 524—528) about which we could not find positive modern data. We have therefore marked in our map only those ancient gold deposits which could be confirmed by modern geology, omitting all doubtful evidence and indicating by arrows regions from which gold seems to have been imported and possible trade routes along which the gold travelled. As far as possible ancient but exhausted deposits have been indicated and so are modern deposits which might have been exploited in Antiquity but which are not mentioned in ancient texts.

A short survey of the deposits indicated on the map (Fig. 38) leads us first to *Egypt* (37) (43) (44) (112) (150), where the principal gold mines were situated on the coast of the Red Sea, in the desert along it and in the Nubian desert. We find more than 100 old mines in these districts and the valleys in the schists are full of alluvial workings. The following groups of mines can be distinguished: 1) Wadi Dara, Wadi Dib and Wadi Um Mongul (all about 27° 50' N. 33' E.), 2) Wadi Foakhir between 26° 48' N. and the route to Qoseir,



3) Djebel Zebâra (Wadi Hamesch, Bir Sighdit, Umm Rus, 25' 40"—25' 15" N.) mentioned in AR III. 289 because of the energetic exploitation by Seti I, 4) the region between 25' and 24' N., 5) the coastal region near Râs Benâs and Berenice (23' 27" N.) and finally 6) Wadi Allâqi, especially near the Nile and to the east of its middle course (AR I. 520). The importance of Nubia as a gold producing province of Egypt can hardly be exaggerated (SCHWEINFURTH, *Ann. du Service* IV, 268), the yearly production of these mines has been estimated as high as 600—800 lbs. As early as the Old Kingdom we hear of military expeditions to Nubia for negroes and gold (127), but the gold must have been mainly Nubian gold. For though the possibility remains that real "Negro gold" from the interior of Africa came to Egypt as early as the VIth dynasty, authorities on African metallurgy state (19) that not until the Middle Ages did the gold trade from real negro areas assume any great value. The important work of Merenre had opened the First Cataract for the Egyptian ships under Pepi Ist's reign and made the approach to the gold mines possible. When Senusret I conquered the Third Cataract and Senusret III fortified the Second, the approach to these gold mines was finally safeguarded and we can state safely that the Egyptian administration of Nubia since the Middle Kingdom guarded one of the most important sources of income of the XIth and XIIth dynasties. Though Coptos does not produce gold it is often mentioned as a "gold country" or the texts mention "gold from Coptos" (AR II, 545, 775). This is probably due to the fact that Coptos owes its importance to the gold trade passing through this town at the Nile head of the road to the coast of the Red Sea and its goldmines.

Much of the "Nubian gold" may have come down from more southerly regions like Aethiopia, Napata or Kush (AR I. 665), where the classical writers found it at Meroë (STRABO XVII. 2. 2. cap. 821) (HERODOTUS III, 23, 114) but it may have come from the region of the Blue Nile (Sennar district) or even farther down from Abyssinia, Somaliland or Madagascar.

Contrary to the fairly common reports that Egypt imported gold from the Sinaï (AR IV, 408, 409), we must state that this can not be true, though imports from Midian were possible. The West coast of Arabia is rather rich in gold and several regions are mentioned by ancient authors. Midian is represented by the "region of the Nabatae" (STRABO XVI. 4. 26. cap. 784). There are several deposits near the coasts of Asir (region of the Debae, STRABO XVI. 4. 18. cap. 777)

and Jemen (STRABO XVI. 4. 19. cap. 778—780), the country of the Sabæans. We are told by STRABO that the inhabitants of these regions do not know how to work gold “which was obtained by digging and found not as gold dust but as nuggets”. They make collars with these nuggets, perforating them and stringing them alternately with transparent stones by means of thread” which means that they still treated gold (in STRABO’s time!) as they would treat stone and had not recognized it as a metal. It is probably in South Arabia too that we must locate that evasive country of Ophir, though many other locations have been suggested, such as Somaliland, South Africa, Malaya, Sumatra, etc. The suggestion made by DAHSE (23) who thought that Ophir was the Gold Coast is obviously wrong, because the ships for Ophir sail from the recently excavated Red Sea harbour of Ezion Geber (I Kings 22 : 48). This Ophir occurs in many passages of the Bible (I Kings 9 : 28; 10 : 11; 22 : 48; I Chron. 29 : 4; Job 22 : 24; 23 : 16; Ps. 45 : 9; Is. 13 : 12) but other sources mentioned are Sheba (II Chron. 9 : 1; Ps. 72 : 15) which certainly is South Arabia, Uphaz (Jer. 10 : 9; Dan. 10 : 5) and Parvaim (II Chron. 3 : 6). The last two are not identified, but we think that they are to be located in the same region, the West coast of Arabia (see also THEOPH. III. 46—49). Apart from these locations gold occurs in the highlands of Nejd which is probably identical with the Havilah of the Bible (Gen. 2 : 11—12, *hawilah*). The genealogies of Havilah given in two passages (Gen. 10 : 7; 10 : 28—29) are contradictory and vague on the point of the location of this country. It has been suggested that Nejd or at least the highlands of Arabia were meant by the “Meluchha” of the Mesopotamian texts (VAB I, 70b, VI, 33 & 39) (83) (156), but the identification can not yet be accepted as final as long as the “Meluchha-Magan” problem remains unsolved. On the coast of East Arabia gold is already mentioned by STRABO (Country of the Gerrheans, XVI. 4. 22. cap. 780).

India may have been an important source of gold, though the texts which mention Indian gold are mostly from classical authors. We do not find any mention of the most important modern gold deposits (Deccan, Jashpur, Nilgiri, Malabar), though the “desert east of India” of HERODOTUS (III. 98) may be the Central Indian Desert. The gold deposits of Haiderabad are mentioned by STRABO as in the “country of the Musicanes” (XV. 1. 34. cap. 701) and the “country of Sopeithes” (STRABO XV. 1. 30. cap. 700 and XV. 1. 68. cap. 718) is probably identical with the “Indian rivers” the Sutelj and other rivers

of Kashmir which are still reported to carry down gold from the mountains, as is the Ganges which PLINY mentions (*Nat. Hist.* XXXIII. 36). In India also the famous "gold-digging ants" lived (STRABO XV. 1. 37 cap. 703; XV. 1. 44 cap. 706) (PLINY, *Nat. Hist.* XXXIII. 66; VII. 10; XI, 111) (ARRIAN, *Indika* XV. 6) (HERODOTUS III, 102—106) (*Apoll. Vit.* 1—2) though they are sometimes said to be griffins or to live in Aethiopia or among the Scythians instead of in India (HERODOTUS III. 116). It is often suggested that this legend refers to the gold from parts of Afghanistan or Chinese Turkestan imported into the Hellenistic world. LAUFER (*T'oung Pao*, IX, 1908, 429) has published a valuable study of the gold deposits in these parts, which should be consulted by those who wish to disentangle the weird legends of the gold-digging ants or griffins of the Arimaspi. The same question was recently discussed very fully by A. HERRMANN (*Das Lande der Seide*, Leipzig, 1938, 10). Of course there is always the possibility that gold was imported from Inner Asia (Bochara, Amur Daria, Turkestan, and Siberia) (70) or even from the Far East (Malaya, Sumatra) (132) though exact records on this subject do not exist and we would not dare to suggest any of these sources for periods earlier than the Hellenistic Age.

In *Persia* several gold deposits are known from modern surveys of the country but very few ancient texts mention them. There is of course the river Hyktanis in Carmania mentioned by STRABO (XV. 2. 14. cap. 726) and it is probable that the "Media" mentioned in Assyrian inscriptions (Tigl. Tt. 32) ("*Skraki* in Media", ii R. 67. 32) refers to the gold in Kawend (Zendjan). The other important deposits near Damghan, between Nishapur and Meshed, two miles east of Meshed, in the Tiran Mts. (W. of Ispahan near Hamadan), the region S.E. of Teheran and that N.W. of the Takhti-Suleiman do not occur in any of the texts published up to now. There are of course the various legends on the rich gold bearing regions of Northern Europe (HERODOTUS III. 116 and I. 215), on the Massagetae or the "Hyperborean rivers" (STRABO XV. 1. 58. cap. 711) and the famous stories of the Golden Fleece, but more definite locations of gold deposits are given in Colchis and surrounding regions, the country of the Suanes (PLINY, *Nat. Hist.* VI. 14; VI. 14; VI, 30; XXXIII. 52) or Soanes (STRABO XI. 2. 19. cap. 499), mentioning the use of "fleeces".

South of the Caucasus (57) in *Armenia* the famous metal workers, the Chalybes, are credited with rich gold mines (ARIST. *de Mir. Ausc.* 26), this probably refers to the deposits near the Taldjun river near

Artwin. The region of Alindjeriv near Batoem and the gold mines in "Sypiritis near Caballa" visited by Menon, general of Alexander (STRABO XI. 14. 9. cap. 529) are probably identical. Other deposits known are south of Lake Van and in the Kedabekbegh and W. Karabegh Mts. In general Assyrian texts often vaguely mention the highlands as the source of imports of gold (Tigl. Tt. 27; VAB VII, 164. 1). Gold is said to come from *Aralu* (the Assyrian Underworld) "the dust of its mountains" (II R. 51. I-II. 11) (LUCKENBILL, A.R. II. 261) (K. 2801. r. 36) (MEISSNER-ROST, BA, III. 295) (KAH. 75. r. 14) or from the Khâbur region (BA III. 234. 21) which may point to gold from the mountains to the North of Assyria. The gold in the Taurus near Kharput may be the gold referred to in the Mesopotamian texts as coming from "Chachu" (VAB I, 70b, VI, 33) (83) (151).

In the rest of *Asia Minor* gold is conspicuously absent. Only two gold deposits were known there in Antiquity, the more famous one embracing the banks of the Pactolus and the slopes of Mt. Tmolus, which were probably not exploited before the Iron Age (25) and though HERODOTUS reports on their riches (I. 93; V. 101; V. 49) they were exhausted in STRABO's time (PLINY, *Nat. Hist.* XXXIII. 66) (STRABO XIII. 4. 5. cap. 626 and XIII. 1. 23. cap. 591) (for "Saparda" *vide* SCHEIL, MMAP, XXI, 8). The second deposit near Astyra in the Troad is always said to be the source of the riches of Priam of Troy (STRABO XIII. 1. 23. cap. 591; XIV. 5. 28. cap. 680) but is also exhausted now. In Cyprus gold and electrum are rare before the Classical Age (REGLING, PW, VII, 978) though a deposit is known at Akamas. There were of course many gold mines in *Thrace, Macedonia and Greece*, but they were exhausted soon after their tapping started in the Bronze Age, at least most of them (25, 26). We just cite the most important: 1) the Hebrus in Thrace (PLINY, *Nat. Hist.* XXXIII, 66), 2) also the Strymon and Maritza, 3) the slopes of the Rhodope Mts., 4) Skapte Hyle (HERODOTUS VI, 46) and many of the islands, Andros, Thasos, Thera, Melos, Kimolos, Seriphos and Siphnos (HERODOTUS III. 57) (PAUSANIAS X. 11. 2) (5), but we believe that these deposits have not played any role in the gold trade of the Ancient Near East unless locally. LUCAS (77) correctly refutes PETRIE's theory that the Egyptians imported gold from the Pactolus (104). Egypt itself was the most important gold producing country in the Ancient Near East and though silver was rarely valuable in the earliest periods and in Egypt valued even higher than gold, its value

in relation to gold dropped rapidly in the course of time and gold remains the most precious metal notwithstanding the fairly large output of the Egyptian gold mines (40) (153) (154) (159).

It will be seen from this short survey that the civilized river-valleys or lowlands of Egypt, Palestine, Syria and Mesopotamia are devoid of important gold mines. This means that gold was practically always imported in these countries from regions which except in the case of Egypt (119), were not permanently or never under control. The very early appearance of gold in Assyria (Tepe Gawra VIII) and in the Early Dynastic Royal Tombs of Ur points to a long history of the goldsmith's craft in these regions and so to an early contact with the gold producing highlands or desert regions.

IV

The gold collected in the mines and places was either refined on the spot, as the description of the Hellenistic gold mines by Agatharchides in Egypt would suggest, or it was exported in the form of gold dust, nuggets, bars, etc. to be refined by the buyer. The original form of the Chinese sign *chin*¹ (gold) represents according to the explanation given by LI-SSU in the *Shou-wên* four nuggets in two layers of earth under the earth's surface. In the same way we would like to see the natural form of gold represented in the early pictographic signs for *kù* (FALKENSTEIN No. 703; LANGDON, *Pict. Inscip.* No. 264), these early pictograms look very much like nuggets. The Egyptian *nub* shows a much later stage of gold technology. Though LEPSIUS, CHAMPOLLION and WILKINSON have held this sign to represent a bowl with a folded cloth over it used for washing gold from auriferous sand (167, III, 224) and CRIVELLI thought that it was a portable furnace used for casting gold (53), the consensus of opinion regards it now (as BIRCH and PETRIE (103, 104) suggested) as the picture of a collar or necklace of gold beads, the "gold of honour" so frequently mentioned in Egyptian texts. We may mention here that *nub* appears early in the King's "Gold-name" as a symbol of the victory of Horus over Seth, the god of the gold town Coptos (134).

It has been wrongly supposed that the native gold was very pure and that all alloys with silver were compounded from the pure metals. PETRIE, for instance, supposes that the Egyptian gold containing 16 % of silver or more was a technical alloy (104). The reverse is true. Nearly all the native gold from the mines and placers is a natural alloy of gold with sometimes considerable quantities of silver, usually

some copper and traces of iron. Other impurities such as tellurium, bismuth, antimony, mercury, platinum occur alongside these more common elements. Nor are any of these impurities sufficiently characteristic of certain localities to warrant theories like the Transsylvanian origin of the sceptre of Khasekhemeui as propounded by PETRIE and PEAKE. Modern gold deposits very rarely produce pure gold. Though 99.9 % gold was found in California, the average from that country was 88.4 %; in Australia it was 95 %; in Japan 62—90 % for placer gold and 57—93 % for vein gold. The same holds good for ancient deposits. DAVIES reports 75—92 % gold for the Aegean islands and W. Anatolia (25), LUCAS found 77—90 % gold in the product of the six most important Egyptian gold mines (77) and nuggets from the Caucasus region are reported to contain 57—70 % of gold (24) (172). GARLAND considers any alloy containing less than 60 % of gold an artificial one, for he states that no lower fineness of natural gold has been found anywhere in the world (46).

It is very interesting to compare these figures with the analyses of gold objects from excavations. For Egyptian objects LUCAS found 72.1—99.8 % (77), WILLIAMS 71—92 % (168) and THOMAS 84—90 % (150) of gold. In Mesopotamia the composition of gold jewelry is according to PARTINGTON 30—48 % of gold, 8—59 % of silver and 0.3—10 % of copper (96). This means that the *gold used in the Ancient Near East was mainly the native alloy* and that *refining of this native gold was not practised until the later phase of the period under discussion*.

This conclusion is not only confirmed by the chemical analysis of many gold objects, but we have more proofs. The alloys of gold and silver present a *range of colours* varying according to the increasing silver content from reddish yellow through pale yellow to white. For instance the modern alloy of silver and gold called "electrum" (spec. grav. 12. 5—15. 5; 22—55 % of gold) varies from pale yellow to white. By adding copper to a silver-gold alloy containing 10 % of silver we get the modern alloy known as "green gold". A gold-silver-copper alloy was known in Antiquity as "Corinthian bronze" (PLINY, *Nat. Hist.* IX. 139; XXXIV. 5—8; XXXVII. 49). The modern "white gold" is a gold-platinum or a gold-nickel alloy and has nothing to do with the ancient "electrum" or "white gold" (HERODOTUS I. 50). This wide range of colours which of course occurs just as well in the *native gold containing varying amounts of silver* was appreciated by the ancient Egyptians and applied to art objects to attain certain aes-

thetical effects. It played a large role in the philosophy of the early Coptic alchemists and even their predecessors the jewellers and artisans of Egypt (HOPKINS, *Alchemy*, 1934) and in Mesopotamia the different colours of the types of native gold were appreciated by the artists too (105) (136). In Egypt these colour effects were produced artificially not only by selecting (and later by compounding) the silver-gold alloys but also by colouring gold itself or by colouring the surface of base metals to give them the appearance of the appropriate gold alloy. Thus the "purple or red" gold was produced by dipping the gold object in a solution of an iron salt and heating it afterwards, as WOOD

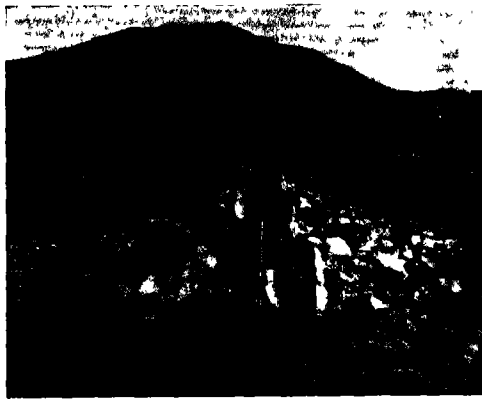


Fig. 39 Querns for grinding gold ore in an ancient Nubian mine
(after GOWLAND, *Metals*)

proved by his experiment (169). A bronze with a blue tinted patina was produced by alloying the bronze with small quantities of gold, and the "Leiden-Stockholm" *papyri* give many recipes for the colouring of metal surfaces to give them the appearance of precious metals. In Lydian objects the silver is sometimes dissolved from the surface to fake a more valuable appearance (25).

A third proof may be found in the extremely complicated *nomenclature of gold* in Antiquity. We hope to discuss this point in a separate essay in detail and we will give here a short survey of this complicated subject. In Sumerian we have *zu* (ŠL 6. 6) and *guškin* (Kù. G1) and its compound (ŠL 69. 22), in Accadian *hurāsu*, *sārīru*, *šaššu* and some 13 more terms (11) (14) (27) (28) (82) (91) (129); in Shubarti *zalhu* and *aiarahi* (83) (158). In Hebrew words like *zābāb*, *pāz*, *bétzer*, *chārutz*, *sāgūr*, *ketem* indicate different types of gold, while *hāsmal* seems to denote electrum (61). In Egyptian two words

nub and its compounds and *dš.m* are used, the latter generally denoting electrum. It was formerly read *uasm* by LEPSIUS (69), PETRIE and WIEDEMANN and compared with the Hebrew *hašmal* and with *asem* but the reading *dš.m* is now finally accepted (12) (45) (98) (166). There is considerable confusion in the Bible between electrum and amber (Ezech. 1 : 7; 7 : 2; Dan. 10 : 5—6; Apoc. 1 : 15) (but see JOSEPH. *Antiq.* VIII. 8) but PLINY correctly defined it as a gold-silver alloy with 20 % of silver (*Nat. Hist.* XXXIII. 80). Apart from this the Egyptian texts often give indications of colour, origin or appearance of the gold mentioned such as „green gold from Emu, gold of two times, fine gold, gold from Coptos, etc.” (9) (16) (69). The conclusion we can draw from this first survey of this riot of names is that they fall into several classes. Some actually mean gold or electrum, indicate forms like gold leaf, etc.; others tell the colour or give information on its purity, degree of refining. Some names clearly refer to the origin of the gold. We are tempted to call this the technological terminology. A second class is formed by names expressing poetical or symbolical designations. A last class is formed by “slang” words for gold, which explanation THOMPSON has already suggested for some expressions (151). Many of these expressions disappear in later texts as the technology of gold becomes better known. For instance the word *dš.m* is rarely used after the XXVth dynasty (12) (77).

Though there is no exact evidence where and when the *refining of native gold* was started we have many reasons to support a statement made by GARLAND that the separation of silver from gold was invented in the North (he says Syria) (46). An important letter from the Amarna collection (Burraburiaš to Amenhotep IV) (KNUDTSON 92, 1.19) states: “The 20 minae which he brought were not “full” for when they were laid in the furnace only 5 minae came out” and we also find the expression *hurāšu sagiru* (Sarg. 8. F., 1. 372) which MEISSNER (83) translates “loss on melting”. Then the expression *guškin-si.sá* (in a text from the reign of Shulgi) has been translated “rectifié” by SCHEIL (RA 17, 1920. 211). This would lead us to believe that the separation of silver and gold had been achieved in or near Mesopotamia before the Amarna Age. But as usual centuries elapse before such a technical process becomes common in other countries we find that this knowledge penetrates only slowly to Egypt. From analyses of gold objects in Palestine the conclusion was drawn by MACALISTER that the gold imported in Palestine in the IV Semitic

Period (1000—550) is so pure that it must have been refined in some way. In Troy II gold is rather common and very pure so that it too must have been refined (96 %). The evidence from Egypt is much fuller. Since the XVIII dynasty we find the practice of debasing gold by alloying with copper, a procedure probably found so lucrative that in the later periods of Egyptian history compounds containing up to 75 % of copper are found. In the XX and XXI dynasty the texts begin to mention more and more qualities of gold like "gold of two times", "gold of three times", etc. which must mean gold refined twice, thrice, etc. (AR vol. IV) Since the XXVI dynasty the word for *electrum* disappears from the texts and in the Persian period (525—332) the first objects of pure gold appear (77). Then DIODORUS informs us of Agatharchides personal observations of the refining process ("parting") used in his days in Egypt (DIODOR III, 14).

Both the texts and analyses of finds prove that refining processes were in common use in the sixth century B.C. and the present evidence points to their development in the first half of the Second Mill. in the North (Syria, Pontus, Armenia?). Before the sixth century it is extremely improbable that gold-silver alloys were compounded on a large scale from the pure metals (104) (83) but native gold must have been used. The spread of the refining processes may have been retarded by the natural advantages arising from the use of native gold instead of pure gold. When gold is alloyed with silver (and the same conclusion holds good for alloys containing (smaller) percentages of other metals like copper) the alloy is harder than the pure gold, it will stand tear and wear better and it can be applied in the same way as pure gold. This native alloy was found in practically every gold mine, even *electrum* is mentioned in Egypt to have come from Punt (AR I. 161; II. 272), Emu (AR II. 298, 387), the Highlands (II. 374, 377), mines east of Redesià (AR III, 403), the South Countries (AR II, 654), the mountains (AR IV. 28). Therefore there would have been no need to compound it from the pure metals prepared at much cost. But its varying properties, even if procured from the same locality, must have been difficult for the craftsman. The development of refining methods created the means of analysing the native gold by simply applying the refining process on a small scale. In this way a proper means of evaluating the native alloy was put into the hands of those engaged in the gold trade. At the same time still easier methods of testing (*assaying*) (142) were discovered and developed. We read of the "testing" of gold in the Amarna letter mentioned

above and the Bible contains several passages referring to the "fining pot" (Prof. 17 : 3; 27 : 21), the "refiner" (Mal. 3 : 3) or to gold that is "tried" in the fire (Zech. 13 : 9). The data on the development of refining are scanty and a future student of this subject may find other interesting facts in tracing the introduction of the touchstone in assaying. This quick way of assaying consisted of making a streak of the gold to be tried on a kind of black stone (Lydian stone or Lydit; PLINY, *Nat. Hist.* XXXIII. 126; THEOPHR. *de lap.* 4. 45) (Basanos; ARIST. *Hist. Anim.* VIII. 12) and comparing it with the colour of a streak made with a gold alloy of known composition. The coming of refining and assaying methods opened up an important application of gold. Until now gold had been employed in the form of rings as

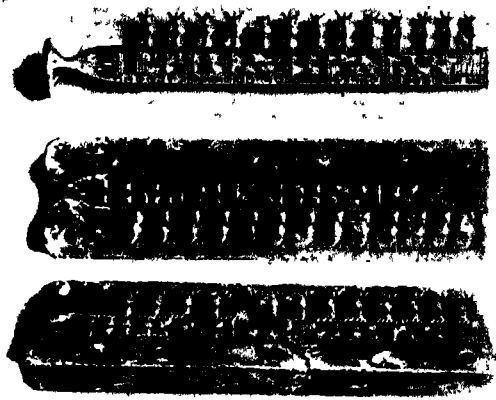


Fig. 40. A Ugarit goldsmith's double mould with an impression therefore (from SCHAEFFER's article in ILN, Feb 20, 1937)

currency both in Egypt (24) (96) and in Mesopotamia (83) (84). But the true development of gold coinage could only start after refining and assaying methods were found. It was only then that the percentage of gold could be adjusted and tested and then only the value of for instance the Phocian electrum coins in Egypt could be compared (87) with that of gold coins. The development of minting in Lydia dates from the centuries when refining methods had come into common use. This, however, belongs to the history of economics and that of numismatics and we must turn to the discussion of the *refining methods known in the Ancient Near East*. These refining methods fall in two distinct classes:

- a) methods for the separation of precious metals (gold and silver) from base metals like copper, and

b) methods for the separation of gold and silver.

a) The *cupellation* process is probably the oldest and most efficient method of *separating the precious metals from base metals* (PLINY, *Nat. Hist.* XXXIII, 59-60). Its principle is alloying the gold with lead in a special pot (*cupel*) and oxidising the product by strong current of air. The base metals alone are "consumed" or "drossed" (the oxides formed are absorbed by the porous cupel) while the gold and silver pass "unscathed through the ordeal" (Ezech. 2 : 18—22; Num. 31 : 22; Zech. 13 : 9; Mal. 3 : 3). For this "trial by fire" a special crucible was made, porous enough to absorb the oxidation products of the base metals, which seemed to disappear from the "fining pot". The modern cupellation hearth is lined with bone ash, calcareous clay (*marl*) or magnesia; the ancient cupels which AGATHARCHIDES (DIODOR III. 14) calls *kerameon*, PLINY (XXXIII. 69) *catini* made from a special clay called *taconium* and CASSIODORUS (*Varia IX*, 3. 3) *fictilia*, were all made of some kind of clay. THEOPHILUS (III. 22) describes in detail both the making of such cupels from clay and powdered old fining pots and the cupellation itself (III. 68). We can not agree with DAVIES (25) that this process was only invented in the Iron Age and probably in Italy; the method described by AGATHARCHIDES as in use in Egypt is a complication of this method and we do not yet know whether it was also used in Mesopotamia or Syria. It will be seen from the above lines that texts on this subject are very scanty; DIODOR (III, 12—14), PLINY and STRABO are the only authors who give us any useful information. Modern discussion of this subject will be found in the works of LUCAS (77), GOWLAND (48) (49), DAVIES (25) and TÄCKHOLM (143). Supplementary evidence is, however, found in the medieval authors who are only too often neglected by archæologists seeking information about ancient technology. The XIth century priest THEOPHILUS (147), the XVIth century doctor AGRICOLA (1) (54) and his contemporary BIRINGUCCIO (in his *Protechnia*, edit. JOHANNSEN, Braunschweig, 1926) when describing the metallurgical methods of their days very often refer to classical methods, quote methods of long standing and, what is most important to us, often add illustrations to these descriptions. In view of the conservatism of technologists in these early periods it is perfectly admissible to regard many of these later methods as slightly improved survivals of older methods, whose principles have remained unchanged. To return to the cupellation processes, in the versions meant for the treatment of washed gold ores

fluxes are added to form a slag with the gangue remaining in the gold ore, while the lead is oxidized in the way described above and leaves the *regulus* of pure gold (and silver) in the crucible. The process is called *liquation* and has been used since the Romans started to work more complex and sometimes sulphur-containing ores for gold (PLINY, *Nat. Hist.* XXXIII. 79; XXXIV, 177). We have no evidence that this process was used in earlier periods.

The *amalgamation* method was known to the Romans "in laboratory and factory" (25) and is mentioned by PLINY for the recovery of gold from gold cloth (*Nat. Hist.* XXX. 32). It could be used for rich gold ores by extracting the crushed ore with mercury, washing off the gangue (pressing the mercury through leather) and heating the solid amalgam (or the mercury) to recover the precious metal (wrong facts in PLINY, *Nat. Hist.* XXXIII. 99). It is effective for simple ores only and could not be used before the Romans started to produce mercury on a commercial scale. It is mentioned by THEOPHILUS (III. 35-36), AGRICOLA (Book VII) and BIRINGUCCIO, the latter calling it a secret process and introduced by the Europeans in the silver industry of Mexico in 1552 (BARTOL. MÉDINA). Was the "water of separation" of the Bible (Num. 31 : 22) mercury?

b) Though several methods were known which made the *separation of silver and gold* possible, we usually find much more complicated combined versions of these methods and the cupellation process. The parting methods which the Ancient Near East knew or could have used were:

1) *Salt process.* The principle consists of the addition of salt to the silver-gold alloy, some reducing agent like straw, charcoal or other organic material being added. The salt attacks the silver and forms silver chloride which is absorbed by the walls of the crucible. It is still used in Japan where the gold is mixed with clay and salt, and the crucible containing the mixture heated in a charcoal furnace for 12 hours at red heat. Then the dish is removed and the gold is washed with hot brine to dissolve the silver chloride formed (48) (49). A slightly different version is given by THEOPHILUS (III. 33-34) and AGRICOLA (Books VII and X). Another version using powdered bricks or tiles instead of clay and adding sulphates is given by BIRINGUCCIO. Though GOWLAND thinks (48) that gold was refined by this salt process in the Persian period, we have only indirect evidence that these cementation processes were known because we find its principles applied in the more complicated processes which are discussed by the classical authors.

There we usually find a combination between the salt process and the cupellation method. Thus the important information given by AGATHARCHIDES on gold refining in Egypt states that the gold was purified by mixing it with tin (lead?), salt and some barley husks, enclosing the mixture in a crucible with a luted lid and heating it for five days in a fire of straw. On cooling the pure gold remains, the base metals would be oxidized and absorbed by the pot, the silver chlorinated by the salt and absorbed, and the bran would prevent the base metals from being oxidized too rapidly. The low temperature obtained by a straw fire which is said to be specially adapted for gold refining (PLINY, *Nat. Hist.* XXXIII. 60) (STRABO III. 2. 8. cap. 146) would prevent the evaporation of too much metal; for gold evaporates appreciably if heated above its melting point. Here gold remains solid but is gradually penetrated by the refining agents.

This combination of cupellation and cementation by the salt process is not only mentioned by AGATHARCHIDES. STRABO (III. 2. 8. cap. 146) takes "styptic earth" instead of salt; PLINY (*Nat. Hist.* XXXIII. 60; XXXIV. 121; XXXV. 183) refines with lead, *misy* or *alumen nigrum*. The *misy* is translated by copper or iron pyrites (BAILEY) (143) and the *alumen nigrum* by a salt of aluminium or iron (BAILEY), borax or salpeter (42), or a nitrate, chloride or bromide (143).

AGRICOLA mentions a similar process with salt and lead, using urine as the reducing agent (Book VII) and in Japan GOWLAND found a process for refining gold using clay and lead oxides (*Archæologia*, Vol. 69, 137).

2) *Sulphur process*. This parting method consists of heating the gold-silver alloy with sulphur-compounds (sulphides) and charcoal. This treatment transforms the silver into black silver sulphide and leaves the gold as a residual *regulus*. The silver can be recovered from the sulphide by cupellation with lead. It is very probable that the processes with *misy* mentioned by PLINY (see above) are of this type. DAVIES considers desilvering with stibnite (antimony sulphide) very probable in the Ancient Near East (25) and he ascribes the antimony content of some gold objects in Egypt to the use of this refining method. The method is described in detail by THEOPHILUS (III. 69), BIRINGUCCIO and AGRICOLA (X. 254-280).

3) Parting methods involving the use of *nitric acid* are not used before AGRICOLA's time.

IV

We do not propose to discuss in detail the development of the *goldsmith's craft*, a subject which should be left to experts. The importance of the goldsmith in Antiquity is evident from the reports that special workshops were built for them by the kings in Egypt (16) and in Mesopotamia an academy for goldsmiths dedicated to the god Nebo was founded (83). Further study of this subject is urgently wanted. Since the publication of ROSENBERG's book (122) much new evidence has been brought to light by the excavations in different countries and



Fig. 41. Egyptian goldwork as depicted in the tomb of Zenone, 1400 B.C. (after WRZESINSKY, *Atlas*, I, 46)

though surveys have been published on this subject (2) (141) (162) (163) (164) (165) (168) and special books have been written on Egyptian jewelry (89) (128) (162) (163) they should be compared with works on jewelry in Mexico (125), China (3), the Far East (56), etc. linking up with earlier work on jewelry in Classical Antiquity (13) (29). Very little work has been done in collecting and discussing illustrations of the goldsmith or refiner of precious metals at work, the present publications refer to a limited set only (93) (94) (139) (167) though we feel sure that far more material is available if a thorough search were instituted in recent archæological publications. Such a study would be important even from the point

of view of the historian of metallurgy in general, for not only is the goldsmith's craft very ancient but at an early date a multitude of applications and treatments of gold were known (101) (107) (77) (68). Contrary to the common opinion, *granulation* for instance, was applied at a very early date both in Egypt (104) and in Mesopotamia (170) and its methods should be studied as has been done for the Etruscan granulation technique (E. J. LEWIS and W. T. BLACKBAND, *ILN* 28/4/1934, p. 658-659) to find the links and the story of its development. In connection with this problem we should like to draw the attention to the publications of BERGSÖE (6) (7) (8) on the granulation work of the pre-Columbian Indians of Ecuador, who were able to melt and granulate the high melting native gold-platinum alloy of their country even when using very simple methods, though they had recourse from time to time to the addition of copper to their nuggets. There is also the question of the *beating of gold leaf*. In Egypt the gold leaf attained a thickness of 1/5000, that is about 20 to 30 times as thick as the present limit of beating gold. The Romans have improved this technique and made gold leaf that was 8 times less thick (PLINY, *Nat. Hist.* XXXIII. 61). The important studies of THEOBALD (148) (149) have prepared the ground. Special attention has been devoted to the manufacture of rolled gold (136).

A thorough study of the history of the goldsmith's craft and the recognition of its services to the development of metallurgy in general will more than compensate the impressions evoked by the pessimistic words of TIMON of Athens:

"Gold, yellow, glittering, precious gold . . . Much of this will make black, white; foul, fair; wrong, right; base, noble; old, young; coward, valiant."

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CHAPTER SEVEN

SILVER AND LEAD IN ANTIQUITY

"Our next subject is the mining of silver, a second manifestation of madness."

(PLINY, *Nat. Hist.* XXXIII, 95)

PLINY's stinging remarks on the greed evoked by the discovery of the noble metals are less bitter in the case of silver, for he justly remarks that the search for silver led to valuable discoveries of other ores: "A small thing it was to have discovered one plague for humanity, but we must needs set a value even to the corruption of gold. Greed sought silver but did not fail to rejoice at having found minium." (*N.H.* XXXIII, 4). But here again moralists and philosophers have combined gold and silver in their denunciations. Many of the classical authors are quoted by AGRICOLA (3), but to such unfair words as "Silver is the life and blood of human beings; whosoever has not collected a large amount of it, wanders about like a ghost amongst the living" he adds the very just remark that greed is not caused by the metals but by the sinful mortals who handle them. His first Book is a very fair exposition of the usefulness of metallurgy and the misconduct of humanity after the discovery of the properties of metals.

After a discussion of time and region where silver was discovered we will survey the nature and characteristics of lead and silver deposits, the different mines in the Ancient Near East will be discussed, followed by a review of the refining methods used for these metals in Antiquity.

Our present essay will confine itself to the early history of silver and lead, their production and refining in the Ancient Near East.

I

It is futile to speculate on the name of the discoverer of silver, for the recognition of a metal is the result of a long series of observations of its properties. Even classical authors have hesitated to mention any name. In fact, silver, being one of the metals found in their native state, occurs very seldom in workable deposits and there is strong technical and archaeological evidence that the real discovery of silver, that is its production and refining, is intimately linked with the

production of lead. Natural silver was collected from the earliest times in different regions but its role in metallurgy remained insignificant until men learned to produce silver from lead and lead-ores.

Further details will be discussed in next paragraph, but we can anticipate these discussions and state that the production of larger quantities of silver by treating lead-ores was a very complicated series of metallurgical processes, the development of which entailed so many trials and observations that, in the case of silver, the priority of a certain region in the development of this technique may be safely assumed. If we propound a diffusion of silver technology from Asia Minor (probably Pontus) this does not mean that the production of silver could not have been invented or improved in any region independently. For though our knowledge of early metallurgy on the American continent is still very incomplete, modern research has proved that silver was very scarce in Aztec and even in Inca culture. The natives of Peru had indeed collected and melted natural silver, possibly even produced it from the rich argentiferous lead-ores at Potosi and spread its use for ornaments over the South American continent. The early Chimu silver objects are probably made of the native metal. This is certainly the case with Colombian silver objects, which are either silver-greenish because of admixture of gold or reddish because of admixture of copper, two types of natural alloys which occur in these regions, but which could have been produced by the peculiar "blowpipe and charcoal" technique so ably described by BERGSÖE (20) (21) (22). Lead does not seem to have been used to any extent. In Central America the knowledge of silver may have been derived from the South, for the Mayas do not seem to have shared it, but it appears in the XI-XIIth centuries together with other metallurgical knowledge amongst the Toltecs. When the Spaniards conquered Mexico, the Aztecs did use silver occasionally, as silver objects were found on their markets, but they must have depended on natural deposits for their supply, because lead seems to have been unknown to them.

In the Ancient Near East things were different. Silver occurs in Egypt from the Middle Predynastic Periods (s.d. 42) onwards; small pieces of lead of the same period were found and PETRIE discovered a wooden hawk coated with sheet lead in Naqada (217). Egypt, however, can never have been the centre of silver production, because lead and silver do not become common until fairly late. Nor did this knowledge come to Egypt from Africa, for, according to a leading

authority on Negro metallurgy, CLINE (62), silver was probably never smelted and rarely worked by the indigenous Negro cultures. Early references to this metal in Africa seem to indicate no more than its discovery and working by foreign pioneers. Even Egyptian influences on Negro metallurgy seem excluded as this art reached the height of its development in those parts of the continent where no early Egyptian contact can be demonstrated. Indeed in the long history of Negro metallurgy Egypt plays no role, neither having been a leader in the craft. Lead or zinc are seldom mined by Negroes. The Stone Age of Africa is immediately followed by the Iron Age, metallurgical techniques having been brought from the West by the Berbers around 400 A.D. and from the East Coast by Arab traders around 600 A.D.

In Palestine both silver and lead come late, apart from a few early finds at Gezer, they can not be said to have been in common use before the second half of the second millenium B.C., the Hyksos period.

In Mohenjo Daro and other Indus civilisation cities silversmith's work was found, but few details on the technique have been published. Silver and lead were not found in Anau I or Anau II. Though silver objects from Persia and Elam do not date back to a very early period, both silver and lead are known in Mesopotamia since Uruk III and were already fairly common in the Al 'Ubaid period, the Ur graves and early Lagaš. In Central and Transcaucasia they are used from the earliest periods onwards. There is no evidence that silver or lead was used earlier in the Far East (1) (2) (18) (176).

In Cyprus silver and lead are rare before the Middle Bronze Age, but in Crete they are found in the Early Minoan Strata, and on the Aegean archipelago they occur since the Early Helladic period; silver objects are also imitated in early pottery (98). On the Greek mainland, for instance in Mykene, silver is still less common than gold in the Mycenaean period. In Europe silver does not occur in any Palaeolithic or Neolithic finds, in the Bronze Age some simple objects occur and even in the early Iron Age its occurrence is rare.

Only in the La Tène period in regions like Hungary, Bosnia, Transylvania and in the Alps wherever argentiferous ores are found, silver becomes more common. Lead is somewhat earlier. In the Lake dwellings of Middle Europe lead balls (weights) have been found which represent exact multiples of the Sumerian Minae. Lead percentages from 4-15 % have been found in Southern European bronzes of the Late Bronze Age. In Middle and Northern Europe lead bronzes occur in the Imperial period only.

However, in view of the occurrence of workable deposits of native silver and exceptionally rich argeniferous lead-ore in Spain, silver and lead may have been produced at an early date. Indeed, SIRET (*Les premiers âges de métal . . .*, 231-232) demonstrated that silver was in use in Spain when implements of metal had only partially replaced stone and this again may be proof that no absolute diffusionist theory can be accepted for the history of silver. There is, however, no evidence that this early development in Spain had any links with Asia Minor, nor is there any proof that this development in Spain was earlier than that in the Near East.

The early history of silver and lead in Asia Minor is still sketchy. Both occur in Troy I; in Troy II they are very common and six skillets of silver of exceptional purity have been found. Again the Cappadocian tablets prove the existence of a fully developed silver and lead production in the second half of the third millennium B.C. In view of this and the many rich argentiferous galena deposits of Asia Minor, the skill of early metallurgists like the Chalybes and other tribes located mainly in Pontus and the inventions attributed to them, it would seem that the refining of silver and lead was worked out in Pontus in about the early Third Millennium B.C. and that this knowledge spread gradually over the Ancient Near East until both metals were in common use in the fifteenth century B.C. By that time producing centres in Armenia, Carmania and possibly Elam supplied the rapidly growing demand for silver, which metal went south in exchange for Egyptian gold as can be easily proved from the ratio of gold and silver values in these countries in different periods.

We have discussed the simple production methods of gold (103) and made it clear that this native metal was not refined until fairly late, say the first half of the second millennium. In the case of silver we may expect a late development from the triviality of its natural deposits and the relative complexity of its production from lead ores. Metallurgy developed its technique from the smelting of copper ores; bronze and iron production completed its experience and gold technology, especially the craft of the goldsmith has contributed many interesting processes to metallurgical methods. Copper, bronze and iron had their use in daily life; these metals formed a class of superior stones, which were plastic when hot. Indeed the transmutation of these "stones" by heat constitutes the main attraction of metallurgy over the working of stone and was a powerful impetus to replace stone implements by metal ones. But metals and ores could only be handled by

smiths having at their disposal a formidable body of experimental experimental experience and industrial lore. Though these were not secrets, in a way, CHILDE, (60) is right in saying that metallurgy means loss of economic independence.

Silver and lead are useless metals from a technical point of view. Silver had its value as a medium of currency or for the manufacture of ornaments and trinkets. Native silver occurs in deposits too small to produce quantities worth melting (at least in the Near East); silver is therefore, produced from lead-ores by smelting these ores, especially galena, and separating silver from lead. Thus the history of silver is inseparably bound up with that of lead. Silver, therefore, played no part in the culture of early man and has never been found before he became acquainted with copper, gold and bronze, or only occasionally. The first and essential process for the extraction of silver was the smelting of lead ores, a fairly intricate process, which must necessarily belong to the later stages of metallurgical history.

Lead and silver must have become common at the same time in ancient history. The smelting of ores was not a chance operation, but the logical outgrowth of melting experiments. Many centuries must have elapsed between the first melting of metals and the smelting of ores. Metallurgy was blind, not literally, for the early metallurgists were very shrewd observers of the external characteristics of ores and metals, but because no knowledge existed of the composition of materials nor were processes or reactions of working ores and metals understood in our present-day sense. A complex process like the smelting of galena to produce silver must have come fairly late. CHILDE (60) argues that lead ores were probably at first valued for the silver they contain, but this could only have been a fact if the lead had already been found to contain silver.

Lead again was a metal entirely wanting in physical properties needed in weapons and implements; it was a worthless constituent of bronze when used as a substitute for tin. In the words of BIRINGUCCIO (edit. JOHANNSEN, Braunschweig, 1926): "Das Blei ist ein unvollkommenes, aussätziges und wenig festes Metall." Lead appears late in the history of metals, and apart from some applications in architecture and magic, was not widely used before Roman times. GARLAND and BANNISTER (111) found that in Egypt lead bronzes were only used for casting bronzes for ornamental and devotional purposes, but never for implements where a metal of great strength was essential.

The actual discovery of the production of silver from lead ores may

have been made in a very early period, for galena was used as an eye-paint in prehistoric periods in Egypt and elsewhere. Its brilliant metallic appearance, high specific gravity and very common occurrence could not have failed to excite the curiosity of early man. Any piece of galena dropped in a fire would be reduced to lead and, if left long enough in the fire, the lead burns away leaving a small drop of silver. Indeed there is every reason to believe that the first lead-silver smelting furnace was the domestic fire. These facts were the foundation for lead and silver production, which reached an industrial stage in Pontus after many centuries. In fact, classical tradition states that King Midas was the discoverer of lead and tin (HYGINUS, *Fabulae*) (CASSIODORUS, *Variae lect.* 3. 31) (PLINY, *N. H.* VII, 56) (See also CARY, *JHS* XLIV, 1924, 169), which leads us back again to Asia Minor.

The discovery of silver is often attributed to chance, a very common theory of classical authors being the "forest-fire" theory (LUCRETIUS V. 1250-1262) (STRABO III. 2. 9. cap. 147 giving POSEIDONIUS' opinion) (ARISTOTLE *Mir. Ausc.* 87) (DIODOR V. 35) (ATHENAEUS 233). It is claimed that forest fires reduced surface deposits of lead- or silver-ores and a small stream of silver flowed from the burning forest or silver was discovered after the fire. According to NAPIER (*Manuf. Arts in Ancient Times*, 1879, 4) such phenomena have been observed in the Alps and the Pyrenees, but this seems rather a remarkable way of producing silver. It is more likely that the Pontic metallurgists developed their methods by long series of trials and heating experiments and that the classical theory is due more to the desire for a "plausible" explanation than to actual metallurgical knowledge.

There are indeed several classical speculations on early silver metallurgy in Pontus. HOMER calls Alybe "the birthplace of silver" (*Iliad* Book II) and STRABO says that the country of the Chalybes "also had silver mines in earlier times" (XII. 3. 19-22. cap. 549-551) and in a further passage affirms his opinion that the country of the Chalybes should be identified with Alybe (XIV, 5. 28. cap. 680). BURY (*CAH* II. 492) identifies the Hittite "Khalywa" (Land of the Hittites) with Alybe and HEHN (134), LEAF (168), BLÜMNER (P. W. III a, 14) and GILES (*CAH* II. 5) have accepted the identity of Alybe, the land of the Chalybes and the "silver country". The problem has been approached from another side by DHORME (85) who remarks that the town of Ḫatti, capital of the Hittites, is often indicated in Cappadocian texts by the ideogram KU-BABBAR (silver) followed by the phonetic determinative *ti*. Therefore not only are the mountains giving

access to this country called "silver mountains" but the very name of the capital written KU-BABBAR-*ti* should be read phonetically *Ḥat-ti* expressing the bond between silver production and the whole country of the Hittites. Though silver was scarce in the earliest periods of Egypt and the metal was imported from Syria and Asia Minor, it must be considered doubtful whether the Egyptian *ḥd* is derived from the Hittite *ḥat* (silver), for unless the latter is a word taken over by the Hittites from the autochthonous population, the Egyptian word antedates it by many centuries. Thus tradition, archaeology, geology, and technical arguments combine with philology to indicate Asia Minor (and probably the Pontic Coast) as the birthplace of that complex of metallurgical processes which we call silver and lead technology.

The most prominent characteristic of silver is its brilliant lustre, which plays a large role in *ancient nomenclature*. "I think that pride of place is given to this substance (gold), not by reason of its colour, for silver is brighter and more sun-light; that is why it is commonly used for military standards, since its gleaming is visible at greater distance" explains PLINY (*N.H.* XXXIII, 58). We need not wonder that this colour is prominent in ancient names for silver. If ancient nomenclature of metals is found to be vague, we must remember that many names must have arisen out of observations confined to external characteristics of fundamentally one (rather impure) substance. When raw materials are used as they are found or acquired by trade, an enormous variety of composition of metals and alloys will be the outcome and an equally bewildering variety of names.

The common Egyptian word for silver is *ḥd*, literally "white". As we explained in discussing the history of gold the natural gold-silver alloy, electrum—often silver coloured—must have been called "silver" as long as no methods for the separation of silver and gold were known. „Silver" was everything that had the external characteristics of silver. Therefore the words "white gold" could hardly have been used for electrum as long as it was not known that electrum was an alloy of silver and gold; indeed both the silver-white electrum and natural silver (rare in early Egyptian history) must have been called "silver". Though *ḥd* is often accompanied by the determinative *nub* (gold), this combination of signs should not be read "white gold". According to DE BUCK *nub* is purely a determinative and therefore silver was called simply "white, white native metal". If STRABO applies the term "white gold" to electrum (III. 2. 9. cap. 147), he knows that he is dealing with a mixture of silver and gold.

In the Graeco-Roman period another term for silver occurs in Egyptian texts. This word 'rêwr (ERMAN-GRAPOW, HWB I, 213) seems to have been derived from the Greek *argyros*, it may denote the pure metal. LEPSIUS (172) (173) gives another late term *ru* or *ruā* which has not been identified.

The Hebrew *keseph* (silver and later a silver coin) denotes the same white, brilliant metal as the Accadian *kaspu* (*šarpu*). The Sumerian KU-BABBAR is said to mean "white, brilliant" (287). It is not known whether the Hittite word *hat* means "white" too, SCHRADER points out that many Indo-European terms like silver, Silber, etc. are derived from the Accadian *šarpu* travelling along trade routes from the Euxine to the Baltic coasts and that the variety of terms in Indo-European languages proves that silver was not known until late in these regions (266). He derives the terms *argentum*, *argyros*, etc. from a root *radj* or *arg* meaning "white, bright shining". Thus in most languages the term for silver means "white and shining metal", showing a singular uniformity as compared with the complex nomenclature of gold and electrum. This again may point to the comparatively late appearance of silver in history.

In the case of lead the ancient nomenclature presents many difficulties which are the outcome of defining materials by their external characteristics. There is considerable confusion in ancient texts when dealing with lead, tin, zinc(?), antimony and arsenic, terms for each of these metals being used fairly freely for the others. Only from the context and careful study of the technical possibility of the translation can one sort them out. Thus CAMPBELL THOMPSON (287) very aptly pointed out that A-BĀR or A-GŪG and the Accadian synonym *abaru* generally mean lead, they are occasionally used for plumbago or antimony; and the word AN-NA (or *anaku*) though generally denoting tin is sometimes used in texts where it can only mean lead. *Abaru* seems connected with the Syriac *Abbârâ*, the Hebrew 'ôphêrêth and the Arabic *abbâr*. *Anaku* is related to the Hebrew *anak* (plummet) and the Syriac *ankâ* (black and white lead) or the Arabic *ankum* (lead). In Cappadocian tablets *anaku* is used very frequently and can denote nothing but lead. The Egyptian word for lead is *dbty* (ERMAN-GRAPOW, HWB, 1921, 221), and as lead was generally regarded as a kind of inferior silver, we find the word used to express "a worthless thing" in later periods. SCHRADER (266) derives words like *Blei* and *molybdos* from a root 'mliwom meaning "blue", which MEILLET considers to have been taken from an Aegean language. Our word lead is

derived from an old Celtic term *luaide* and the Latin *plumbum* originally meant "tile, bar".

The confusion of lead, tin and antimony (which will be discussed more fully in our next chapter on these metals) is very obvious to anyone consulting classical authors. PLINY calls lead *plumbum nigrum* and tin *plumbum candidum* or *album* (N. H. XXXIV. 158), his *stagnum* meaning "Werkblei, crude lead, work-lead", and not *stannum* (tin). Medieval alchemists call lead and tin masculine and feminine lead. But then even AGRICOLA talks of *plumbum nigrum* (lead), *plumbum candidum* (tin) and *plumbum cinereum* (antimony) and modern Arabs distinguish tin and lead as white and black lead (287) (132); which terms will remain confusing if one does not take into account the external characteristics of lead, tin and antimony in studying the ancient texts. It must be left to expert philologists to decide whether these ancient terms for lead are based either on its dark-grey-blueish colour or its easy fusibility.

Both metals play an important part in religion, mythology and magic (1) (9) (112) (140) (176) (237) (245) (249) (288). Silver is the metal of the moon-god Sin, both being described as "green" (149). In a Sumerian hymn Gibil, the god of fire, is said to purify gold and silver. The connection between silver and moon is common all over the Ancient Near East. In Egypt Hathor, the moon-goddess, is goddess of silver (125), while in the magical papyrus Harris (IV. 9) and other papyri the bones of the god Rê and other gods are fashioned of silver (125) (160). Silver was often called Luna or Diana by the later alchemists, its symbol is a crescent moon because it has the silvery colour of moonlight. Silver weapons or bullets never fail to kill and there is no charm against them. This is a very persistent tradition in the East. Silver is one of the most frequent metals used for charms and amulets, it has special affinity for some precious and semi-precious stones, which should on no account be set in gold. The fact that crude lead can be reduced to plumbago and silver is the basis of ancient technological processes. This may have led to the early Syriac tradition of the transmutation of lead into silver, which was repeated in the Middle Ages, in the heyday of alchemy, by VINCENT OF BEAUVAIS and others, who considered lead to be debased silver.

Lead plays a very peculiar part in magic. Its dark colour and high specific gravity must have led to the superstition that it had chthonic connections. It is also said to be a "very cold" metal. In Egyptian

magic it is the metal of Osiris, in Babylonian magic that of Ea; later alchemists call it the metal of Saturn, whose symbol is used to denote lead. Both THEOPHRASTUS and GALEN (*Mat. Med.*) are the first to call it "cold". It was considered eminently suitable for magical tablets containing inscribed curses or prayers for the sick; lead being used for "defixiones" from Assyrian times onwards. The lead tablet mentioned in Zach. 5 : 7 is probably inscribed with figures of demons. In Graeco-Roman times lead tablets are in common use for devotions and carmina and continue to be used for these magical purposes and practices up to the present day. Again the future can be prophesied from figures formed by congealing lead poured molten into water, and many other magical rites are performed with leaden objects (288) (A. DEISSMANN, *Licht im Osten*. 1923, 119) (M. LIDZBARSKI, *Eine punische tabella devotionis*, *Eph.* I, 1900, 26) (D. OPITZ, *Altorientalische Gussformen*, *Oppenheim Festschrift* 1933, 192) (R. WÜNSCH, *Antike Fluchtafeln*, 1907).

When Demas tempted Hopeful on Lucre Hill saying: "Here is a silver mine, and some digging in it. If you will come, with little pains you may richly provide for yourselves", Christian was right in deterring his friend from following this advice. There is more truth in the old Spanish proverb, which states that it takes a gold mine to run a silver mine.

Silver is fairly widely distributed in minerals in quantities less than $\frac{1}{2}$ %. Very few gold ores are free from silver and it is almost invariably found in sulphides, that is in ores consisting of sulphur compounds of lead, copper and zinc. Granite rocks contain on the average 6 parts of silver per million, sandstones 0.44 parts, marbles about 0.2 parts and silver is invariably found in minute quantities in ashes of land-plants, blood or herbivora, corals, volcanic ash, etc.

The largest part of the present world's production is derived from lead and copper ores because smelting lead and copper includes the production of silver (and gold) as by-products, whose market-price does not have such a strong influence on the amount of the silver production. The discovery of America opened up new sources for the production of silver and 1,511,050 Troy ounces were produced between 1493 and 1520, a figure which increased enormously after copper and lead began to be extensively worked and reached a total of 171,200,000 ounces in 1920. More than two-thirds of this silver were produced in Mexico and the United States.

Silver in comparison with gold is of rare occurrence in nature in the native state. *Native silver* is not found in alluvial deposits or sands and gravels of rivers, but has to be sought in mountainous regions where it is embedded in mineral veins. Except for the extraordinary deposit in Kongsberg, Norway, silver is not found in lumps or nuggets but in delicate filaments and foils formed by the oxidation and decomposition of lead and silver ores. Native silver rarely occurs at the surface or in outcrops of veins because it is liable to have been converted into chloride by traces of chlorine invariably present in rain water, and washed away. When tracing the history of silver it is important to remember that silver objects which remain in the earth for a long period come to be covered with a white greyish crust by the action of chlorine or converted entirely into soluble chlorides by the action of rain and salt sprays from the sea. Even Roman objects have by now often been converted into unrecognisable masses. No wonder that such masses may have been missed in excavating! The absence of silver in early periods does not prove with absolute certainty that the metal was then unknown.

Native silver is usually found in quantities not worth melting to larger lumps which can be worked. It crystallises in cubic crystals which may be very pure (FORBES, *Phil. Mag.* XXX, 1865, 143, on Peruvian native silver) but are usually alloyed with gold, copper (in France up to 10 %), mercury, arsenic, antimony, iron, etc. Native silver rarely occurs in lumps or leaves which without melting can be fashioned even into the simplest objects and therefore we may safely conclude that it can hardly have played a part in the life of early man.

Several *silver ores* are known such as Argentite (silver glance, black silver ore, glance ore), a sulphur-silver compound, Proustite (light red silver ore, arsenical silver blende), Pyrargyrite (dark red or ruby silver ore, antimonial silver blende) and Cerargyrite (silver chloride, horn silver) which all occur in the strata overlying lead ores as decomposition products of such ores. Deposits of these ores are rare; apart from rich deposits of this type in the New World, they are found in the deposits of lead ores in Spain and in parts of Cornwall and Hungary, but they are of no importance in the Near East. Though HILLER (137) concludes from a passage in PLINY (*N.H.* XXXIII, 95) that these ores were worked in Spain by the Romans, we can safely assume, that they were included in the silver production from lead ores, if they were ever worked to any extent in the Ancient Near East. Simple heating (or roasting) and reduction of these ores with charcoal will produce silver.

Native gold alloyed with silver, the ancient *electrum*, formed an ancient source for silver production as we have pointed out in a former paper (103). Even nowadays 1,500,000 ounces of silver are extracted from bullion gold though more than two-thirds of the world's silver supply is produced from lead, zinc or copper ores containing less than 0.5 % silver.

The ores from which the metal was first produced in larger quantities were no doubt ordinary *lead ores* and not the rather rare silver ores associated with these lead ores. Prominent amongst the lead ores is *galena* (lead sulphide, a compound of sulphur and lead) which is of very common occurrence. In many localities (especially in Asia Minor if we keep the Ancient Near East in mind) vast almost inexhaustible deposits occur at the surface. Its brilliant metallic appearance and high specific gravity can not have failed to excite the curiosity of the primitive miner. After using it as an eye-paint, he conceived methods to produce from it lead and later silver. The indirect method of producing silver from galena must have been a hindrance to the development of silver technology. For though practically every type of galena is argentiferous, the quantities of silver (usually expressed not in percentages but in ounces of silver per Ton of lead) are minute. The average silver content of different galena samples varies from 20 to 200 ounces per Ton of lead; 0.5 % of silver (about 150 ounces per Ton of lead) being regarded as very rich. In some cases special lodes or veins may contain higher amounts, one of the richest being found in Karahissar (Asia Minor) containing 600 ounces or 1.84 % of silver. The majority of the ores contain 0.15 % (50 ounces) or less. By selecting special lodes for production in periods when refining methods were wasteful, material containing a high average such as 3 % of silver could be got. This is the category which AGRICOLA calls a rich ore, but which is now considered quite exceptional as improved refining methods enable us to work much poorer ores. It is quite possible that AGRICOLA really meant true silver ores when he speaks of these rich lead ores. In the production of lead from these ores all the silver, which readily dissolves in lead, is concentrated in the baser metal and not in the other by-products from lead ores. This fact may have led many an alchemist astray and may have led him to believe that he had transmuted lead into silver when he started refining the crude lead.

Apart from galena, two other lead ores have a certain importance as raw materials for the production of lead only. The more plentiful

of the two is Cerussite (lead carbonate), clear or slightly coloured crystals like calcite, but rather soft and brittle. CAMPBELL THOMPSON (287) has identified the Hūlalu stone (or *ZA-ṬU-KUR), which occurs so often in the Amarna letters, with cerussite, and though these brilliant crystals could have been used in the ornamental objects in which they are stated to have been applied, there is no doubt that their brittleness must have been a serious hindrance for a wider application as a semi-precious stone. The second lead ore of some minor importance is Anglesite (lead sulphate) forming crystals like gypsum but with a more brilliant lustre. Both cerussite and anglesite occur with native silver and silver ores in the oxidised portions of lead ore outcrops on the surface of the earth for instance in Asia Minor and Armenia. There is no doubt that the ancient miners knew this connection between the ores of the oxidised top portions and the lower-lying lodes of unchanged galena.

This is what PLINY says about silver-mines in Spain (*N.H.* XXXIII, 95-98): "Silver is only found in shaft-mines and there is no previous indication of its presence for there is no glinting spark as in the case of gold. The earth is red in places (by the presence of minium, a natural lead-oxide) and ash-coloured in others (unoxidised galena) (see also XXXIII, 111). Silver is found in almost all the provinces but the best comes from Spain. Like gold it occurs in barren soil and even among mountains and wherever one vein is found another is not far to seek. This is the case also with most ores, and seems to be the source of the greek word *metalla*. It is wonderful that the mines opened by Hannibal in Spain are still productive. The vein of silver that is found nearest to the surface is called *crudaria*. The early miners use to cease operations when they came to *alumen* (see p. 50), seek no further, but the recent discovery of veins of copper below that *alumen* has removed this limit of their hopes. The exhalations from silver-mines is poisonous to all animals but especially to dogs (evolution of sulphur-dioxide gases)."

Indeed lead ores are very often associated with copper ores, many examples of this association are to be found in the mines of the Ancient Near East. THEOPHRASTUS mentions the same facts and states that such minerals as Arrhenikon, Sandarake, Chrysocolla, Minium, Ochre, and Kyanos are very common in gold and silver mines. Also minerals containing gold and silver are much heavier in weight and smell according to THEOPHRASTUS, but only the silver is visible (that is to say the mineral has a silvery colour because of the high silver

content) (137). In the time of AGRICOLA and BIRINGUCCIO this was common knowledge.

In mapping out the lead and silver deposits in the Ancient Near East we have therefore confined ourselves to the indication of the galena deposits because any one of them will have native silver, silver ores of the less important lead ores associated with galena in its surface outcrops, in more or less important amounts.

The *mining of galena* for silver and lead production was similar to that of gold to a certain extent (DIODOR III. 13) (PLINY XXXIII. 66). Of course here the surface lodes were far less important and silver is never produced from alluvial deposits. Therefore, panning, placer mining and hushing as described for ancient gold were rarely used. The only way of approach to the deeper galena deposits was vein-mining by means of shaft-mines. In Laurion alone, more than 2000 shafts have been found on a depth up to 250'. PLINY states (XXXIII. 97) that the silver mines of Spain had shafts which extended 1500 paces into the mountains and the Romans were the first to achieve the tapping of the veins below the subsoil water level by complicated systems of drainage using water-wheels, pumps, Archimedian screws, etc. Primitive lead-mining practice as used at the present time at Ajmir (India) (240) may be used to illustrate mining practice in the Ancient Near East. After collection of the galena mixed with gangue and other useless stony material from the lead-bearing stratum, the ore was brought to the surface, crushed, washed with water and sieved to concentrate the ore. These methods are discussed in detail by AGRICOLA (3), whose books show clearly that the methods described are survivals from Roman and pre-Roman times, like so many technical processes, but gradually perfected by many generations of miners and metallurgists. STRABO gives a good description of what happened in Spain (III. 2. 10 cap. 148): "Silver bearing ore is carried along in the streams, is crushed and disengaged in water by means of sieves, then the sediment is again crushed and again strained through (the water being in meantime poured off) and crushed; then the fifth sediment is smelted and after the lead has been poured off, yields pure silver." The sieving of the crushed ore in a stream of water is called *jigging*, during the process the heavy particles of galena fall through the sieve to the bottom, the lighter gangue forms a layer on the top of the sieve and is thrown away. The sediment, as STRABO calls the galena particles, is washed five times to remove all the stony particles and concentrate the ore. Concentration of the ore to a lead content of

70-85 % means the possibility to use simple smelting processes for the production of silver and lead.

III

If we wish to draw a *map of the silver- and lead-ore deposits* known in Antiquity there are more reasons than one why we should confine ourselves to the mapping of the galena-mines. We have mentioned the geological reasons which urge us to simplify matters by selecting galena as the representative of the complex of silver, silver-ores and lead-ores. A second reason is the lack of proper mineralogical information about the deposits in the Ancient Near East. Even such handbooks as the *Handbuch der Regionalen Geologie* rarely state any details about the minerals found in a certain region and, as a matter of course, archaeological handbooks are still more vague and mention silver-mines without even saying whether the silver is found native, in the form of silver ores or in lead-ore. Both history of science and archaeology would profit by an exact and complete compilation of all geological data on the Ancient Near East. A third point is equally confusing to any student: different writers on these subjects use various spellings of geographical names; not only the ancient names but even modern Turkish towns are spelt in so many versions that without detailed maps it is impossible to find them at all. Again a mine is said by one writer to lie in a certain district, the other will locate it near a town or a hamlet, the third will mention the province or river only, so that one mine is mentioned under five or more different guises by the authors. It would be most important if some agreement could be achieved internationally to use a given standard map as a basis for all geographical details, this would avoid much confusion for expert and layman alike.

Too few details are known about the different galena deposits to sort out mines that have been worked in Antiquity, those that have been abandoned and those which are new discoveries. Such details, as far as known to the present writer, will be given in the discussion below. There are hardly more than vague indications about the locations of mines in the pre-Roman texts known up to the present.

Again we must carefully avoid taking too much notice of texts mentioning silver and lead as tribute, because in many cases the regions paying this tribute could not have produced the metals in question from their own mines. The many tributes of silver paid to Egypt by Syrian towns, for instance, must be interpreted as tribute

only; Syria and Palestine had only few deposits and probably got all their silver and lead from other districts such as Asia Minor.

In the map we have also indicated by arrows trade-routes by which these metals may have been imported, though the countries mentioned between brackets near these arrows can hardly have been engaged in silver and lead trade with the Near East in Antiquity.

In *Egypt* there are four important galena deposits apart from the numerous gold mines, the gold of which always contains silver, but unfortunately the lead ores contain only slight amounts of silver. There is the argentiferous galena containing only about 30 ounces of silver about two miles south of Safaga Bay near the Red Sea near the ancient Mons Claudianus (36) (87), where in Roman times lead and silver were exploited. Galena practically free from silver occurs in large quantities at Gebel Rosâs (25° 17') about 70 miles south of Qoseîr (87) (144) (212) and cerussite and native silver are found associated with it in small quantities. This deposit was certainly worked for lead during many centuries as even in the third century A.D. the Romans exploited it and a tax was raised on the production which must have been important enough to justify such a measure. These mines were reopened in 1913 by a European company. A third deposit of galena is found in the Bahram Mts., 25 miles east of Syene in the Thebaid, south of Apollinopolis Magna (Edfu) (87) (99). A last deposit of galena is associated with the Um-Samiuki copper ore at Gebel Abu Hamamîd, 50 miles north-west of Râs Benâs near the Red Sea coast (144) (180) (181). Thus, contrary to GOWLAND's opinion that there were no silver ores at all in Egypt (123), deposits do exist (99) (144) (180) (see also *Mines and Quarries Dept. Report on the Mineral Industry of Egypt*, 1922), but they are practically valueless for silver production, although rich in lead.

Lead and above all galena has been used from predynastic times to the Coptic period, the mineral is very common as an eye-paint throughout these centuries. The lead used for small ornaments, sinkers of nets, plugs and rings since Old Kingdom times may have been of local origin, but it becomes common only during the XVIIIth dynasty, together with silver imports, which facts tend to show that a local industry did not develop until late when the correct methods were learnt from the North. Thothmes III brought back large quantities of lead from his Syrian campaigns, the total tribute obtained from Retenu, Isy, Tunip and Syria in general amounting to 90 blocks of

lead, 1200 pigs of lead and a quantity of over 1760 Kgr (47). In the XXth dynasty the Papyrus Harris mentions such large quantities as 3090 Kgr. (twice) and 7100 Kgr (47)! But a XVIIIth dynasty lead net sinker was not desilvered and indeed pure lead remains rare until Roman times. Lead was used in glazes from the XVIIIth dynasty onwards and Saïtic and later bronzes contain appreciable amounts of lead instead of tin (6-12 % average and sometimes up to 20 %) (111) (BUSCH, *Z. f. Angew. Chemie*, 1914, 512). These lead bronzes were of course more fusible and fluid and easier to cast, engrave, etc., probably also cheaper, but they were suitable only for casting ornaments and devotional objects where no great strength of the bronze was required. Lead coffins are found in Egypt since the Ptolemaic period. If Hellenistic papyri mention *kollytis* and *molybdourgos*, plumbers, who repair and make water-pipes, this is a clear proof of the penetration of Graeco-Roman technique into Egypt.

Both lead and silver occur in Egypt since the Middle Predynastic Period (50) (217) (218) (219) (220) (221) (222), the sign *ḥd* for silver occurs since the Third Dynasty (36) but the metal remains rare for many centuries. In the Pyramid Age it is rarer than gold and precedes this metal in lists and texts (111). It may have been imported from Syria and Asia Minor, but because the silver production was hardly developed in those regions, it is more probable that the "silver" used in Egypt was the silver-coloured electrum (180). The analyses given by LUCAS of silver objects dating before the XVIIIth dynasty prove this as they contain far more gold than would occur in silver derived from galena. Early silver contained 60-92 % of silver, 3-38 % of gold and traces of copper, certainly a natural product not obtained by smelting. This silver is often patchy from gold particles as a natural product would be, but not a molten one.

The beautiful silverwork of the Middle Kingdom (200) (260) and the picture of rings and necklaces in the tombs of that period (DAVIS, *Tomb of Siptah*, plate 9f) show that the Egyptian goldsmiths had turned their experience to this new metal, either imported or held to be pure silver when found as electrum. Silver remains more valuable than gold, even in Hyksos' times (Papyrus Rhind) it has double the value of gold. In the New Kingdom more plentiful supplies change the ratio gold/silver to 5/3, both lead and silver being imported or taken from Syria and the North mostly in pigs, blocks or rings as the reliefs show us. The "Keftiu" bring silver to Amenhotep III, the silver merchants are Syrians (*Grab des Rechmerê*, I, plate IIa, IIb), the lead

comes from Asia (SETHE, *Urk.*, IV, 1101). Thothmes III receives silver rings from Hatti (GARSTANG, *Land of the Hittites*, 1910, 322) and the peace-treaty with Hattušil is written on a silver tablet (WEIDNER, MDOG, 58, 68) (MEISSNER, ZMDG, 72, 50).

But if Egyptian goldsmiths make silver rings (260) and the King of Alašia exchanges silver objects from Egypt for copper, as the Amarna letters prove, this does not mean that a silver industry existed, but only that the clever Egyptian goldsmiths worked imported silver by their own methods, developed by an age-old craft. If, therefore, silverwork in Cyprus shows Egyptian style-elements this is due to the craft of the Egyptian goldsmith and is no proof of a silver production in Egypt. The texts of the New Kingdom mention large quantities of silver (98, 25, 360, 24, 37 lbs, etc.) taken from Naharin, Kheta, Retenu, Zahi, etc. as booty or tribute. The enormous quantities of silver given by Ramses III to the temples (figures like 9 cwt and 20 cwt are given (221)) prove that by then silver had become more common in Egypt. Assurbanipal took two silver obelisks weighing 75.000 Kgr. (?) as spoil from Thebes in 661, but still the metal was not as plentiful in Egypt as in Persia by the Persian period, the gold-silver ratio being still 2/1. Alexander tried to enforce a 10/1 ratio but only in the reign of Ptolemy II did the normal 13/1 ratio exist in Egypt. Before that time Egypt remained a country poor in silver if compared with the rest of the Ancient Near East. Silverwork profited from improved goldsmiths technique; a XXth dynasty bowl was probably made by spinning and since the Ptolemaic period raising was known to the Egyptian silversmiths (111).

The deposits in *Africa* had no importance in Antiquity. Lead ores occur in the Sudan in the Gebel Kutum and there are deposits at Broken Hill, North Rhodesia. Some authors mention silver imports from Ethiopia into Egypt (99) but it is not clear where these deposits should be sought. The lead-ores of Nigeria, Algeria and Tunis meant nothing to the Ancient Near East and if HERODOTUS tells us (III. 13) that the Cyreneans gave Cambyses 500 minae of silver this means tribute not production. Indeed silver was so scarce in Africa that Mungo Park finds the gold/silver ratio to be 4/3 in the Sudan in 1796 instead of the Egyptian ratio of 13/1 (RITTER, *Erkunde, Afrika*, II, 1822, 469). This and the observations of CLINE (62) prove definitely that Africa did not produce silver for Egypt nor was there any diffusion of the knowledge of silver technology from Egypt to the Dark Continent.

Arabia is notoriously poor in lead or silver ores (107). On the east coast of the gulf of Akabah the Midian mountains contain galena rich in silver. This is the source from which the Nabateans produced it (STRABO XVI. 4. 26. cap. 784) and exported it from the harbour of Makná. But on the rest of the western coast of Arabia no deposits of lead or silver ores are reported. For STRABO correctly says that the Debae exchanged gold for silver (XVI. 4. 18. cap. 778), not that they produced it, and the Sabaeans may have had vast stores of gold and silver (STRABO), but no deposits are known to exist in their country. Argentiferous galena is reported from the mountain of Oman.

Both *Palestine and Syria* are very poor in ores, the only two deposits are Gebel Akra (Mt. Tasio), north of Ladikiye and the region south-east of the Dead Sea, but silver and lead seem to have been imported in early days. We may be told that Abraham was "rich in silver" (Gen. 13 : 23) or that he paid "Ephron 400 shekels of silver, current money with the merchant" (Gen. 23 : 16) and that Joseph was sold for 20 silver shekels (Gen. 37 : 28), but silver and lead are rare in the remains of ancient cities in these regions. Indeed apart from silver and lead found at Gezer (VINCENT, *Excav. at Gezer*, I. 293, 303), at Ta'anach (SAYCE, *Patr. Palestine*, 243) and the two horned Hathor statuettes from Tell Ajjul these metals are rarely found in early strata in Palestine, but somewhat more abundantly in Syrian cities. The Israelites possess silver in the wilderness and a silver image is cast for Micah from 200 silver shekels (Judges 17 : 4), but the metals become plentiful in the days of the kings. David stamped silver and it figures largely in the descriptions of Solomon's reign. He is said to have obtained it from Arabian kings (II Chron. 9 : 14) or from Tarshish (II Chron. 9 : 21; I Kings 10 : 22; Jer. 10 : 9). *Tarshish* has been identified with *Tartessos* and this silver was believed to be Spanish silver brought to the East by Phoenician traders. But the Tarshish problem remains unsolved, the "navy" or "ships" of Tarshish may even be just synonyms for sea-going ships and it would be unjustifiable to assume silver production in Spain and trade between Spain and the East at so early a date on such slender evidence. Apart from such finds as the silver vases and objects at Gerar both metals become common only in Hellenistic times. Then it is even reported that the river bed near Jerusalem is lined with lead (Letter of Aristeas cap. 90) and JOSEPHUS mentions large stocks of lead (Wars VII. 8. 4). The Maccabees coined silver money and hence the new meaning "coin"

given to the word *keseph* (silver). Lead is generally considered to be "reprobate" silver (Ezech. 27 : 12), it is mentioned in lists of metals after tin or iron (Numb. 31 : 22; Ezech. 22 : 18; 27 : 12), but this means only that it was considered the most worthless metal not the most abundant.

The classical authors tell us many stories about silver deposits in *India*. According to STRABO it is found in the country of the Musicanes (XV. 1. 34. cap. 701) (by which he probably means lead-ores from Baluchistan) and also in the country of the Catheans, in the mountains of the Punjab (XV. 1. 30. cap. 700), but he does not indicate any closer location. Nor does KTESIAS (Indika, cap. 11), who remarks that there are many rich mines which were not so deep as the Bactrian mines. There are many galena deposits in India, some of which (Ajmir) have been worked for a very long time, others like those of Upper Burma or those further east in Annam, Tonkin and South China (Fo-kien) can not have been of any importance to the Ancient Near East. The origin of the silver found in Mohenjo Daro is still a mystery (182). MACKAY believes that local sources may have been tapped but is more inclined to postulate supplies coming from the argentiferous galena of Afghanistan. On the one hand he rightly remarks that extraction from electrum or galena at so early a date seems doubtful in view of the lack of correct appliances. Still, though less common than copper, bronze and gold, silver is by no means rare in the Indus civilisation. The local silversmiths were skilled craftsmen who understood soldering and made beautiful ornaments. He, therefore, hesitatingly suggests that extraction from galena may not have been beyond the local craftsmen. Further detailed study on this silver-work is urgently needed to settle this question; we are inclined to doubt this early extraction from lead and refining and suggest that the "silver" is really electrum, but analysts must have the last word.

There were important sources of silver and lead to the north of India in *Bactria* and *Transoxania* which have been worked from the Persian period onwards and possibly still earlier. The only excavations going back to very early stages of civilisation tell us nothing about these metals. PUMPELLY found lead in Anau I only, but silver seems to be unknown. Still, Afghanistan and the regions to the north of the Oxus contain many deposits of lead-ores which like those in Persia are always argentiferous (182). Badakshan contains old mines of silver and lead, which MARCO POLO (Book I, xxiv) mentions as very productive and which occur in the writings of ABULFEDA and IBN

HAUQAL. In Farghana (Transoxania) other deposits are located, especially in the Mawarannahr mountains and the Waisli-kara range. South of the Oxus, Mt. Bangahir near Anderab on the way to Kabul was still worked in the days of Abulfeda, and further south halfway to Kabul the mines of Panjhîr were known to the same writer after having been seen by the Chinese pilgrim HIUEN TSANG in the seventh century (*Si-yu-ki*, edit. BEAL, II, 278); they are still worked (STAHL, *Chem. Z.*, XVIII, 1894, 364). The Chinese valued the silver from P'o-tzu (Bactria). In Bactria proper there are mines to the north-east of Balkh, in the neighbourhood of Mughab and in Pendjeh all of which have been abandoned. The Chaliphs used these mines in Transoxania, Ferghama, Fars, and Kerman but above all those in Khurasan, but the mines in Afghanistan and north had to be abandoned in the ninth and tenth centuries because of lack of wood-fuel. Imports from the Altaï region or further east from China (especially the central province of Hunan) and Japan are improbable in the period we are dealing with.

In *Persia* many important deposits are found. First of all in Khurasan there are ancient lead mines near Mt. Nich (45) as well as on Mt. Binalud and other mountain-sides between Meshed and Nishapur (CURZON, *History of Persia*, II, 510, 517). In the province of Kerman there are many ancient mines south and east of Kerman up to Murghab. In the present Fars, the ancient Carmania, galena is found in the neighbourhood of Niriz. HERODOTUS (V. 49) says that Darius got silver from Cappadocia and Carmania and STRABO mentions these mines (XV. 2. 14. cap. 726) on the authority of *Onesicritus*. They may be the silver mines mentioned by Marištusu in the so-called Cruciform Monument in his story of his wars against a coalition of 32 cities (CAR I. 141). More to the north there are galena deposits in the central mountain range in the district between Kashan and Isfahan, further south near Yezd and north near Anarak. The mountains in Damghan and above all the Elburz range contain many rich veins of galena. Some of the ancient mines near Isfahan were abandoned in the ninth century. There is little lead and silver in Azerbaijan (MALCOLM, *History of Persia*, II, 369) except near Mt. Sahund.

Both silver and lead appear late in Iranian history, but then we must remember that much of the early history of this country is still a blank. In the Elamite period (about 1100 B.C.) fairly pure silver occurs and the lead is practically pure, which would point to a penetration of the processes for desilvering lead to those regions (MORGAN,

DP VII, 1905, 72-91). DESCH considers the silver used in Luristan to be native metal (*B. A. Report*, 1931, 271) and KING (*Sumer and Akkad*, 262) says that supplies of silver came from the hills of S. Elam (311), but no further indication of these deposits can be found, unless those of Carmania are meant. Lead is mentioned in the *Vendidad* as material for vessels but both metals become common only in the Persian Empire, when the gold Darics and the well-known Persian sigloi were coined. The huge accumulations of gold and silver in the palace of the Persian kings can be judged by the reports that Alexander the Great found 40,000 talents of gold and silver ingots and 9000 talents of coined money.

Mesopotamia did not contain any galena deposits but many rich mines existed in the mountains of *Armenia and Kurdistan*. There is galena on the sloped of the Takht-i-Suleiman near the upper course of the Diyala river. Large amounts of lead-ore containing an average of 20 oz/Ton of silver are found in the mountains near the sources of the Greater Zab and Khabur rivers, especially in the Tiyari mountains, in the neighbourhood of Lisan near Lake Urumiyah, and to the west on the Judi Dagh in the region north-east of Niniveh. From Muşaşir in this region Sargon II took large quantities of silver (287) (LUCKENBILL, AR, II, 95, 109) and before him Tukulti Ninurta II (LUCKENBILL, AR, I, 130). Further north there are important galena deposits near Erzerum (Carana) on the frontier of Armenia and many other mines round Erivan, north of the Araxes river in the ancient districts of Colchis and Iberia. On the western frontier of Assyria two very important mines are found. The first was Ergenimadeni (Arghan Ma'den) near the ancient Arsinia in the neighbourhood of Diyarbekir (Amida) on the Tigris (123) and the second Keban (Keban Ma'den) on the border of Cappadocia near Harput and Maltya. Keban is regarded by some authorities as the site of the "silver mountains" which Sargon I and Maništusu record (POEBEL, UMBS, IV, i, 178, 206) but these are more probably the Cilician Taurus (123) (274).

In *Asia Minor* (53) (107) there are no less than 26 important deposits, seven of which are located in Pontus in the district south of Trabzon (Trapezus, Teribizonde). They are located:

1—Near Artvin on the river Chorokh.

2—At Baiburt near Domana and Erzerum on the northern frontier of Armenia, where at the time when MARCO POLO visited this district there was still a mine "rich in silver" (Book I, chapter iv).

3—At Gümüsane (Gümüş Ma'den) on the Harsut river east of

Karahissar, south of Tirebolu (Tripolis, Pharnacia) where the ore contains much silver (like the other galenas in Pontus), about 48-120 oz/Ton. These are probably the mines to which STRABO refers (XII. 3. 19-22, cap. 549-551) but which were exhausted in his time according to his information, which must be wrong as the mines still contain enormous amounts of galena.

4—At Lidjessi near Karahissar (Colonia), where galena contains over 70 % of lead.

5—The Gebel Bel Ma'den.

6—Near Niksar (Neo-Caesarea, Cabira).

We have already referred to the Chalybes-Alybê problem and would only add that these Pontic mines were so rich that Pompey took 6000 talents from them and that they are still by no means exhausted.

7—Gümüşacıköy (Hadjy koi) near Amasya (Amaseia) on the Paphlagonian border (MYRES, CAH III. 661).

8—Kargi, east of Kastamonu in the Ilgaz Dagħ.

9—Ak Dagħ Ma'den between Sivas and Kayseri (Mazaca Caesarea), which mines were probably the source of the silver and lead which the Assyrian traders at Kaneš (Kül-tepe) 10 miles north-east of Kayseri buy and send home (LANDSBERGER, AO, XXIV, 1925, No. 4) (37). Tiberius founded a mint at Mazaca, which proves that they were still working in Roman times.

10—Berektlu Ma'den in the AlaDagħ (Anti-Taurus), which has been tentatively identified with the "Tunni mountains" where Salmenassar III got his silver. These mines are now exhausted (188).

11—One of the two important mines in the Cilician Taurus is Bulgar Ma'den where the lodes of galena contain up to 600 ounces of silver (1.84 %) and which still produces 168,000 Kgr. of lead and 1500 Kgr. of silver per year. Hittite inscriptions were found here (VON DER OSTEN, OIP, No. 6, 1929, 130) (OLZ, XV, 148) and this is more probably the "Tunni" of Assyrian inscriptions (KAH XXX, iii, 2) (LUCKENBILL, AR, I, 206, 246) (123) (274) (188). The silver was exported to Egypt and shipped from Mallus on the coast (OLZ, XV, 246).

12—Ala Dagħ in the southern Cilician Taurus near Gilindre (Kilindria) where the ore contains the high average of 1 % of silver. The Cilician Taurus is probably the silver mountain which Sargon I and Erimuš claim to have reached. It is claimed that the silver was shipped from here to Egypt since the Old Kingdom (46) and PLINY mentions that silver was shipped from the Taurus from Elaeussa, Corcyrus and Zephyrium (N.H. XXXIV. 18).

Two other deposits are located in the Lycian Taurus about which we have no information from ancient texts and so we do not know whether they were exploited in Antiquity.

13—In the Lycian Taurus near Antalya (Adalia, Adana).

14—In the Ak Dagh south of Kemer (Chimaera).

15—At Tris Ma'den in the Sultan Dagh west of Konya remains of old mines have been found (124).

16—In Galatia, Denek Ma'den on the Cicek Dagh near Karakecili half-way between Kayseri and Ankara (RAWL., Mon., II, 294; III, 146, 159). This mine lies to the south of Boğazköy (which name according to Sayce means "town of silver" (JRAS, 1920, 68)) and may well have been exploited by its inhabitants.

17—In the Dumanich Dagh (Mt. Olymp range) in Bithynia near Kariye Seunluk and Bursa (Brussa) (123).

18—Balya Ma'den in the Kaz Dagh north east of Mt. Ida in Mysia, which is the Perichraxis worked by the Romans (MDAI, XXIX, 1904, 268) and in 1903 still produced 7.600.000 Kgr. of lead containing 63 ounces of silver (37) (107). These two mines were the sources for Trojan silver which was found so abundantly in the Second Town.

19—Menteshdere, the ancient Ergasteria, "between Pergamum and Cyzicus" mentioned by GALEN (IX. 3. 22).

20—Mytilene, the ancient Lesbos (73).

21—At Gümüldür near Seferihissar west of Ismir (Smyrna).

22—On the Gümüş Dagh (Silver Mountain) near Bayındir on the Tmolus range in the neighbourhood of the ancient Tralles. Here the galena contains up to 560 ounces of silver but the mines failed in Roman times.

23—The Murad Dagh between Usak and Karahissar.

24—Samos (Zestor), where old mines were reopened by a Belgian Company (134).

25—Gümüşli (Myndos) near Bodrum (Halicarnassos), where remains of old mines have been found (124).

26—On the isle of Rhodos (Rodi) white lead was mined according to PLINY (N.H. XXXIV, 175) (Diosc. V. 103) and galena was found (140).

No wonder that with these plentiful sources at hand the Ionians and Lydians were skilled in silverwork (HEROD. V. 49).

This abundance of silver-bearing rich galena deposits in the surrounding mountains led to an early use of lead and silver in *Mesopotamia*. Prehistoric silver occurs in the graves of Al Ubaid and Lagaš.

Early lead samples from Kiš seem to have been smelted from simple ores (DESCH, *B. A. Report*, 1928, 440). In early dynastic times silver is well known though still rarer than gold, but its use as a medium of currency is very early (191). It was found at Adab, Kiš, Nippur, Tello, al Ubaid, and Šurruk but not at Uruk. But here we must remember that individual silver (and leaden) objects may have been destroyed by corrosion in the wet soil of Mesopotamia. Silver is general in the "Royal Tombs" at Ur (58) (311) and the silversmiths' work is very clever. Some of this silver is of a good quality, though much of it is really electrum and heavily alloyed with gold and small amounts of copper (229). Both this silver and that of Tello must have been imported, it may have been partly as native metal and partly refined near the mines. There is no proof that it was refined at Ur. The lead sheat in the graves (229) seems from the analyses to have been made by smelting a simple ore, it was not desilvered.

Presargonic lead is known though not abundant (ITT, I, 1388, 24) and it occurs in some early bronzes though hardly accidentally as the percentages tend to prove (RA, VI, 148).

One of the most beautiful examples of silverwork from Sumer is the vase of Entemena of Lagaš now in the Louvre.

The texts about Sargon I's expedition to the "silver mountains" are known in versions from Assur, el Amarna and Boğazköy (6) (65) (85) (300). GADD and LEGRAIN are inclined to look to the extreme west of Cilicia for these mountains (*Ur Excav. Texts*, 1928, I, 79) and others suggest the Taurus in general (6) or even Elam (KING, *Sumer and Akkad*, 262). The identity of the "Tunni" Mts and the Taurus range (mentioned in Egyptian & Hittite texts) has been accepted by DELAPORTE, SMITH (274) and LUCKENBILL (AR, I, 246). In this case too the exact location can hardly be proved but Asia Minor is a far more likely spot to export silver as the mines of Elam may not have been exploited very long (if at all at such an early period) and the Cilician ores are far richer in silver than those known from Persia (311).

During Sargon's reign lead weights in animal form became current as money (ORTH, PW, Suppl. IV, 112) (LANDSBERGER, AO, XV, 21), the metal may well have come from the Kurdish mountains nearby. We have already mentioned Manišusu's inscription on the so-called Cruciform Monument referring to an expedition against a coalition of 32 cities in Elam which possess silver mines and diorite quarries. These mines may have been those in Carmania, if the cities

are to be sought in Elam which is not yet sure. In that case they are the earliest silver mines we know of in Persia, and were only just opened.

Maništusu was the first to establish a regular money system of talent, mana and shekel based on silver weighed out by the merchants. Erimuš is said to have been the first to have a statue cast of lead (AO, XV, 24), he visited Sargon's silver mountains (POEBEL, UMBS, IV, I, 178, 206).

Gudea too obtained "silver from the mountains" (VAB, I, 106, XVI, 21). The location of these mountains was sought in the Taurus and more particularly in the Bulghar Dagh or sometimes more vaguely in Asia Minor in general (HALL and LANGDON, CAH, I, 428, 545, 586), while WOOLLEY thinks that the Zagros region is meant, probably because Meluchcha is mentioned in the next line of the text. We are inclined to accept the first mentioned location as no dates are available on the state of metallurgy in the Kurdish mountain region at this date, where supplies of silver and lead were also plentiful and where Gudea fetches so many other commodities. He is also said to have a store of lead in his palace (VAB, I, 120, XXVIII, 14).

In the Agade period the ratio gold/silver is reported to be 8/1 in the reign of Sargon I (ORTH, PW, XII, 112) but in the Ur III period silver seems to have become more common as a ratio of 10/1 under Bur Sin and 7/1 under Gimil Sin would lead us to believe. In Ur III texts (100) sums of silver are lent at various rates of interest. HEICHELHEIM has inferred that the production of silver was larger (135) or the contacts between Asia Minor and Mesopotamia may have grown closer as the famous Cappadocian tablets which date from this period tend to show. The Ur texts also mention silver objects such as rings, gems and vessels and silver is taken into the palace as revenue but actual payments in silver are very rare. A tablet from Dungi's reign contains accounts of amounts of silver (Br. Mus. 19.031). Imports of silver and lead to early Assyria are mentioned in the Cappadocian tablets containing the correspondence between Assyrian traders in Asia Minor (Kaneš) and the firms to which they belong in Assur. But silver seems to have remained a money standard only, actual payments being made in copper or lead bars, rings, etc. (KAVI, I, 5, 7) seldom actually in silver. The lead is said to have come from the "Chachu and Mašgungunnu" mountains which must probably be sought in the Kurdish and Armenian mountain ranges. The silver production of Cappadocia and Elam seem to have become larger,

silver in the form of rings or pieces (*Hacksilber*) is mentioned more frequently than in earlier periods and is now certainly much more common than gold.

Although during Hammurabi's reign the gold/silver ratio is reported to be 6/1 which may point to a temporary shortage of supplies from Asia Minor and Armenia due to the troubled times there and in North Syria, the ratio remains very constant at 10/1 during a long period afterwards. Though some Old Babylonian sites yielded very few silver objects the metal is now commonly used for foundation tablets of temples and even deposits of some value have been found (ANDRAE, *MDOG*, LIV, 1914, 36) especially in Assyria. Lead seems to have been very common in Assyria from early periods onwards. Weights up to 500 Kgr. are by no means rare in the temples and large sums of lead are mentioned as fines in Assyrian law-texts (KAVI, No. 1, II, 81, 102). The metal was probably not obtained in Assyria itself but imported either from Asia Minor or from the mountains in the North. The production of silver from lead becomes more widely known, lead being generally considered as an adulteration of the silver (RA, VI, 142). Leaden clamps are used in Assyrian buildings.

Bactria and Carmania have also been suggested as sources for the silver supplies of Mesopotamia but we have no exact data on silver production there, though it would seem from the now more frequent silver finds in Elam and Persia that the metal became more common towards the end of the second millenium and could of course have been produced locally from the deposits mentioned. The location of "Mount Šaršu" has not yet been identified (II R. 51. 10).

In the Amarna period silver and lead have taken up their definite places in metallurgy, they are widely spread over the Ancient Near East except Egypt, and huge amounts of tribute and booty are mentioned in the inscriptions of Assyrian kings. Tukulti Ninurta takes enormous quantities of silver and lead from the region of the Tiyari Mountains (LUCKENBILL, AR, I, 130, etc.), such quantities as 32 or 11 talents of lead, 18 pigs of lead, 3 talents of silver being mentioned. This would lead us to believe that silver and lead metallurgy was by now well developed in the region between Lake Van and Lake Urumiyah, the ancient Urartu. In the earlier Assyrian tribute lists silver preceeds gold but this is hardly due to this metal being rarer, as the gold/silver ratio proves.

Silver spoils from Syria and Phoenicia are taken by Aššurnasirpal II (LUCKENBILL, AR, I, 144) and by Salmenassar III (LUCKENBILL, AR,

I, 211, 217). Sargon I gets his silver from Mušāšir (LUCKENBILL, AR, I, 95, 109) near Lake Urumiyah and a tribute of 2100 talents(?) from Carcemiš (LUCKENBILL, AR, II, 9, 96).

The Amarna letters contain several passages that point to the beginning of an export of silver to Egypt in exchange for Egyptian gold, which does not always prove to be pure if we can believe the complaints of Burriaburiaš.

It has been suggested that the Phoenician traders were responsible for the frequency of silver in the Near East in the first millennium and that this silver was obtained by them from the mines in Sardinia and Spain, but the part which Phoenician trade played in early history has been grossly overrated on account of misleading classical information and no value should be attached to such reports for early periods. Closer contacts in the Ancient Near East in this period, the abundance of rich deposits and metallurgical skill in several regions are the reasons for the abundance of silver in this period and fit into the logical development of metallurgy in the Near East. The practice of desilvering lead was not yet common, Assyrian lead of the VIIIth century still contained 0.11 % of silver (108).

Copper and lead money (9) were soon displaced by silver in clippings, bars, rings, spirals or sheets, weighed out on a balance for payment. Refined silver was stamped in each separate town. Refined silver appears in many contracts (for instance at Tell Halaf about 650 B.C.). An early stamped bar from Zindjirli weighs exactly one mina (REGLING, PW, VII, 979) and dates from about 700 B.C. and there are traces of an early pre-Lylian coinage in Assyria (274) (275). Sennacherib states that he cast shekel and half-shekel pieces in silver in the same period (CT, XXVI, 25, 16). In the Neo-Babylonian period the gold/silver ratio was 12/1 under Nabonidus, rising to 10/1 during the troubled times at the end of the dynasty but falling to 12/1 to 13/1 during the Persian period, when the kings established silver standard money throughout their Empire. The silver of Carmania and Bactria may have contributed largely to the store of "sigloi" found by Alexander the Great in the King's palace (138) (162). As in the case of gold, when silver refining and testing had become public knowledge this metal could be used for coins and here again we can not ignore the fact that the development of proper testing methods and the development of coinage between the VIIIth and VIth centuries play a large part in the later history of silver.

There are very few historical data on silver and lead production in

Asia Minor. BITTEL (37) states that in the early third millenium copper, lead and some silver are known, the latter probably produced at the Ak Dagħ near Sivas. Analyses have not been published and we can not decide whether this was native or refined metal. It would be interesting to investigate whether this silver was indeed refined for then we would have proof that the refining methods were tried out in those early periods in Asia Minor. In Alishar a few pieces and seals of lead were found (OIP, XIX, fig. 65) and lead occurs in very early bronzes at Thermi and Hissarlik.

Dating early finds from Central and Eastern Anatolia is still very difficult, and we can not fit early silver and lead finds into the scheme we propose here. But the antiquity of refining methods in Asia Minor is definitely proved by both the finds at Troy and the Cappadocian tablets. The latter date from about 2250-1950 B.C. and deal with many transports and sales of lead and silver. The silver is mostly sold in bars in quantities of 4 to 15 minae, a single mention of silver in the form of a chain weighing about $\frac{1}{2}$ mina (a form very common for gold) occurs in the texts. Crude silver called "silver from Kaneš" and "refined silver" are mentioned. Pure lead and "loose lead" in sealed containers (probably pigs of lead) are mentioned. The ratio silver/lead varies from 3.5/1 to 6/1, the average is 4/1; lead is usually measured in talents. These facts prove beyond doubt that both silver and lead were refined at that date and that several grades were manufactured and sold.

In the Hittite Empire both metals were plentiful, supplies being exported by the Keftiu of the south coast to Egypt where it suddenly grows more plentiful in the fifteenth century. Close connections with the Aegean islands and the Minoan civilisation existed without doubt (65) (232). Hittite bronzes, especially those of early periods, sometimes contain lead, no doubt added intentionally. Six rolls of lead with Hittite inscriptions were found at Assur (CAH, III, 112) (143).

The earliest strata at Troy (Troy I) contained small amounts of silver and lead but in Troy II refined silver and silverwork appear. Several techniques like hammering, chiselling, engraving, soldering and granulation seem to have been mastered by the local silversmiths (DÖRPFELD, *Troia und Ilion*, 1902, 327, 366). The silver objects found include 11 vases (containing up to 5 % of copper), bars with about $2\frac{1}{2}$ % of copper, crucibles (124) and six remarkable ingots weighing exactly 40 shekels of the heavy mina, varying from 6.0 to 6.1 ounces only. These ingots are very pure, equal to Roman refined

silver (73) (108) (124) (FORRER, RL, 78, 737, 750) and their low gold and lead content point to manufacture from argentiferous lead ore. This is also the case with the other silver objects from Troy II, the average analysis being 95.61--95.15 % of silver, 0.17-0.47 % of gold, 3.23-3.44 % of copper, 0.22-0.44 % of lead and traces of iron. Though MEYER has not ventured to locate the galena mines from which this silver was obtained, we agree with EVANS, CARY (55) and many others that there is no doubt that the galena from Mt. Ida and Mt. Olymp was worked as they were used in later times though of course both the Pontic field and even Bulghar Ma'den may have supplied the ore or the metal at the beginning of this period. Small leaden idols were also found in Troy II and lead was used in some bronzes.

There is no doubt that the *Aegean islands, Crete and Greece* have learned the use of lead and silver from Asia Minor whatever trade connections they may have had at much later periods. There are no deposits in Crete but many in the Aegean islands. The Cyclades, Milos, Paros, Santorin, Kuphonia (73) contain galena deposits. Kimolos and Thasos had mines which were exploited up to the VIIIth century like those of Siphnos (123) (HEROD. III. 57) which were at their height in the sixth century but were flooded (according to PAUSANIAS X. 11. 2 and SUIDAS) by the sea in the fifth. These smaller mines were soon eclipsed by the rich galena deposits of Laurion which were vigorously exploited in the sixth century and where the rich stratum was tapped after 500 (STRABO IX. 1. 23. cap. 399). Detailed studies of production methods in Laurion have been written by the score (10) (33) (34) (52) (73) (93) (128) (140) (141) (198) (199) (254) and many references from classical authors deal with these mines and the effect of their great production on the social and economic life of Greece (STRABO III. 11. 8-10; IV. 5. 2; IX. 1. 23) (PLINY, N.H. XXXIII. 23, 33; XXXIV. 47) (HEROD. III. 57) (ARIST. *Polit. Athen.* XLVII) (XENOPHON, *Econ. Athen* IV).

In *Macedonia and Thrace* many mines were worked under the Macedonian kings who also vigorously developed production in Asia Minor. There were mines near Kassandra (Salonica) (253), Lake Prasias (HEROD. V. 17), Pangeum (STRABO VII. 34) (HEROD, VII. 112), Thrace (HEROD. V. 23) and many others (73) (74) (75) (Casson, Macedonia) but most of those were only tapped in classical times. Then of course supplies from Western Europe were available, from Hungary, Tirol (159), the Harz mountains, Britain (STRABO IV. 5. cap. 199), France, (Brittany and Auvergne (STRABO IV. 2. 2. cap.

191), Tuscany, etc. The mines of Sardinia were worked by the Phoenicians according to SOLINUS (Polyhist. 4), but modern research would not claim production earlier than the fifth century (117) (123) (166) (242). The rich deposits of Linares, Sierra Morena, Ciudad Real, Murcia and Cartagena in Spain (110) may have been exploited earlier but it is doubtful whether this production reached the Ancient Near East before classical times (STRABO III. 2.8-10, cap. 146-148). Though DIODOR (V. 35) claims that the Phoenicians found so much silver that they exchanged the stones on their anchors for silver (in ingots) it is doubtful whether this Phoenician trade is earlier than the period of Greek colonisation.

Lead and silver have been found in the Aegean islands from the Early Cycladic period onwards (176), lead in the form of small votive boats (CAH, I, 600). In Crete they occur since Early Minoan times, silver daggers have been found at Kumaressa (98) and small lead votive axes occur in E.M. II graves. By trade with Asia Minor they became more common in later periods. Trade connections with the West may have existed in later times and silver may have come from Spain in the L.M. period. The rarity of silver objects at Knossos has been attributed to the fact that the palace was destroyed by plunderers. Egyptian monuments tend to show that the Keftiu or Minoans(?) were engaged in silver trade between Asia Minor and Egypt from the XIIth dynasty onwards. Silver objects are imitated in early pottery in Crete (EVANS, I, 193, 194) (98). Crete never produced silver and lead but traded them.

Small silver plaques found at Enkomi and Knossos dating from Late Minoan times seem to be coins. They are marked with a sign H or J for the half-bit. Gowland has concluded from parallels from Japan (the manufacture of the so-called Mamma-ita-gin) that they were made by pouring drops of silver on a metal surface thus marked (140).

In Mycenaean Greece silver grew more common though still less so than gold (264). Some of the silver is very pure like that of Troy II, though some is alloyed with no less than 30 % of lead. The analyses tend to show that refining lead and silver was known, probably from Asia Minor. In this period the use of silver spread and must have led to the openings-up of local sources, in the islands and on the mainland. Production at Laurion may well have started by now. (SCHRAEDER, RL, 95) (FORRER, RL, 94) (40). Silver was fashioned into jars, rings, wire, and discs at Mykene and both here and at Tiryns lead was

used for clamps and in the form of sheets, pigs and lumps. After Mycenaean times the refining of silver must have fallen in disuse. The Iliad and Odyssey refer to finished silver objects only. But production was taken up again when the disturbances were over and in early Historic Greece both metals grew common again. Classical Greece was flooded with Persian silver, and imports from Spain and Sardinia by Phoenicians and Greeks from the colonies may have added to the abundance of silver in classical times. The Macedonian conquest of Asia Minor contributed largely to the intensive production from all the deposits mentioned in Thrace, Macedonia and Asia Minor (52) (55) (113).

Silver and lead appear in *Cyprus* after copper and bronze in the Middle Bronze Age about the fifteenth century B.C. Some of the early silver is reported to be pure (RICHTER, *Kypros*, 339, 368) but in the Early Iron Age it was still widely alloyed with lead and only imperfectly refined. Rich finds date from the fifth century only, silver finds at Amalthus copy earlier copper and bronze trinkets. Several classical authors mention silver mines in Cyprus (STRABO XIV. 6. 5. cap. 683) (PLINY N.H. XXIV. 130. 170) (DIOSC. V. 100) and though some modern writers repeat this information (140) (ORTH, PW, Suppl. IV) no confirmation can be found for this opinion, STRABO mentions silver in connection with copper mines and possibly the production of silver from copper was meant, though this is rather early for the intricate methods necessary for this refining. OBERHUMMER (*Die Insel Cypern*, 1903, I, 183) says definitely that no lead or silver is found on the island. Lead objects are fairly common in early periods but seem to have been imported from the mainland together with the early silver. Only in the Greek period in the fifth century silver is far more common than gold, this silver is pure and these later silver objects can, therefore, be distinguished very easily from the earlier manufactures of silver-lead alloy (impure silver either imperfectly refined or an intentional alloy). In the Amarna letters the kings of Alasia exchange copper for silver objects with Egypt and some of the early silverwork found does indeed show signs of Egyptian manufacture. This proves that local silver production either from galena or from copper ores was certainly unimportant in the fourteenth century B.C. if silver was produced in Cyprus at all.

This short survey of the deposits of lead- and silver-ores and the few important data on the development of silver and lead technology show how fragmentary our knowledge still is and how urgently fur-

ther analyses of both composition and technique of silver and lead objects is required to fill up the gaps in the sketchy outline we have given. When discussing the refining methods we will have occasion to point out that new analytic methods will prove fruitful in this connection and that the analysis of the impurities is more important than that of the silver content as these impurities enable us to decide what type of refining was used.

This is what the data discussed above tend to show to be the development of silver and lead technology:

Silver and lead production started in the early third millenium in Asia Minor gradually spread to the west (Aegean and Crete) and to the east, where first the Armenian mines, then those in Elam, Carmania and finally Bactria were exploited until at the beginning of the first millenium silver and lead were common metals in the Near East except in Egypt where they did not become common until the Persian period.

Much interesting information will be obtained from further excavations in Asia Minor and the Armenian highlands.

We will now turn to the discussion of the early refining methods.

IV

Before discussing refining and smelting methods in pre-Roman Antiquity it will be useful to summarize modern methods of lead and silver production. This will give an opportunity of indicating the principles underlying these methods, introducing the archaeologist to the metallurgical terms and sorting out by a process of elimination those processes which, for various reasons, could not have been known or used in Antiquity.

It is at the same time easier to discuss the reactions underlying the metallurgical processes when discussing modern methods. For in Antiquity, in the early days of metallurgy, processes were found and developed by trial and error, methods and apparatus borrowed by one branch from another, and every student will be struck by the rather haphazard methods used and the lack of uniform technique and implements as illustrated by some excavation reports. Only gradually have countless generations of miners and metallurgists learned to understand the reactions occurring during the treatment of their ores and metals, and gradually several phases of the treatment have been separated. Thus each stage of production could be better observed and directed and the product profited from this specialisation. The under-

lying physical and chemical principles have, of course, only recently been found, studied and developed, but the specialisation already existing in the days of AGRICOLA (3) has a very modern appearance; and yet it was developed, by means of shrewd observation and thorough knowledge of every aspect of the trade, by skilled metallurgists, who knew neither physics nor chemistry. Specialisation existed in Roman times and the rudiments date back much earlier. But the undifferentiated early methods will be difficult for the layman to understand as they are even a puzzle to the expert in many cases. Several reactions proceed at the same time in the primitive furnace and thus the "primitive method" is much more undifferentiated and far more difficult to guide and to understand than the modern method. For there are very few texts to guide us. Those gleanings which we pick up in PLINY or STRABO have often been written down by elegant writers but bad metallurgists, and it is often difficult to make any sense of their notes.

It should, therefore, always be remembered that the deliberate differentiation and recognition of several reactions is the modern phase and the 'simple' method of primitive metallurgy is really a complicated mess of reactions which could only be duplicated with much practical skill and keen observation of product and process, because the reactions were not understood as they are today.

We will start with the *production of lead from lead ores* because this lead was also used for the larger part of the silver production in Antiquity and even up to modern times. Lead is produced from galena in three stages: I—Smelting of galena, II—Purification of the crude lead, and III—Desilvering of the soft lead.

I—There are three ways of *smelting galena*.

Ia. In the *Air Reduction or Roasting process* the galena is first gently heated in a blast of air. The sulphur-lead compound, galena, is then decomposed, most of the sulphur escapes as sulphur dioxide gas, some is left in the form of lead sulphate, some galena remains intact but most of the lead is oxidised to lead oxide (litharge). When the correct stage of desulphurisation is reached the temperature is raised and litharge, lead sulphate and galena interact to form lead, which collects at the bottom of the furnace, while the remaining sulphur now escapes as sulphur dioxide gas.

Ib. In the *Reduction process* the galena is first roasted until practically all the galena has been transformed into litharge, which is then reduced by means of carbonaceous matter (Charcoal, Coke, Wood) to lead.

Ic. Precipitation process (Matte smelting process) in which galena is heated with metallic iron. Lead is set free from the galena by the iron which forms (together with part of the galena) a complex of iron and lead sulphides which pass into the slag. This method is a modern refinement, which may be combined with one of the two former ones, it was unknown in Antiquity and need not be discussed further in detail.

The product obtained by smelting galena is called crude lead (work-lead, base-bullion) (German 'Werkblei'), the stagnum described by PLINY (*N.H.* XXXIV, 159), it contains 45-180 ounces of silver, but in case of rich ores these figures can be considerably higher.

At the present time this smelting is carried out in reverberatory furnaces or, in the case of ores containing a low lead percentage or much silica, blast- or shaft- furnaces are used. The primitive furnaces and even those at Laurion were much simpler, the earliest being simple cavities in the ground; the Laurion furnaces mostly built up of clay and stones, which were re-used when the furnace broke down after a relatively short life.

Roasting lead ores before further treatment was already in use in Roman times as a separate process (75) and AGRICOLA describes no less than four different methods (Book VIII). Usually in primitive metallurgy roasting is done in a very crude manner and subsequent refining requires careful watching. It is often done in troughs or trenches dug in the side of the hills in which fuel and ore are mixed and fired, while the wind is used to provide the blast. Even after classical times the Derbyshire smelters built their furnaces on the top of a hill using the west wind for the necessary air supply (124). Primitive smelting was carried out in Britain in wind-furnaces ("boles") which BARBA (3) also found in ancient Peru in Inca metallurgy. The early settlers in America made their lead bullets by smelting galena in a hollow tree stump using the wind as a natural blast.

II. The second stage in lead production is the *purification of the crude lead and production of soft lead*.

The crude lead as produced in the first stage is still contaminated with antimony, arsenic, copper and tin. In this state it is too hard and too deficient in malleability for most of the common applications of lead, hence its name "hard lead". These admixtures are at the same time a serious obstacle in desilvering. The lead is, therefore, submitted to two treatments:

IIa. Liquefaction. In this process we profit from the low melting point of lead as compared with that of most of its contaminants.

The lead is separated from the compounds held in solution by slowly melting the mass at a low temperature. The molten lead flows away, leaving behind the "dross", a mixture of copper, lead, antimony and arsenic. The silver remains in the lead. This process was also used in medieval (THEOPHILUS III. 66) and even Roman times (75) for the extraction of silver from copper ores. Even Early Iron Age copper ingots from Italy show an abnormally high lead content, probably they have been submitted to liquation. The copper obtained from the first crude smelting represented a highly impure ingot which would need much refining. Precious metals can be extracted by alloying with lead



Fig. 43. Liquation of lead ores (after AGRICOLA, *de re Metallica*)

and heating to a temperature between its melting point and that of copper whereby the lead would liquate out carrying gold and silver with it.

Iib. Oxidation. This is achieved by melting the lead in a reverberatory furnace with a shallow bed and exposing the metal surface to a current of air. The impurities left over by liquation oxidize first and the dross formed is skimmed off from time to time until a sample of lead taken at regular intervals has the correct properties. The speed and efficiency of the operation depends, of course, on the exposed surface area. This process formed part of the early lead smelting. In Laurion, for instance, air is blown over the rim of the hearth and the same method of drossing the impurities is still in use in primitive smelting in Japan (280). The lead is now ready for the next stage, the desilverisation, if the silver content makes it worth while.

III. *Desilverisation* is now possible in three different ways:

IIIa. The lead is now often purified *electrolytically*, in this case the precious metals collect in the anode slime which can be treated separately for the production of silver, etc. This process was of course unknown in Antiquity and so was the second method:

IIIb. The *Parkes process*, by which silver is extracted from the lead by zinc and the zinc-silver alloy purified by distilling off the zinc and collecting the silver in the residue.

IIIc. The third process, the *Pattinson process*, utilises a peculiar physical property of the lead-silver mixture. If melted and cooled



Fig. 44. Smelting lead (after AGRICOLA, *de re Metallica*)

again, the first crystals formed consist of pure lead and the remaining solution will, therefore, become richer in silver. This formation of pure lead crystals will go on until the remaining lead contains about 2.4 % of silver. Then the remaining molten metal will set all at once. By pouring off the molten metal before this happens the silver is concentrated as far as possible and the lead thus enriched can be desilvered by the very old cupellation process and the lead recovered from the litharge formed thereby (see under *Vc*). It seems from the muddled account which PLINY gives of the refining of lead (*N.H.* XXXIV. 159) that the principle of the Pattinson process was known and probably even applied at least in Roman times. His account becomes intelligible if we take both *stagnum* and *argentum* to mean "crude lead" and the *galena* in this passage to be "purified lead". The

passage then clearly illustrates that the first crystals formed after melting argentiferous lead are almost pure and being denser sink to the bottom. The portion that remains longest liquid is much richer in silver and can be laddled out or poured off to be treated separately for silver (11) (75).

By cupellation lead was generally desilvered in Antiquity with remarkable efficiency considering the primitive technique. It is true that FRIEND and THORNEYCROFT found Spartan votive figures of lead to contain 0.057 % of silver but they have no right to conclude on so few figures that no desilverisation was practiced before the Romans.



Fig 45 Oxydation of crude lead to produce silver
(after AGRICOLA, *de re Metallica*)

We need only point to the analyses of Troy II lead. When considering the development of any metallurgical process it is imperative to draw conclusions on a statistical basis only, every analysis should be taken into account and indeed, owing to the general lack of cooperation of archaeologists and museum directors, who do not know generally that modern analytical methods demand only minute quantities of materials and no longer damage their museum pieces, the analytical data to work on are still insufficient. But we can already safely say that the Greeks desilvered lead upto 0.02 % of silver. The Etruscans learnt the art from the Greeks and applied it with the same succes (126), while the Romans could extract down to 0.01 % or even 0.002 % in some cases. Roman lead pipe was found to be desilvered very com-

pletely (67) (88) and contain only slight amounts of oxidic compounds probably due to the recovery methods of the lead. But, in general Roman lead pipe is unusually pure when compared with modern technical material. AGRICOLA mentions that in his days the limit of extraction was 0.008 % of silver, not a very appreciable advance on Roman technique, while modern extraction brings the silver content down to 0.0002 %. We will see below that this ancient extraction of silver only seemed very efficient but that even the Romans were extremely wasteful in treating lead ores and that part of the silver disappeared in the slag of lead production. If we now turn to the production of *silver from electrum, silver- and lead-ores* we must first mention a method that is now rarely used to produce silver but that certainly played a part in Hellenistic metallurgy.

IV. For *production from electrum* Antiquity possessed two methods which we have mentioned in discussing gold technology. Both are complex methods in which cupellation is combined with conversion of the silver into chloride or sulphide which is taken up by the slag into the cupel. The silver can be recovered from the slag or dross by roasting and reduction with charcoal.

The *Salt process*, IVa, (or cementation) is described by THEOPHILUS (III. 69) and after him by AGRICOLA, who calls it "Scheiden im Guss mit gemischtem Pulver", it eliminates the silver in the form of silver-chloride with common salt.

The *Sulphur process*, IVb, called "Scheiden im Guss mit Schwefel oder Spiessglaserz" by AGRICOLA, transforms the silver into silver sulphide by the addition of sulphur or antimony sulphide (stibnite). Both methods depend upon a thorough knowledge of the cupellation method which must have been used for centuries before complications like the two methods described above could have become common practice. They were certainly used in the Hellenistic period. We have concluded from evidence given in a former chapter that the cupellation method was known and used about 1500 B.C. but that the desilvering of electrum become common in later periods and was in general use about 600 B.C. We will revert to this method below.

V. For the production of *silver from silver- and lead- ores* (or copper-ores) three types of methods are known:

Va. *Wet methods* by which the ore after preparation (by roasting or converting into chloride) is leached with a suitable solvent (cyanide lye, brine or strong salt solutions) from which the silver is precipitated (Augustin process, etc.) Another variant treats the suitably

prepared ore with sulphuric acid and converts the silver in the solution into an insoluble form (Reduction with copper or Ziervogel process). Both are modern refinements unknown in Antiquity.

Vb. Amalgamation was known to the Romans (103), it had by then reached the manufacturing stage and is mentioned by THEOPHILUS and BIRIBUCCIO, the latter calls it a secret process. It is introduced in 1532 in Mexico by Bart. Médina and since then known as the *Patio process*. Usually the finely divided ore is mixed with salt, copper sulphate and mercury, and exposed to the air in heaps which are constantly worked. The silver-amalgam (silver-mercury compound)

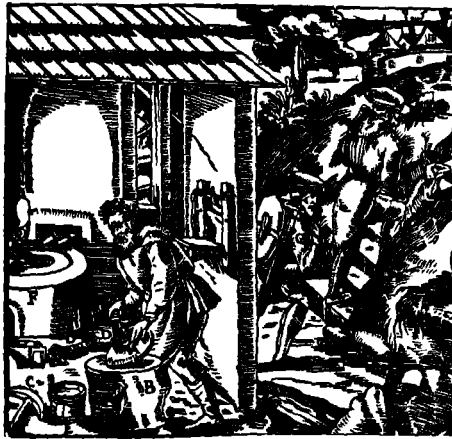


Fig. 46. Refining crude silver (after AGRICOLA, *de re Metallica*)

is then distilled, the mercury recovered as distillate, the silver as residue. A variant consists of roasting the silver ore with salt, mixing it with metallic iron and then following the procedure described above.

As mercury was only produced and used by the Romans as far as we know, no application to silver ores can be expected before the Roman period.

Vc. Dry methods are far older and have been used from the very beginning of the silver industry.

The lead ore is first *smelted* (see method Ia) to crude lead, copper ores are treated by liquation (method IIa) and the lead-silver alloy thus obtained is concentrated by the *Pattinson* process (method IIIc). Silver ores are roasted and the oxide formed reduced with coke or charcoal. Both this crude silver or the concentrated silver-lead alloy

are now *cupelled*. In the case of lead ores liquation was, of course, unnecessary, but in the case of copper ores it was imperative to extract the silver by alloying the crude copper with lead and liquating it. In Antiquity it was customary to smelt silver ores with lead to ensure complete extraction of all the silver (PLINY, *N.H.* XXXIII, 95) (124). The same method is used by AGRICOLA, but by his time metallurgists have learnt that many ores contain sufficient lead to keep the silver in solution and only in the case of ores containing insufficient lead is this metal added during the smelting process. Though the principle of the Pattinson process seems to have been known to PLINY it is doubtful whether this method of concentrating the silver was applied on a large scale and usually the crude lead was used for cupellation without concentrating. Now *cupellation* was a process that had been known for centuries, this last stage of the process has carried out with extreme efficiency and we have already pointed out the very good results obtained, a thoroughly desilvered lead. But the first stages were not yet differentiated in metallurgical practice and a varying complex involving roasting, smelting, oxidation, liquation and other reactions was the common way of treating the lead or silver ore. This complexity defeated the purpose of the early metallurgist to extract all the silver from the ore, his knowledge was not yet sufficient to control all these reactions happening at different places in his crudely constructed furnace. Though his lead was very completely desilvered afterwards, he was very wasteful of the lead in the original ore and with the lead he wasted a considerable part of the silver, that remained in the lead lost in the slag. The Greeks in Laurion, for instance, treated an ore containing blende (aluminium and zinc compounds) and other impurities and when trying to obtain a fairly pure lead they had to use a high temperature when smelting to ensure a complete slagging of the impurities in the ore. This defeated their purpose as a great deal of lead passed into the slag and some volatilised. Thus the slags at Laurion contain about 10 % of lead, those in Sardinia up to 30 %, in Cartagena 8-17 %, in Arles 10-15 % (75). DE LAUNAY (166) calculated that more than 1/3 of the original silver was lost in the slag, which contained 25-30 % of lead with 0.07-0.1 % of silver, though the refined lead contained only 0.001 % of silver. As Roman silver technology improved and with close attention paid to the furnaces, in several regions less lead (and therefore less silver) was lost in the slag. In some mines in Jugoslavia (Ralja) the slag contains only 7 % of lead, but ores less rich in silver, for instance those in Britain, were

treated very negligently. Slags from the same period at Mendip contain 20-26 % of lead (280). Here possibly old Celtic methods have been used, the Celts understood the production of silver as the fame of British silver had reached the Romans before they conquered Britain. As the smelting technique improved in Antiquity better results were obtained and it was even possible to work slags from older periods. This is what happened at Laurion as STRABO tells us (IX. 1, 23, cap. 399): "The silver mines of Attica were originally valuable, but they failed. Moreover those who worked them, when the mining yielded only meagre results melted again the old refuse, or dross, and were still able to extract from it pure silver since the workmen of earlier times had been unskilful in heating the ore in the furnaces." But when production stopped at Laurion in the second century it would still have paid to extract another 0.1 % of silver from the 2.000.000 tons of ancient slags. Indeed, when these mines were reopened in 1864 the old slag, which had already been desilvered in the later period of Laurion was still found to contain 81½ ounces of silver (302).

Wasteful as this ancient smelting process may have been it is clear from the evidence that the essence of the process was the production of a lead alloy in which the precious metals were concentrated. Lead must therefore have been known before silver. We have no proofs that lead production existed before the early third millenium and this date must necessarily from the furthest limit which we can fix for the technical production of silver (124). Indeed, BIRINGUCCIO was right when he said that without lead the extraction of gold and silver would have been impossible, though he could not know that electrum was used for gold and silver production in later Antiquity as these methods were used in his days for the testing of gold and silver only but no longer for production.

AGRICOLA's book no longer describes the exact classical methods for in his days considerable specialisation had taken root in the metallurgy of silver and lead and the smelting was carried out in a separate furnace, followed by oxidation in another furnace before desilvering was applied. And even then the crude silver was again refined in small cupels or in crucibles in special muffle-furnaces.

But in Roman and pre-Roman days the only method of producing silver apart from the gold/silver separation from electrum and the (very unlikely) reduction of silver ores consisted of the treatment of galena in two phases: 1) a combined roasting, reduction and oxidation,

and this smelting was followed by 2) cupellation. The Romans marked their cupelled desilvered lead "EX ARG". Those ores which contained too little silver were smelted for lead only as there might still remain a small quantity of silver in the lead "though not enough to make refining of it profitable" (STRABO III. 2. 10. cap. 148).

We know very little about the type of furnaces used for the "smelting process" in the Ancient Near East and research on these furnaces near the ancient mines is urgently needed. But the furnaces described from the Roman world confirm us in the belief that a large variety of types will be found, each type adapted to the special needs



Fig. 47. Refining silver by cupellation (after AGRICOLA, *de re Metallica*)

of the ore found locally. What is imperative for further research is that these metallurgical finds shall be studied by experts who will be able to learn more from the remains than any interested archaeologist, however clever he may be in his field.

In Laurion the furnaces were very high, the upper portion being used for the smelting operation, the lower part being used to oxidise part of the lead previous to further cupellation (280). The smelting ovens of Spain were provided with chimneys "so that the gas (sulphur dioxide) from the ore may be carried high in the air, for it is heavy and deadly" (STRABO III. 2. 8. cap. 146).

GOWLAND describes an oven from Silchester used for the extraction of silver from copper ore with the help of lead. Other furnaces are about 10-12" wide and filled with alternate layers of charcoal and ore. BLÜMNER (40) describes a Roman furnace for smelting lead found at

Arles, an immense crucible 3.20 M. deep and 2.50 M. wide with walls of brickdust and clay 14 cm thick, sunk in the earth. The contents, alternating layers of wood and ore were fired. The molten crude lead and slag flowed into a vessel, after separation of the slag, the lead was poured into a vessel or small crucibles for cupelling. All these furnaces use artificial blast, which is sometimes introduced at the top rim of the hearth (124) (169) (280), they are mostly constructed of stones lined with clay to resist attack from the slag. But the earlier furnaces are often no more than trenches dug in the ground, like those at Siphnos dating from the VIIth century (19) (169). We believe, however, that this is a simplification and that Asia Minor, a country where metallurgy developed at so early a date, will have known good, though perhaps small, furnaces from the smelting of copper and other ores when they used them for silver production. After all, when no claim of efficiency is made, any sufficiently heat-resisting construction, either a cavity in the soil, a simple hearth-furnace or a sloping trench will suffice to produce lead from its ores. The fuel is mixed thoroughly with the ore or alternating layers are built up and artificial blast (bellows occur very early in metallurgy) or natural draught supplies the necessary amount of air. The crude lead produced by this primitive smelting is then cupelled, it contains not only the silver, but also antimony, bismuth, nickel, arsenic and gold which follow the silver. The cupellation is carried out in a crucible or a furnace (in later stages of metallurgical history) which is dressed with a porous substance such as bone-ash, calcareous clay (marl), magnesia or any other suitable earth that resists corrosion by the oxides of the baser metals formed during the process and is capable of absorbing these oxides. The early Middle Ages possess such cupellation furnaces; THEOPHILUS describes them at some length (III. 23) and AGRICOLA mentions several types. In the earlier phases of metallurgy the ordinary type of furnace is used and lined with bone-ash, which seems to have been the common material for cupels (or crucibles) and for the lining of these furnaces. GOWLAND proved that it was used at Laurion, as the slag contains over 2.4 % of phosphoric acid together with the litharge derived from cupellation. In the primitive furnaces pre-heating may have been used and after the fire had been lit, the correct temperature obtained and the lead melted, the fire must have been raked towards the sides, the blast introduced and the lead oxidised. The lead-oxide or litharge (*plumbago*) formed is absorbed by the bone-ash together with the oxides of the other metal impurities and a cake of silver (together

with gold and small amounts of lead, copper and other metals) which the alchemists called "regulus" remains behind in the furnace. This primitive method which GOWLAND saw in Japan is very effective (124), the average from 555 assays was a product containing over 99 % of silver. If the silver content is lower than 97 % the cupellation was very carelessly executed, but silver contents below 95 % point to intentional impurities or the manufacture of an alloy. The blast should impinge on the surface to be effective and the molten litharge floating on top (PLINY *N.H.* XXXIII 95) is skimmed off regularly. The litharge slag is of course not lost, it was used for the production of pure lead oxide in Antiquity (PLINY *N.H.* XXXIII. 107-109) by washing it with salt to remove impurities, or it was reduced with charcoal to recover the lead (see also PLINY *N.H.* XXXIII, 105-106; XXXIV. 159 and Diosc. V. 101) (103). Both Ezech. 22 : 20 and Jerem. 6 : 29 contain graphic descriptions of "trial by fire" and the manner in which the base metals are consumed and 'drossed' while the noble metals pass unscathed through the ordeal. The furnace described by Jeremiah is considerably too hot for cupellation. There are several references to the "fining pot" (cupel) in the Bible (Prov. XVII: 3; XXVII: 21; Mal. III: 3) or to the dross obtained in cupellation (Prov. XXVI: 23; Isa. I: 22, 25; Jer. 6 : 29-30; Num. XXXI: 22), to cupellation furnaces (Ezech. XXII: 18; Ps. XII: 6) and to the bellows used (Jer. VI: 29).

If we want to find out when this cupellation was discovered, we must remember that it must antedate considerably all specialisation in the smelting process such as liquation, etc. because these refinements were specially introduced to lighten the task of the cupellation furnace and eliminate as much lead as possible before cupellation. It was certainly known at Laurion and practised at Siphnos in the VIIth and VIIIth centuries. But it must also antedate the salt process and the sulphur process mentioned above, as these are refinements for certain purposes combined with the principle of cupellation to a new complex reaction. Refining gold is mentioned in the Amarna letters but both the Cappadocian tablets and the finds in Troy II mentioned above prove that very pure silver was made in the twenty-fifth century B.C. We must therefore conclude that the cupellation process was invented in Asia Minor in the first half of the third millenium B.C., shortly after the discovery of the manufacture of lead from galena. By the first half of the second millenium cupellation was applied to the refining of natural gold (*electrum*) with a few additions to eliminate the silver from the gold and recover it from the dross.

The use of cupellation for the production of silver can be proved easily by analysis, as LUCAS has already argued (180). For the silver produced in this way differs considerably from the silver produced from electrum, the ratio of silver and gold in silver produced from galena is something like 95.4 to 0.3, that is to say there are only traces of gold in the silver together with lead and other metals, but the silver produced from electrum contains much more gold and different metals as impurities. The attention of the analysts should therefore be fixed on the impurities in the silver. The spectrographic analysis introduced by GRASSINI (126) will help considerably as it requires only minute quantities of material while it supplies all the valuable information desired.

But we need not anticipate the results of further analysis in saying that LUCAS' conclusions (180) hold only for silver in Egypt. If he maintains that the earliest silver in Egypt and by inference that of Mesopotamia was the natural gold-silver alloy, electrum, which contained sufficient silver to be mistaken for that metal, he is only partially right as far as Mesopotamia is concerned for that country had ample opportunity to import the refined silver from Asia Minor, and did so as the Cappadocian tablets prove. True, in the earliest periods, for instance at Ur (230) electrum was mainly used and mistaken for silver, but pure silver appears fairly soon afterwards. LUCAS' other conclusions about galena being the primary ore for silver production and the relatively late importance of silver in history remain, of course, intact. HOOVER in his edition of the work of AGRICOLA argues that the smelting of silver from ores and refining by cupellation were known before 2000 B.C. but he does not support his conclusions by sufficient evidence from ancient texts and finds. It will be clear from the arguments brought forward in this paper that HOOVER was right and that the conclusion of LUCAS holds good only for Egypt, which country took an exceptional place in the history of silver and lead.

There are also many philological arguments that go to prove that silver was obtained by refining at an early date. The Cappadocian tablets call refined silver *kaspum šarruṣam* (LANDSBERGER, AO, XXXIV, Heft 4) (CONTENAU, TTC, 71) and this addition to the word *kaspu* (silver) is derived from a verb *šarāpu*, to refine, smelt (VAB, II, 290, 18) (IV R 4, 3, 40-41) (compare also the Arabic *šarīf* for pure silver). If the word *šarpu* is used as a synonym of *kaspu* it may have been intended to denote "refined metal" (or metal obtained by smelting). The "silver from Kanaš" mentioned in the Cap-

padocian tablets was an inferior product as is shown by the price, possibly cupellation was repeated in the earliest phases of refining to obtain a purer silver as indicated in the sevenfold purification mentioned in Ps. XII : 6 and also known from gold technology.

Another early term used in connection with refined silver is *misu* (LAḪ), which is usually translated "washed, refined" and must denote some technical purification. The silver vase of Entemena is said to be made of KU-LAḪ-ḪA (HEUZEY, RA, 1897, 35) and 1/3 mana of the same product is mentioned in a Šuruppak tablet (THUREAU DANGIN, RA, 1907. 149), it is also mentioned in later documents (JOHNS, *Ass Deeds Doc.*, II, 277). An old Egyptian text of the time of Sahurê is also said to refer to "washing of silver" (MILNE, JEA, XV, 1929, 150). In later periods such references become more common. The word *bašlu* (cooking) is applied to silver (HARPER, *Ass. Bab. Letters*, No. 152, Rs 4) just as the early alchemists of the Leiden-Stockholm papyri speak of *poiésis* (preparation) and *krasis* (mixing) when they describe the manufacture of alloys, or *baphé* (colouring) and *leukósis* (whitening) when they refer to the colouring of metal surfaces by boiling with chemicals. In Late Assyrian and Neo-Babylonian times such terms as *šaginnu* (standardized, pure standard quality) (JOHNS ADD, 612) (HROZNÝ, BA, 1902, 546), *kalû* (roasted, purified) (DHORME, RA, 1928, 55, 67), *pišû* (white) or *nuchchutu* (inferior) (NBK, 12, 1; Dar., 44, 1, etc.) are used. Special terms for pure silver (*damqu*) and specially refined silver (*watru*) occur in later documents (188) (VAB, II, 290, 18, etc.). No such refinements are known to have been applied to lead, the only two qualities the Cappadocian mention are "pure lead" (here the word *anaku* is wrongly applied to lead) and *anak katim* which is translated as "loose lead" as the "pure lead" seems to have been shipped (in the form of pigs of lead?) in closed and sealed containers (*šuklum*). It would therefore appear that some terms referring to the use of refined silver appear early in Sumerian and Accadian documents, later periods creating new terms as the need arose. The terminology of lead is far simpler as no special requirements for the purity of lead arose in these early times.

The spread of silver technology in the second millenium acted as a stimulus to the development of testing methods, for commerce was impossible as long as no correct estimation of the purity of silver existed. This testing played an important part in the history of coins and money. There was of course the test by cupellation which even in later days continued to be used for the testing of precious metals

apart from its production. The testing of gold is mentioned in the Amarna letters and we have had occasion to point to many Bible passages mentioning this "testing by fire". A simplification may have been used as such a method was still current in Egypt in the tenth century. QALQASHANDI mentions that in those days silver was kept molten (no blast) during 24 hours and weighed to test whether a loss in weight indicated admixture of base metals which would have been crossed by that time (*Geography*, transl. WÜSTENFELD, 1879, 166). The "testers of money" mentioned in Hellenistic papyri, apart from gold- and silver-smiths, may have used this test or the specific gravity to ascertain the purity of the metal, as the touchstone would only indicated the quality of the surface layer, which is less important in the case of a coin. The specific gravity, discovered by Archimedes as the story goes, was used by him to test the purity of the crown of Hiero of Syracuse and this property of metals played a large part in the early history of assaying. The ancient Coptic alchemists of the first centuries A.D. tested silver and gold by the colour of the smelt and by testing it in the *kaminos* (cupel). There was of course the touchstone, which still forms part of the assaying equipment. PLINY mentions some simple tests to discover the purity of silver (*N.H.* XXXIII. 127): "A filing is placed on a shovel which has been heated until it glows. If the filing remains bright it is accepted as pure. Second-rate silver turns red, while that which blackens has no merit. But deception made its way into this test too. If the shovel is kept in human urine the filing absorbs some while it is heated and counterfeits brightness. The other test, if the specimen is polished, is to breathe on it and observe whether it fogs immediately and easily shakes off the dew."

One of the peculiar properties of lead is that black lines can be drawn with it. PLINY (*N.H.* XXXIII, 60 & 98) comments twice on this property and says that copper and silver give black lines too, but this must be a mistake for silver gives a silver-white streak and could not possibly be used for lining. The Latin *plumbum* taken in the meaning of drawing material passed into the German *Bleistift* and the English *lead-pencil* though a modern pencil no longer contains lead but a core of graphite, which makes marks on the paper. The Italian *lapis* and French *crayon* point to the use of chalk.

Silver-alloys are important in jewelry, an alloy of silver and copper is now used (7½ % of copper only in Sterling silver) and in minting. For coins nowadays 10 % of copper is used, an alloy that agrees quite

well with the "1/8 part of copper added to silver" in Roman coins since Livius Drusus (PLINY, *N.H.* XXXIII. 46). The precious metals play an important part in the history of coins. In the earliest periods they were used by weight but gradually a special form of ingots arose (rings, bars, etc.) and form and weight of these ingots were more or

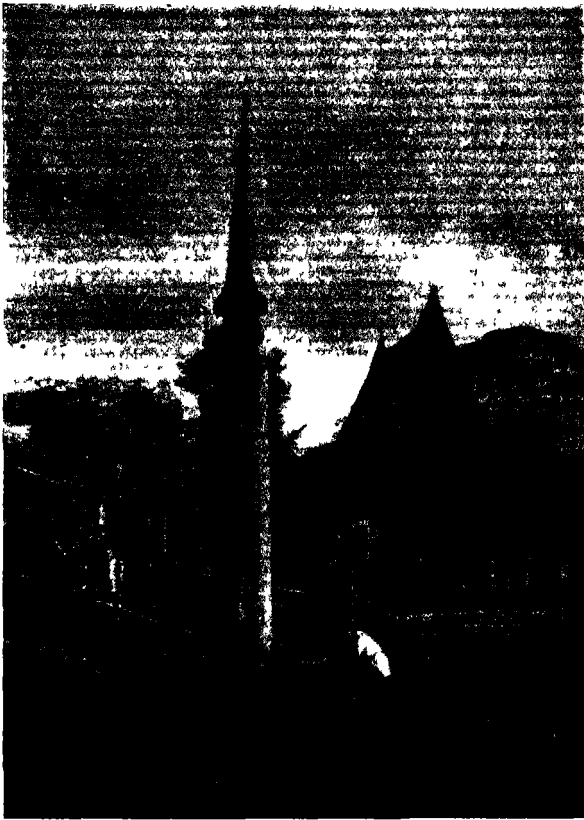


Fig 48 Drawing silver wire from a bar of silver in the Batak country
The goldsmith is holding the end of the silver bar which is drawn out
by the women or men running round the pole

less regulated (201). Silver remained the standard of currency in the Near East (38) and gold is more or less a commodity used for large values of silver. Silver and gold were passed by weight at market prices, stamps like "good gold" or stamps of certain towns were only taken at face value. When HERODOTUS mentions the coining of pure silver by Aryandes, the Persian satrap of Egypt (HERODOTUS IV.

166), he makes a mistake, which MILNE (193) (194) has explained. The silver coins of Aryandes were probably the ordinary Persian sigloi imported into Egypt by Aryandes at their proper value in the Persian Empire where the gold/silver ratio was 13/1, but sold as ingots to the Egyptian goldsmiths for whom a gold/silver ratio of 2/1 held. It is for this abuse of the Royal currency for his private purse that Aryandes was punished, for in other Persian satrapies the governors were allowed to strike their own silver coins without interference of the Persian King of Kings, no adverse gold/silver ratios existing outside Egypt. Analysis of ancient coins reveals much on composition and technique of minting which is important to numismatics and the detection of forgeries. Forgeries of Greek coins (90) were found to contain copper and sometimes zinc; they were cast, while the original coins were always stamped between dies (126) (HILL, *Ancient methods of coining, Numism. Chron.*, 5th ser., 1922, Nos 5 & 6). Some important modern alloys of gold, silver and lead are tabulated below for comparison with ancient alloys. German silver or Argentaan contains no silver, it is an alloy of 35 % copper, 25 % zinc and 20 % nickel.

Alloy	Gold in %	Silver in %	Copper in %	Lead in %	Other metals in %
Purple gold . . .	79	-	-	-	21 aluminium
Dark red gold . .	50	-	50	-	-
Grey gold	86	0-8.6	-	-	7-17 iron
Green gold	30	70	-	-	-
Blue gold	75	-	-	-	25 iron
White gold	75-85	-	-	-	8-10 nickel 2-9 zinc
Pale yellow gold	92	0-8.3	-	-	0-8.3
Silver jewelry . .	-	76-84	16-24	-	-
Lead shot	-	-	-	99.8	0.2 arsenic
Chemical lead . .	-	-	0.08	99.93	-
Plumber's solder	-	-	-	50-67	50-33 tin
Silver solder . . .	-	70-75	20-30	-	5-7.5 zinc
Silver solder (best)	-	40	14	-	40 tin, 6 zinc

The composition of the solders should be compared with the many recipes mentioned by PLINY (*N.H.* XXXIII. 86; XXXIV. 161). The staining of silver which played such a large part in the earliest chemi-

cal papyri where it is called *iosis* or *baphé* is mentioned by PLINY too (*N.H.* XXXIII. 132, 133, 157).

Our remarks on the necessity of compiling the data on ancient goldsmith's work with a view to a new history of this craft apply to silver-work as well. Attention is drawn to the many publications referring to certain areas of the Ancient Near East only (7) (23) (68) (83) (161) (167) (200) (208) (220) (223) (246) (247) (248) (259) (260) (297) (307) (309) (311) and to those of countries or periods outside the scope of this chapter where the development of certain similar techniques can be studied for comparison with those just mentioned (48) (63) (70) (71) (80) (129) (130) (146) (147) (156) (174) (186) (210) (230) (250) (251) (258) (267) (278) (284) (285). The attention of future students in this field is drawn to a series of lectures published by the Worshipful Company of Goldsmiths (115) where detailed scientific explanations are given of several phases of silversmith's craft and the correct terms for the different techniques explained.

It has been said that "all gold and silver rather turn to dirt and it's no better reckoned, but of those who worship dirty gods" (*Cymbeline*, Act III, sc. 6) but even this cloud has its silver lining and the history of silver and lead like that of gold has much to contribute to the better understanding of certain phases in the history of the Ancient Near East.

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CHAPTER EIGHT

TIN, ANTIMONY AND ARSENIC IN ANTIQUITY

*Old words have strong Emphasis, others may look upon
them as Rubbish
or Trifles, but they are grossly mistaken and Posterity
will pay us in our own Coyne*
(ELIAS ASHMOLE, *Theatrum Chemicum Britannicum*, 1652)

Though tin, antimony and arsenic were not used separately in Antiquity but mainly in the form of alloys their history belongs to the most important and at the same time the most complicated chapters of ancient metallurgy.

Tin is by far the most important of the three. AGRICOLA in commenting on the general opinion of the usefulness of metallurgy remarks: "Weil die Donnerbüchsen aus einer Mischung von Kupfer und Zinn gemacht worden sind, schelten die Leute Kupfer und Zinn noch mehr als das Eisen", but he quite correctly points out the immense importance of tin and bronze in the history of mankind.

For even to these days steel has never fully displaced bronze in metallurgy, as this alloy is still valued for many specific uses. Thus its important component can be said to have played a major part in metallurgy for more than 4000 years! Still the production of tin was no more than 10,000 Tons a year at the end of last century, but more efficient mining and refining methods brought this figure to 188,000 Tons in 1929.

As the shadows hovering over the prehistory of the Ancient Near East are being dispelled by the spade of the archaeologist we are learning to discern the movements of the tribes descending to the Near East from Central Asia. We have also learnt that they knew gold, silver, lead and copper and perhaps bronze too in the later stages, though fuller analysis of the finds may still reveal more. Still the production of tin and bronze remained small as tin supplies in the Near East are scarce and there is no reason to suppose that they have been much greater in Antiquity. The production of tin developed slowly until larger supplies became available as international trade relations grew.

From the Bronze Age upto the present time tin kept its important place in metallurgy notwithstanding the metal itself does not lend itself for industrial manufacture of tools and weapons. But it still is

the undoubted master in the field of transmission of power (bearing metals), the transmission of food energy (tin cans and tinfoil) and the transmission of mental energy (printing). The strangest part of its history, however, is the fact that the pure metal played a secondary role only, it was always the alloy with copper (bronze) or that with lead (pewter) which was used in Antiquity. Finds of pure tin objects date from the Late Bronze Age only. Simple ornaments in the Swiss lake dwellings and in Persian graves, bronze inlaid with strips of pure tin, then in classical times the "tinning" of bronze and copper objects in Gaul, the manufacture of cheap trinkets and its use as a substitute of silver form the few applications known at present. This may be partly due to the fact that tin is not very resistant to corrosion. THOMAS OF CANTIPRÉ knew already that "tin rusts away when it lays long in water" and indeed, the tin is the first component to corrode in bronze, causing separate layers of tin oxide and copper oxides which again prevent the proper restoration of bronzes if the attack is allowed to proceed too far! It is evident from the archaeological data that bronze was known at least a 1000 years before the metal tin was produced industrially from its ores to be found as worthless a metal to the ancients as lead. The use of tin almost exclusively in alloys has not emphasized the properties of the metal itself and we find therefore that it plays no part in the older magical texts though it was often confused with lead, the magical metal "par excellence". The magical qualities of tin were recognized in the Hellenistic period only. Tinfoil (*petala, lipides*) is mentioned in magical texts (DIETRICH, ABRAXAS), in alchemy tin is the symbol of Hermes and vice-versa (OLYMPIODORUS, EUSTATHIOS), then that of Venus (CELSUS) and finally that of Jupiter (VETTIUS VALENS, STEPHANOS OF ALEXANDRIA, Syrian and Arabian alchemists and in the Middle Ages). It occurs in the theories of the transmutation of metals as a stage between lead and silver (Hermetic writings), ZOSIMOS considers it to be "solid mercury" and PSEUDO-DEMOCRITOS mentions it with copper, lead and iron as the "Philosophic Egg" from which the precious metals can be prepared. It plays a similar part in the transmutation theories of the Chinese alchemists.

In China tin is considered to be produced by the feminine principle in nature and it is classed between silver and lead. Arsenic generates itself in 200 years and after 200 more years it is converted into tin, which is feminine because of its tender qualities; by applying the masculine principle to it, it can be converted into silver. In the late Lapidary of (pseudo-)ARISTOTLE tin is considered to be unclean silver

which has to be purified because of its weakness, its smell and its cry (the typical "tin-cry" emitted by a bent bar of tin and caused by the internal friction of its crystals). Not until the Middle Ages it is used side by side with lead for defixiones (THOMAS OF BOLOGNA).

The story of these three metals is greatly confused by the loose use of the words "tin", "antimony" and "arsenic" to denote either the metal, the ores or both as though the difficulties raised by the ancient texts were not yet sufficient, for the ancients did not clearly distinguish the same three metals from lead. We shall revert to this point when dealing with the nomenclature of these metals. In unravelling the early history of these metals care should be taken not to enhance our difficulties and to use the proper terms which is the only way of finding our way in this maze of data.

Before discussing the early history of tin (which is partly that of bronze) it will be useful first to turn to the mining and refining of tin.

I

Though small nuggets of native tin are said to occur in Australia and Nigeria, they are very rare and of no importance for the production of tin. The only important ore is *cassiterite* or tin-stone, a tin-oxide. It is a heavy ore, usually dark brown or black and except the weight there is nothing to tell us that it is a metallic compound, as PLINY already recorded. This tin-stone of "black tin" is found in two distinct forms. It is found as *vein ore* (Bergzinn) in veins of granite or granitic rocks, consisting mainly of quartz in which the cassiterite is embedded either in fissure veins or dispersed through the rock masses as small crystals. The main impurity causing the dark colour of the cassiterite are iron compounds, in the case of other impurities the colour may vary, these varieties are called "ruby tin", "wax tin", "rosin tin", etc. Where these lodes of granite or other acid eruptive rocks bearing cassiterite reach the earth's surface they have often been eroded and disintegrated. In that case the debris including the cassiterite has been carried away by water and the ore and other heavy minerals deposited on the way in alluvial gravels as well-worn crystals deformed into rolled lumps, grains and sands called *stream tin* (alluvial tin, float tin, Seifenzinn, Waschzinn, shode) heavily contaminated with clay and sand. It is important to remember that not a single tinfield in the world has tinstone in situ except near granite or granitic rocks, alluvial tinstone only if the debris is derived from granitic rocks. This

both limits the number of tinfields and gives us a clue as to veins or lodes now exhausted but formerly bearing tinstone. The alluvial stream tin deposits are still the most important source in tin-mining, no less than 5/6 of the present world tin production is derived from such alluvial deposits, at present only in Bolivia and Cornwall is vein ore mined.

In Antiquity too the bulk of the tin stone seems to have been drawn from these alluvial deposits. Though THEOPHRASTUS does not mention cassiterite, PLINY is emphatic on the point of stream tin (*N.H.* XXXIV, 156-157): "Next let us consider the properties of lead, of which there are two species, dark and pale. The latter the Greek cassiteros, is the more valuable. The legends say that men seek it in the isles of the Atlantic and that it is transported in boats of osier covered with hides stitched together. We know, however, that it occurs in Lusitania and Gallaecia where the surface strata of the ground are sandy and dark-coloured. The only property which serves for its identification is its weight. Small nuggets appear occasionally, especially when the torrential streams by which they have been deposited have dried up. Metallurgists wash this sandy material and roast the concentrates in a furnace. It is also found in gold-mines which they call alutiae. Water is driven in and washes out the nuggets which are black with a splash of white here and there. Their weight is the same as that of gold and they therefore accumulate with gold in the pans in which the latter is collected. The ore being subsequently separated from gold in the furnace is after fusion resolved into pale lead."

Though PLINY makes a small mistake in the course of his description, for the specific gravity of tinstone is about half that of gold, he has all the essential facts on hand. This description allows us to conclude that the ancients were aware of the association of stream tin and gold, a very important factor in the history of tin.

Though pure cassiterite contains 78.6 % of tin, the vein ore is so contaminated with the quartz matrix that it generally contains only 0.2 to 2.0 % of tin. In the case of alluvial tin this percentage is considerably higher because the natural washing action during its deposition has removed a large part of the useless debris from the granite. This higher percentage of ore in alluvial deposits together with the association with gold and similar concentration methods to be used formed an important stimulus to work the stream tin as soon as it had been recognized as a metallic compound useful in bronze production. This association also accounts for the fact that so many old deposits

have been depleted in the course of time. AGRICOLA favours the use of a divining rod of spruce-wood in the search for cassiterite and he mentions earth of the colour of lead-oxide (yellowish) as a certain indication of stream tin deposits.

A second important factor in the history of tin mining is the association of copper ores with tin ores in certain localities such as Cornwall, Bohemia, Tillek, and China. This means that both tin ores and copper ores are here found in veins close together, which is rather exceptional as tin ores are genetically different from copper ores. In this case mixed ores may have been produced by the ancient miners,



Fig 50 Collecting stream tin (after AGRICOLA, *de re Metallica*)

in other, more frequent, cases where copper ores are found in the neighbourhood, that is at some distance of deposits of tinstone, the separate production of these ores could lead only to the combined refining and therefore to the production of bronze from this mixture if the mixing was done deliberately which again could occur only after the time when cassiterite had been known to be a metallic compound or at least an ore beneficial to the production of the "better" type of copper which we call bronze.

But before discussing the early history of tin and bronze we shall deal with the production of cassiterite itself. In the case of alluvial stream tin the operations were simple enough. Remembering the association with gold in alluvial deposits we need only repeat the methods

discussed for gold-production from such deposits, viz. 1) panning or pan-washing, 2) placer-mining (ground-slucing) and 3) hydraulic mining (hushing). In fact it meant only the adaptation of gold-mining methods to deposits of tinstone after the recognition of the black unseemly by-product of the gold-mines as a valuable ore for bronze-production. All these methods were undoubtedly applied to tin-mining in Antiquity, the third method of tin production on a large scale was adapted by the Romans in Spain. It gave them the means of totally depleting these tin fields by means of an enormous water-supply for which they built large aqueducts. The application of these mining methods to the tinfields of the Ancient Near East has not been investigated but we know far more about their application to Cornish stream tin. We know that the ancient Britons worked stream tin there, concentrated it by gravitation in sluice-boxes or "tyes" like gold and after sufficient concentration and washing purified the ore further by hand-picking. Such is still the essence of the methods used by the natives of Malaya, Sumatra, and Borneo, and we find many variants described by AGRICOLA from everyday practice in his times in Saxony and Bohemia (1). Modern tin production is still based on these old methods but the quantities of tin-stone produced have been greatly increased by development of dredging and washing technique in the course of this century.

The mining of decomposed surface outcrops of vein ore proceeds on the same lines. Undoubtedly the ancient miners when the alluvial deposits began to be exhausted searched for further tin-stone, hit on the larger fragments of vein ore (called *shode* in Cornwall) in these decomposed rocks and were thus led to the true source of the cassiterite, the veins below these outcrops. Until the days of the Roman Empire the alluvial stream tin and the weathered outcrops of vein ore (mainly those in Spain) were the most important sources but from then onwards vein ore was mined in increasingly larger quantities especially in Cornwall. The methods were similar to those used in reef-mining of gold. The oldest shafts and corridors of Cornish pits still show practical and efficient application of stopping and hand-laid stones (the debris of tin stone washing) used as props. AGRICOLA describes special fire-setting methods to break up the vein ore underground. The vein ore could not be refined as such, it required elimination of the quartz matrix and to this end the stone is calcined, which facilitated the breaking up and at the same time removed such harmful impurities as sulphur and arsenic compounds. The rock was then crushed and

washed; this cycle was repeated until the cassiterite had been sufficiently concentrated to warrant smelting. Apart from the crushing the same methods were applied for concentration as those used for stream tin; AGRICOLA (1) describes a series of these methods which by their primitiveness show how long they must have been in use already. Usually the ore is classified after concentration according to size prior to the actual refining, such groups as lumps (AGRICOLA's *glarae majusculae* or *Graupen*) (called after the mining town of Graupen where German tin mining was reopened in 1146) to the size of 60 to 15 mm, "sands" and "slimes" are distinguished and sorted to



Fig. 51. Sluicing tin ore (after AGRICOLA, *de re Metallica*)

fill the furnace more effeciently and to improve the separation of the slag.

Before discussing different tin deposits in the Ancient Near East and also those that may have been important for this area we must devote a few lines to a tin mineral which is sometimes mentioned in connection with the history of bronze. This mineral is called *stannine* (stannite, "bell-metal ore", "tin-pyrites", Zinnkies), a compound of tin, copper, iron and sulphur, containing about 25 % of tin. Its appearance, however, is entirely that of normal copper or iron pyrites, nothing suggests its connection with cassiterite, even if by smelting it would have been possible to obtain a 50 % bronze. Its rarity in the Old World and the complicated refining methods necessary to extract

bronze from this iron and sulphur bearing ore preclude the possibility of its use in ancient times to any extent, though it is now mined in Bolivia and Cornwall.

II

The present tinfields are not those of Antiquity. Though 5/6 of the world's tin production is obtained from stream tin, most of the important centres are situated far outside the ancient world. In 1936 the total world production was 182,500 Tons, Malaya producing 37.2 % of this amount, the Dutch East Indies 17.6 %, Bolivia 13.4 %, Thailand 7.1 %, China 5.9 %, Japan, Germany and England being minor producers.

In the eighteenth century tin was produced mainly in Cornwall, Saxony and Bohemia. In the Near East deposits of cassiterite are scarce. Though CASSIODOR ascribes the discovery of tin and lead to king Midas of Phrygia (*Variae*, lib. 3, cap. 31) no important fields are known in this region. In *Asia Minor* there are a few veins of tin stone near Darmanlar, south-east of Smyrna, 2) near Eshkishehir (9) (10) in Central Anatolia and 3) near Uşak in the Murad Dagh. No further details on these fields are available. Stream tin and vein ore are found 4) near Kastamuni, 5) in the Ak Dagh near Sivas, 6) near Tillek (Erzincan) in association with copper ores on the south-west slopes of the Dudjik Dagh and the Kubaba Dagh (17) (16) (37), in the mountains between Karasheikh and Erzeroum, 8) near Erganimadeni (vil. Elaziz) where rich copper ores abound too.

In the *Caucasus and Transcaucasia* JESSEN and other authors have described tinfields lately (17) (22), the most important are:

- 9) The basin of the Belaia river (Kuban) near copper ores.
- 10) The region between Elbrus and the river Terek in the central Caucasus, the upper Racha and south Ossetia, the Alikhan Dagh containing tin, copper and iron ores.
- 11) The region of Sharopani, Gori and Phorzom east of Tiflis.
- 12) The region between Allaverdi and Gandža, which is also rich in copper ores up to the river Terter.
- 13) The Kara Dagh and Karabakh mountains on the banks of the Araxes near Migri (37).

In *Persia* we find tin ores:

- 14) On the Kuh-i-Sehend near Tabriz.
- 15) On the southern slopes of the Elburz near Asterabad and Sharud and stream tin in the goldsands of the Kouh-i-Zar near Damghan (16).

16) In the Kuh-i-Benan and the north-western part, the Qara Dagh, but it is uncertain whether this is stream tin or vein ore, tin ore is also reported from the southern parts of this mountain range near Bam.

17) In the Rabotje Alokband mine 22 miles west of Meshed, 75 miles south of Kutshan near Mion Abot and then on the slopes of Mt. Binalud (17). Though some consider the tinfields of Chorassan very uncertain (16) (17), the early reports of VON BAER not being very clear (3), still most authors and especially geologists like DE LAUNAY accept them without reserve.

18) There are no exact data about the reports on tin ores in Transoxania, the ancient Drangiana (Paraopamisus), Kafiristan and the Tarim basin or the uppercourse of the Hilmend. These are regions mentioned by STRABO (XV. 2. 10) and Arabian authors such as IBN HAUQAL, ALISTHAKRI, etc. who report tin mining in these regions around 975 A.D. Tin from the Tarim basin is mentioned by the pilgrim HIUEN TSANG. It is therefore not correct to reject STRABO's report without further investigation, but these regions are insufficiently explored geologically. Still the natives of Kafiristan wear small tin ornaments which they fashion themselves.

In *Asia* tin ore occurs near Lake Baikal, in several Japanese provinces and large quantities are mined in China (Kwangsi, Hunan and especially in Yunnan (stream tin). Very important is the "tin belt" ranging from Burma and Thailand, via Malaya to Bangka and Biliton, which now produces the bulk of the world's tin, in the form of stream tin. That this tin would have reached Egypt in 2000 B.C. as SCHUMANN said (53) is ridiculous. Not only has this belt a fairly young history—Bangka tin was not discovered before 1710—but ancient India got its tin from the West, the Arabs did not find tin in India and they mention the Malayan fields in the ninth century only. Small deposits in India itself were found in the southern part of Bombay Presidency, Bihar and Orissa (near Pihra, Donchurch, Harzibagh district, Chattapund and Nurunga). They were probably unknown in Antiquity.

The southern and western part of the Near East are singularly poor in tin ores, though some have supposed that the Sinai contained tin ores which had been depleted since (9), perhaps because of the report on Midian tin in the Bible (Num. 31 : 22). But neither in Midian nor in the Sinai there is any trace of tin ore. Some stream tin and vein ore occurs near Byblos in Kasrouan between the Near Ibrahim (Adonis) and the Nahr Feidar (Phaedrus) and as copper ores are

found in the neighbourhood this deposit has attracted much attention (37). Some tin ore is also said to occur near Aleppo north west of Beyrouth. As Egypt stood in regular contact with Byblos in very early times there were reasons to suppose that the knowledge of bronze would have penetrated to Egypt at an early date from this region. But archaeological and other data show that this is not the case and we can therefore conclude safely that no tin mining was conducted here at any early date and no centre of bronze manufacture existed in this region.

In Egypt no tin ore is known to occur and therefore imports from *Africa* were proposed. However, this is very improbable. There are three important tin fields in Africa, first of all Transvaal and Rhodesia, who are mentioned as the sources of supplies for Egypt, because of the Zimbabwe culture and its knowledge of bronze. Without discussing this problem fully we may safely conclude after the investigations carried out by CATON THOMPSON that the Zimbabwe culture is far younger than originally supposed. The tin refining methods in this region have been studied by GORDON, WAGNER and STANLEY, especially the refineries near Watersberg. There stream tin was refined and as heaps of ore near different sets of furnaces showed tin ores and copper ores were treated separately and the bronze made by smelting tin and copper. This points to a late phase of bronze manufacture. It would seem from the remains that these refineries are hardly older than 300 or 400 years. Again the Zimbabwe bronzes show a very close range of composition which points to their manufacture by mixing tin and copper as metals. It would seem that these South African tin mines were opened when the Arab traders came down the coast looking for tin, reaching Sofala in the tenth century, when the Zimbabwe culture was at its height. Though there are no Arab records of tin trade in these regions, part of the tin may have been sold directly to Malay or Hindu merchants following in the wake of the Arabs. It is therefore inconceivable that these mines were worked in the Egyptian Bronze Age or that any tin from countries south or south-west of Egypt reached Egypt and passed through it to Mesopotamia and Europe, no evidence of traffic or knowledge of tin and bronze was ever found on this route which can be ascribed to so early a period. A group of tinfields close by in Katanga (Belgian Congo) and Portuguese Nyassaland were discovered only shortly ago.

The placers of the Gold Coast and Nigeria are very important now but fairly recent discoveries. In the Middle Ages the Buachi of

Nigeria possessed tin ornaments according to DIMESHQI, but he added that they loved tin because of its rarity and they valued it more than gold, which shows that these fields were not exploited then. The Kano conquerors of the Bauchi stopped the tin production but started trading the ore along the northern trade-routes. The local smelting was never efficient the Yoruba and Hausa being the only tribes who use the tin-bearing slag in subsequent smelting, which again goes to show that the tin production never developed out of the local production phase. The tinstone found here is very pure, some records even state that metallic tin was found with the cassiterite in the river sands and gravels.

Disclaiming any importance to the tinfields of the Far East and Africa for the ancients leads us to the discussion of the *European tinfields* which though unimportant now may have been chief sources of supply in Antiquity.

Three fields are grouped along the Atlantic seacoast. The first is situated in the north-west corner of the Iberian peninsula, in the Spanish provinces of Orense and Zamorra and the Portuguese districts of Beira, Minho, and Tras-o-Montes. The Spanish fields are the most important, lodes and placers occur near Allariz, Monte Balcobo, in the district north-west of Orense between the rivers Avia and Leire, and east of Carballino. Quite close copper ores have been found. RICKARD has estimated the amount of tin ore produced in Cantabria to be 4,000,000 m³ near Salabe only and a similar amount seems to have taken from Ablaneda south of Sales. In both places the Romans constructed aqueducts for the washing of the ores (19) (30) (35). It is manifest from the passages of PLINY and STRABO that stream tin was exploited here and Pliny mentions that the methods of gold production are used (N.H. 34. 158), though lodes seem to have been worked too. Some writers have claimed Spain to be the Kù-ki or Tinland of SARGON's annals, but this must be reconsidered in the light of more recent evidence! Further tin fields are known near Salamanca and in Almaria and southern Spain, but they were of local importance only. Of course they may have been exploited first, but as they were soon exhausted, their prominence must have given way to the fields or northern Spain.

France contains two groups of tinfields. In Central France the districts of Haute Vienne, Creuze and Vaulry contain stream tin which placers were in production from the Late Bronze Age to the Early Iron Age. On the Atlantic coast the south Breton tinfields in

the extreme north-west of the province of Loire-Inférieure and the Josselin-Morbihan massif are considered to have been in production from the Middle Bronze Age up to the Early Iron Age. They are certainly pre-Roman, probably shut down because of Spanish competition (19), the small islands off the coast may be the Oestrymides mentioned by AVIENUS.

The third important field is situated in Cornwall. Though cassiterite is found in Ireland in the gold placers of Wicklow, this can not be considered a source of primary importance. In Cornwall alluvial ore occurs regularly though most of the references speak of vein ore. Copper ores occur in the same region and indeed side by side with tin ores. In fact Cornwall is the standard example of both ores occurring in the same mines, copper lodes in the surface strata, cassiterite in the deeper strata, but mixed ores are found in the boundary zone. There are no Cornish remains with which tin is associated before the Late Bronze Age (29), HAVERFIELD considers any exploitation before 1500 B.C. extremely improbable. Though WHITTICK claimed the exploitation of stream tin only even in the Roman period, this is now considered wrong and lodes have been worked certainly from classical times onwards. These three fields must be discussed together with the problem of the Cassiterides which HERODOTUS is unable to locate. Though these islands were considered by BESNIER to represent the islands off the Morbihan coast, others have included Cornwall and the Scilly islands (where tin ore is extremely rare!). Again the evidence of DIODOR, who describes the Cassiterides as islands off the Spanish coast and distinct from Cornwall, has led others to believe them to be the Spanish tinfield. It is now generally accepted, however, that the "Cassiterides" stand for a general name of the tin localities in Western Europe (HAVERFIELD, HENNIG, CARY, BAILEY) and later narrowed down in classical tradition (HESIOD 258, ARISTOTLE, de Mirab. Auscult. 81; STRABO 3. 2. 9; 5. 11; 5. 15; 5. 30; CAESAR, de Bello Gallico 5. 12; POMP. MELA 3. 6. 2; DIODOR 5. 38. 4; 5. 22. 5; HERODOTUS 3. 115) to certain islands which took part in the tin trade (30). CARY has discussed the three tinfields in order to establish the chronology of tin production in these regions (13) and he reached the following conclusions:

a) The mines of Spain were in operation from the beginnings of the Bronze Age and were probably worked continuously up to the Roman period (PLINY, POSEIDONIUS). Tin was mined and exported to France and the Mediterranean region before the beginning of the Iron Age.

b) The deposits of southern Brittany were worked about 500 B.C. and followed Spain, but as no evidence of their production exists from later periods, they must have been abandoned soon because of Spanish competition.

c) So long as Brittany worked the Cornish mines were not exploited. Cornish tin production therefore enters international trade about 500 B.C. (though local production may have started earlier) and continues up to Caesars' days (43 B.C.). Their exploitation was partly suspended in the Early Empire but resumed after the failure of the Spanish mines about 250 A.D. when the Romans penetrated the Cornish tin area and constructed good roads for the trade caravans.

d) Tin or tin ore was thus continuously produced from the Bronze Age onwards, Cornwall being an important centre from the fifth or fourth century B.C. until it was overtaken by the efficient exploitation of Spanish tin mines under the Early Roman Empire. In the first and second century A.D. the placers of Lusitania and Gallaecia had almost the monopoly of the Roman market, even in the third century the best "bullæ" on the market in Egypt and elsewhere is still Spanish tin (Pap. Holmiensis and Aetius Istricus). In the course of the third century A.D. the Cornish mines regain their old prominence by the failure of the Spanish mines.

Though tin ores occur in *Etruria* there is no proof that the Etruscans exploited the Campagliese tin at Cento Camarello (19), Monte Valerio, Monte Rombolo, and east of Monte Fumacchio. Vein ore is found there sparsely in iron ore (limonite) with copper minerals. The time of their exploitation is not known, present evidence does not allow us to believe any exploitation before the second century B.C. and the deposits are of secondary importance only.

The tinfields of *Central Germany* (Vogtland, Fichtelgebirge, Erzgebirge, Böhmerwald) play a large part in the development of early bronze industry in these parts as Witter (59) has proved definitely. They are often accompanied by copper ores, mixed ores occur fairly frequently. Undoubtedly these fields play a large part in the tin supply of the Ancient Near East. An embarrassing fact arises from the fact that no classical writer mentions them (33), there is no evidence of tin or tin ore trade to the head of the Adriatic or to Mediterranean ports along the well-known trade routes carrying amber and other northern products valued by the ancients. Indeed no evidence of their exploitation occurs in literature before the XIIth century A.D. THOMAS OF CANTIPRÉ is one of the first to mention the new German tin

production in 1240 and ALBERTUS MAGNUS mentions in his *de Mineralibus* that this German tin is softer than its Cornish competitor. The value of WITTER's monograph will be discussed later on.

Less important fields occur in the Urals, Finland and Eastern Europe. Tin ore has been found in the Szemenik mountains in the Banat, between Resita and Karánsebes, but the deposits are small and the time of their working uncertain.

Cassiterite is rumoured to occur near Pangaeum, but HEMHACKER's assertions have not been proved; equally uncertain are rumours about tin ore at Voloastro (Thessaly). Finally DAVIES has found small smelting works at Cirrha near Delphi but the local provenance of the ore is doubtful.

III

Recently the refining of tin has grown more complicated. Firstly much tin is now recovered from tin plate or other used materials. Germany for instance produced 2300 Tons of tin from local ores and 4000 Tons from spent materials in 1936! As the different modern uses of tin require a high standard of purity and as pyrites and vein ore are treated too, there is now usually a calcination at 600-700° C to remove as much sulphur and arsenic as possible at the start, followed by "rag-roasting", a part-oxidation of the iron and copper compounds which are then leached out with water. Further "sweet-roasting" to remove the remaining sulphur and electromagnetic separation of wolframite are followed by concentration to marketable "black tin" by water. This pure cassiterite can then be easily reduced with charcoal or with other material in suitable furnaces, the tin being specially refined to remove the last traces of copper, lead and antimony. Of late tin is often produced electrolytically to obtain the purest tin possible, as iron, lead, copper and arsenic even in small quantities spoil the malleability, colour, gloss and toxicity. Of course refinements like these were unknown even to AGRICOLA and were undoubtedly not practised in Antiquity, as tin was then practically always used as an alloy either with copper (bronze) or lead (pewter). In that case the influence of the impurities is felt much less.

The old simple refining methods of cassiterite are still practised in different parts of the world, and we must use these and also conclusions drawn from the remains of old furnaces, etc. because there are no texts on tin refining even from classical authors, though undoubtedly tin was produced as a separate metal then. GOWLAND found in

Japan (29) that the ore was broken in foot-stamp mills, derived from types used for the decorticating of rice, and afterwards ground to powder on hand-mills or querns. In some cases the ore was previously broken with stone hammers or anvils. The powdered ore is then again washed to remove the clay and earth and charged wet into the furnace with alternating layers of charcoal. When reduced the metal is ladled out of the furnace after raking aside the supernatant slag and cast into rods in an open mould. Originally the furnaces have been worked without a blast which caused great loss of tin in the slag and unreduced oxide remaining in the metal. Such is the method used by the natives



Fig 52 Roasting tin ores (after AGRICOLA, *de re Metallica*)

of Borneo, Sumatra, and Malaya in producing tin for their private use. In Borneo the furnace is simply a hole in the ground (20' deep, 14' wide), still when improving the reduction by the use of piston-bellows three men were able to produce 25 lbs of tin in $4\frac{1}{2}$ hours. We know from finds in Cornwall (30), Central France, and Greece (55) that such primitive methods were indeed practised in Antiquity. Simple clay-lined holes or trenches were dug in the ground and wood was piled into it and lighted. If it burned fiercely charges of ore and wood were thrown in alternatingly and the slag tapped from the furnace into a second hole until enough tin had been assembled in the furnace to be ladled out. The trench was really only necessary to hold the embers and keep the metal together. Many of these slag-hearths

have been found in Cornwall, retreating the slag was not considered worth while. Still slags in Gaul contained no less than 21 % of tin! It was, however, gradually recognised that cassiterite requires a fairly high reduction temperature so that for instance the gold will melt from mixtures before the tin ore is reduced. This high temperature ensures a good fluidity of the slag but it involves a tendency for the tin to enter the slag. Careful control of the temperature is therefore necessary to ensure a maximum degree of extraction. This is only possible in a well-built furnace and thus we find that as soon as tin ore was no longer considered to be a useful mineral in adding to copper ores



Fig 53 Grinding tin ores (after AGRICOLA, *de re Metallica*)

to produce bronze but was used as a source for tin production, that is to say shortly before classical times, furnaces were built and worked with blast-air. Circular tuyères were fixed at the hearth bottom to introduce the blast air and a lower flow hole served to tap the metal. Such were the furnaces of Cirrha Maghoula and Volo Kastor (55), of Tereife (Cornwall), of the old tinsmelters of Transvaal, whose smelting sites were studied by GORDON and WAGNER and a similar type was still in use in Zamorra, Spain, in 1856 (46). They were usually lined with clay, even in the time of AGRICOLA, who, however, advises the use of a sandstone block for the bottom of the hearth. He adds rightly that the blast air-opening should not be too wide if the temperature should not rise too far. In his time too lime was some-

times used as a flux, it was certainly used in earlier times as the old furnaces and slags prove. As in the case of most refining methods in Antiquity a remarkably pure metal was obtained at the cost of a heavy loss of ore in the slag and in the case of tin by volatilization. In later centuries the efficiency of the process is investigated. So we find AGRICOLA insisting on effective temperature control to avoid these losses and he advises to superimpose a small chamber over the furnace to collect the metal-bearing dust that might escape during the process. AGRICOLA was the first to deal with the impurities and to advise



Fig 54 Smelting crude tin (after AGRICOLA, *de re Metallica*)

liquating (Saigern) the crude tin to free it from iron. The process is similar to that used for the separation of silver and lead, the test for pure tin being its liquidity which changes rapidly if it includes iron. It is, however doubtful whether this refining method was conceived or used even in classical times.

The metal is usually cast into bars of 28 lbs or slabs of 100 lbs today. In Roman times special double-T form slabs called *astragali* were used in Cornwall, it is claimed that two of these slabs were loaded on a pack-animal and that their form is adapted to this means of transport. We know nothing about the forms of the tin bars of earlier periods.

It is indeed very strange that no metallic tin was found in foun-

der's hoards nor any bars or slabs (though those of copper and bronze abound) neither any tin ores. The latter may have been overlooked because of their earthy appearance but the former even if they had

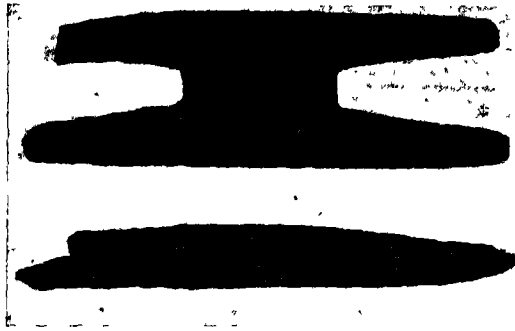


Fig. 55 Block of tin found at St. Mawes, Falmouth (after GOWLAND)

been corroded would have left obvious remains of white tin-oxide. This may be taken as a secondary proof that tin was not produced separately on a large scale before 1500 B.C. but that tin ore was treated together with copper ore in making bronze.

IV

In trying to trace *the history of tin and the origin of bronze* it is well to remember two important facts mentioned earlier:

- a) the association of stream tin and gold in many placers and alluvial deposits;
- b) the association of vein ore with copper ores in a few localities such as Cornwall, Tillek, Bohemia and China.

As to the first fact, one of the earliest authors on Cornish tin, CAREW, wrote: "Tinnors do also find little hopps of gold among their ores which they keep in quills and sell to the goldsmiths" and SIRET pointed out the ancient connection between tin- and gold-mining in France where we find place-names like Auray (Auricia, on the Armorican islands) and Ariège (Aurigera, in central France).

The second fact has been used by many authors to claim that this led to the discovery of bronze. COFFEY even went as far as stating: "Only when it has been shown that copper is obtained from ores that are free from tin does it seem allowable to argue that the tin has been added", quite forgetting that this close association of copper and tin ores in the same matrix is very rare though there are of course

several places where tin ores occur at some distance of surface lodes of copper ores. GOWLAND has proved that the smelting of artificial mixes of copper and tin ores always gave bronze and so it was rather plausible to argue that these natural mixtures led to bronze discovery. This is what Siret claims for Spanish bronze; SMITH, LUCAS (41), (42), REID (49) and others have adopted it. The difficulty in this theory remains how to explain that the ancients were led to perceive that the cassiterite in the mixed ore was the compound to cause the "improvement" of the smelted copper, and to identify these cassiterite crystals with the earthy lumps and sands of stream tin. For it remains a fact that in Antiquity the stream tin was used predominantly, if not exclusively, and only in the Later Roman Empire we have any proof of vein ore exploitation. Nor have we any proof that the centres where these mixed ores occur play any important part in the early history of tin and bronze in the Ancient Near East, whatever their part may have been later on. It would, therefore, seem that the origin of tin and bronze was not initially connected with the mixed vein ore.

WITTER (61) has elaborated the theory for the Middle European tin and copper regions to explain the development of bronze industry in these parts. By an admirable presentation of the facts and research supplemented with modern scientific analysis of the crude products and bronzes found in ancient mines and excavations he has undoubtedly solved the general line of development in these regions, whatever we might have to say towards the dating of this bronze industry and the priority claimed for this region over the Orient as elaborated by his collaborator in the appendix to his book. There can be no doubt whatever that the metallurgy of gold, copper and lead was known in the Near East in early sites of Mesopotamia and Iran such as Tepe Hissar and Anau at a period far earlier than any chalcolithic site in Europe and before any connection between this region and Middle Europe can be proved. WITTER's theory of the development of copper metallurgy will be repeated here in outline only as far as it touches the early history of tin and bronze. He claims the following stages:

A—*Natural mixtures treated*: a) Tin-bearing oxydic copper ores heated with wood or charcoal, b) mixtures of oxydic copper ores and tin ores treated with charcoal and wood, c) later mixtures of sulphidic tin and copper ores smelted. In the course of these phases the true value of the tin ore was discovered and from then onwards a further quick development took place along the following lines:

B—*Artificial mixtures treated*: a) naturally mixed copper and tin

ores selected and smelted, b) mixes of cassiterite and copper ores treated and finally c) cassiterite and charcoal smelted together with crude copper previously smelted.

This theory suits the Middle European facts admirably but it can not be upheld in all details in the Ancient Near East. LUCAS, who first propagated a similar theory (41) has now adopted a slightly different one (42) which we should like to elaborate on a few points which remain unexplained. It would seem from the present evidence that the early history of tin and bronze proceeded along the following lines: 1—Cassiterite in the form of stream tin was discovered in working goldplacers.

2—This cassiterite was reduced by metallurgists already in possession of the fundamental knowledge necessary for the production of gold, copper and lead. The tin produced was held to be lead, for as we shall see the ancients at least in the earliest periods did not distinguish lead, tin and antimony.

3—The tin was added to copper to form bronze or more probably at an early date stream tin was mixed with copper ores before smelting (WITTER's stage B. b) to produce the "improved" copper. Early bronzes are often found to contain lead or antimony, but as the tin ore was found to give better bronzes the addition of lead and antimony ores was discontinued, for the supply of stream tin was still sufficient.

4—At a later stage stream tin is reduced with charcoal together with the crude copper already obtained by separate smelting (WITTER's stage B. c.).

5—In the mean time certain mixed ores were worked unintentionally for copper and thus "natural" bronze was produced, generally with a small tin content which varied greatly according to the ore used, sometimes with a higher tin content. In the latter case a true bronze was produced (all bronzes containing over 2 % of tin are most probably artificial products, only very few mixed ores from selected localities would give such true bronzes on smelting!) and recognized to be similar to the product obtained by smelting cassiterite and copper ore (our stage 3). It is highly improbable that the cassiterite from the mixed ore was ever isolated and proved to be a tin compound. At the same time this new fact was remembered and used when the stream tin supply began to fail or used in such localities (Bohemia) where the type of the deposits is better suited to the working of mixed vein ore.

It may even be true that the production of this "natural bronze"

sometimes preceded that of the "artificial bronze" in certain regions but it was probably not recognized as a special ore until the production of tin and bronze from cassiterite and copper ore (our stage 3) was well established and the properties of bronze well known. This "artificial bronze" can be found in the earlier bronzes which show not only a higher tin content than would be expected from mixed ores but also less variation in the tin content. A still better bronze and a more stable composition could be obtained by reducing the stream tin with charcoal in molten crude copper (our stage 5) and as the composition of bronze stands in rather narrow connection with its efficiency for certain purposes this was an important advance of bronze technique.

6—Gradually the stream tin deposits in the Near East began to give out or could no longer cope with the growing demand, but many a small surface lode was depleted in early times. Thus we find in the Sargonid era inferior hammered axes of unalloyed copper replacing the earlier mould-cast bronze ones (14) after the splendid bronzes of Ur. CHILDE has ascribed this dearth of tin to the reaction of the supply countries towards the imperial aggression of the rulers from Agade, but the length of this "low tin content" period in Mesopotamia is better explained by the depletion of the known deposits and the growing demand for tin. Prospectors, metallurgists and traders struck out West to look for further supplies. Without claiming direct contact this explains the gradual introduction of Sumerian metal types in the Danube regions and finally in Middle Europe where the tin supplies were found in Bohemia and Saxony. No Sumerians came here, it means only that when Caucasian, Iranian, and Anatolian supplies became insufficient, the tin trade (in the form of tin, bronze or cassiterite, this is still a point which needs serious research!) with Bohemia overland via Troy to the Near East was gradually established.

7—Around 1500 B.C., as far as present evidence goes, a further technical improvement was achieved. The cassiterite was reduced separately and tin-metal produced industrially to be mixed with copper to form bronze. This not only allows a better dosing of the tin content but gradually led in centuries to come to the production of different alloys each specially adapted to certain purposes, special bronzes for weapons, mirrors, statues, bells, etc.

In the same period the earliest tin objects begin to appear in mass in the excavations. Also Aegean traders now bring tin from the West to the East. This tin is passed on by many links in the chain of trade stations as is the case with Middle European tin. Cross-dating and

relative dating of Near Eastern excavations have now excluded definitely the formerly maintained powerful and stimulating influence which reached the East from the West. Quite contrary to this early opinion the West is now widely believed to have been influenced, if only slightly, by the East. Early tin imports from Spain or Gaul can not have been of much importance in view of the striking poverty of the early Iberian Bronze Age when compared with the aeneolithic period. This trade developed in the Late Bronze Age and gradually ousted Bohemian tin from its front rank.

From Hittite sources we hear that bronze was imported from Cyprus where no tin-ores occur, so Aegean tin must have been added there to the local copper and the bronze sold as a valuable trade object. Still some curious compositions of bronzes from this later period remain to be explained. We agree with PREZŹORSKI that bronze must have been remelted often because of the expensiveness of tin which process, however, holds many dangers such as part-oxidation of the tin and lowering of the tin content. From collections of letters of this period such as the Amarna letters we must conclude that tin trade was mainly trade in crude bronze.

8—Again in the classical period as the alluvial tin of the West got insufficient too vein ore was worked, especially in Cornwall in Later Roman times.

Tin now becomes more and more a separate object of trade, it is still much traded as bronze (or pewter), but finds of stragali in England, etc. seem to show that at least near the mining centres tin was made up into blocks or slabs and tin objects become more frequent. in the Near East in classical times. Still the bulk of the tin was worked up to alloys and as bronze metallurgy was first practised in certain centres only to spread out gradually over the Near East we will have to look to the bronze trade in further unravelling the mysteries of the history of tin. This, however, belongs to a separate chapter, and we are now left to deal with the question whether it is possible to determine where this tin and bronze metallurgy was born.

In *Egypt* the situation is perfectly clear. There is no doubt that the earliest tin objects date from the XVIIIth dynasty, a ring of pure tin, one made of a gold tin alloy and a pilgrim bottle from Abydos. Tin occurs in Egyptian glass of this period. No tin ore is known to occur in the Egyptian gold placers, no traces of it were found either in the

Sinai copper ore or the slags near these mines. Bronze does appear in the Old Kingdom, probably introduced from abroad, but not until the XVIIIth dynasty do we find undoubted bronze objects in sufficient quantities in Egypt to justify the assertion that tin bronze was then in common use. In dealing with the nomenclature of tin it will be seen that any possible Egyptian term for tin is of a late date. The old statement of W. M. MÜLLER that Keftiu brought tin to Egypt in the Old Kingdom remains unproved. These "Keftiu" probably do not hail from Crete but from Northern Syria or Southern Asia Minor and they bring ḏḥty that is lead which was certainly imported at such an early date from the North (25). Nor is the thesis of Wainwright correct who pointed to the copper-tin ore of Kesrwan near Byblos and asserted that the Egyptians had learnt the manufacture of bronze in these regions. This can hardly be true seeing the old connections of Egypt and Byblos and the late appearance of bronze in Egypt. If there ever existed a centre of local bronze manufacture in Kesrwan it was probably of late date and local importance only. The oldest bar of tin was found on an Egyptian mummy (15), it is free of lead and silver and must have been manufactured from a pure cassiterite, its date is not later than 600 B.C. No Egyptian texts state any source for tin, it was probably imported in the form of bronze as we suggested above. More finds of tin objects belong to the later part of the New Kingdom and classical times, such as two finger rings from Karanog, tinned bronze bowls and a bowl of pewter. It occurs also in late classical Egyptian coins.

The bronzes from the fifth century B.C. onwards, such as dies, show by their higher tin content that the tin supply became more abundant. Later Hellenistic papyri mention "tinworkers" and quote receipts for solder consisting of 4 parts of lead and one part of tin, but the tin mentioned is always used either as bronze or as a tin/lead alloy. The most important source for Egypt is now England; STEPHANOS OF ALEXANDRIA calls tin *è brettanikè métallos* and we know from the Perig. Mar. Erythr. (cap. 28) that it was reexported again to Somaliland and India. The source of early Egyptian tin seems to be the North, but this can only be considered in the light of evidence from other regions.

As regards Crete which after 1500 B.C. certainly served as a link between Western European tin and the East, there is no doubt that this tin trade can hardly be proved to have existed earlier. Though both bronze objects and small tin buttons of types found in Celtic and

Iberian graves have been found in EMIII remains (2400-2200 B.C.) this must have meant the opening of a source of local importance to Crete only, which very slowly grew to be the object of an important trade to the East. FIMMEN has supposed this early Cretan tin to come from Spain and SAYCE, ALBRIGHT, and CASSON have connected it with a *Kù-ki* mentioned in a Sargonid tablet which would go to prove that a connection between Spain and the East existed at so early a date. This is, however, extremely doubtful and Cretan early tin may still have come partly from Anatolia and Caucasia as the new supply slowly won later.

In *Asia Minor* Troy was an important site for the history of tin as it lies on the overland trade route from Bohemia to the East. In Troy II bronzes are well known but they still show large variations in their tin content; those of Troy V however are well proportioned. A pure tin ring was found at Thermi IV. The early bronzes of Anatolia date from at least 3000 B.C. but copper forms are still used for a long period and as tin seems scarce the tin content is hardly ever outside the 2-10 % range. Only from the Middle Bronze Age onwards, say from 2200 B.C., true bronze forms are used and higher percentages of tin appear more regularly and not only for intricate forms as in the earlier period. Before the Iron Age tin is still more or less a precious metal, it is often used for inlay-work in bronze, for instance at Tell Halaf, while the *Iliad* mentions it three times (as a substitute of silver) in decorative work (the shields of Agamemnon and Achilles and the war chariot of Diomedes). It is not mentioned at all in the *Odessey*!

In the *Caucasian region* it came into use around 3000 B.C. according to JESSEN (22). Its use spread widely in Transcaucasia and the central Caucasus towards the end of the second millenium and reached its height around 1000 B.C. Local tin was used upto that date but gradually and increasingly tin from Western Europe was imported in the classical period and the local sources ceased to be worked. JESSEN's dates are now generally considered to be on the low side.

True bronzes occur in the Djemdet Nasr and Early Dynastic sites in *Mesopotamia* that is around 3000 B.C. The Royal Cemetery bronzes from Ur are true bronzes which show that the Ur metallurgists were fully acquainted with this branch of their craft. In *Mesopotamia* many types of lead and antimony bronzes preceed the true bronzes. It is doubtful whether the term *anaku* can be translated "tin" in any text prior to Hammurabi, though BOSON supposed that tin was always meant in the case of weapons and tools. The earliest direct allusion to tin occurs in the *annals of the Assyrian kings* who take "white bronze"

as a tribute from the Northern and Eastern border regions, mainly from Muşaşir (on the Upper Zab) and Ellipi (between Behistun and Hamadan). Such sources as mount Ha-ar-ḥa-a or mount BAR-GÙN-GÙN-NU still remain unidentified. Most favoured sources of Mesopotamian tin supplies are the south-eastern Caspian region and Chorassan. In later periods tin comes from the West, thus Assurnasirpal gets his tin from the Phoenicians. In Neo-Babylonian times the price of tin was still eight times that of copper and in early bilingual texts it is mentioned after silver but before bronze and iron.

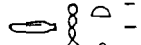

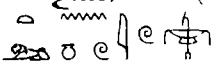
In the *Indus civilisation* bronzes occur containing 4½-13 % of tin though copper is still generally used for tools and weapons in this latter half of the third millenium. The source of this tin must be sought in the western mountain boundary as the tin from Bihar and Orissa is unknown even in classical times in India. Summing up this scanty evidence it would seem that the tin (and bronze) industry developed in the Armenian and Persian highlands around 3000 B.C. or perhaps somewhat earlier. It is possible that we have to look further east and at an earlier period for this discovery but this is a problem more readily discussed when dealing with the data about copper and its alloys.

VI

Some interesting facts can be gleaned from a discussion of the ancient nomenclature of tin. We must then first draw the attention to the great resemblance which lead, tin, antimony and arsenic bear to each other for an observer who has no knowledge of chemistry and has to judge from external characteristics only as had the ancient metallurgist. It is almost certain that arsenic was not known in Antiquity or at least not known as a separate metal but the confusion in ancient (and alas in modern literature too!) of the first three metals and their ores already presents sufficient difficulties. The following table gives some essential data:

	Lead	Tin	Antimony	Arsenic
Colour	Bluish white	Silver-white	Lustrous white	Silvergrey
Specific gravity	11.3	7.3	6.7	5.7
Melting Point °C	327	232	630	814
Boiling Point	1613	2270	1380	615 (sublimates)
Hardness (Moh's scale)	1.5	1.5-1.8	3.0-3.3	3.5
Hardness Brinell	4.2	5.0	30	147
Crystals	cubic	tetragonal	hexagonal	hexagonal
Tensile Strength Kg/mm ²	2.0	3 4	10	-

The first three metals differ slightly in colour and no wonder that PLINY considers them to be lead and speaks of *plumbum nigrum* (lead) and *plumbum album* (tin) and even Agricola has terms like *plumbum nigrum* (lead), *plumbum candidum* (tin) and *plumbum cinereum* (antimony). We find that throughout Antiquity these metals are confused held to be three rather similar types of lead. Taking the figures of the above table we see that there is little difference in colour but a greater one in melting point and mechanical properties. Arranged in decreasing order of brittleness we get the order lead, tin and antimony; for the malleability the order is lead, tin, antimony; for the ductility antimony, tin, lead.

The ancient Egyptians had a definite term for lead  *dhṭy* (Coptic *taḥt*) but a similar term  *dh(y)* occurs thrice in the Papyrus Harris, twice in a list of metals (quantities of 95 lbs and 2130 lbs) immediately after lead. It seems fairly certain that this late word denotes tin. Another instance of its use in the stela of Tanutamon (Period of Tarhaka, AR IV, 929) mentions double doors of electrum with two bolts (*krty*) of *dhṭy*, which suits tin. This suggestion also fits in with the third occurrence of the word in the Papyrus Harris (Pl. 41. 14) in a list of statues of the Nile God made of different materials and metals. The old theory of Dufrené that *kesḥpet* meant tin and that this word was connected with *Kasbek* or *kaspa* still haunts technical literature, but this is wrong since the word *kesḥpet*, more correctly written *hsbd*, means lapis lazuli. It can not be decided from the context whether the *dhṭy ḥd* or "white lead" mentioned in the London Medical Papyrus means tin or lead carbonate, both being used in drugs, etc. In later Coptic documents we find a new term for tin $\Theta\rho\alpha\text{N}$, *tran* (in the Bohairic dialect only, sometimes written  *trn*. SETHE pointed out that this term, also written $\Pi\Theta\rho\alpha\text{N}$, was derived from Britannia. In the Sahidic dialect the word for tin seems to be $\text{BACN}\Theta\text{C}$, which SETHE derives from *bi3.n.pt* (BE-NI-PIET), the old term for iron and especially meteoric iron.

It is clear from the classical texts that both *kassiteros* and *stagnum* may mean alloys with or without tin and also tin itself. The *stagnum* of PLINY is crude lead (Werkblei) (25), but in the fourth century the term *stagnum*, *stannum*, appears to denote tin solely. PRICE did already record this fact and he was the first to connect the word with

the Celtic *stean, sten* (Welsh *ystaen*) from which terms like *stagnò, estano*, etc. were derived. The earliest rendering of *kassiteros* by *stannum* occurs in the IV-Vth century translation of the Periegesis of Dionysios. PLINY identifies the *plumbum album* with the Greek *kassiteros* (N.H. 34. 156). This *kassiteros* has been the subject of a prolonged dispute between different schools of philologists. REINACH believes it to be derived from the Cassiterides, which he holds to be a Celtic word, PISANI (41) wants to connect it with a Celtic root *kas-* meaning "grey-white", but this would mean early connections between Gaul and Greece and Celtic tin coming to Greece in pre-Homeric days! Others look eastwards for the origin of this word. LENORMANT tried to prove that it was a Caucasian word and he compared it with the Georgian *gala*, Ossetic *kala*, Turkish *kalai*, Armenian *klajek*, which was the opinion of SAYCE too. One of his school even tried to connect the word with the name of the town of Qalah (Malaya)! It was believed to have been derived from the town of Kaspatyros on the frontier of Bactria and Persia in the country of HERODOTUS' gold-digging ants. POKORNY and HÜSING (34) have derived it from an Elamite *kassi-ti-ra*, "the land of the Kassites", but even if it were true it does not help us very much as we do not know exactly where the Kassites lived in the third millennium and whether their home was a tin-producing country. Others have tried to connect it with the "Caspian" without proof (HROZNY). As both the Babylonian and Sanskrit related words are late it is probably an original Greek word and Siret may be right to connect it with *taxéros* (fusible). If not, we will probably have to look to Anatolia for the original term.

The related Neo-Babylonian term is *kastira* (SCHRADER, RL, 995), which must be derived from the Greek as there is no Assyrian *kāsa-šatira* or an Accadian *id-kasduru* as BAPST and some others have claimed. The same late date must be assigned to the Sanskrit word *kastīra*, which does not occur in the classical literature. It is probably a loan-word from the Hellenistic traders exporting tin from Egypt to India. The same trade connections are probably responsible for the Arabian word *kasdir* and the Central African *kasdir*, which latter term proves that tin was an object of Arabian trade. The classical Sanskrit word for tin is *trapu*, a later synonym is *piccaṭa*. The terms *śīśaka* and *nāga* which some translate tin really mean lead. The word *trapu* is fairly common in the older classical literature but better distinction between lead and tin is made by later writers such as KAUTILYA, SUSHRATA, CHARAKA, etc. The Sumerian *nagga* (AN-NA)

(Accadian *anâku*) generally denotes tin, but in the Cappadocian letters and some other texts there is no doubt that lead is meant (25). Probably the ancient meaning was both tin and lead which were not yet distinguished while gradually separate terms grew up. Thus lead is usually denoted by the Sumerian *a-bâr* or *agar*₅ (A. GÚG) (Accadian *abâru*), but this term may also mean antimony in some cases. *Abâru* is directly connected with the Hebrew *ôphêrêth* and there is no doubt that this word means lead in the different texts though translated *kassiteros* and *stannum* in the Vulgate. The passage (Num. 31 : 22) also contains the word *bedil* which also occurs in Ezech. 27 : 12 and Isaiah 1 : 25 and which is rendered *kassiteros* in the Septuaginta but *molybdos*, *plumbum* in the Vulgate. If GESENIUS is right to connect it with the root *bdl* meaning "to separate, eliminate", it would seem that "lead" would be a better translation or perhaps the original meaning, as the metal tin is not separated from any other metal during its production, while lead is of course the by-product of silver. On the other hand it may be connected with the Arabian *bedal*, "substitute", which would suit tin, often used as a substitute for silver in inlay-work as we have mentioned. It is clear that the meaning of the two Hebrew words is still vague because there was no proper distinction between lead and tin in those days outside the metallurgical craft. Even in later documents like the Syriac version of the writings of ZOSIMOS "soft metal" or "easily fusible metal" may denote both lead and/or tin. PISANI's suggestion connecting the Irish *crêd* and the Basque *cirraida*, *urraida* for tin with the Sumerian *urudu* (bronze or copper!) must be rejected (47).

It is claimed that the word *aonya* in the Vendidad meant tin, but this word really means "heating device" and the passage where it occurs gives no food for the assertion stated above. The term *arjiz* for tin is a late one occurring in such writings as the Dâmdâd Nask, etc. Unfortunately, therefore, there are no philological proofs of an early knowledge of tin in Persia. Probably here too the early confusion between tin and lead reigned, even in modern Arabic *raşâş* still denotes both tin and lead!

The tin produced by the Romans (we can not judge the earlier tin for the lack of tin bars or slabs!) was very pure, all Cornish ingots analysed contained more than 99.9 % of tin, but this efficiency went hand in hand with considerable loss of tin in the slag during refining. A test for its purity mentioned by PLINY (*N.H.* 34.163): "The papyrus test is used for pale lead; the molten metal should seem to burst the

leaf by its weight rather than by its heat", in reality a melting point test, and this is what he says about its qualities (*N.H.* 34, 158 & 161) "Silver which is abundant in dark lead is absent from pale lead. Dark lead can not be welded together without pale lead, nor pale lead soldered to dark without oil and even two pieces of pale lead can not be united without dark lead Pale lead is naturally dry, while dark lead is pre-eminently moist, and so pale lead if unalloyed is useful for nothing, and silver cannot be soldered with it, since the silver liquifies first (sic!)." The types of solder mentioned here are still the common solders of the present plumber, we now usually recognize three types differing in ratio tin/lead. This ratio is 2/1 for fine solder, 1/1 for common solder and 1/2 for plumber's solder. The Romans never used pure tin for household uses but they used a lead/tin alloy for pewter! This is of course no longer done to avoid lead-poisoning, but the Roman pewter containing 2.5 parts of tin and 1 part of lead, still has its modern equivalent in our 4 to 1 alloy for art objects and in the Middle Ages pewter always contained from 5 to 15 % of tin. Household objects are now usually made of pure tin hardened by the addition of antimony and small percentages of copper and bismuth.

The tinning of metal objects especially of bronze and copper seems to have been invented in Gaul, for PLINY says (*N.H.* 34, 162): "The method of plating copper articles with pale lead (*incoctilia*) was devised in Gaul" and this statement is confirmed by DIOSCORIDES (L. 38). The tinned copper objects found in Egypt were probably imported. Originally this plating was done with *stagnum* (crude lead) and PLINY gives several recipes for counterfeit stagnum (*N.H.* 34. 160) consisting of 2 parts of brass and 1 part of tin, another called *argentarium* (1 tin/1 lead) and also one called *tertiarium* (2 lead/1 tin). It is probable that these alloys were made by simple practical considerations and that their composition was found by trial and error only.

VII

A few pages must needs be devoted to antimony and arsenic here, because these metals (or at least metal-like substances, for chemically speaking they are metalloids!) are so much like tin and lead to the early metallurgist devoid of chemical knowledge, that their use instead of these two metals and the constant confusion between the four of them need not astonish us. In the case of antimony and arsenic the confusion is aggravated by the extra difficulties introduced by prac-

tically all modern authors without a chemical training who insist in calling both metals and ores from which they are prepared by the same name, thus often stating scientific impossibilities! For in the case of both antimony and arsenic it seems extremely doubtful whether their intentional preparation was carried out on a large scale in Antiquity though the ores were known and used.

In the case of antimony we must distinguish the metal (antimony) and the sulphidic ore, stibnite, the ancient *stimmi* or *stibi*, which many authors insist in calling antimony too.

The metallic antimony does occur naturally in granular masses with silver, but this is very rare. Still it is one of the most common elements, though not produced in large quantities, for it has only few important applications such as hard-lead, bearing metals and Britannia-metal. It is mostly produced from compound ores, upwards of fifty minerals contain antimony, but only a few are worked commercially. These are mainly ores containing compounds of antimony and/or sulphur with copper, iron, lead and other metals.

Some of these minerals are auriferous or argentiferous and in that case they are refined to obtain the precious metals, antimony being a by-product. Such an ore is the silver-bearing pyrrargyrite or ruby silver. Other compound ores containing large quantities of antimony are tetrahedrite (*Antimonfahlerz*, *Schwarzerz*, a copper ore), *chalko-stibnite*, *zinckenite*, *hypargite*, etc.

A very common pure antimony-sulphur compound is *stibnite* (antimony glance, *Grauspiessglanzerz*), a brittle mineral with a metallic gloss like galena.

Its decomposition product (*Weisspiessglanzerz*), the oxyde, occurs in surface lodes. At present China produces the bulk of the stibnite used (about 87 %), minor producers being Mexico, France and Algeria. As the metal was produced in a few localities only and the stibnite seems to have had a few cosmetical and pharmaceutical applications only, the mining of stibnite can hardly have been important. Thus there is no evidence of any important stibnite mining in Roman times in Europe, though a high antimony content in the coins of the *Ileuici* and *Sequani* suggests stibnite mining at Markkirch or Giro-magny. Furthermore the Romans understood the extraction of gold from such arsenic ores as *mispickel* and *realgar* (PLINY N.H. 33. 79; 34. 177) and from stibnite as is shown by the high percentage of antimony and arsenic in slags from Malbosc, Porna and Pangaeum and from numerous workings of quartz veins carrying *mispickel* in

Creuze and other provinces in France. Again stibnite was used in desilvering natural gold (24) (25).

It is described by *PLINY* (N.H. 33. 101): "In the same silver-mines is found what we might best describe as petrified foam, white and shining, but not transparent. It is variously called stimmi, stibi, alabastrum and larbasis. There are two varieties: male and female, of which the female is considered the better. The male is coarser, rougher and less dense. Its surface is not shining and it contains more grit. The female, on the other hand, glistens and is easily broken, showing a lengthways cleavage instead of crumbling into small lumps." *DIOSCORIDES* (V. 99) makes the same distinction, which is, in fact, much older as the Papyrus Ebers which mentions stimi speaks of "true and male" stibnite no less than 36 times. Though *PARLY* and *VON NIES* have thought the male and female stibnite to represent the quartz-containing, impure, light and the pure, brittle form, it is more likely that the male represents the granular type of stibnite, the female the acicular form, though there is little difference in density between the two forms. On the other hand *BAILEY* (4) declares that the male stimi is stibnite and the female native antimony, but the latter is very rare and if the identification be correct it can only be cast antimony prepared from stibnite, which resembles the ore in many respects and may have been confused with it by the ancients.

When mapping the antimony ores in the Near East we have limited ourselves to the most important deposits only. In Asia Minor we have to record deposits on Mytilene and Chios. On the mainland there are the deposits of Kordilio, Cinlikaia and Avdin near Smyrna, at Bilecik, Trebzon, Karahissar and Keban Ma'den. The lead ores of the Kura valley in Transcaucasia contain large percentages of stibnite. The deposits in the mountains near Burshanda which are mentioned in the Epic of the King of Battle, Sargon, must be somewhere over the Cilician mountains, but cannot be located exactly. In Persia the present Taht-i-Suleiman in the province of Afshar represents the "mountains of Gizilbunda near the town of Kunika" which was the source of stibnite for the Sumerians and Assyrians (43). Other deposits occur near Teheran, Mt. Demawend, Rey, Asterabad, Isfahan and the Kuh-i-Benan. Those near Isfahan Rey and Mt. Demawend are mentioned by *AVICENNA*, *ABULFEDA*, and *ALQAZWINI*. Several deposits are known to exist in Afghanistan and British India (North-West provinces, Punjab, Baluchistan, Madras, Mysore, Bihar, and Orissa) and

in the Far East in Burma, British North Borneo, Indochina, China (Hunan, Hupeh, Yunnan, Kweichou, Kwangsi) and Japan. In Africa antimony ores are found in Damaraland, Transvaal, South Rhodesia and Algeria. None have been found in Egypt, traces occurring in the well-known copper and lead deposits. The ores from Midian have not been confirmed. Stibnite also occurs in Northern Syria near Alexandretta and Antioch. Many European countries such as Great Britain, France, Portugal, Spain, Switzerland, Bohemia, Yugoslavia, Greece, Germany and Sweden contain deposits.

It would have been easy to produce the metal on a large scale even in early days by oxidizing the sulphidic ore to the oxide and reducing the latter with charcoal at a fairly low temperature to avoid volatilization of the metal. This process was actually known in Antiquity, for we have a long description of it in *PLINY'S Natural History* (33. 103-104): "It is roasted (the *stimmi*) in an oven, after smearing with lumps of cow-dung, then quenched with mother's milk and ground in a mortar after addition of rain water. Next the turbid liquid is transferred to a copper vessel and purified with soda. The precipitate which sinks to the bottom of the mortar is considered to be very rich in lead, and it is rejected. Then the vessel into which the turbid liquid has been transferred is covered with a cloth and left overnight. The supernatant liquid is poured off next day, or removed with a sponge. The solid that subsides is considered to be the best and is dried in the sun with a cloth over it, but not so as to remove all moisture. It is then ground again in a mortar and made up in little tablets. It is a matter of prime importance that the roasting should not be too vigorous, lest the product turn into lead. Some workers use fat instead of cow-dung in the roasting; others strain through a triple cloth the product which has been ground up with water and reject the residue. The filtrate is transferred to another vessel and the deposit collected and used for mixing with plasters and eye-salves."

DIOSCORIDES (V. 99) has a similar description of the roasting of stibnite to obtain the pharmaceutical important white oxide of antimony. It is important that both authors warn not to carry the reaction too far lest the product "turn into lead" and *DIOSCORIDES* calls the heavy precipitate "*faex plumbosissima*". This means that the antimony-metal obtained during the process by part-reduction of the oxide by the cow-dung was held to be lead and therefore rejected. This goes to show that the classical metallurgists did not go further than the

preparation of the oxide, as they had no special use for the metallic antimony. That this preparation would have been easy is shown by their description, indeed, stibnite melts in the flame of a candle!

The metal is lead-like, silverwhite but less susceptible to oxidation by the air so it retains its lustre far longer than lead. It is, however, brittle and easily pulverised. It mixes readily with metals such as copper, iron, lead, silver, gold and tin and usually decreases the malleability and increases the hardness, if the percentage is not too high.

We find many antimony-bronzes among the oldest copper alloys, but these need not always have been intentional. Indeed in most cases the percentage of antimony is so low that we can safely ascribe it to the natural impurities of the copper ore used and not to any addition of antimony ore during the smelting of the copper. Thus some of the oldest Mesopotamian bronzes contain up to 3 % of antimony, it was found in Anau I copper, in old Abyssinian alloys, in Japanese, Indian, Chinese and Gallic bronzes.

There are, however, a few centres in Antiquity where the addition of antimony to copper was standard practice, in this case the percentage may be as high as 15-20 % and objects of pure antimony are found there too. Such a centre is Velem St. Vid in Hungary. VON MISKE thinks that the ore used does only contain lead and arsenic as impurities and that the antimony was added intentionally because tin was lacking in the region. Others believe that the mixed copper-antimony ore was so rich in antimony that the alloy was obtained unintentionally. It was a success, for we find objects from this centre in Silezia, West Prussia and Bavaria. Some of the lake dwelling bronzes containing upto 15 % of antimony may have come from Velem St. Vid. For weapons, however, this alloy was too brittle and tin ore was imported from Bohemia for their manufacture (18). Though PETRIE proposed at a time to ascribe some Egyptian bronzes containing antimony to export from Hungary, there is no proof for any trade-connection at so early a date. The antimony may well have been derived from local copper ores and some of the "antimony" of earlier analyses was later found to be bismuth!

In La Tène times another centre of antimony-bronzes grew up in the Vosges mountains. In the Near East the Caucasus region was another centre of the manufacture of antimony and antimony-alloys. Many antimony objects were found in the graves of Redkinlager on the Aksatfa, a tributary of the Kura river, near Tiflis, including footrings, bracelets, etc. These objects are said to date from the ninth

or tenth century B.C. Others have been found at Koban. Gradually these objects disappear and tin objects take their place. It can be proved that they were made by roasting and reducing stibnite for some of them still contain an appreciable sulphur percentage due to insufficient roasting. Other antimony objects have been found near the copper mines of Khedabek. Most of them are cast, but their use must have been restricted, as they are very brittle. Other objects were beads, amulets, buttons, etc. The Caucasus may have been the source of some of the antimony objects found in Mesopotamia. There is a bowl of the Gudea period and the vase found at Tello and analysed by Berthelot. The metal was also used from time to time in the Assyrian period for Sargon II mentions it among other metal tablets of the foundation deposit of his new bit-hilani at Chorsabad.

Antimony occurs in some Sumerian bronzes, but simply as an impurity of the ore used for the preparation of the copper. Stibnite (*guhlu*) is known in Mesopotamia since the days of Gudea and earlier as an eye-paint, it was probably not produced in Assyria itself but imported. Tiglath Pileser gets a tribute of 1 homer from Malatia and the annals of Tukulti Ninip and Shamši Adad mention that *guhlu* is obtained from the mountains of Gızılbunda near the town of Kinaki in Afshar. The oxide seems to have been used for tinting glass yellow.

In Egypt there are no proofs that the metal antimony was known and used. GARLAND suggested it but he confused antimony and stibnite! The sensational discovery of FINK and KOPP that the ancient Egyptians understood the art of plating copper objects with antimony was disproved by LUCAS, who quite correctly points out that this "antimony-plating" is due to the electrolytic reduction of the copper object, the antimony is simply an impurity of the copper and the so-called plating due to the method of restoration and not a process applied to the original object. The only instance of antimony in Egypt is the find of a few beads in a grave at Lahun of the XXIIth dynasty. PETRIE quite correctly infers that these are imports as antimony ores are not known to occur in Egypt. Several older bronzes contain antimony. The eye-paint used from immemorial times in Egypt is usually held to be stibnite. It is pictured on the Deir el Bahri reliefs (39) as one of the products obtained from Punt and, indeed, the Periplus mentions many centuries later the existence of a stibnite trade from the coast of East Africa to India (1st cy. A.D.), while the Pap. Kenyon mentions stibnite from Coptos, Italy, Calchedon and

"Occidental". Still modern analysis has proved that the ancient Egyptians did not distinguish well galena and stibnite and the term *msdm(t)* usually translated stibnite applies to both. Out of 34 eye-paints analysed no less than 21 were pure galena, the rest mainly mixtures and a few consisted of pure stibnite, being of New Kingdom or later date! In the same period antimony begins to appear in Egyptian glazes and somewhat later in enamels too.

Stibnite is also mentioned in the Bible. The Vulgate renders both the kahâl of Ezech 23 : 40 and the pûkh of II. Ki. 9 : 30 and Jerem. 4 : 30 as stibium. Early finds of *koḥl* pencils at Tell el Hesy and Gezer open a long row of finds of later date. In these cases no analyses are available but probably both galena and stibnite were used indiscriminately.




Stimmi or stibi was used not only as a "plathyophtalmon" but also in ancient medicine according to the testimony of the Papyrus Ebers, CELSUS, PLINY, DIOSCORIDES and many others. The *stibi tetragonon* of HIPPOCRATES (209.14; 211.2) were probably small cubes of ground stibnite mixed with fat or talcum.

In the Middle Ages and in Iatrochemistry stibnite was used in pharmaceutical recipes and as an emetic.

The nomenclature has mainly suffered from the modern confusion of antimony and stibnite, for it is quite clear that we have only one word which probably denotes the metal antimony, the others all describe the sulphide stibnite!

CAMPBELL THOMPSON has identified LIŠ-A-BĀR (*abaru*) with antimony. Though *abaru* generally means lead, it may in several cases, such as the foundation tablet of Sargon II at Chorsabad, mean antimony as lead is then mentioned separately. The old translation *abaru*: magnesite is now of course untenable, it does not fit the many passages where this word occurs. THUREAU DANGIN has identified the NE-KÙ of an alloy with antimony (RAss. 6, 1906, 142) but this remains uncertain. HAUPT has suggested the *dagassu* of the mountain of Buršhahanda to be antimony (OLZ, XVI, 492), but he probably means to say "stibnite"! The usual word for stibnite is SIM-BI-ZI-DA (*guhlu*), an equivalent of the Hebrew *kahâl* and the Arabic *koḥl* (from *ḵhl*, to stain), another synonym is *šadidu*, the Syriac *šadîdâ*, a more general term for eye-paint which is also and more frequently used for chrysocolla.

Though formerly translated "antimony" the Egyptian *msd.t* is most certainly not stibnite or antimony, for the correct term is


 , OR   *msdm(t)*, the Coptic *stêm*, Greek *stimmi*, Latin *stibium*. It is usually translated antimony, but this should be stibnite, though we have seen that this ore was confused with galena and so the term may denote both and should be more correctly translated "eye-paint". The metal antimony could of course not be used as such for it is far too gritty and the sulphide is clearly meant. CRUM gives a Coptic term BACOYⲒ (*Coptic Dict.*, 44. b)

The classical authors have added to the confusion by using *stimmi* indiscriminately to denote both the metal and the ore. This is clear when we read that DEMOCRITOS calls *stimmi* "our lead", that OLYMPIODORUS makes "lead" from galena, lead oxide and *stimmi*. No proper distinction is made by the early alchemists between lead and antimony; the source of the "Great Work" is said to be "lead" obtained from *stimmi*, galena or cadmeia! But MARIA calls it *molybdos emeteros* as distinct from *molybdos melas*, the true lead.

Our present "antimony" is of course not derived from "anti-moine", a story still appearing in our textbooks like that of the fake discoverer BASILIUS VALENTINUS. The "Lapidary of Aristotle" calls *stimmi* or galena *ihmid*, *itmad*, *azmat*, and RUSKA thinks that "antimony" is derived from *al-ihmid*. More probably DIERGART is right in deriving it from *anthémonion*, a term occurring already in the writings of CONSTANTINUS AFRICANUS and VINCENT OF BEAUVAIS, while a treatise of jewelry of the XVth century mentions *antémonium*.

VIII

It is exceedingly doubtful whether the metal arsenic was ever produced intentionally in Antiquity. The earliest writer using arsenic compounds who devines that they might contain a metal is ALBERTUS MAGNUS. It has no specific uses and even at the present time the only important application is 0.3 % of arsenic in lead-shot. Arsenic (Scherbenkobalt, gediegener Fliegenstein) occurs in the native state as a dull-grey, brittle mass with a tin-white fracture often associated with native antimony or silver. This fairly rare mineral may be the IM-ŠIM-TĀK-SAHAR, ²AŠ-GE₄-GE₄ (*ašgiku*) of Mesopotamian texts. Though some arsenic ores occur in a fairly pure state, they are usually found as admixtures or mixed ores with sulphides of copper iron and lead, such as cobaltite, arsenopyrite, proustite, energite, mispickel, etc. Therefore the metals refined from such ores tend to have a small percentage of arsenic if the refining is not carried out in a special way to avoid this unwanted impurity.

One of the most common purer arsenic ores is *realgar*, which got its name only in late Arabian literature. It was formerly called *sandaraché* or *sandyx* (FESTUS) which name is probably connected with the root sand- or sard- meaning red, which we also find in the name of the Hittite god of agriculture Sandan, Santas. In ancient times this beautiful orange red or deep red mineral was found in Lycia (STRABO 11.14.9.c. 529) (PHILOSTR. APOLL. 3. 14), in Paphlagonia (STRABO 12.3.40. c. 562) and Carmania (STRABO 15.2.14. c. 726). Mines on Topazus island in the Red Sea are mentioned by PLINY (*N.H.* 35.39) and ISIDORE (19.17.11). It also occurs in Kurdistan near the Taht-i-Suleiman and it was known to ARISTOTLE and THEOPHRASTUS. CAMPBELL THOMPSON identifies it with šIM-GUŠKIN (*leru, šīpu*).

A second pure arsenic ore was orpiment, another sulphur compound of a bright yellow colour called *arsenikon* in ancient times. This term is probably due to metathesis of the Persian *az-zarnīkh*, Old Persian *zaranya*, Armenian *zariē*, Syriac *zarnīkī* and Hebrew *zarnīq* meaning "golden". The ancients found it in Carmania, Mysia, Pontus, Cappadocia, Shiraz, on the Taht-i-Suleiman in Kurdistan and near the river Hypanis (Bug) in the Ukraine (VITRUV. 7.7.). This is probably the šIM-BI-SIG₇-SIG₇ (*lêru, šīpu damatu*) of ancient Mesopotamian texts. Its relation to arsenic was already known to THEOPHRASTUS (Lap. 89).

These two minerals reached a certain fame as pigments though their poisonous properties were well recognized (STRABO 12.3.40) (ARISTOTLE Hist. Anim. 8.24) (AETIUS ISTRICUS 4.45). Sandarache was often mistaken for red lead (VITRUV. 7.7) (ISIDORE 7.9. 11) while arsenikon was also sometimes called *arrhenikon* (VITRUV 7.7) (CELSUS 5.5) (DIOSCORIDES 5.121).

This is what PLINY has to say about these arsenic compounds (*N.H.* 33.79): "There is moreover, a recipe to make gold from orpiment which occurs near the surface of the earth in Syria, and is dug up by painters, its hue is similar to that of gold, but it is brittle like the "mirror stone." (34.177-178) "Sandarache occurs both in gold and silver mines and its excellence is proportional to the depth of its red colour, its sulphurous smell and its brittleness. Arrhenicum is another derivative of the same substance. The best kind is coloured a fine shade of gold, specimens which are paler or which resemble sandarache are thought inferior. It resembles sandarach in its properties but its actions are less severe. To make it more active it is roasted in a new earthenware vessel until it changes colour." Similar reports on the roasting of orpiment are told by DIOSCORIDES and OLYMPIODORUS,

the white product obtained being "white arsenic", the oxide, which is very poisonous. It occurs in nature as the decomposition product of the two former minerals (Arsenolith, Arsenikblüte), probably the ancient $\text{MUH-AŠ-GE}_4\text{-GE}_4$.

These minerals are also found in the Caucasus (Topprakaleh, Tushpa) and in Persia (Mt. Demawend) but their application in Antiquity was mainly pharmaceutical and medicinal, though they have been used as poisons and pigments too.

The metal could have been made by roasting and reduction of the three last-mentioned minerals taking great care to avoid volatilisation of the metal. It was done by the first-century Coptic alchemists, but we have no proof of any earlier preparation. Of course the occurrence of arsenic ores as admixtures to copper and iron ores was the cause of small percentages of arsenic in ancient copper and bronze. Its influence on the properties of copper have been greatly overrated and several authors have concluded that artificial arsenic-copper alloys were made in Antiquity on purpose. Though upto 0.5 % of arsenic increases the toughness of copper; the brittleness increases rapidly as soon as this percentage reaches 1 %. As it increases the casting properties of copper only in quantities of more than 1.5 % the ancient metallurgists would have overshoot the mark by making a copper well suited for casting but very brittle and hard too.

In the Caucasus copper objects contain upto 12 % of arsenic, but they are mainly rings, etc. but not tools. Two small objects, a ring and a needle of pure arsenic are reported from Kumbulte, in this case the native metal was probably mistaken for lead. In Hungary early copper and antimony bronzes contain upto 4 % of arsenic due to the ore worked. Some Indus bronzes have 3-4½ %, while even the copper of Anau sometimes contains some arsenic. In early Mesopotamian bronzes the percentages seldom rise above 0.6 %, as we might expect from impurities of normal ores.

Intentional arsenic-copper alloys have been claimed for Egypt, but the early copper which may contain upto 4 % of arsenic was never found to be annealed and it was probably a natural alloy too. As we have already stated the hardening properties of arsenic are of a low order and it is also found in objects where softness is essential. There is no arsenic in either ore or slag from the Sinai but some copper ores of the Western desert contain it.

WITTER has proved that the natural copper-arsenic alloys have been recognised and used as a kind of "better copper" very early in Middle

Europe. In most cases the copper was further hardened by hammering at low temperatures.

Arsenic played a large part in alchemical theories from the first centuries A.D. onwards. DEMOCRITOS calls orpiment "yellow sand" and realgar "red sand", and MARIA and KLEOPATRA mention them. ZOSIMOS obtained arsenic metal and called it a second mercury which burns up to the "soul of the colour", the white oxide.

There are still many dark points in the history of these three metals and especially the confusion of tin, lead and antimony in the few ancient texts that deal directly with them makes it difficult to present more than an outline of their history. Much will probably be gained by a closer study of the history of bronze from this point of view:

"But if thou wilt enter this Campe of Philosophy
with thee take Tyme to guide thee in thy Way"

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CHAPTER NINE

ZINC AND BRASS IN ANTIQUITY

I pray *God* that this turn not me to Charge
For I dread sore my penn doeth too large
THOMAS NORTON, *Ordinall of alchimy*

The history of brass and zinc proves once more that ignorance of the metallic component of an ore did not prevent the ancients to use this ore when manufacturing an alloy. It is well known that the use of bronze preceded the production of tin by many centuries, but this example is still more striking. In Europe zinc was certainly not known until early in the sixteenth century though the metal was produced earlier in the East.

Though neither AGRICOLA nor BIRINGUCCIO know zinc, LIBAVIUS received from a friend a metal from India, which he considers to be "a kind of tin", but the connection of this metal with the common zinc-ore calamine was not recognized by him. PARACELUS remarks in his *De mineralibus* (edit. TOXITES 1570, p. 450) that calamine, then usually called "Blende" or "Glanz", was called "Zincke in Carintha" and he goes on to say that "Das Ertz Zincken ist ein gar frembdes Metall, der ein Metall ist und auch keins, ein Bastart von Kupfer" thus calling both metal and ore "Zincke". In another of his books he states that zinc was the "spirit" of tin (18). This term "Zincke" or "Zacke" was given to the ore because of the sharp needlelike form of the local calamine; it is not derived from a Persian word as some authors state, it clung afterwards to the metal, when its manufacture from the ore was learnt as metallurgical technique advanced. In PARACELUS' time brass was still made by smelting calamine with charcoal and copper and though zinc was afterwards known to be the metal of calamine this knowledge spread only slowly. Only in 1718 STAHL refuted his former theory that calamine was absorbed by the copper as an earth and stated clearly that brass was an alloy of zinc and copper. Even BOYLE did not yet recognize the connection of metal and ore and he calls zinc 'spelter' to distinguish it from "pewter" by which he meant tin or tin-lead alloys. For brass was very long considered to be a special metal, not an alloy but a "mock gold" (Konterfeh, Counterfei). Thus ALBERTUS MAGNUS comments on the calamine from Goslar, which turns copper into gold, but when heated leaves only ashes as the metal evaporates (*De mineralibus*). This failure to

perceive the connection between calamine and its metal zinc was not only due to the lack of analytical methods, but also to the peculiar properties of zinc which made it impossible for early metallurgists to prepare this metal on a large scale for many centuries even after its discovery. As brass seems to have been discovered early in the first millennium B.C. there is a difference of more than 2500 years between the manufacture of the copper-zinc alloy, brass, and its metallic constituent, zinc. As the preparation of zinc is intimately connected with the evolution of distillation, which started in the first century A.D. only, we may safely conclude that zinc was unknown to the ancients. But we will still have to trace the history of brass.

I

To understand the history of brass we must look into the *geology of zinc*. Zinc does not occur in the native, metallic state but its compounds are widely distributed. Zinc ores are more particularly associated with the ores of lead, silver, copper, antimony and arsenic, often in the form of complex ores. This fact should be remembered when looking at the map of the zinc deposits where only some of the most important deposits in the history of brass have been indicated, but further localities are to be found on the map of the lead deposits.

At present one of the most important zinc ores is sphalerite or zinc blende (black jack, Zinckblende), a zinc sulphide, forming reddish-brown to black, transparent to translucent, heavy masses of complex crystals. This ore not occurring on the earth's surface was probably treated only when its nature was recognized a few centuries ago.

The following two ores were very important to the early metallurgist as they occur in the upper layers of the earth. The true *calamine* (galmei, smithsonite) is a carbonate of zinc which forms heavy crusts of crystals, usually coloured green, blue, yellow, gray or brown by impurities.

A second ore sometimes called electric calamine is a silicate of zinc, *hemimorphite*, forms crusts or masses of glittering crystals or needles.

As these ores were always confused in Antiquity and even modern authors do not always distinguish them clearly, we shall use the term calamine for both of them, as correct distinction in ancient texts is neither feasible nor necessary for our subject. Indeed, the ancients did not only use one word for these two ores, but they used the same term for the white zinc oxide formed in different guises and forms when treating copper, lead or iron ores, thus making it generally impossible

to apply the correct term smithsonite, hemimorphite or zinc oxide. Thus the Greeks use the word *cadmeia* for both the natural and the artificial products, the Arabs use the term *tūtiyâ* (the medieval *tutia* or *totia*) indiscriminately, but if the texts permit us we shall use the proper term zinc oxide for the artificial product. The natural product is often associated with ores of lead, silver, iron and copper and in that case the artificial product, zinc oxyde, is obtained during the treatment of these ores as a by-product, but the zinc ores are also frequently contaminated by large quantities of clay, oxides of iron or calcite and in that case they have an earthy appearance. This latter form was recognized in Antiquity as a special "earth", which had the property when smelted with copper to give it the colour of gold. In the case of the mixed ores the ancients probably failed to perceive the zinc ore and only knew that the white zinc oxide was formed when smelting some specific silver, copper or iron ore. At present calamine deposits are practically exhausted and the metal is obtained from more complex ores. The zinc deposits are found in America, England, Germany (Rhineland, Westphalia and Harz; Silesia) Italy (Sardinia and Tuscany), Spain, Sweden and Norway, France, Belgium (Vielle Montagne, Moresnet), Carinthia, Styria and Tirol; outside Europe they occur in India, China (Hunan), Japan, Indochina, Altai Mts., Algeria, Tunisia, Nigeria, Rhodesia and Transvaal, but few of these had any importance in Antiquity. In Egypt there are no zinc ore deposits of economic value though calamine is found together with the lead ores at Gebel Rosas and a mixed sulphidic copper and zinc ore is found in the deeper strata at Gebel Abu Hamamid.

The copper ores of Georgia and Caucasia very often bear appreciable quantities of zinc ores. Pontus has several important zinc deposits, they are also found in the Murad valley near Lake Van and in the Qara Dagh, north-east of Tabriz. Southern Iran is particularly rich in zinc ores, the main deposits are situated between Isfahan and Anarek, in the Kuh i-Benan, north of Yezd, and north-east of Kerman, where MARCO POLO saw the important *tūtiyâ* factories at Cobi-nam (the present Shah Dad) which exported their product to India. Many Persian authors mention these deposits apart from those in India and Sind, and even BONTIUS still knows that there were large quantities of *tutia* in Kerman, though in his time the centre of the brass manufacture was round Isfahan. Pseudo-Aristotle mentions quarries in Sind and India too. The zincbearing copper ore of Cyprus is mentioned by PLINY (*Nat. Hist.* 34, 100), STRABO (III, 4.15, c. 163)

and GALEN (*De simpl. med.* IX, 9, 11). The galena of Laurion has an appreciable zinc content, the old slags show beautiful crystals of smithsonite formed by reaction with saline waters, and the treatment of the galena must have yielded zinc oxide as a by-product. Further deposits of cadmea were known to PLINY, especially those in Campania (which however did not exist and must represent a confusion of the cadmea deposits with the Campanian brass industry) and in the country of the Bergomates (*Nat. Hist.* 34, 2). In the same line he mentions that "a further discovery in the province of Germania is recently reported". This alludes to the calamine deposits of Gessenich near Aachen (8). Arabian authors often allude to the zinc oxyde from Spanish and Sardinian copper ore and these sources may have contributed to the cadmea production of the Imperial Era.

II

The calamine can be reduced with charcoal to produce the metal zinc, but easy as this reaction may seem a peculiarity of the metal forces the metallurgist to use a special apparatus for this reduction. Zinc melts at the fairly low temperature of 419° C and molten zinc boils at 918° C, that is below the reduction temperature of its ore calamine. Therefore, when reducing calamine the zinc formed will immediately distill and condense against the roof of the furnace as solid zinc crystals. This sublimation is, however, only possible if there is no air present in the furnace, for if there is, the gaseous zinc will immediately be oxidized and form zinc oxide, which then in its turn will condense on the upper part of the furnace. This is the pompholyx of DIOSCORIDES (V. 85) and the *lana philosophica* of the later alchemists, a white woolly mass of small crystals, part of the zinc oxide being retained in the slag to form the *spodos* of DIOSCORIDES (V. 85), an impure zinc oxide, which looks like pumice-stone. As long as the ancients were only preparing this zinc oxyde or cadmeia, they were content to collect the pompholyx and the spodos, but of course they never succeeded in producing zinc in their open furnaces usually working with a plentiful blast of air. Only when furnaces were constructed in the form of retorts connected with a receiving vessel and well shut off from the air, the zinc could be produced by simple reduction of the calamine with charcoal. This is why the production of zinc is intimately connected with the evolution of distillation and why the proper apparatus was only developed in the course of the 18th century. Therefore zinc could not have been produced in Antiquity

on a commercial scale and if ever obtained it must have been accidentally.

There is, however, no evidence of metallic zinc in Antiquity. DAVIES (8) thought that zinc was known in Italy in the Iron Age, but the examples which he quoted are very doubtful. The date of the zinc(?) filling of a silver bracelet from the necropolis of Cameiros (RHODES) is uncertain, the Dacian finds are too vaguely described and it is doubtful whether the Roman cup from Laktaši (KELLNER, *Wiss Mitt. aus Bosnien und Herzogovina*, I, 1893, 254) is really made of zinc!

Brass was, however, certainly produced from the classical period onwards. It has been claimed that some mixed zinc-copper ores contained sufficient zinc to produce brass on smelting (KIRCHER, *Mundus subterraneus*, 1665, II, 218) and this statement has often been repeated. To produce brass from mixed ores might be possible in modern metallurgy, but it is doubtful whether this delicate process could have been executed in Antiquity.

It may be that some Spanish mixed ores would give brass on smelting (8) but VON LIPPMANN rightly contended against SEBELIEN and WITTER (33) that the zinc content of the large majority of such ores is far too small and that nowhere large deposits of ores exist which could have given brass on smelting. Indeed the manufacture of brass must have been a deliberate process after a fortuitous discovery in the past. We must be misled by the accidental zinc content of ancient copper or bronze objects, because many copper ores contain small percentages of zinc ranging from several hundreds of a percent up to 2 % and such small percentages in the resultant copper do not make brass. Thus ancient Egyptian copper objects from Naqada and Ballas contain up to 1.5 % of zinc, bronzes from the Late Bronze Age from Gandža, Karabağ, Goliat, and Koban in the Caucasus up to 2 %, an ancient copper bar from Crete 0.63 %, a needle from Thermi 0.29 %, copper objects from Portugal up to 3 %; but we have to wait until the Graeco-Roman period to find brass spreading all over the ancient world, except for a few exceptions which we will discuss later on. Then only brass occurs in the fringes of the civilized world, then only we find two Romano-British needles with about 14 % of zinc (6) and a crucible containing copper with 15.5 % of zinc (MOSS, *Proc. R. Irish Acad.* 37, 1927, 175). Though PETRIE claims that zincblende was used by the prehistoric Egyptians for beads (*Prehistoric Egypt*, 1920, p. 43) this identification must be regarded as very doubt-

ful, and it would, of course, not infer the knowledge of brass at such an early date. But we need not speculate as to the manufacture of brass in Antiquity for all our texts agree on this point and state that brass was always made from calamine and copper (*Festus* III, 36). Either the "earthy" natural calamine or the artificially prepared zinc oxyde or *cadmeia* (and all its varieties) were used. Even as late an author as ISIDORE had no idea of the zinc content of the calamine and thought that it was simply a drug for purifying copper (*Etym.* XVI, 20, 3). This method of preparing brass remained the only practical one until methods were devised to distill zinc from its ores. The correct term for this process would be the cementation of copper with zinc.

If calamine or zinc ore is finely ground and mixed with powdered charcoal and copper embedded in this mixture in a furnace or crucible, the zinc formed on heating will alloy with the copper giving it the golden yellow colour characteristic of a low zinc brass. It is not even necessary to heat the mixture above the melting point of the copper, but at temperatures of 800° C the zinc will slowly diffuse into the copper to form brass. This is the method mentioned by BIRINGUCCIO early in the sixteenth century. He says that "Copper is coloured yellow by calamine and then often resembles gold. There is also an earthy mineral found in Italy in a mountain between Como and Milan and near Fosini in the province of Siena, which also colours copper exactly like the calamine from the German leadmines. This is an heavy, earthy ore of a yellow (zinc ore mixed with clay!)."

But the process is much older and therefore the frequent statement that it was discovered by ERASMUS EBNER in Nürnberg around 1509 is untrue. For in the eleventh century THEOPHILUS describes exactly the same procedure when he indicates how to prepare brass in crucibles suitable for casting (III, 64-65) (31). It was also known to AVICENNA and it was the standard procedure for brass production in that important centre Persia, whence its knowledge spread to China and India. Probably its secret was more or less forgotten in the later Middle Ages when brass was mainly imported from the East and the 'discovery' by EBNER may simply mean a rediscovery, in a period when metallurgy received a new impetus from the Renaissance scientists. Possibly EBNER was the first to make the metal zinc in Europe, though its industrial manufacture did not start until several centuries later.

This cementation-process is also mentioned by 'GEBER' in his *Summa perfectionis* and in a work attributed to ZOSIMOS we read the

same way of treating Cyprian copper with *tutia* (zinc oxide). It is the standard method of brass manufacture in the Roman Imperial Era. PLINY, for instance, says: "Brass (here *aes* is clearly brass!) is also prepared from a coppery mineral called *cadmea*, the most well-known sources of which are across the sea, although it used to be found in Campania (sic!) and is still mined in the territory of the Bergomates" and "Livian copper has the greatest power of alloying with *cadmea*" (*Nat. Hist.* 34, 2 & 4) and THEOPHRASTUS describes the earthy calamine thus: "The strangest kind of earth is that which is mixed with copper, for apart from possessing the faculty of mixing and melting it strikes one by its remarkable lustre" (*Lapid.* cap. 49). But the process is older than that and its discovery should be sought in Pontus in the beginning of the first millennium B.C.

We have already pointed out that earlier bronzes may contain some zinc, but this is generally due to contaminations of the copper ore used as in the case of the early Mesopotamian bronzes. Neither are zinc or brass found in *Egypt* before Roman times, the first true brass was found at Karanog (WOOLLEY, I, 62, 67). There is no term for zinc in Egyptian, and probably the brasses of the Roman period were introduced in a manufactured state. It was reexported in the form of ornaments and vessels to the Abyssinian kingdom of Aksum where it meant an important medium of exchange (*Periplus* cap. CCLXXXII-CCLXXXVI) in the market of Adulis. This statement is confirmed by the many brass finger- and earrings found in late Nubian graves. Nor did brass or zinc come to Egypt from Africa for the negroes never or seldom mine zinc or lead even now (7). All the brass found in Africa must be ascribed to European or Arab trade, which began very early, the same term *nabas* being used for copper, bronze and brass. In the Niger and Guinea regions it was probably introduced by the Arabs and Moors and European coast-trade and it was brought to the Central Sudan by the Muslim invasion. KOSMAS INDIKOPLEUSTES states that even in the seventh century A.D. the natives of Upper Abyssinia valued brass more than silver! We must therefore look to the north for the discovery of brass. Palestinian bronzes sometimes have a slight zinc content which is more marked at Gezer but this can be explained by the impurities of the local copper ores. An exception must be made for the true brass objects from Gezer of the Semitic III period (1400-1000 B.C.) which contain as much as 23.4 % of zinc (MACALISTER, *Gezer*, 1912, II, p. 265). These isolated examples must be due either to the accidental working

of a special ore or to imports from the north, as brass remains a rarity until Roman times, when Josephus could tell that the Outer Gates of the Temple were made of brass.

Cyprus was an important centre of brass manufacture in the Roman period and we have DIOSCORIDES' description of a brass-furnace (two-storied) from that island (V, 85), but all the information dates from this period and there is no earlier text or find of brass objects.

In Iran brass came into use in the Achaemenian period. Darius is said to have possessed an 'Indian' cup which looked like gold but had a disagreeable smell, which points to brass (PSEUDO-ARIST., *De mirab. ausc.* cap 49). As zinc-ores were discovered in this country a brass industry grew up here in later times, but this cannot be the country of origin as is proved by the analyses of early bronzes from these regions in which zinc appears only as a minor impurity. Nor is brass common in Mesopotamia and the earliest reference is Sargon II's Khorsabad inscriptions which often mention that he "covered the door-leaves of wood with a sheating of shining bronze" which "shining or white bronze" (*erê pišû*) came from Mušasir, from the northern highlands. If this 'white bronze' is really brass, and this is fairly probable, we have here the earliest reference to this alloy in the eighth century B.C.

We have a most interesting text in PSEUDO-ARISTOTLE (*De mirab. ausc.* cap. 62) referring to the discovery of brass: "They say that the bronze of the Mossynoeci excels because of its gloss and its extraordinary whiteness. They do not add tin but a special kind of earth, that is smelted with the copper. They say that the inventor did not disclose his secret to anyone, therefore the old bronzes of this region are remarkable for their excellent qualities and the later ones do not show them." This clearly refers to the cementation of copper with 'earthy' calamine, which therefore was the original process. We are inclined on account of the evidence mentioned above to date this discovery in the beginning of the first millennium B.C., somewhat earlier than PRZEWORSKI suggested (27). The Mossynoeci were a tribe living in the region south of Trebizond (16) in Pontus where zinc ores abound. STRABO mentions them under their late name of Heptakometai (XII. 19, c. 549), they were possibly of Thracian-Phrygian stock and lived in the many-storied mountain dwellings still used by Ossetic tribes, but not in pile-dwellings as sometimes supposed. As a mountain tribe they were undoubtedly engaged in metallurgy as many other tribes in Pontus who brought fame to this region, where so many metallurgical problems were solved.

Can we identify these Mossynoeci with the *Muški*, the redoubtable enemies of the Assyrians in the early half of the millennium B.C.? These *Muški*, *Moschi*, or *Meshech* appear in power after the fall of the Hittite Empire around 1200 B.C. Though LEHMANN-HAUPT considers them aborigines of Asia Minor, SIDNEY SMITH and many others agree that they were immigrants of Thraco-Phrygian stock and identical with the Phrygians, possibly speaking an Indo-Germanic language (GOETZE) and invaders from the Balcan regions. About 1200 they have occupied, together with the *Kaşki* the region south of the bend of the Halys. Growing in power, they do not only reign from the Sangarius up to the mountains behind Cilicia, but in the reign of Tiglath Pileser (about 1170 or 1160) they overrun Alzi and Purukuzi, which were within Assyrian dominion and form a state with the Tibareni in the eastern part of the Anti-Taurus range, which the Assyrian forces reach in a campaign from N. E. Cilicia! This *Muški* state in central and eastern Cilicia probable had Tyana as its capital and the town of Mazaca reminds us of their dominion. Tukulti Ninurta II raids them from Nisibin in 885, and they bring Ašur-našir-pal tribute including vessels of copper (884/3). They are probably identical with the *Meshech* (Ezek. 27 : 13) who "traded the persons of men and vessels of brass". Allied with tribes of the north Mita (*Midas?*) of the *Muški* is the most formidable assailant of Sargon II who only partly subdues them in several campaigns (715-709). In the tenth century a body of *Muški* is still settled on the foothills near the source of the Tigris, but their state seems to have been destroyed by the Cimmerian invasion which drove part of them in isolated positions, for instance in Pontus, where the *Moschi* and *Tibareni* are included in the XIXth satrapy of Darius. Other parts of the tribe were subjects of the Vannic kingdom (700). HERODOTUS mentions both *Mossynoeci* and *Moschi* in Pontus (III, 94), probably as parts of the original tribe, they are again mentioned together in the army of Xerxes (VII, 78). Though some of XENOPHON's information (*Anabasis* IV, 8, 3; V, 4, 12 & 13) must be doubted it is important that he mentions that they conquered some iron-working *Chalybes* to act as their blacksmiths. This seems to prove that the *Moschi* themselves were no metallurgists but learnt the craft from the aborigines!

From this centre the manufacture of brass spread west and east but the method was gradually improved. Instead of the primitive use of the early *calamine* it was found that this should be refined

separately by heating it with charcoal. It was also soon noticed that a similar material was obtained when smelting certain copper, lead or silver ores. Of course it was not known that the original material was the natural calamine but that this new artificial product was zinc oxyde, produced by heating zinc ores or as a by-product of copper and silver-smelting. Indeed both products were generally *cadmeia* or *cadmea* and most classical authors do not distinguish the natural from the artificial product. We have seen that the natural cadmea or calamine was found in Cyprus (PLINY and GALEN) and that PLINY also mentioned deposits in Campania, Bergomum and Germania. But GALEN knew that a similar, artificial cadmea came from the silver mines and DIOSCORIDES has a long passage on both types of cadmea (V, 84-86). He mentions natural calamine from Macedonia, Thrace, and Spain which he considers of inferior quality. The best quality is that produced when smelting copper ores, especially those from Cyprus. When heating them the zinc oxyde sublimates against the roof of the furnace and can be collected after cooling down. The bright, white kind is pure zinc oxyde, which DIOSCORIDES calls *pompholyx*, while the kind more or less contaminated, with soot and dust in the lower regions of the furnace is called *spodos*. Apart from this general classification of pure and impure, he mentions several terms indicating slight varieties of zinc oxyde coloured by impurities or condensed in peculiar form, such as *botryites*, *onychitis*, *placodes*, *zonitis*, *ostracitis*, etc., while PLINY also mentions the kind called *capnitis*.

This zinc oxyde condensed against the furnace-roof is called 'Ofenbruch' by German metallurgists and AGRICOLA remarked that "when smelting the siliceous lead-ores of Goslar a kind of white liquid flows from the furnace, which is noxious to silver because it burns this metal. Therefore this liquid is drawn off after removing the supernatant slags. The walls of the furnace exude a similar liquid", but he does not seem to recognize this zinc oxide as the well known *tutia*. This *tutia* is described in the widespread medieval treatise on alchemy called *Summa perfectionis* wrongly ascribed to 'GEBER' and there purification by sublimation from the crude product of the furnaces is recommended (cap. 48). BIRINGUCCIO (20), however, knew it quite well and so did the classical authors, for DIOSCORIDES remarks that the best qualities of *pompholyx* and *spodos* are obtained from the Cyprian copper ores and that the degree of whiteness is an indication of the heat of the furnace and the purity. He recommends

it for diseases of the eyes and ascribes to it all the healing powers of similar lead-compounds. For this purpose it is further refined with wine etc. PLINY makes similar remarks and says that the *cadmea* derived from silver ores is inferior to that from copper ores. He also advises refining by heating the crude product with charcoal (*Nat. Hist.* 34, 100). The reason why the lead furnaces of Laurion were rather high may be found in the observation that these ores contain zinc compounds, which could be won in the upper part of the furnace as fairly pure zinc oxide and used for brass manufacture. *Cadmeia* thus means both the natural zinc ore and the artificial product and though the only method of brass manufacture consisted in cementation of copper with zinc compounds there was some evolution in this process. The first stage was cementation with the crude natural product calamine, the later stage worked with separately refined zinc oxide which was then used to obtain a pure brass. This refinement may be a discovery of the period. It was then used all over the world for many centuries later MARCO POLO sees it in Persia. This is what he tells us about the tutia manufacture of Cobinam near Kerman: "Much antimony (zinc!) is found in the country, and they procure tutty which makes an excellent collyrium, together with spodium, by the following process. They take the crude ore from a vein that is known to yield such as is fit for the purpose, and put it in a heated furnace. Over the furnace they place an iron grating formed of small bars set close together. The smoke or vapour ascending from the furnace in burning attaches itself to the bars and as it cools becomes hard. This is the tutty; whilst the gross and heavy part, which does not ascend, but remains as a cinder in the furnace, becomes the spodium" (I, 20).

The spread of brass manufacture to the west was slow. In Greece neither HOMER nor HERODOTUS know anything of brass, though texts are often wrongly translated and would seem to prove the knowledge of brass. We will revert to this point when discussing the nomenclature of zinc. VON BIBRA (3), whose analyses DESCH has recently rightly showed into the limelight again in the first report of the Sumerian Copper Committee (1928), gives a wealth of material which goes to prove that brass was quite exceptional in Greece until the Augustean Age, if we use the word brass in the true sense (30-38 % of zinc sometimes up to 50 %), and do not give it to any alloy containing only a few percents of zinc.

In Rome some Republican coins are known to contain up to 4 %

of zinc but the true brass coinage was issued in the Augustean Age. The earliest brass coins contain about 17.3 % of zinc, but the percentage gradually grows. Still brass must have been comparatively expensive for the price given during the reign of Diocletianus is still 6 to 8 times that of copper. Manufacture of brass on a large scale began in the west in the first century B.C. and gradually spread. The early Imperial coinage in Greece, Egypt and Asia is always made of alloys of copper with tin or lead, it never contains zinc until much later. It is claimed that this brass industry exploited the ores of Etruria and ACHIARDI and GRASSINI (15) may be right though Etruscan exploitation seems very doubtful in view of the rarity of brass among the early archaeological finds, though the exploitation of local lead ores may have led to the discovery of the zinc ores. Another important centre of brass production was the province of Germania, where the deposits of Gressenich in the Stollberg district near Aachen were discovered between 74 and 77 A.D. in the neighbourhood of galena deposits. This centre flourished notably between 150 and 300 A.D. to suffer a decline in the third and fourth century but to be rediscovered in the fifth as brass objects in Aachen prove and to become prominent again in the eleventh century together with the deposits in the Meusevalley.

The production of *cadmea* as Ofenbruch from the Laurion ore may also date from the later Graeco-Roman period. It is mentioned by GALEN (*De simpl. med.* IX, 3, 25) and PLINY (*Nat. Hist.* 34, 13 & 132) who calls this special spodos *lauriotis*. The growth of the Cyprian brass industry is of the same date. In the east little progress was made for many centuries as it seems. We have no data on the Achæmenian brass industry and we do not know whether the local ores were exploited as they were at a later date. It seems that the situation remained rather stagnant here and that the bulk of the brass in Roman times was import from the west as we have seen to be the case in Egypt. Zinc compounds gradually become more prominent in Hellenistic chemical literature. The Leiden-Stockholm papyrus mentions *cadmeia* and *oreichalkos* as ingredients for the preparation of "asem". For the *chrysophanès* and the *xanthosis* of copper PSEUDO-DEMOCRITOS uses *cadmea*, which is also called *magnesia* or white lead! ZOSIMOS is quite conversant with the manufacture of brass from *cadmea* and copper he says that the preparation of the "yellow or Persian alloy, wholly like natural gold" (brass) and that of the "glittering, light alloy" (bronze) are important secrets invented by a

mythical Pabapnidos, son of Sitos. It is remarkable that he calls brass a Persian alloy, which goes to show that there was a brass industry in Iran in his time. Manuscripts of the eighth century and later date (for instance the Coptic medical papyrus edited by Chassinat) abound with references to the manufacture of brass, copper and *cadmea*, now more frequently called *tutia*. This "gold" is only to be distinguished from natural gold by its smell as it will neither rust nor tarnish like true gold, but the *krâma* (*krasis*: alloy) is a great secret.

In Persia brass production seems to have started scale in the sixth century A.D. when it was exported to India and some two centuries later passed to China. In Persian legend the feet of Gayôpard are said to be of brass, POLLUX gives the term *oreichalkos*! Persian scientists like AL-JAHIZ (died 869) know that gold can not be made from brass, they call both brass and bronze *sifr* or *sufr*. IBN AL-FAQIH (900) states that brass manufacture was a government monopoly at Mt. Dumbâwand and at Kerman, where the *tûtiyâ* was mined, and IBN HAWQAL (950) states that it also comes from Sardan and India, and AL-FÂDIL knows that the "*tûtiyâ* of the Sages" or *al-qalamî* comes from many countries, but that Spain has the largest number of varieties. AL-DIMAŠQÎ (1300) is the first to mention the metal zinc which comes from China, where its preparation is kept secret, it is white like tin and it does not oxidize but its sound is dull. Finally from the fifteenth century onwards brass and bronze are well distinguished, the first *birindj* is made from copper and *tûtiyâ*, the second *sefidruy* from copper and tin. We do not hear about zinc being made in Persia itself, this seems to have been done for the first time on an industrial scale in China. Still in China the earliest reference to the metal zinc is embodied in an encyclopædia, the *Tien Kung Kai Wu* written in 1637, and there it is stated that it was then known to modern writers only! Zinc is called *ya-yuen*, that is inferior lead, its industrial manufacture therefore seems to date from somewhere near 1600, its modern name is *hsin*¹. Brass is of course known far earlier, references are found in sixth century texts, archæological finds at Kuchâ in Khotan show the way by which this knowledge penetrated from Persia. It seems that the earliest term *t'ou shi* may mean both calamine and brass, though the latter is later called *totan* from *tûtiyâ*. HIUEN TSANG, the travelling monk speaks of brass made from copper and *yu-shih* (calamine?). Though the value of the old Indian alchemists and their modern commentators is very doubtful it seems that zinc was prepared by Indian chemists since the twelfth century, but that this remained a laboratory

experiment and never was applied to industrial production. This zinc or "the essence of tin" as it is sometimes called was prepared by distilling calamine with organic substances in an apparatus suitable for "destillatio per descensum", where a substance could be heated in an upper flask and the drippings could be collected in a lower one.

Zinc is also mentioned as the "spirit of *tūtiyā*" or the "brother of silver" and perhaps the Tantras around 1100 also mention zinc, which was the seventh metal known to the Hindus. Brass was of course known far earlier and brass figurines and ornaments became common from the sixth century A.D. onwards. It was from the East

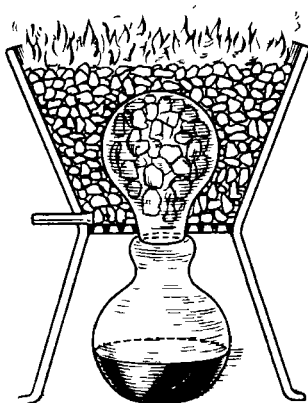


Fig. 58. The apparatus used by the Hindu metallurgist for the manufacture of zinc by the "destillatio per descensum" process

that zinc was introduced by the Portuguese and Dutch traders to Europe, where zinc manufacture started only in the 18th century. VALENTIN's *Oostindië* mentions *tintenaga* or spelter, the Portuguese name for zinc being *tutenago* (the Persian *tūtiyā* with the suffix *-nak*, this was later corrupted and formed the English trade-name "tooth and egg"! (5). In Akbar's time zinc was produced in India, for we hear from ROGERIUS' *Open deure tot het verborgen beydendom* (Edit. CALAND, 1915, p. 121) that taxes were paid to the temples on the *spiauter* produced. The *calaem* often mentioned in these books on the first contacts with the East was not, as is often supposed, zinc. *calaem* is not a corruption of calamine but it is derived from the Arabic *kalā'i*, that is "what hails from Kedah (Qalah) in Malacca" and it means tin! (See JAN VAN LINSCHOTEN's *Eerste Voyagie*, edit. KERN, I, 1910, p. 72).

III

The nomenclature of zinc and its alloys is a difficult chapter of ancient metallurgy, for the ancients did not readily distinguish the alloys of lead, silver, tin, zinc and antimony, they could not analyse the components and chose the names very arbitrarily. This is the reason why they often vary their meaning in the course of the ages. Thus for instance the Sanskrit *nāga* is really lead, but it is used for tin or zinc too!

STRABO tells us in an interesting passage (XIII, 1, 56, c. 610): "There is a stone in the neighbourhood of Andeira which when burned becomes iron, and then, when heated in a furnace with a certain earth distils *pseudoargyron* and this with the addition of copper makes the mixture (*kráma*) as it called which by some is called *oreichalkos*." Now this is "technical nonsense" and DIERGART has proposed to leave the *pseudoargyron* untranslated or to say "mocksilver". Though zinc-iron ores exist this procedure is impossible. It would seem that DIERGART (10) is right here and that this *pseudoargyron* is a silver-like alloy of unknown composition. Though arsenical copper and iron ores abound in the Troad, it is doubtful whether an arsenic-copper or arsenic-iron alloy could be prepared in the way STRABO suggests!

There is a similar doubt as to the early meaning of *oreichalkos*. Though many interpret this word as "mountain-copper", authorities suggest an Asianic original. It certainly means some kind of copper, though it is equally certain that its meaning "brass" was only acquired in Late Republican times. Neither HERODOTUS or HOMER know brass and archæology does not support this translation, *oreichalkos* may therefore have meant originally a special copper alloy or a kind of bronze. HESYCHIUS still calls it a copper resembling gold! The Latin *aurichalcum* is a corruption of *oreichalkos*, it denotes brass from the Christian Era onwards. One of the earliest references to brass may be found in CICERO's *De officiis* (3, 23), where he discusses the ethics of selling brass for gold, the value of the latter being a thousandfold of that of the former. In early texts before the first century B.C. one should therefore be careful to translate *aurichalcum* or *oreichalkos* by "copper alloy" and not by "brass"!

As one would expect from archæology there is no Egyptian word for brass. The equation *thst*: brass suggested by BUDGE must be dismissed. There is a curious Coptic term *chomt n barot* (ϣⲟⲙⲧ ⲛⲃⲁⲣⲟⲧ), which CRUM first called brass (*Coptic ostraca*, London, 1902, p. 42, No. 459), but which he translates "a composite metal"

in his *Coptic dictionary* (Oxford, 1939, p. 44. a). Its Greek equivalent is *chalkolibanon*, and it may be brass, though we possess too little texts to fix its true meaning. It is certainly a copper alloy (*chomi!*); *barot*, given by SPIEGELBERG as "Erz" is derived from the Egyptian *bi³ rwd* (see GUNN, JEA 3, 1917, 36, and WAINWRIGHT, JEA, 18, 1932, 6).

EBBELL's identification of the Egyptian *h³tm* with calamine (*cadmea*) in the Papyrus Ebers seems very probably as the *h³tm* figures largely in collyria where we would expect zinc-compounds!

We can not point out an Hebrew term for brass, as *néḥôšeth* just like *aes* or *chalkos* may mean brass in late texts, but usually should be translated copper or bronze. The "fine copper" mentioned in Ezra 8 : 27 may well be brass, which alloy was certainly used for cymbals in Hellenistic times.

CAMPBELL THOMPSON (32) has some interesting suggestions to make on Akkadian terms for brass and zinc compounds. He holds *elmu(e)š³u* (š³.UD ÁG) to be brass and he claims that the text KAR 307 is a symbolic picture of the brass-founder's furnace. Further proof is, however, needed for so early an Assyrian manufacture of brass! He further identifies *tuš³kú* (š³.ḪÉ) with *spodos* and *lulú* (kù-ḪÉ) with *pompholyx*, but these identifications are of course connected with his reading of the text KAR 307 and his assertion that the manufacture of brass was generally known to the Assyrians.

We have already identified the *spodos* and *pompholyx* as forms of zinc oxyde and *kadmēra*, *kadmia* as the general name for zinc ores. The latter term was corrupted by the Arabian alchemists to *kalmēia*, *kalamiya*, *kalimīna* and early in the fifteenth century we find the terms *kalmis* or *galmei*.

The origin of the word *messing* is not known. Some claim its descent from the Latin *massa* (lump of metal) and the Greek *maza*, others like SCHRADER trace it back via an early Slavonic form **mosengjú* to an early Caucasian root **moss* or **mossum*, but this remains to be proved.

Equally doubtful is the etymology of the Turkish *birinḡ* (brass and bronze!) from the Sanskrit *vṛibi* and the Greek *óryza*, *bryza*, because brass has the gloss of polished rice!

The general Persian term for zinc ores and zinc oxyde is *tūtiyâ*, which occurs frequently in medieval literature as *tutia* or *totia!* LAUFER has suggested that the Chinese *l'ou shi* (a metallic product from Sasanian Persia) was brass, but this is not sure, neither is its connection with *tūtiyâ!* The Sanskrit *tuttha* is derived from *tūtiyâ* and it came

to mean "vitriol" (compound of sulphuric acid with different metals) to the great confusion of early translators. There is no Persian term which can be identified with zinc. The term *roy* (zinc) originally meant "copper", we find it in the compound term *isfid-roy* (first "bronze" then "brass") which though forms like *sepidrui*, *isbâdârih* was corrupted to *spelter* or *spiauter*, the sixteenth century term for zinc!

The Persian alchemists use *ruh-i-tûtiyâ* (spirit of *tutia*) for zinc. The true Sanskrit term *yaśada* (Hindi *ṣastâ* or *dastâ*) may go back on a Persian original (vide the Arabian *jasad*: 'body) which arose from the same speculations on the connections of zinc and *tutia*.

Another early European word, occurring, side by side with *spelter*, is *tutenago*. This early word for zinc is usually explained as the Persian *tûtiyâ* followed by the suffix *-nâk*, the whole corrupted by the Portuguese to *tutenago* and still worse by the English tradefirms to *tooth and egg*! Further confusion was introduced by the use of, *tutenago* to denote *paktong* (*pai-t'un*, a natural Chinese copper-zinc-nickel alloy) and the use of *spelter* for both *tutenag* and *pewter* (the Chinese *peh-yuen*, a lead-tin alloy) (5).

The terms *laiton* (Tudor: *latten*), etc. in Romanic languages for brass are derived from the Italian *latta*: sheet brass.

These few lines will go to show that the etymology of zinc and zinc compounds is by no means solved and still remains an intricate, often puzzling, chapter of the history of these metals and alloys, "Yet such as you and I, who are not impractised in the trade, must not suffer ourselves to be imposed upon by hard names or bold assertions". (ROBERT BOYLE, *Sceptical Chymist*, part III).

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CHAPTER TEN

COPPER IN THE ANCIENT NEAR EAST

Our intended Discourse is now of *Venus* or *Copper* (GEBER, *On the Sum of Perfection*, XII)

I

According to the definition of GEBER copper is "a *Metallick Body*, livid, partaking of a dusky *Redness*, ignible (or sustaining *Ignition*), fusible, extensible under the *Hammer* but refusing the *Cupel* and *Cement*".

But then this was in the Middle Ages when ALBERTUS MAGNUS could speak of "workers in copper in our parts, namely Cologne and Paris and in other places where I have been and seen things tested by experience to investigate nature and characteristics of copper".

However, this scientific spirit was fairly recent, for even the Hellenistic alchemists had used copper only as a base-product for their experiments. The Leiden papyrus, one of the earliest chemical papyri, mentions the leukosis of copper. Sometimes copper is coloured to imitate gold, this was effected by heating copper with a mixture of powdered lead and gold. OSTANES invented a "divine water" to tinge copper like gold, and the Transmutation series of DEMOCRITOS, HERMES, AFRICANOS, and ZOSIMOS start with copper. OLYMPIODORUS starts the "work" by the treatment (*ergasiá*) of copper, and STEPHANOS by a "battle between copper and mercury".

In alchemy copper is represented by the sign of the planet Venus. Some have recognised this sign on Old Kingdom seals from Egypt, but have been misled by the sign *nefes*, beautiful. Others have derived it from the well-known Egyptian *anch* (life) sign, but this too is antedating a sign that belongs to Hellenistic astronomy.

Though copper figures in early chemistry and even in earlier magical practices to some extent, it is far more important as the earliest useful metal of mankind. For though the use of gold may have preceded that of copper in some regions, the precious metal could not be fashioned into tools and weapons and its production had little influence on early technology though the goldsmith's art was of great importance to later metallurgy. But copper production and working is the earliest branch of metallurgy, that art which has changed the face

of Neolithic mankind. Has not CHILDE described the discovery of copper metallurgy as the most dramatic leap in the history of mankind? For it was with copper that early mankind learnt to experiment and to discover the astonishing changes that fire would work on these shining stones, the miraculous transformation by fire of certain brightly coloured stones into this metal and the possibilities that slumbered in this new kind of stone. Armed with this experience gathered in centuries of transition from Stone to Metal Age they attacked other stones, produced other metals, mixed metals or ores to get still more



Fig. 59. Huge copper nugget found near Lake Superior

useful alloys and changed the face of the earth by applying the metals to art and industry.

Copper occurs in the native state in many places in the world and as such it was first found and used by neolithic man. A good survey of the different links between the early native copper and the later copper industry can be had by a short glance at the stage of copper metallurgy in the New World by the time of its discovery by the whites.

One of the early students of the pre-Columbian Indians, SCHMIDT, remarked already (98) that copper was no more than a stone to these Indians, who at the time of the discovery of the New World were just settling down as semi-nomads and were only recently acquainted with agriculture. They collected native copper and treated it as any other

stone. These facts led SCHMIDT to state that civilisation comes only with the Bronze Age and we have hardly any reason to speak of a Copper Age. In the United States of America near Lake Superior (State of Michigan) there are large outcrops of a ferrous sandstone which contains appreciable masses of native copper (1.3 to 1.4 %) mainly in the form of dust, but also nuggets and lumps ranging from several pounds upto many tons occur. In the weathered outcrops of these strata big copper boulders had been found by the Indians and early travellers found that "they had taken off every projecting point which was accessible by pounding with stone hammers or mauls, so that all the exposed surface was smooth". Modern mining has followed the stratum to a depth of 4000-5000' and by grinding, sieving and washing extracts a copper that is practically pure and contains only 0.15 % of silver, 0.002 % of arsenic and 0.002 % of antimony. Smelting and pooling this copper yields a very pure product. It is now certain that the surface outcrops were worked by the pre-Columbian Indians (15, 66). There are no early mines in our sense, they are just galleries or open-cuts to dig out nuggets, in some of which PHILLIPS found nuggets of 99.4 % purity. Remains of charcoal fires near the big boulders of Lake Superior and at other places show that the Indians used fire to detach pieces of copper-bearing rock, not for smelting. Other important copper finds were excavated in the burial mounds of the Mississippi plain. The "float" copper found in the neighbourhood is really carried by the ice masses from the strata of Lake Superior as far south as the mouth of the Ohio river and deposited there as native copper among the detritus of the rocks. The Indians used this native copper to make ornaments (92). The copper of these ornaments is very pure (usually 99.9 % with traces of iron and silver), it can be distinguished with absolute certainty from imported copper of the earlier discoverers, which was seldom over 98 % pure in that period and contained traces of nickel, cobalt, arsenic, antimony, sulphur, silver, and iron. No piece of copper from the burial mounds of the Plains is either alloyed or smelted, every piece being hammered float copper (84, 85). Their manufacture shows considerable skill and taste though they are of types closely related with stone tools. The Indians seem to have known only the malleability of native copper (93), they cut and trimmed it with stone tools and smoothed it by abrasion with stone. Most of the artefacts were made by that alternate hammering and heating which we call annealing. Casting was not practised as C. C. WILLOUGHBY of the Peabody Museum showed,

whose work is at present continued by WHARTON and WEST of the Milwaukee Museum (119), all the ancient artefacts could be reproduced by these simple means.

Very little positive evidence is given on the copper metallurgy of the Aztecs. Some authors claim that they worked only native copper, for instance at Zocutallan and Oaxaca and could melt and cast it, and had even passed on this art to the Mayas (93, 85). Others maintain without proof that copper was produced by the Aztecs from ore and smelted with three kinds of herbs to guarantee good copper produc-



Fig. 60 Implements fashioned from native copper by the American Indians (after ANDRÉE)

tion (Sahagun). Nor is the situation in South America very clear. Some claim that no native copper was used by the Incas (5), though other point to exploitation of the deposits of Coro Coro (92). BARBA says that in his time the Incas mined and smelted chalcopyrite at Cerro de Pasco, Colquijirca and Hualgayoc using small furnaces with natural draught as they did not possess bellows. At any rate if they could smelt copper this must have been a recent acquisition and perhaps introduced by the Spaniards for HELPS and PRESCOTT mention that they valued copper more than silver or gold at the time of the Conquest. A few modern analyses of Ecuadorian samples showed that they consisted of pure copper, while Mexican axes of the same type contained a small but natural percentage of tin. In both types of axes

some process had been employed to harden the cutting edge, but there is no evidence against the hypothesis that the hardening was effected by hammering (128).

It would seem, therefore, that the New World did not know the production of copper from ores, or if they (the Incas or Aztecs) knew it, they had learnt it shortly before or after the conquest. In the case of the Indians of North America it is certain that they were still in the Stone Age and treated their copper like stone, having no idea of its metallic qualities. This is also clear from the terms which Indians use for copper. The Algonquins call it *musquabik*, e.g. "red stone", the Chippewas *ozabwabbik*, "yellow stone", the Zuni *hi-we*, "soft stone", and the South Californian Indians *er-reck*, "stone, also metal in general". Only a few like the Virginian Indians have a word for copper *Wassador*, which is also used as a general term for metal (93).

True copper metallurgy, therefore, begins at smelting copper ores and casting native or produced copper. Before discussing copper metallurgy we must describe copper ores and their distribution in the Ancient Near East as far as they were of importance to the Ancients.

The production of copper was greatly enhanced by the prominent part which electricity plays in modern life. More than 50 % of the copper produced at present is used for electrical apparatus, wire, etc. Its malleability and toughness make this metal very suitable for coins and its small value as compared with gold and silver makes it eminently suitable as a material for small change. The greater part of the copper now produced is used in the form of alloys with other metals, many specific alloys have been developed for every special applications. Though pure copper and bronze formed the main materials in Antiquity, there existed already a tendency to develop special bronzes, etc. in later ages, especially in the Hellenistic and Imperial method. These alloys are very important in modern machine industry and armaments and they play a large part as bearing metals.

Copper is very widely distributed in nature and is found in soils, waters and ores. *Native, malleable or virgin copper* occurs as a mineral, especially in the surface strata of deposits of copper and iron ores. In the upper workings of these deposits it is found in arborescent, dendritic, filiform, moss-like or laminar form. Small nuggets are frequent in the Ural mountains, larger lumps are found in Siberia, the Altaï and North-East Asia and Mexico, large boulders occur in the famous deposit of Lake Superior (Michigan).

We mention here only the principal *copper ores* (with their copper content):

<i>Cuprite</i> (red oxyde of copper, ruby ore), a copper oxyde, which occurs in small quantities only	88.8 %
<i>Malachite</i> , a green (basic) carbonate of copper	57.3 %
<i>Azurite</i> , a blue (basic) carbonate of copper, which should be clearly distinguished from lapis lazuli or lazulite	55.1 %
<i>Chrysocolla</i> , a copper silicate, that is not identical with the ancient chrysocolla of Pliny and Theophrastus	36.0 %

These ores together with native copper occur in the weathered surface outcrops of deeper strata of copper ores which belong to the second group of sulphides or copper-sulphur compounds:

<i>Chalcocite</i> (vitreous copper, redruthite, copper glance), a copper sulphide	79.8 %
<i>Chalcopyrite</i> (copper pyrites, towanite, yellow copper ore) a copper sulphide usually mixed with the sulphides of iron	34.6 %
<i>Bornite</i> (purple copper ore, peacock ore), a rarer variety of chalcopyrite	55.5 %
<i>Covellite</i> (indigo or blue copper), a less common copper sulphide ,	66.5 %
<i>Enargite</i> . a compound of copper, sulphur and arsenic	48.4 %
<i>Tetradrite</i> . a compound of copper, sulphur and antimony	52.1 %
<i>Fablore</i> , a compound of copper, iron, mercury and zinc sulphides	30-48 %

Nearly every copper mineral is distinguished by some bright hue, which made it very obvious to the ancient miner. It is certain that the earliest mining of copper ores started with the surface deposits of oxyde and carbonate ores. Many early exploited lodes must have been depleted and many widely distributed deposits of ores of poor quality have left hardly any trace for the archaeologist. It is also certain that even in Antiquity the demand for copper grew already so great that deeper strata were mined and sulphide ores were worked. This may have been general practise in Roman times when nearly all the surface deposits within reach of the Romans had given out. The working of widely distributed pockets of surface ores with widely varying composition accounts for the many different systems of working the ores and the highly intricate methods. Only some of the

older mines such as those at Mansfeld had larger ore bodies of a fairly constant composition. At present very poor but huge ore bodies are worked of a very constant copper content (from 0.85 to 6% but an average of 2%) where mass production has made the exploitation economical. Such are the modern ore bodies of Kazakstan, Chile and Arizona and only in Katanga a richer ore of 6% of copper is worked. The figures for the copper content of the minerals given above are those of the pure minerals; if we take the gangue in account the ores worked by the ancients may have held something like 10-20% of copper, but patient selection and washing led to the working of very pure ores in the smelting furnaces by methods, which would of course be considered very uneconomical at present. Now the economy of working certain copper ores is often determined by other metals such as gold, silver, lead, zinc or rare metals.

Very little is known for certain about ancient copper mining. The first to describe the bright coloured copper ores correctly was THEOPHRASTUS and of course these bright colours have led earlier miners to ore deposits. The Romans knew something about the connection between the oxydes on the surface and the deeper sulphides for as PLINY says (Nat. Hist. XXXIII, 98): "The early miners used to cease their operations when they came to alumen seeking no further, but the recent discoveries of the veins of copper below the alumen has removed this limit to their hopes." BIRINGUCCIO in the sixteenth century mentions the bright colour of the ore, the taste of water near the deposit and the micaceous fracture of the rocks as sure indications of ore bodies. Still the ancient knew several copper ores though they do not often distinguish them quite clearly.

DIOSCORIDES mentions (in his *Herbal*) *chrysocolla* (our malachite!) and says (V. 104): "That of Armenia is the best very much resembling leeks in ye colour, but that of Macedonia is ye second, then the Cyprian and of this the pure is chosen." He also mentions *chalcitis*, which (V. 115) "is to be preferred if it looks like brass and is brittle being without stones and not old and moreover having somewhat long and glittering veins", but PLINY says (XXXIV. 117): "The name *chalcitis* is given to another mineral from which copper is smelted. It differs from *cadmea* in that the latter is hewn from exposed rocks on the surface of the ground while *chalcitis* is mined from deeply-buried deposits. Again *chalcitis* is soft by nature, like condensed wool and crumbles quickly. Another point of distinction is that *chalcitis* contains three constituents copper, misy and sory to be described each in its

proper place" and his following paragraphs (XXXIV, 118-123) give vague descriptions of *chalchitis*, *misy*, *sory*, *chalchantos* (flowers of copper) and *melanteria*. There can be little doubt that some of PLINY's *chalchitis* may have been our chrysocolla, but that all of these products comprise the sulphide minerals of copper and iron and their alteration products, the latter including shoemaker's black or *chalchantum*. *Chalchitis* can be translated more or less as "weathered pyrites". DIOSCORIDES also describes *misy*, which may be copperas (V. 117). The *cadmea* described by PLINY is not only the zinc ore which we have already discussed (Chapter IX) but often a mixture of copper and zinc ores either natural or artificial. STRABO (III. 4. 15) is more correct in applying the name *cadmea* to zinc ores only.

PLINY also describes *pyrites*: "The name is sometimes given to the millstone, because there is much fire in it; but there is another and more porous variety and yet another pyrites with a resemblance to copper. They assert, that the two kinds are found in the mines in the neighbourhood of Acamas in Cyprus, one with the colour of silver (our marcasite!) and the other with the colour of gold (iron-copper pyrites!)" (XXXVI, 137).

It is certain that every form of mining from open-cut mining to the driving of galleries into the mountainside to follow up the copper bearing strata was practised in Antiquity. But the details given on ancient mines are few and they should receive closer attention from younger generations of archaeologists. Fire-setting and other means were used to break up the rocks and stone tools were used upto the advent of iron as both copper or bronze tools are unsuitable for mining being either too soft or too brittle. In Sinai it was proved that stone tools remained in use until the Early Iron Age and it is the same in many other copper mines, especially those of Tirol and Salzburg which have been studied in detail (4). By washing, handpicking and crushing the ore was purified from the worthless gangue. Often the ores were immediately ready for use, especially as extraction was not very perfect in Antiquity and old slags have been retreated with profit in modern times, for instance in the copper districts of Spain.

As little is known about the ancient copper mines in the Near East. We have given only a few of the most important surface deposits in Fig. 61 mentioning those which are prominent in ancient literature or have some interest because of their situation amongst ancient sites. Many older deposits have given out or were cleared so well of their ores that they have escaped the often superficial investigation of

travellers. Here again there is a lack of proper geological information which should be corrected as soon as possible.

There are several important copper deposits in *Egypt*, which have been enumerated and discussed by LUCAS (67, 69). The principal deposits occur in the peninsula of Sinai. In Wâdî Maghârah and Serâbît el-Khâdim the ore consists largely of malachite with a little azurite and chrysocolla, at Gebel Um Rinna of malachite as at Wâdî Malḥa and Wâdî Khârig. Wâdî Nasb and Sêh Baba contains large ancient slagheaps, along the plain of Senned azurite is found and in the hills west of the Nebk-Sherm plain malachite.

In Wâdî 'Arabah, east of Beni Suef in the eastern desert, chrysocolla occurs but it is doubtful whether it was mined in Antiquity. Chrysocolla occurs again at Gebel Dara and copper ores are found at Gebel Atawi and in the Dungash gold mine. Malachite occurs at Wâdî Gemâl and Hammamîd, the latter deposits showing shafts upto a depth of 80'. Malachite also occurs in the Sufr hills west of Jemsa and in Wâdî Sibrît, the slagheaps at Kubbân may originate from these mines. At Hamish chalcopyrite incrustated with blue copper compounds is found and at Abu Seyâl pyrrhotite and copper sulphides with some chrysocolla.

Of these deposits the Sinai mines are by far the most important and practically the only source of Egyptian copper upto the XXI dynasty as we shall see. The Kubbân mines may have been exploited from the XIIth dynasty onwards but Aby Seyâl not earlier than the XIXth dynasty. Egyptian records mention no tributes of copper from the south. In the light of this information it is not probable that the Meroë mines mentioned by STRABO (XVII. 2. 2. c. 821) existed before classical times. On the other hand graves in Nubia dating from pre-dynastic and Old Kingdom times contain copper objects, which may, however, have been imported from Egypt. DIODOR (I. 33) mentions these mines too.

In North Africa more than 60 mining sites have been discovered, which by their crude methods of working can hardly antedate the Arabs. Still STRABO says (XVII. 3. 11, c. 830): "that there are also somewhere here in Massesyli (the present Algeria) copper mines", he probably refers to deposits near the modern Tenes. The mines of Maghreb (Morocco) exported copper to the negroes though they had mines of their own in the Congo regions in the period of Al Bekrî (1050 A.D.), though nothing is known of any pre-Arab working.

It is very improbable that the deposits of practically pure carbonate ore of Hofrat en Nahas on the banks of the Bahr el Arab, a confluent of the Bahr el Ghazal in the Sudan, were worked before the XIXth century. The copper mines in the Thebaïs mentioned by DIODOR (I. 15) can not be located.

The modern copper mines of Katanga and North Rhodesia and the deposits of Transvaal (Zoutpansberg, Ookiep) play no part in the supplies of the Ancient Near East, though they are most important in modern times.

Syria and Palestine have some deposits of more than local prominence, that are also mentioned by ancient authors (ORTH, PW, suppl. Bd. IV, p. 113). There are some vague references to copper mines in Palestine or close to its borders in the Bible (Deut. 8 : 9; Job 28 : 2). Lately GLUECK has described the important copper mines of Edom near Khirbet en Nahâs and Umm el 'Amad and its refineries both near the mines around Pheinan and at Ezion Geber that were certainly of Solomonic date and may go back to the XVIIIth century B.C. The deposits around Madiana in Midian contain malachite, chrysocolla and pyrites, but it is not known for certain whether they were worked in Antiquity. Pheinan is the Phinom mentioned by EUSEBIUS (Hist. eccl. VIII. 13. 5) (Mart. Palest. XIII. 1), who states that there were copper mines in the Lebanon range and Syria too.

Near the ancient centres of copper and bronze industry Sidon, Tyrus and Sarepta we find the deposit of Mount al Araba'in near the ancient Calchis (now Antschar) and the Lita river, a site probably to be identified with the pre-classical Kinnésrîn, which may be the mine referred to by EUSEBIUS. This district Riha near Damascus has been identified with the Nuḥašše of the Amarna letters and some authors have tried to prove that the Hebrew word *nechošet* for copper was derived from this Nuḥašše, the "copper-land", but this identification can not be true as KNUDTZON has proved beyond doubt that the kingdom Nuḥašše was situated near Nii between Aleppo and the Euphrates (113). The region around Aleppo in North Syria has many copper ores. Not only do they occur near Aïn Tab, Chirbet es šamra and Wadi Rwebe, where ore was dug at least in Roman and Byzantine times, but in Roman times the district around Calchis was called Chalcidice and around Chalybon Chalybonitis. As Syria was always an important centre of copper industry these mines may have been exploited in pre-classical times.

Arabia is not very rich in minerals but apart from the copper ores

of Midian we find them at Gebel Shamar and in the Jabal al Ma'dan in Oman near Sohar, which may have been the source of early Sumerian copper, the Magan and Meluhha of early texts. Some copper ores are found on the Bahrein islands.

On the other side of the Persian Gulf Carmania was said to have copper mines (STRABO XV. 2. 14. c. 726) which may have been near the present Kirman. Mâsûdî mentions the copper from Oman, but not that from Carmania.

The ancient civilisation of Waziristan and Baluchistan discovered by AUREL STEIN and related to the Sumerians and the Indus civilisation used copper and bronze freely but its sources are not yet known. Still copper is found in the Râs Kûh and the Khwaja Amrân ranges. Slagheaps have been found near Shâh Ballaul and Robot.

These mines in Baluchistan may have formed the sources of the Mohenjo Daro copper and bronze, but there are many other copper districts in India proper. There are old workings in the Shan states, Indore, Nellore, the Kistna district, Rupavati in Kathiawar, Ambra Mata and Kumbaria in North Gujrat and in Nepal, though it is doubtful on other grounds that they were worked before Hellenistic times. There are rich outcrops in Merwâra Ajmer, Rohira in Sirohi state and in Jaipur (Chetri and Singhana). The Singhbhûm district (Mosaoni, Dhobani, Matigara) contains a fairly important copper industry; other deposits in the Orissa-Bihar region are those at Chota Nagpur and Hazârîbagh (Bengal). There are many other small workings in the south for instance in the Madras presidency and in Sikkim. Most of these deposits contain mainly pyrites and other sulphidic ores. STRABO mentions "Indian copper" (XV. 1. 69) without any specification.

Afghanistan is rich in copper, many mines are mentioned by HIUEN TSANG. There are the mines of Shâh Maksud worked by Nadir Shah, other deposits at Safed Kûh (between Kabul and Kurram), at Tezin (east of Kabul) and the Shâdkani and Silwâtû passes.

In Eastern Turkestan there are mines near Onbash of the Musart river and at Kodscha-Masar on the Tisnaf river.

There are rich deposits in the Altai mountains at Ridder and other sites with ancient workings, while in Kasakstan there are the rich orebodies of Makain, Boschtschekul, Kounrad, and Dscheskasgan, which have been worked since 1930. A primitive but extensive copper industry was found at Temba Bulach in the Kizil Kum desert but its date is uncertain as that of the extensive "Chude pits" built and

worked by the legendary Chudes which extend from the Altai mountains upto the Ural mountains but are particularly extensive near Abakansk on the Jenessei and on the banks of the Tscharysch, a tributary river of the Ob. In Usbekstan there is an important ore-body near Almalyk. The Ural mountains contain very rich deposits at Pyschmin with 3-6 % of copper and in Baschkiristan to the south the mines of Tanalyk, Bogomolowsk, Degtiarka, and Bljawa. They were possibly the sources whence the Massagetæ drew their copper (STRABO XI. 8. 6. c. 513). The ancient copper mines of Bamian near Kabul and in Kafiristan and the Parapomissus form the eastern extension of the belt of copper deposits which runs though Northern Persia upto the Caspian Sea and beyond to Transcaucasia. IBN HAUQAL mentions copper mines in Transoxania, but those on the eastern border of Persia were very important too, even in his times. There are the mines of Kal-SebZarre, Sabzawar and Fahr Daud near Meshed, Kaleh near Astrabad and in the Elburs mountains. The districts of Kashan, Kohund and Isfahan contain many important mines. The mines of Isfahan, Anarek and Bochara were the most important sources of copper for the Arabian Chalifs of the ninth century A.D., they payed no less than 10.000 dinars in taxes. There are easily reducible carbonates at Binamar and Pankaleh. In the North Mount Sahend and the Kara Dagh are extensions of the Transcaucasian deposits and probably the sources of Luristan copper. The deposits discovered in 1846 by LAYARD in the Ashishtha valley of the Tiyari mountains are often mentioned in Assyrian and Babylonian records. The Kara Dagh ores are rich in gold and silver too.

In *Caucasia* and *Transcaucasia* there are so many deposits that we could not possibly enumerate them in this short essay. The different copper districts have been described by HANĀAR (59), they have not been detailed on the map. The pyrites around Kedabek, Allaverdi, and Shamlugk about 3.5 % of copper, the ores near Sangesur upto 18 %, the chalcopyrite and pyrites at Angarak upto 10 %, the latter strata are covered by a fairly deep deposit of oxyde and carbonate ore which contains laminar native copper. Native copper, covellin and chalcopyrite occur in the particularly rich ores of Chagali-Heliar where the copper content runs up to 25 %. These Transcaucasian deposits are continued into Turkey by the deposits of Artvin (Kubarshane) with 7 % of copper and the deposits of Gümüşkane and other Pontic districts in the famous ancient metallurgical centre of the Mossynoeci and Chalybes. Other continuations of the Transcaucasian deposits are

the ores of Tillek and Arghana Ma'den both worked in Antiquity. The whole Armenian-Transcaucasian region and the Urartu of the foothills was most important as a centre of supply of Mesopotamian copper and there are plenty of traces of primitive mining and refining around the old deposits.

The copper mines of the Taurus region are old mines too, they are mentioned in Mesopotamian records and by EUSEBIUS (Mart. Palest. XI, 6; XIII. 2). Opposit the Cilician coast there is the island of Cyprus, from which copper derives its name. The copper mines of Cyprus are prominent in classical literature, they are mentioned by HOMER (Odyssey I. 182), THEOPHRASTUS (de lapid. 25), GALEN (de simpl. med. 9. 3. 21), DIOSCORIDES (Herbal V. 106), PLINY (Nat. Hist. V. 89 VII, 195; XXXIV. 2; etc.), ISIDOR (Orig. XIV, 6. 14), STRABO (III. 4. 15; VI. 1. 5; XIV. 6. 5) and others. The old mines are near Tamassos, Amathus, Soli, Kurion and Krommyon near the edge of the andesite outcrops of the Troodos massif. At present these mines are still exploited, that is the strata on the north-west coast of the Morphu bay at Skuriotissa and Mavriuni, where 35.000 Tons of copper were produced in 1938.

The other deposits on the mainland of *Asia Minor* are far less important. There are several deposits on the mainland opposite to Samos where the inhabitants were clever bronze and copper-smiths according to PLINY (Nat. Hist. XXXV. 12) and PAUSANIAS (VIII. 14; X. 38). North of the ancient centre of bronze industry, Pergamum, there are several mines amongst others that of Cisthène (STRABO XIII. 1. 51. c. 607). ARTEMIDORUS states that the mine at Adramyttium was still in use at the time of Alexander the Great. The district to the south of the Lake of Marmora contains several copper deposits which are exploited at the present time. There was an ancient mine on the island of Kalki, the Chalcitis of Theophrastus (de lapis 25) and Pollux (V. 39) off Chalcedon. Other deposits are known near Kastamonu and Tokat which do not seem to figure in ancient literature.

Ancient Greece was no copper producing country and the small local deposits that are said to have existed near Sicyon and in Attika and Argolis seem to have been exhausted at a very early date. There are still small ore bodies on Syra and Paros. In Euboea copper ores of Mons Ocha and Aedepsos are mentioned but these are not confirmed by geological handbooks and it is held by many that Euboea had its fame as a copper-smithing country only ranking with Aegina and

Rhodus, or Delos (PLINY XXXIV. 9-10), not as a producing centre. On the other hand STRABO says (X. 1. 9. c. 447): "Above Chalcis is situated the Lelantine plain and in this plain was also a remarkable mine which contained copper and iron together (probably in the very common form of pyrites!) a thing which is not reported as occurring elsewhere; now, however, both metals have given out."

In Macedonia copper ores occur and near the present Burgas (29) at Karabajir and Rosenbajir tools and slags of the La Tène period were found. The copper was probably shipped thence to the south by the Greeks who took other products from the Euxine.

Jugoslavia has some important deposits near Bor (Čuka Dulkan) and at Majd Pek, mainly pyrites and chalcopyrite.

Italy had several copper mines which were mostly abandoned when the Spanish mines were opened in the Early Empire. Prominent amongst the Italian mines are those in Tuscany between Volterra and Populonia at Montecatini, Montanto and Monte Calve already exploited by the Etruscans (1). There are others in the Campiglia Marittima and PSEUDO-ARISTOTLE seems to indicate these when he speaks of mines on the island of Elba (c. 93) where there are no copper ores! In Sardinia there are the ores of Calabona and in Bruttium there was a mine near Tempa of which STRABO says (VI. 1. 5. c. 255): "People say that Homer has in mind this Temesa not the Tamassos in Cyprus (the names are spelt both ways) when he says "to Temesa in quest of copper". And in fact, copper mines are to be seen in the neighbourhood, although now they have been abandoned." Then there are copper ores in Agordo in the Alps of which PLINY says (Nat. Hist. XXXIV. 3): "The next best kind of copper (after the Cyprian) was the Sallustian from the land of the Ceutrones in the Alps. This did not last long and was succeeded by the Livian from Gaul. Both names are derived from the owners of the mines, the friend and wife respectively of the emperor Augustus." And he continues: "Livan copper also gave out very quickly for very little is now found. To-day it is the turn of the Marian variety or Cordovan to give its alternative name (XXXIV. 4)." Indeed the copper deposits in France are very poor. There are some in Haute Savoie and the Aude Department and also at Cabrières (Dépt. Hérault), Rozières (Dépt. Tarn) and Baiyory (Dépt. Basses Pyrenées). Most of these can hardly have had more than local importance, even in Antiquity.

The most important copper deposits in *Europe* both in Antiquity and at the present time are those of Spain and Portugal. The classical

authors have long laudatory passages on these mines. This is what STRABO says (III. 2. 8. c. 146-147): "But as for Turdetania and the territory adjoining it there is no worthy word of praise left to him that wishes to praise their excellence in this respect. Up to the present moment, in fact, neither gold, nor silver, nor yet copper, nor iron, has been found anywhere in the world in a natural state either in such quantity or of such good quality. But for the Turdetanians mining is profitable beyond measure because one-fourth of the ore brought out by their copper-workers is pure copper" and he mentions the copper and gold ores of Cotinae (Almaden?) (III. 2. 3. c. 142). PLINY praises the Cordovan copper (XXXIV. 4).

This Turdetania refers to the Rio Tinto ore body of the southern Sierra Morena. The provinces Almeria, Andalusia, Cordoba, Sevilla, Huelva, Estremadura and Asturias and Catalonia (Lérida) and the Portuguese districts over the southern border contain the valuable copper ores.

Germany has several important deposits in Sauerland and Siegerland of which Mansfeld and Rammelsberg are prominent. Other deposits near Salzburg and in Tirol, Styria and Carinthia were very important in the Late Bronze Age and Early Iron Age and are still exploited.

The English and Irish copper ores are practically exhausted. The main deposits of historical interest are found in Cornwall, Devon and Anglesey. Skandinavia and Finland have several deposits which, however, play no part in our story. They are the deposits of Aamdal, Evje, Sulitjelma and Rörös in Norway, Falun and Boliden in Sweden and Orijärvi and Outokumpo in Finland.

III

Over 50 % of the world production of copper is now used in the electrical industry, 9 % in the automobile industry and 11 % for building and architectural purposes. Though the electrical industry uses mainly pure copper it is generally used in the form of alloys of which those with tin (bronze) and zinc (brass) are prominent. The centre of the world's copper production has shifted considerably. Thus, for instance between 1831 and 1840 England produced 49 % of the world's production, from 1861-1870 Chile came first with about 44 % and in 1891-1900 the United States were prominent with 52 %. At present three rival regions compete for the first place, the United States producing 25.8 %, Chile 17.6 %, the English domin-

ions Canada and Rhodesia together 28.9 %, the Belgian Congo (Katanga) 6 % and Russia 5 %, minor production centres being Cyprus, India and Australia. As the Russian mines are mostly located in the Ural or east of these mountains, it can be said that European production is no longer prominent as it was of old. With the shifting of the production centre other types of deposits were attacked and this meant new production methods no longer based on working small bodies of varying composition but large ore-bodies of constant though much lower copper content are now worked. New methods such as concentration of the ore by flotation, furnace treatment, combination of roasting and smelting in the convertor process, hydrometallurgical treatment and electrical refining have been introduced. Of late there was a tendency to return to older methods as the copper produced by modern mass methods, such as the convertor process, was not always of the quality required and this made refining more costly.

The refining processes discovered in Antiquity were very gradually developed until the middle ages and except for a few minor changes then it can be said that even upto the beginning of the twentieth century there was this same slow development directed to obtain a greater recovery of metal from a given quantity of ore. From Roman times to the days of BIRINGUCCIO and AGRICOLA the main struggle was the perfection of the method of dry extraction of copper from sulphide ores, after this period heat economy by better and larger apparatus came to the fore.

Before the new methods were introduced and exploitation of enormous orebodies of comparatively uniform composition and electrical refining completely changed the face of copper metallurgy one had to distinguish the treatment of two types of ores.

The first type of ores, the *oxydes, carbonates and silicates*, could be refined in principle by heating and reduction of the ore with charcoal or wood with the help of blast air in some suitable type of furnace, after which treatment the crude copper was refined.

This treatment formed the second stage only of the production of copper from the second type of ores, the *sulphides*, because in this case many impurities which had a bad effect on the quality of the copper produced had to be eliminated. These noxious impurities were mainly sulphur, arsenic and antimony.

The first stage of copper production from sulphides was *roasting the ore*. This roasting consisted of calcination of the ore in heaps or

furnaces, it is now effected in special roasting furnaces as the sulphurous gases involved are now recovered to serve for the production of sulphuric acid. This roasting is necessary to remove as early as possible the arsenic and antimony compounds present in the ore and the greater part of the sulphur, it requires little fuel as the process develops sufficient heat to maintain the roasting until the end.

The second stage is the *smelting of the roasted ore* to a mixture of copper and iron sulphides known as "copper matte" or "coarse metal", which contains only little arsenic, antimony and silica. This

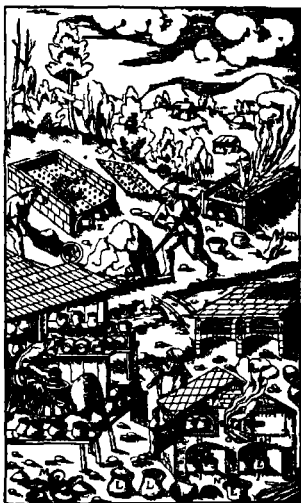


Fig 62 Roasting copper ores according to AGRICOLA (*de re Metallica*)

is effected by smelting with charcoal in a shaft furnace, at present of course coke is taken instead of charcoal being the modern substitute to the far more expensive ancient fuel. This stage is often combined with the next one, the *smelting of the coarse metal* with charcoal (coke) and siliceous fluxes. These fluxes consist of quartz in the form of lumps or pebbles and it serves to take away the iron oxide present, to form a slag with these and other basic slagging compounds and by covering the smelting product saves it from oxidation, which though not important in this stage is a most important function in later stages when the smelting product is pure copper liable to absorb oxygen and to form copper oxide in the heat. The smelting of the coarse metal does not yet produce pure copper, but purifies the copper sulphide formed during the second stage. The coarse metal usually contains

30-40 % of copper, the smelting product 65-75 %. It is called "blue metal" when more or less iron is still present, "pimple metal" if richer in copper or "fine metal" ("white metal") if it consists of comparatively pure copper sulphide (German Kupferstein: matte). In the case of very rich pyrites with a high copper content it is possible to skip the second stage and to proceed at once from the first to the third stage. Another method of achieving the same result is mixing the sulphides with carbonate or oxide ore.

At this stage the blue metal would be a product that could be



Fig 63 Roasting copper matte (after AGRICOLA, *de re Metallica*)

economically transported and traded, but usually it is refined on the spot. This production of matte is at present achieved in reverberatory furnaces which, however, were unknown in Antiquity.

The fourth stage, the *resmelting of the blue metal*, is usually achieved in a shaft-furnace (or in a modern blast-furnace or reverberatory furnace) again with charcoal and fluxes and with the aid of blast air. Now the remaining iron sulphide oxidizes and the iron oxide formed combines with the flux to form slag. The blast air further oxidizes the sulphides present and the sulphur escapes in the form of sulphurous gases, the charcoal present reduces the copper oxide formed to copper. Apart from the copper and slag produced a small quantity of unreduced matte forms an intermediary layer in the furnace and it is returned to the third stage. The copper produced is called "coarse copper" or "blister copper" and contains about 95-97 % of

copper with the following impurities: gold, silver, iron, lead, arsenic, antimony, nickel, cobalt, zinc and tin in varying quantities but in too large a percentage to use this copper as such. The coarse copper also called "black copper" (Schwarzkupfer) is then refined. Some of the impurities like gold and silver are valuable, sometimes even dominate the economy of copper production in such a way that they are the real cause for the treatment of the copper ores and copper itself only a by-product. On the other hand black copper is an easy form of copper to transport and to trade and it did form an object of early trade as many of the slabs or cakes of copper found in classical and pre-classical times are no other than black, unrefined copper, to be refined by the local smith.

The fifth stage, *refining the black copper*, requires considerable skill. The undesirable impurities are removed by a combination of oxidation, slagging and volatilisation. The black copper is heated and oxidized by blast air, agitation of the molten metal being aided with iron rabbles. This "flapping" is continued until about 6 % of copper oxide is formed in the molten metal. At that moment the iron, zinc, tin and cobalt and the traces of sulphur are almost completely removed in the slag, the "sett copper" produced contains the silver and gold present in the ore as well as traces of arsenic and nickel. It is now necessary to reduce the copper oxyde present (which would only embrittle the copper and render it useless). This is effected by "poling", that is forcing green logs or trees under the molten metal. The wood reduces the oxyde formed and the product is called "touch-pitch copper". This last step is very delicate as it is easy to refine the copper too long, causing the copper to absorb the gases evolved by the wood and producing "over-poled" copper. The refined copper is now from 98 to over 99.5 % purity dependent on the percentage of precious metals present.

As we shall see it is quite possible that the Romans understood the principle of refining by "pooling", but in earlier ages refining was certainly conducted by melting the black copper with charcoal over a crucible or in a charcoal fire with blast air.

If the percentage of precious metals is worth while extracting the black copper is alloyed with lead and the alloy liquated. Liquefaction, an important process for the refining of lead, is effected by heating the leadbearing alloy between the melting point of lead (which is low) and that of the alloying metal (in this case copper with a high melting point). The lead then sweats from the alloy and at the same time

extracts those impurities that are very soluble in lead among which the precious metals are prominent. The extracted copper can then be refined as described above. Complicated as this procedure may seem, it will be seen as we work our way back down the ladder of ages that each of the stages described is essential and can not be left out. It will be clear that what could be accomplished forty years ago in five stages could not be achieved by the earlier metallurgist in so short a time; he had to use either more stages and therefore a still more complicated flow sheet or else he had to sacrifice efficiency and extract a smaller



Fig 64 Liquefaction of crude copper (after AGRICOLA, *de re Metallica*)

percentage of the copper present in the ore and leave more copper in his slags. In fact, if the earlier processes may seem simpler they were so at the expense of efficiency. Now if we turn to the processes known to AGRICOLA (1550 A.D.) we find that he already treats sulphides as fully as we should wish. He mentions different forms of initial roasting and afterwards describes methods of crushing and washing the ore. This crushed and roasted ore is then again roasted, washed with water to remove the sulphurous acid formed, crushed and re-roasted until it has undergone seven roastings. Then follows smelting in a shaft-furnace with open hearth so that the black copper produced, the matte and the slag constantly flow from the furnace in this fore-hearth and a second one in which slag and matte can be removed from the black copper after cooling a bit. The shaft-furnace allows constant refilling and it is an improvement on earlier furnaces.

Now AGRICOLA states that all ore whether copper-coloured, lead-coloured, malachite, azurite, brown or black is smelted in the same furnace, that silica is added as a flux and that after three smeltings, the product is broken up and roasted three times to be resmelted to give black copper. Only the malachite and azurite give black copper after just one smelting. For liquation of gold and silver the black copper is alloyed with the lead in a special furnace (Frischofen) and liquated in another (Saigerofen), the lead separated (Saigerblei) and the remaining copper (Kienstöcke) refined. The liquated copper is then heated without melting in a special furnace to remove the remaining lead in the form of lead oxide. This process is called "Darren" and the refined copper bars ("Darrlinge") are now melted in a special furnace (Garherd) with charcoal and blast air over the surface of the molten metal, which is pooled after the slag has been removed. The refined copper is called "Garkupfer" by AGRICOLA.

His contemporary, BIRINGUCCIO, does not describe the earlier stages of these complicated methods very clearly but he goes in for more details when he comes to the refining of copper.

An earlier handbook, the *Mittelalterliches Hausbuch* of 1480, gives the earliest picture of a complete copper refinery. Here we see a shaft furnace with a hearth in which the ore after roasting and crushing is smelted, the matte is then enriched in a second shaft furnace, the black copper alloyed with lead in a "Frischofen" and the alloy liquated in a fourth furnace (Saigerherd) by surrounding the blocks with glowing coals. The copper is refined in a "Darrherd" and a "Garherd" in the way of later generations except that no current of blast air is pictured in the last furnace to slag the traces of impurities, which is no doubt a mistake of the artist.

Going back to the tenth century A.D. we find a short description of the production of copper (108) from a special lead-bearing malachite or oxydised copper ore. After handpicking it is roasted "like lime" (chapter LXII) whereby "the ore does not lose its colour but only its hardness and then can be crushed". It is now smelted in a furnace at fairly low temperature with blast air and the liquated lead flows off with the gold and silver. The copper is collected and THEOPHILUS (108) now goes on to describe the refining in a crucible. He fills a iron, clay-coated crucible with copper and charcoal, embeds the whole in charcoal and heats the crucible with blast air, part of which blows over the surface of the crucible. If after heating long enough the molten copper collects in the crucible, some ashes of coal are thrown in and

by stirring with a piece of wood the slag is made to adhere to the ashes and can be skimmed off. The copper is then cast out and hammered. If it is still brittle, refining should be repeated, if it remains "healthy" it is cooled in water. This description is always thought to contain the earliest reference to pooling.

We now reach the classical authors who are not very clear in their descriptions of the refining of copper. GALEN gives a short description of the smelting in a shaft furnace with charcoal and blast air. PLINY does not mention the washing and crushing of the ore, its roasting, etc. before the alloying with lead-bearing fluxes and most of his passages referring to the refining of copper are very muddled. It is at least clear that charcoal, sometimes of special plants, was used to smelt copper ores (THEOPHR. *hist. plant.* V. 9. 3.; THEOPHR. *de lapid.* 16; PLINY (*Nat. Hist.* XVI. 23). TÄCKHOLM (106) points out that DIOSCORIDES (V. 75) describes a "two-storied" furnace working with blast-air, which may be the type that PLINY describes in rather a loose way (XXXIV. 100). A furnace depicted on a vase in the British Museum is very similar to this Cyprian type. The Berlin vase reproduced by JAHN does not picture a smelting furnace as formerly supposed, but forms part of a casting equipment. These double furnaces had a lower narrow part to be filled with charcoal while the ore was filled into the wider upper part. We find similar furnaces in Africa (VON LUSCHAN, *Z. f. Ethn.*, 41, 1909, p. 37) and this type was found in the mining district of prehistoric Tirol (Schmaltal, Tarxdorf). There is no doubt that these furnaces permitted continuous smelting as their long use proves, they must have worked with a forehearth in which slag and black copper were separated. Shaft furnaces of early date were found near Mitterberg and in the Roman mines of Populonia and Rio Tinto furnaces of the "bloomery fire" or "Catalan hearth" type common in the production of wrought iron seem to have been used for the smelting of copper ores, or may be the refining of black copper. Better suited for this refining process is the "camera", a cupola furnace like the pottery kilns described by PLINY (*Nat. Hist.* XXXIV, 101) which was also found near Salzburg and in Lorraine and which is far better suited to reach high temperatures and to melt copper. It seems from the few remains that have been inspected by experts that the Romans enriched their ore by handpicking until it contained about 5 % of copper as a higher percentage would give a high loss of copper in smelting. Roasting seems to have been carried out on beds of stones or loam. Several of these

covered with copper slags have been found at Mitterberg and Roman practice does not seem to have differed.

The fluxes used in smelting depended of course for a great deal on the impurities of the ore to be smelted. In Cyprus the Romans used a flux with a high manganese content, in Rio Tinto different forms of quartz, in Thasos lime has been used. The matte recovered in the last of the two smeltings commonly executed was returned to an earlier stage and also played the part of a flux. It seems that this was already understood by the early prehistoric smelters of Mitterberg. After the double smelting refining of the black copper followed, perhaps not only in some type of furnace, but also in crucibles. In a passage of his Natural History (XXXIV. 94) PLINY says: "At Capua it is melted by a fire but not of coals but of wood, poured into cold water and cleansed by means of a sieve of oak." BAILEY in commenting on this passage (6) suggests that *cribo* stands for *ligno* and that PLINY really meant to describe pooling, which would make this the earliest passage. The purity of Roman copper would allow this supposition. It is hardly possible that the Romans got 25 % of copper out of their ores in Spain as DIODOR (V. 36) and STRABO would have us believe. No exact analyses of Spanish-Roman slags are available but the Roman slags from Dacia often contain up to 50 % of copper! The Romans were certainly the first to work sulphidic ores generally. Most of the Roman copper in trade or refinery hoards consists of copper which by the peculiar structure and the surface of the bars and cakes together with its sulphur content can be shown to belong to copper prepared from sulphides. This form of black copper seems to have been the regular trade quality, though we do also find smooth, sulphur-free cakes of refined copper.

DIOSCORIDES and PLINY give many passages referring to the medicinal uses of the byproducts of copper smelting and refining. Roman copper was often intentionally alloyed with varying percentages of lead "to make it pliant and giving it a pleasing hue" as PLINY says (Nat. Hist. XXXIV. 94, 96, 97, 98). In the same passage (XXXIV. 96) he says: "In Gaul they only roast twice, though the quality of the metal depends to a very great extent on the frequent repetitions of this operation." For small quantities of refined copper for medicinal use roasting with coals and honey is mentioned (Nat. Hist. XXXVI. 137). PLINY also recognizes several qualities of refined copper, which he describes in another passage (XXXIV. 94): "We shall now turn our attention particularly to the different kinds of aes and their com-

position. Cyprian aes comprises crown-aes (*aes coronaria*) and bar-aes (*aes regulare*), both of which are malleable. Coronaria is beaten into leaves and dyed with oxgall to make imitation gold for stage crowns. Both bar-aes and aes caldarium are manufactured in other mines also, differing in this that aes caldarium is brittle and can only be cast, while bar-aes is malleable some, therefore, give to the latter and indeed to all Cyprian aes the name ductile." BAILEY explains this passage thus: "Heated copper cooled slowly becomes brittle, if cooled



Fig 65 Smelting copper in Old Japan (after GOWLAND, *Metals*)

rapidly malleable and ductile." It seems that the *aes coronaria* is sheet-copper, the *aes regulare* normal malleable refined copper and aes caldarium either the more impure black copper or perhaps cast copper containing some zinc. Far more analyses of Roman copper would be required to make sure that a special quality of copper was made for casting purposes. As already explained most copper was immediately alloyed with lead, tin or zinc.

Before tracing back the earliest refining processes and their development it will be valuable to review some of the primitive processes still to be observed in other parts of the world and to mention some of the results of investigations into the methods used at Mitterberg and other prehistoric smelting sites.

The Chetri in India crush the sulphidic ore they have gathered, mix it with cowdung, dry these balls and roast them. The roasted product

is then smelted in a furnace built up of rings of fireclay in which alternate layers of charcoal and roasted ore have been filled. The slag of iron production is used as a flux (5). The gypsies use very similar methods and apparatus, but they refine old discarded pieces of bronze, brass and copper in graphite crucibles, which is clearly a later acquisition and does not belong to the traditions of smithcraft exported from their original home in India.

The natives of Persia (109) roast their sulphidic ores after hand-



Fig 66 Removing the copper from the smelting furnace (after GOWLAND, *Metals*)

dressing in a cone-shaped mud furnace about 7' high with airholes and a door for drawing the roast product. This roasting requires about 35 % of fuel. The smelting of the roasted ore is effected in a small blast furnace about 9" in diameter and 18" deep.

The Japanese used very primitive methods until lately (53, 55). Roasting and smelting their ore in a simple "hole in the ground" clay-lined furnace with the aid of blast air from handbellows (*fuigo*) or footbellows (*tatara*). The copper is desilvered by alloying with lead and liquating. A bowl-form refining crucible made of clay and chopped straw is used for refining. The cakes produced from the smelting furnace are 8-10" in diameter and 1½" high, they are broken by fracturing the cake near its solidifying point as is proved by the "columnar" structure of these lumps. To get a brilliant coloured copper

0.1—0.2 % of lead are added. GOWLAND correctly calls them "Bronze Age methods" yet as he says with this simple furnace all the copper, lead and tin required in Japan were produced as late as 1884 when the production of copper was no less than 8816 Tons!

The negroes of Katanga have more complicated methods than the Japanese. The Basanga clan who hold the secret of working the copper ore, extract the malachite from shafts dug into the soft siliceous dolomite. The ore is crushed and washed in streaming water in the way gold is "panned". Two furnaces of 3' diameter and 5' high are used for roasting and smelting. Charcoal from hard wood is used for smelting. The furnaces built up of termite-cones in half an hour and propped with branches are filled with 3" of charcoal and billets of wood. These are ignited, charcoal is filled on top of them, a layer of ore added, then charcoal again until the total charge of 80-100 lbs of ore is charged. After 1½ hour the dehydration and roasting of the ore is finished, the charcoal is consumed and now fresh charcoal is added and the bellows are worked to reduce the matte to metal in about ½ hour. First ritual water and bits of the bark of six sacred trees are added and many incantations are chanted throughout the work. When the work is finished the furnace is broken up and the lump of copper is detached from the hearth by a few strokes of a hammer and cleaned by scraping. About 60-70 % of the copper in the ore is recovered and in the whole period of less than 2½ hours 24-28 lbs of black copper are produced. Refining is now carried out by breaking up the cakes and mixing them with charcoal in crucibles made of termite cones. The crucibles are heated in a furnace and ingots of 4-6 lbs could be made from each charge, but generally the copper is cast into X-shaped moulds into ingots of 25, 50 or 100 lbs. Characteristic for their work is the lack of a proper basic flux for the silicious gangue of the malachite, whereby the efficiency of the process is less than possible with more suitable methods.

The prehistoric refineries of Mitterberg, Bischofsofen and others have been studied in detail (47, 63, 127). The pyrites worked in Mitterberg sometimes contain from 20-40 % of copper but the average is about 12 %. The roasting was conducted in heaps of ore and fuel. Further smelting furnaces were constructed of slabs of slate smeared with clay. The oldest furnaces had already a fore-hearth to avoid stoppage by the settling of copper matte under in the furnace in front of the tap hole. In the earlier furnaces we find one temporary fore-hearth, later two are built together with the furnace. In the fore-hearth

slag and matte were separated. The smelting was conducted in three stages, the first to produce a copper matte of 30-40 % copper content, the second to make a blue-metal of 65 % copper, then a third produced a black copper of 95-96 % copper. The black copper was then refined but seldom on the spot as the ingots and cakes found have only 94-97 % copper and the commercial product seems to have been black copper.

It will be noticed that even in its simplest form which does not seek any efficiency of extraction of the metal from the ore, the operations consist of a series of roasting and of smelting followed by refining. Sometimes it is possible to combine these operations in one continuous smelting but always at the cost of efficiency, and always the two distinct phases of roasting and smelting remain traceable when sulphide ores are worked. It will also be noticed that even when working such simple ores as malachite fluxes may be necessary to slag the gangue.

In retracing the steps which led primitive man to work native copper and copper ores these primitive methods are of great help and we must also draw on the practical tests made by GOWLAND, COGLAN (25), and WITTER (124). The latter's work should be especially noted for the careful and scientific way in which he retraces the bases and evolution of copper metallurgy in Central Germany and the correct and inspired application of modern research to the ores and copper objects discussed. COGLAN's paper is of outstanding importance because he has for once repeated and improved upon the experiments of GOWLAND and he has placed the theories on the origin of copper metallurgy on a firm base.

WITTER, who was not yet in possession of COGLAN's dates, drew a table of the different stages of copper production, which we have amended (page 324)! It would then seem that we must distinguish five stages of evolution, which were already discussed when we tried to solve the mystery of the origin of metallurgy in general (chapter II).

The earliest stage is the *shaping of native copper*, which we fixed tentatively in the sixth of fifth millennium B.C. When looking for gold in the beds of the mountain streams the prehistoric prospector noticed larger lumps of dark stone which when hammered looked like gold. The native copper looks like purplish-green or greenish black nodules, which once scratched or rubbed show their yellowish-red kernel of pure copper. However, not all forms of native copper would be useful, for though native copper is a soft metal and as found in

nature unfit for tools, it can be shaped and hardened by hammering. The massive lumps, however, are very tough and hard to work, because they embrittle by hammering, and the spongy form is naturally brittle. But the thin plates and arborescent growths of native copper are useful and they are found in relatively large quantities in Cornwall, France, Hungary, Central Germany, Russia, Ankara, Arghana and the Semnan district of Iran near Damghan, and also in the Ural mountains, the Altai and Pamir ranges. This native metal was soon worked by hammering, cutting, bending, grinding and polishing, which means that prehistoric man applied all those operations which he also used in fashioning objects from bone, stone and fibres. Therefore he still remained a Neolithic artisan and he had not yet become the first smith to herald the dawn of Metal Age. Objects of this type fashioned from native copper are found at Badari in Egypt, in Vinca I, in the Danube valley, in the earliest remains of Asia Minor and Palestine and in the few copper remains of the early pre-Sumerian marsh-dwellers of Mesopotamia.

Annealing native copper that is alternately heating and hammering native copper was the next step, a discovery that may be dated about 5000 to 4500 B.C. Copper until then had no advantage over gold, it could be used for small ornaments only, but by annealing it was possible to shape it into further forms without making it too brittle and to use the frequent forms of native copper which hitherto had been excluded from use. How this discovery was made we do not know. It may be that primitive awls were heated to assist penetration, that a lump of copper dropped into the fire and its better malleability was then discovered, or that prehistoric man applied the "heat-test" which remained so common with unknown or less useful substances in early technology and science and still forms the readily applied test of the youthful dabbler in chemistry. Anyhow by making the metal soft in the fire and by hammering which sequence of operations could be repeated ad libitum the first smith could avoid to embrittle the copper object and fashion it after his taste far easier than hitherto. Especially the larger lumps and nuggets which require annealing in order to avoid the formation of cracks could now be worked and smaller lumps could be forged together to some extent. It can be truly said that this discovery meant the birth of the smith, who thus preceded the first metallurgist, who reduced ores. Annealing was an achievement known to the early agriculturists. Further analyses of early copper objects are urgently required to make it possible to review

the extent of this phase. It is fairly easy to prove that a certain object was made of native copper and how it was worked. Not only is native copper very pure but also only few impurities are known to occur in it, viz. gold, silver, iron and sometimes antimony. Hammered native copper has a peculiar "twinned" microstructure, cast pieces show the typical "cored" microstructure. Thus it was possible to prove that an Hungarian axe-hammer of about 1700 B.C. which was thought to consist of hammered native copper, really was native cast copper (25).

Reduction of oxyde and carbonate ores together with the next stage, the melting and casting of copper form the beginning of the true Metal Age and the start of industrial copper metallurgy. It was formerly generally thought that the casting of copper preceded the reduction of ores but COGHLAN's experiments have proved the contrary. Once it was discovered that the application of heat made the red stone more useful than the yellow gold the value of this red stone must have been greatly enhanced, it may have been considered even more valuable than gold, as it still was in early historic times in some regions. Now the search for further supply must have led to the finding of other green and blue stones, which did not become red by rubbing only, they had already been used as an eyepaint or for glazes and their reduction achieved in the pottery-kilns must have been a logical extension of the "heat test" so often applied. COGHLAN proved that the favourite camp fire theory was untenable as the heat in camp fires does not exceed the reduction temperatures of the oxydes and carbonates of copper which are fairly high ($700-800^{\circ}$ C), though the campfire was hot enough ($600-700^{\circ}$ C) to achieve a maximum annealing effect of native copper. In the pottery kilns then well known as is proved by the wellbaked prehistoric pottery of Egypt, Mesopotamia and Iran the high temperatures required for the reduction of the ores as well as for the melting of copper (1085° C) could be easily reached. Ground ores mixed with charcoal heated in such kilns give a perfect regulus of copper. The later way of reducing ores was to heat the ores mixed with charcoal in a claylined hearth of furnace with the aid of blast air. The primitive "hole in the ground" furnace so often mentioned by GOWLAND would not do the work without this blast air, and therefore the construction of furnaces for the reduction of ores presupposes the knowledge of forced draught, which is one of the outstanding principle of a good pottery kiln. The furnaces with natural draught used in Derbyshire until the XVIIIth century and the primitive furnaces with air-pipes built in to encourage this draught all

show that the users were quite conversant with the idea that blast air was necessary to reach the high temperature required which could not be attained in an open fire alone.

The development even of this simple furnace must have required many years during which some form of crucible melting in a pottery kiln must have been used. The early furnaces were small and the amounts of copper produced can be measured by weighing early copper ingots or cakes which are something in the way of 140-160 grammes, that is sufficient copper for one tool only. It was only by gradual experimenting that the early metallurgists hit on the idea of filling up the furnace with alternate layers of charcoal and ore thus increasing their production. The earliest reduction experiments were not as easy as they looked, for the first product of primitive smelting does not look very encouraging, it is a spongy mass of incompletely fused metal still containing cinders and extraneous matte and not like the beautiful red regulus which crucible smelting in a pottery kiln would yield. Reheating and hammering liberates the cinders and bits of unreduced ore and a lump of unrefined black copper is obtained which can be refined by returning it to the fire and remelting it. The size of prehistoric ingots of somewhat later date than those mentioned above point to a hearth of about 1' diameter which would give the ingot a diameter of about 8-10" and a height of 1½". Lining the furnace was another refinement for such a clay lining would tend to keep the copper purer. It would also seem that very early a distinction was made between the smelting of the ore in a furnace and the refining of the black copper obtained for which reduction in crucibles still remained common.

The peculiarity of early metallurgical crucibles is the effect of heat on side and rim only. This points to the heaping of charcoal and black copper over the crucible and either heating it in a kiln or heaping a fire around it and increasing the temperature with the aid of blast air from a blow pipe (as is still common among negroes and as we find depicted in Egyptian tombs) or from bellows. We know that the blow pipe was used by early prehistoric metallurgists because we have found the clay nozzles or balls with which the end of the blow pipe was protected against the effects of the fire, but we do not exactly know the date of the earliest bellows. The earliest picture of bellows occurs in a Theban tomb of the New Kingdom and it has often been said that bellows were invented around 1580 B.C. but from the look of these first bellows they must have quite a period of evolution behind

them, thought it is still impossible to fix a further date for their inception. Clay nozzles for bellows have been found in many Late Bronze Age sites in the Near East and in Europe.

Melting and casting copper, that mysterious cycle of melting, casting and solidifying, must have followed the earlier discovery of the transmutation of the blue and green stones into the red tough metal very closely. It is probable that both inventions took place and spread rapidly in years from the AIUbeid period to the Uruk period, so about 4000-3500 B.C. The possibility of thus remoulding old tools which had become unsuitable must have led to the recasting of many of them, as the copper was still an expensive and valued material. This may account for the disappearance of many implements originally made of hammered native copper and the comparatively rare finds of stage II. This is quite plausible in view of the many battered and broken implements found in founders hoards. Crucible melting was probably known from this time as we argued from the earliest method of melting shown by the crucibles found. CLINE thought that the negroes adapted it to copper metallurgy from their imported knowledge of steel manufacture, but this can not hold true for the Ancient Near East. At Mitterberg it was found that the crucibles would hold about 5 to 6 Kgrs of copper. With crucible smelting go not only blow-pipe or bellows but also such instruments as tongs, etc. without which no handling is possible.

Casting also introduced new methods of forming the metal or rather pre-forming it in open moulds, then in closed moulds or valve moulds, and gradually more complicated forms of casting such as core-casting and the *cire-perdue* method were evolved. The lack of a proper statistical-chronological series of analyses does not permit us to fix the exact date of the transition of this early metallurgical state to the last phase of copper metallurgy, the *smelting of sulphidic ores*. It comes no doubt later than the smelting of oxydic ores though WIBEL and MUCH had a different theory and the slight possibility remains that early metallurgists chanced to smelt sulphides now and then under especially fortunate circumstances. SIRET found proofs that carbonates were smelted in early Southern Spain, and in the pile dwellings remains of carbonates and silicates of copper were found near smelting sites, etc. Always in the case of sulphides we find preliminary roasting followed by smelting and refining, though the latter is often absent as the impure black copper was the common commercial product. The earlier stages when outcropping veins and lodes were worked were over

when these soon gave out due to the increasing demand for copper especially as its properties were improved by the discovery of bronze. It is difficult to fix a date for the introduction of sulphide smelting, but it is certain that this had practically completely supplanted carbonate smelting by the Roman period. The principles of roasting are connected with the production of lead and silver from galena and from the few analyses of copper known at present one would venture to place the earliest smelting of copper sulphides in the Amarna Age or thereabout. We have already pointed out the evidence of Mitterberg and other sites as to the early understanding of the different phases of working sulphides and the early evolution of the appropriate apparatus. The copper from these sulphide ores is easily recognisable in the puckered surface of the cakes of ingots, the analysis is quite like that of modern blister copper, but if only a trace of sulphur is found it is not prepared from sulphides and may belong to an earlier period.

The black copper produced was not generally cast into ingots in the earlier periods but broken while still brittle (just under the solidification point!), as shown by the columnar structure of these pieces. Later we find ingots mainly in the form of hides in the Eastern Mediterranean and in the shape of round cakes in Western and Central Europe, where neck-rings or torques seem to have been a common of barter too. Copper wire was mostly fashioned by hammering often in V-shaped grooves, it seems that the drawing of wire was in use in Egypt since the Middle Kingdom. Joining was often effected by riveting, but brazing was known to the Sumerians and soldering in different forms was very common in the East until Hellenistic times, casting-on being a Central European speciality. Much can still be learnt from a better chronological studies of copper and bronze hoards and their distribution in time and space. Four types can be distinguished, viz. *domestic boards* consisting of a few pieces of many types, *votive boards* of objects to propitiate the deity, *founders' boards* made up of old implements, cakes and ingots and *commercial boards* of raw, and half finished tools and weapons and ingots.

Before turning to the history of copper in the individual regions of the Ancient Near East we have to mention a few details on general characteristics.

Copper whether native or smelted has always a slight percentage of impurities; even refined copper contains arsenic, antimony, lead, iron, zinc, tin, nickel, silver, gold, and sulphur, of which gold, silver, iron, and antimony belong to native copper proper, the others to smelted

copper. As these impurities may amount to something like 3 % in ancient copper, they have some influence of the casting properties and the hardness, especially the silver, arsenic, antimony and nickel content. These rather impure copper types might be called "pre-bronzes", though the earliest true alloys are intentional mixes of copper with lead and antimony. These impurities of ancient copper are not always a fault of the refiner as even modern electrolytic copper still contains 0.1 % of impurities.

Many stories are circulated of lost secrets by which the ancients could harden their copper tools, but the Bureau of Mines (U.S.A.) has definitely proved that the only possibility of hardening copper is cold hammering, that is hammering at not too high temperatures (126). It is impossible to harden copper by heating and quenching like steel!

In scientific terms: hammering copper brings Brinell hardness from 87 to 135, that is more than is achieved by the alloying with the normal 10 % of tin to make bronze and it approaches the hardness of mild steel. The ancients seem to have been very conscious of this fact as the normal way of getting a good cutting edge on a tool after fashioning the object by casting and annealing is hammering along this edge. The difficulty lies in the fact that this hardness is only temporary and that the operation needs to be repeated regularly to ensure a good tool for cutting hard stones. In that case they refashioned their tool by annealing and hammered the cutting edge afterwards. This frequent reworking of tools had its disadvantages, for photomicrographs of ancient copper show that the ancients not only adopted cold-working, but also often heated their product in open fires, causing the formation of copper-oxyde, which alloyed with the copper and though initially hardening it, somewhat larger percentages will soon embrittle it. Then the entire tool has to be remelted, refined and recast (99).

The gradual evolution of copper metallurgy has been doubted by some authors who point to the widely varying composition of ancient copper and bronzes but modern analysis made it clear that these structural peculiarities may be readily attributed to the crude methods of smelting and refining and that the products grow more uniform as the skill of the ancient metallurgist grows (43). Modern research has also made it clear that there was no change or disintegration in the structure of metals even in 6000 years under normal condition except the formation of a patina and may be corrosion of the surface layers.

STAGES OF EARLY COPPER METALLURGY

A. *Shaping native copper* (hammering, cutting, bending, grinding, polishing)

B. *Annealing native copper* (heating and hammering)

C. *Smelting oxide and carbonate ores*

1) Smelting ore (in wood- or charcoal-fire over clay-lined pit with air)
 regulus ← → slag (thrown away)

D. *Melting and casting Copper*

Melting native copper or regulus from C. 1 in furnace or fire over crucible and casting into stone, clay, or sand moulds. Fashioning as under B. 1 or by hammering cold, finishing by grinding and polishing.

E. *Smelting sulphide ores*

1) Roasting the ore (to remove majority of sulphur)

2) Smelting roasted ore (with charcoal in low shaft furnace)

copper matte (copper-iron sulphide)

slag

3) Roasting copper matte

4) Smelting roasted matte (with charcoal and silica flux) (in low shaft furnace)

blue metal (rich in copper)

slag (rich in iron and copper)

5) Roasting blue metal

6) Smelting roasted blue metal (with charcoal)

black copper

rich copper matte

slag (rich in copper)

with charcoal over crucible

7) Melting black copper (with blast air in charcoal fire or refined copper)

slag (rich in copper)

8) Fashioning refined copper by casting etc. (D)

Note. The possibility of returning intermediary products of refining to earlier stages to increase efficiency has been indicated. In earlier periods of smelting such refinements were of course not yet appreciated.

The features of initial corrosion and of patina form our most reliable proof of the ancient origin of metal objects. That the characteristics of these objects vary much is also partly due to the different origin and composition of the ores smelted and may in some cases give a lead as to the origin of these ores.

It is impossible to give a reliable estimate of most ancient copper mines but in two cases a tentative figure can be given. Lucas calculated the total copper output of Egypt (including Sinai) during 1400 years at about 10.000 Tons, that is 7.7 Tons a year and the production of Mitterberg during 1200 years was 20.000 Tons that is about 17 Tons a year.

Copper is not found in *Egypt* in the Merimde culture, but it is the earliest metal as several copper objects were found belonging to the Badari culture (s.D. 30-38), while gold and silver come in s.D. 42 only. Here again copper is employed before gold. BRUNTON found in Badari graves some beads of narrow ribbon copper and a stout pin or borer, needles and a fishhook. The pins may have served to fasten the mats in the burial pit. The copper is fashioned by cold working and in imitation of the shaping of flint and bone and therefore belongs to our stage I. Malachite is already known. These early Egyptians had not long abandoned the hunting stage though they have their copper and ground celts. A lump of copper found at Qua would point to local working though there is no proof according to Lucas that native copper was ever found or used in Egypt. Still he admits that some of the Badarian beads may have been made of native copper and probably as the technique is very much like that of stage I we must wait for the proof until some of these finds have been properly analysed. In the Early Predynastic, Naqada I, or Amratian period the forms multiply and grow somewhat more complicated though still native copper seems to have been worked. We find an adze, bracelets, rings, chisels, harpoonheads, needles and tweezers in the Middle Predynastic, Naqada II, or Gerzean culture (s.D. 50-63) taking the place of the earlier flimsy tools. There is a gradual change to the metal types though only a dagger of s.D. 60 can be said to have a specific metal shape. Still the Gerzean period means contact with Mesopotamia and Susa according to SCHARFF and in the next Late Predynastic period (s.D. 63-80) we definitely reach the Metal Age of practical copper weapons and tools, flat axes, double-edged knives, harpoons, rhomboid daggers, flat tanged spearheads and a copper ferrule. The Badari copper was already supposed

to come from the North (may be from Sinai) and when after s.D. 50 the flaking of flint deteriorates and metal types begin to conquer many have thought of Asiatic influence. DE MORGAN speaks of a Sumerianised Dynastic race which came to Egypt by the way of Magan!

Recently a predynastic axe was analysed and found to have been cast of impure copper, then hammered and annealed by heat treatment under 800° C. Afterwards its cutting edge was hammered to increase its hardness (17). The copper was 97.35 % pure, the rest consisting of 1.28 % of nickel and 0.05 % of arsenic with minor impurities. This proves that by Late Predynastic times the principles of our stages III and IV were understood. By Early Dynastic times heavy axe heads, adzes, chisels, knives, daggers, spears, ornaments and household utensils show that metallurgy was then fully appreciated in Egypt. Some early Dynastic chisels consist of pure copper with 2.5 % of silver and 4.1 % of gold and this led Desch to consider them manufactured from native gold, but Lucas doubts this and points to ores from the eastern desert, which contain precious metals in the same relative quantities.

Many and wild are the theories as to how copper metallurgy was introduced into Egypt and by whom. WIEDEMANN suggests Asiatic invaders, NAVILLE South Arabian Hamites and so does BUDGE, O'LEARY and SPIELMANN claim Caucasian origin, but PETRIE more cautiously suggests "from North Syria". HALL had suggested an Asiatic origin and would look for the earliest imports of copper to Cyprus, because he held that the earliest Egyptian weapons showed a Cypriot style but, he was fervently attacked by ELLIOT SMITH (103) who claims that copper metallurgy was invented in Wadi Alaqi when mining malachite there and he adopts the "camp-fire" theory which we have already discussed and dismissed. It was shared by REISNER, BREASTED, MORET and LUCAS though the latter showed that Wadi Alaqi was an unlikely spot for the discovery as the exploitation of the ores there started much later. QUIRING was quite right in connecting the invention with copper glazes, though he thinks it was made in Egypt during the Gerzean period. LUCAS also favours an Egyptian origin as he reasons: "Unless it can be clearly proved that copper was known outside Egypt at a period anterior to its use in Egypt (which has not been done and here we find the complete evolution from the simplest object to the most complex one!) it is only reasonable to credit the Egyptians with the discovery!" We have

already pointed out that it was mainly a question of Near Eastern chronology, but the archaeological work of the last ten years has changed the aspect of the problem as LUCAS put in 1934 and we may now safely assume an Asiatic origin and claim that true copper metallurgy (our stages III and IV) was brought to Egypt by the Asiatic invaders of Gerzean culture. Thus in the long run DE MORGAN may have been right and DYKMANS (39) had no right to say that he sacrificed everything to his false god "le mirage asiatique".

The claims for an original African centre are very poor. FROBENIUS looked for a centre of metallurgy in Nubia, but even very late in historic times bronze had to be imported there! Still PARTINGTON says: "Quite likely that archaeological investigation will establish Africa as an early source of copper, but the evidence so far available is not convincing." Indeed there are even few signs that Egyptian metallurgy had any influence on negro metallurgy as we know it now and which seems a fairly recent growth. CLINE in his detailed study of Negro metallurgy states that copper came to Africa long after iron and until recently was used almost entirely for ornamental purposes as iron was far more suitable for tools and weapons. It also serves as a medium of exchange. It may be true that DIODOR states that gold was dug in the Nubian mines by means of copper or bronze chisels and that HERODOTUS states that Lybian women wear bronze ankle rings (IV. 168) like the Nubian women (STRABO XVII. 2. 2. c. 821), but on the other hand ABULFEDA states that the natives of Sofala held copper more valuable than gold and that Darfur still imported copper from the Mediterranean until late. The negroes of Katanga learnt copper metallurgy from traders (5) and IBN BATUTA mentions large imports of copper from Takadda (Agades) to the South. LEO AFRICANUS mentions copper trade by the way of Numidia and West Africa got its earliest copper from traders. It is now smelted by negroes in Transvaal, Katanga, Angola and parts of the Congo territory but copper metallurgy fades out north of Lake Nyassa. The Muslim works at Hofrat en Nahas date of the XIXth century. The claims for early contacts between the prehistoric refineries of Rooiberg, Transvaal and Egypt depend upon the correct solution of the Zimbabwe problem and there is no evidence that these contacts were so early, that one could suppose with Dart that Egypt, Elam and Mesopotamia got their ore from South Africa (27). South African archaeology is still in its infancy.

The possession of good knowledge of copper metallurgy at the

beginning of the Dynastic Period in Egypt does not at all mean that copper now had superseded stone as a material for weapons and instruments. This can easily be illustrated by studying the Egyptian weapons. Though since predynastic times daggers were made of copper and flint was dropped as a material for these arms, arrow heads for instance were still made of flint when the earliest copper arrowheads appear in the XIth dynasty and they do not become common before the XVIIIth dynasty but are quickly superseded by bronze arrowtips. Still in the Persian period flint arrowheads are far from rare. Of course this may have something to do with the properties of copper and bronze which are not always more suitable than flint or other stone for every application and in the case of arrows flint has proved to have more penetrating power than copper (125). In the Old Kingdom the king's weapons were very often still made of stone and so we find the usual stone mace-head side by side with the copper battle-axe, but often for obvious traditional reasons!

Many authors have thought that iron must have been known at an early period because it seemed impossible that the Egyptians worked hard stones like granite with copper instruments only. It is probable that this idea was initiated by WILKINSON (122) who writes: "No one who has tried to perforate or cut a block of Egyptian granite will scruple to acknowledge that our best steel tools are turned in a very short time and require to be retempered." But then steel a hundred years ago was not what it is now. Still his opinion is endorsed by such metallurgists as GARLAND. Others believe in secret hardening processes. This started already with HOMER, who said that chalkos could be hardened by quenching, but in reality it would become soft. Neither does quenching in special waters, such as PAUSANIAS (II. 3. 3) advocates, improve copper. We could cite an analogous case from the New World and stress PRESCOTT's statement that the Aztecs worked granite with copper implements and siliceous sand, if archaeology did not bring us the proofs in Egypt itself. We need only mention the actual tool used for stonecutting as found at Sakkara by LAUER. The time-element so worthless in the East is often forgotten and almost infinite patience together with hammered copper, emery or obsidian cutters and grinders and abrasive powders were probably the agents employed in achieving the stupendous results which we admire after so many centuries. Therefore the "iron or steel theory" even if supported by an expert like HADFIELD should be discarded (16).

The Egyptian copper ores are mainly easily reducible ores, fer-

rugineous and siliceous sands for fluxes abound. The main ore of the Sinai was a friable sandstone with nodules of malachite and chrysocolla (and native copper as DE MORGAN reports?), which by crushing and sieving could easily be concentrated. Azurite was mined in Egypt for copper and pigment of the artificial blue frit, malachite for eye-paint, mural painting, glazes but principally for copper-smelting; chrysocolla was mined both for copper and eye-paint. According to LUCAS (69) the Sinai ore contains 5-15 % of copper (sometimes up to 18 %), the south-eastern mines an average of 3 %, Abu Seyal 36-49 %, Abu Mammamîd 13 %. On the evidence of the slag heaps at Wadi Nasb, etc. LUCAS estimates the output of the Sinai mines upto the XIIth dynasty at 5500 Tons of copper. The slagheap at Seh Bab points to 13-25 Tons of copper, at Kubban 12 Tons. Taking into account that the imports from Asia began to pour in and mining at Sinai stopped the total for Sinai may have been 8000 Tons, that of all the Egyptian mines 10.000 Tons by that time. Though this figure seems small we must not forget that this was the entire world's production in 1800 A.D.!

Kubban fort was not occupied before the XIIth dynasty and therefore mining there is unlikely for earlier periods. On the other hand no tribute of copper from the South is mentioned in Egyptian texts. The eastern desert mines were always in the hands of the Egyptians, but at Abu Seyâl it is doubtful whether any serious mining took place before the days of Seti I and Ramses II (XIXth dynasty). The copper mines there are mainly open cut workings or tunneling for strata near the surface.

There is no proof that the mines of the eastern desert or Sinai were worked in Roman times, though it remains possible that they supplied local needs. Mention is made of copper mines in the Fayum at Dionysias and Pelusium discovered under the Ptolemies on the south bank of the Birket Karûn in several papyri (BGU 197; SPP XXII, 48). It appears that they were abandoned in the Early Imperial Period to be reopened later on, for in A.D. 104 an impost is taken of 3 denaries for 72 Minae of copper. When they were abandoned again we do not know, nor do we know anything about the mines of the Thebaïis which DIODOR mentions (I. 15).

Copper was smelted as early as the Middle Predynastic period as is proved by the manganese content of a copper axe-head of that date and of metal bands of the Ist and IInd dynasty mentioned by LUCAS. This smelting at least in a charcoal fire with the blow-pipe (or

perhaps melting copper is only represented?) is pictured in the tomb of Ti (Vth dynasty). Early Egyptian copper is of course still impure, it contains arsenic, bismuth, iron, nickel and copper-oxyde as impurities. The small amount of arsenic is usually attributed to the working of Sinai ores in which this element does occur. SEBELIEN analysed an ore from Wadi Nasb which contained 21.65 % of copper and 0.45 % of arsenic (101). Still notwithstanding the often repeated statement to the contrary these small amounts of arsenic have no effect on the properties of copper. The occasional high percentages of 3-4 % do have the effect of hardening copper, but they embrittle it

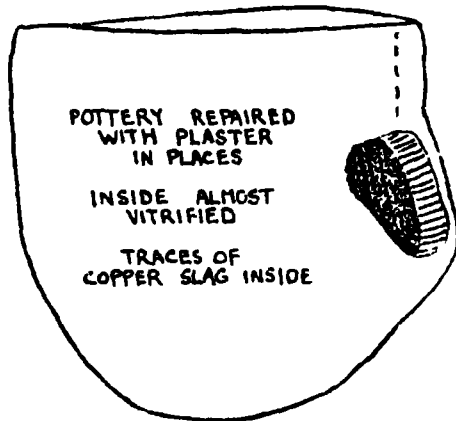


Fig 67 The earliest copper crucible, found at Qau (after BRUNTON, *Qau and Badari*)

at the same time and render the copper practically useless for cutting hard stones (48). It is true that 1 % of arsenic or bismuth has the effect of decreasing the viscosity of molten copper and therefore it facilitates the casting of pure copper, which is always a difficult job. In later periods the arsenic content is far lower, usually not more than traces which is ascribed to the working of Egyptian or Asiatic ores. The bismuth (which SEBELIEN wrongly wanted to use as an indication of Cyprian origin of the copper!) has good effect on the results of cold hammering, but the iron taken up from the flux or from the ore itself has more hardening effect than the other impurities. In general early Egyptian copper has all the characteristics of "underpoled" copper.

Casting and cold hammering of the cutting edge seems to have been the standard method of manufacturing tools and weapons. The

cold hammering was, so LUCAS thought, necessary because of the lack of proper tongs to handle heated lumps of copper! As a matter of fact a 1st dynasty dagger, a XVIIIth dynasty copper knife and a small chisel of Hellenistic date were all found to be hammered into shape cold from a cast rod of copper. Sometimes, especially at later date we find that the "cored" structure specific of cast objects has disappeared because it was annealed. For annealing was not too easy in these days. The anvil was usually but a flat piece of diorite, basalt or granite on a short foot and the hammer was usually a piece of stone without a shaft. Only in the Iron Age the shafted hammer came into use in metallurgy for now the craft of the smith was mainly the use of the hammer. It is strange that though the stone-cutter and miner knew shafted hammers as early as the Old Kingdom, this implement was not yet used in metallurgy at least we never found an example of a picture of such a hammer. Still as hammered and annealed objects are fairly frequent at this early date some sort of tongs must already have existed. Cold hammered copper sheet is often employed. The 400 M. long waterpipe in Sahure's pyramid temple is made of beaten copper without a trace of solder; ewers and basins, for instance the ewer of Hetepheres are mostly beaten copper as are parts of the large statue of Pepi I and his son. Possibly these objects were made by hammering copper on a wooden core (68). Spouts and other parts are often cast and inserted; joining by rivetting or nails are practised.

Casting is of course known and practised. Open mould casting was soon practised in stone (steatite or serpentine) moulds if the objects were meant as mass products. Core-casting using a core of clay and charcoal is practised from the IIInd dynasty onwards, but it came to the fore only when bronze came into general use, as casting copper in a closed mould is very difficult. Still parts of the Pepi statue were cast by the *cire-perdue* process (77). Examples of moulds were found at Illahun and Kahun.

After casting the hard skin was removed by grinding. We possess pictures of casting but they date from the Middle Kingdom only or later (Tomb of Rehmire, Tomb of Menkheperresonb) and in that case the closed mould would point to the casting of bronze. The colour of the cast metal is given as yellow brown and may indicate bronze as copper is usually coloured blue or red. Though the colour blue was formerly thought to indicate iron only (LEPSIUS) and red copper, it is now thought that these colours on Egyptian wall-paintings indicate objects with a patina, mostly tools by the blue colour and new copper

by red. Of course one should not use these colours as strict arguments but one must be led by colour and inscription.

Pictures of metallurgists smelting copper with the aid of a blowpipe have interesting inscriptions which have been discussed both by ERMAN (*Reden, Rufe und Lieder . . .*, APAW No. 15, 1919) and MONTET (*Scènes de la vie privée . . .*, Strassbourg, 1925). One important one reads: "It is molten, knock hard at its bottom, here is a new pot", which probably means that copper has been molten and the foreman is summoned to thrust open the clay stopper at the bottom

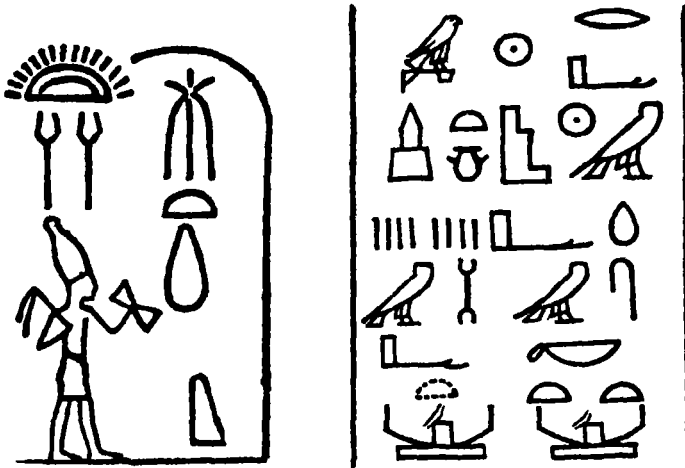


Fig. 68. Two feats of the ancient Egyptian copper workers commemorated on the Palermo stone (after SETHE)

of the melting pot to let the copper flow into a new pot. Another one reads: "Come quick to the good sight, and stirr well in the crucible", which probably refers to the refining by "poling" or some other refining manipulation in which the contents of the crucible are stirred.

Apart from the archaeological evidence there are some interesting references to two lost works of art executed in copper, which show the high skill of the Egyptians at an early date. SETHE (102) found these inscriptions on the Palermo stone:

(Recto, year 4, row 5) "making copper the king's statue 'High is Kha'sekhem-wy'"

(Verso, year 2, row 5) Re in the sun temple "Heart's desire of Re" copper, 8 ells the evening boat and the morning sunboat.

of which the first refers to a statue of the king in copper and the second to two copper boats, 8 ells long, for the sun temple of Re;

both large pieces which indicate that these metallurgists had no fear to make larger works of art in copper such as we have found in the case of the Pepi statue.

We have now to consider the Sinai mines where as BREASTED claims "autocrats set their feet on the way to aggression 5000 years ago" by becoming masters of the supplies of copper, the material for their weapons of war. No prehistoric remains were found in the peninsula by the Woolley and Lawrence expedition of 1913/14. Still

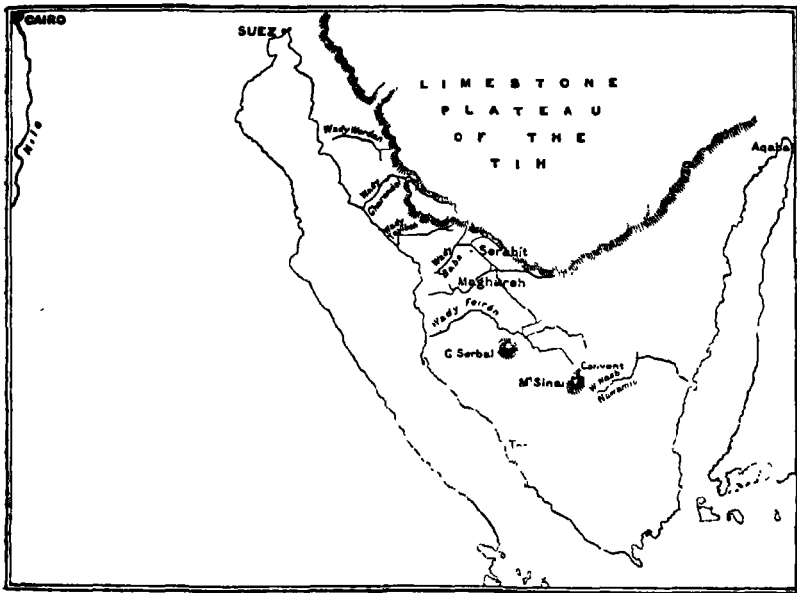


Fig. 69. Map of the Sinai district (after PETRIE)

it is possible that the mines were visited in predynastic times, though probably the malachite and turquoise were obtained from the local inhabitants, the ancestors of the Mntw of the Egyptian texts, by barter as long as these stones were appreciated as semi-precious stones. At least as early as the First Dynasty the mines became important as a source of copper ores. JARVIS' statement that the mining rights were acquired from the Mntw in the XIIth Dynasty lacks proof, but it is certain that mining in the Sinai met opposition from the local Bedawi and every expedition was accompanied by troops. Apart from the mining centres and the temples belonging to them there are no signs of Egyptian civilisation. The greatest problems were the Bedawi and the lack of water and proper fuel, though DE MORGAN states

that there was more water in ancient times. The Egyptian word for malachite, *mfk3t*, first became the name of the earliest mining district, Wadi Maghara, then it became a synonym for the whole peninsula, where Hathor was worshipped as the Mistress of Malachite in the great Serabit el-Khadîm temple. The exploitation was already intense in the reign of Smerkhet of the First Dynasty and continued throughout the Old Kingdom, though Snefru was later regarded as the great founder of the Egyptian mining there and he became a patron god of the region and gave his name to several roads and stations of the Eastern Delta. There seems to have been a break of the production between the VIth and the XIth Dynasties, the old centre Wadi Maghara has 45 inscriptions of which 22 are Old Kingdom inscriptions mainly of the Vth Dynasty and 21 date of the Middle mainly of the XIIth Dynasty. Then the most important centre seems to have been the region of Serabit el-Khadîm, where the great temple has no less than 189 Middle Kingdom inscriptions, mainly of the XIIth and XIIIth Dynasties and 83 dating mainly from the XVIIIth to the XXth dynasties. There are no inscriptions later than the reign of Ramses III (about 1175 B.C.), when the copper ores seem to have given out except in one shaft of Wadi Nasb. Fuller inscriptions giving us some details on the exploitation date from the Middle Kingdom onwards, the earlier mention the names of the kings and leaders and officers of expeditions only. It is strange to note that the expeditions to Sinai started from Upper Egypt by Wadi Hammamat and thence by sea to Sinai. The eastern desert route seems to have been difficult because of the unruly Mntw and the sea route through the Gulf of Suez was full of shoals and unfavourable trade winds.

The ores of the Sinai mines consisted of turquoise nodules in sandstone, chrysocolla, sandstone impregnated with malachite and chrysocolla (which would give a poor yield if exploited), but principally veins of malachite, containing some azurite and a little chrysocolla. The Sinai ores were not as rich as those of the eastern desert of Egypt, but the latter consist mainly of chalcopyrite, which could not yet be worked in these early days. But in Sinai the oxidation zone of the copper ores extends to a depth of 250' and thus allows the mining to a far lower level. The veins of ore vary from 2' to 5' in thickness, assaying from 5-15 % of copper, they were exploited upon a depth of 135'. In the different districts we find galleries driven into the rocks and great caves excavated leaving pillars of natural rock to support the roof. Most of these shafts are horizontal and ventilated by

vertical air-shafts. Shelters and walls across the wadis were erected to protect the miners from sudden floods. The settlements consisted of groups of stone huts generally built on a mound and encircled by walls like a kind of fort against sudden attacks by the Mntw. The mines of Wadi Maghara were the earliest, then in the XIIth Dynasty the Serabit el-Khadim region was the centre and in the New Kingdom the mines of Wadi Nasb were exploited too. Upright memorial stones and heaps of stone (gangue?) show the entrances of the ancient mines.

The amount of copper ore in Sinai has been exaggerated by some authors and LEPSIUS made the mistake of holding banks of mangan-



Fig. 70. Copper mines of Magareh of the XIIth dynasty, with huts of the miners in front (after PETRIE)

ese ore to be slags of copper refining, but DE MORGAN belittled the production of Sinai. LUCAS' conservative estimate of the total output of Sinai in the 1400 years of mining amounts to 8000 Tons and it seems that GLANVILLE's attack on these figures (JEA, XIV, 1928, p. 189) on behalf of RICKARD's lower estimate is unwarranted. The production in later centuries may have amounted to about 5 Tons per year. From the remains found in miner's huts it would seem that the exploitation for turquoise and malachite as precious stones continued after the value of these ores for copper production had been appreciated. The houses do not only contain pieces of turquoise, malachite and copper, but also great amounts of copper slag and waste scrap of smelting. Chips of copper ores, many broken crucibles and part of an ingot mould were found. The debris of the furnaces consist of double rows of stones filled in with gravel or blocks of sandstone.

The ancient slag contains upto 2.75 % of copper of which half is often in metallic grains indicating that only the oxidized mineral was smelted, the *bi3 hr h3st . f* (ore of the desert). Picks and pounding instruments, mostly of stone or flint served the miners. A few picks and chisels of copper were found and must have been used though they are too soft for mining in heavier gangue.

It must have been difficult to get good fuel for smelting purposes. The charcoal used for reduction of the ore was made of acacia wood (as BAUERMANN proved as far back as 1868) and the fuel for the furnaces must have consisted of desert plants and shrubs if not the

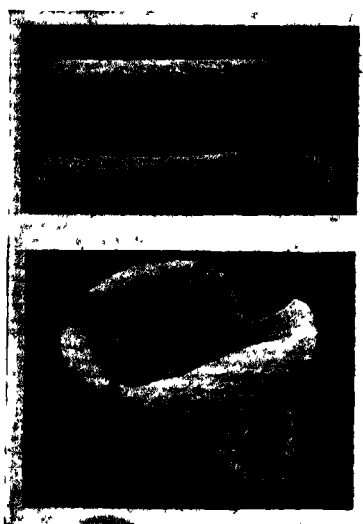


Fig 71. Copper chisels and crucible found in the Sinai mines
(after PETRIE)

roots of the high sari-grass and of the papyrus plant were used as they were in Egypt itself (PLINY, Nat. Hist. XIII, 23, 45; XXXIII, 5, 30) (THEOPHR., Hist. Plant. IV, 8.3-4). Nozzles and end-pieces of blow-pipes made of clay were found and indicate that the smelting was conducted with the aid of blast air. The crucibles were made of clay mixed with quartz sand, but were too weak to be transported and must have been emptied by tilting. Their form is hemispherical like the sign for copper in hieroglyphs. It is possible that black copper was produced on the spot and sent to Egypt to be refined, but the presence of moulds for ingots of copper would point to refining (48) (82) (116). The copper was cast in brick form, of which the sign *dbn*,

the common weight of 91 grams reminds us. The later blocks of imported copper have either the hide-form common to the Eastern Mediterranean, or the shape of round cakes. It is not known whether

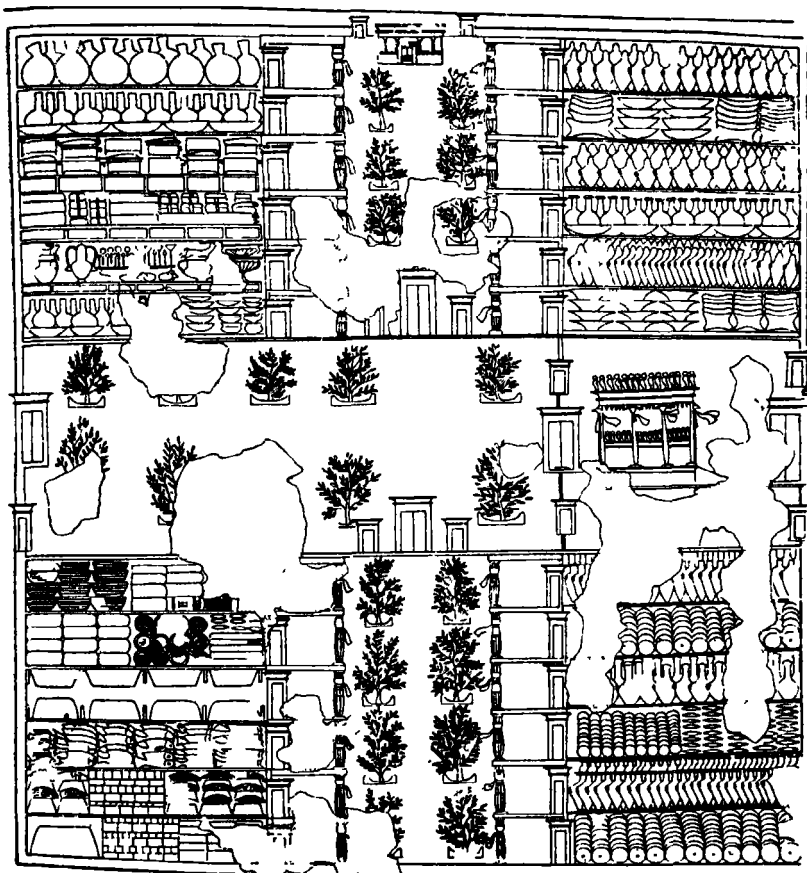



Fig 72 Ingots of copper and bronze in the storehouse of the king at Tel Amarna (see right hand top corner)

the ingots had standard weights, but this would appear from their pictures in treasure-houses.


The mining season lasted from January 15th to May 15th, thus avoiding the hot season (82). It seems that certain daily impost (*bkw*) was exacted from the miners, who according to the inscription of an official Amenemhet worked in small groups of 5 (or 15?) (AR,

I, 726). An official called Harrure left an interesting stela which mentions that this expedition arrived in the third month of the second season (*prt*), although "it was not the season of coming to these mines" for "the highlands are in the summer's heat and the mountains burn". He asks the workmen who either are already present and stay in the settlements or perhaps are old-timers and have visited Sinai more than once, whether the season would still be favourable for mining and they reply: "There is always malachite in the mountain, but the *imm* does not come in this season. We have heard the like before, the ore (copper?) did come in this season, (but) the *imm* lacked." But Harrure perseveres as his expedition had gone well up to that moment and his energy is rewarded. He succeeded better "than anyone who was here in times of old" and the copper "left nothing to be desired, the *imm* was good, a treat to the eyes and the product was better than in the accustomed season".






Now the word *imm* () used in this text means "skin" and is also used in the meaning "outward appearance". There are two possible explanations of this otherwise unintelligible text. For the first explanation we should remember that many primitive tribes still add certain substances to the smelting furnace without which the proper metal was not thought to form itself from the ore. The negroes of the Katanga region for instance sprinkle the empty furnace with ritual water and add to the ore and charcoal six bits of bark of certain sacred trees. The *imm* in our text might therefore refer to the bark of certain plants or trees which was added to the smelting furnace but which was not in the proper "magical" condition in summer. There are also several traditions which allow a second interpretation. Some African tribes such as the BaLuba and others believe that the smelting furnace should never be placed in the sun, especially not in the full heat of the summer sun, and the copper should always be run into the mould in the shade as otherwise the copper would blister. It is possible that there was a similar Egyptian tradition which said that copper, reduced in the heat of the summer sun, would have a bad skin and not the usual hard skin (a thin oxide layer on the surface of the cast copper) which after removing by grinding would reveal a beautiful bright copper.

In charge of these expeditions we usually find a high court official very often connected with the treasury for instance the *iry 't n pr . hd* (official of the White House) of *wr pr . hd* (chief of the White

House) or often *sd3wty* (sealbearer). Such are the leaders of expeditions of the XIIIth dynasty, Khnemsu, Harnakht, Sebekdidi, Ameni, Sebekhirhab, Ptahwer, Amenemhet, and Harrure, who erected stelae in the Sinai region. They command chiefs of transport and their sailors, generals with their troops, scribes, guards of the storehouse, etc. The mining staff consists of prospectors, collectors, controllers, copper-smelters (*hmty*), foremen of 45, and the common labourers. It would seem that all these expeditions were state affairs and that


bi3, hmt (?)
"Erz", iron {BE(NINE)}

Determinatives for copper and bronze objects

<p>Dynasties III-V  X3 loaf of bread (t)</p> <p>XII  W13 "red earthen ware pot" (d3rt)</p> <p>XVII  N34 "ingot of metal"</p>	<p> N.41 "well full of water" (hm)</p> <p> W10 "basket" (i'b)</p>
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ḲAPOT, ḲAPWT (S.F.A.) = "Erz"

ḲOMNT (ḲAMT) ḲAPWT = Messing.    (bi3. rwd)

hmt    nm-ty = smith, artisan

Fig. 73. Egyptian terms for copper

the copper smelting of Sinai was a state monopoly, an ancestor of the later Ptolemaic monopolies.

There are still several difficulties in the reading and interpretation of the sign and determinatives for the Egyptian word copper. The word for copper is now generally read as *bi3* (formerly *tsd*) (though LEPSIUS still read it *hmt*) by ERMAN, WEILL and others, though GARDINER still wavers and gives *bi3* as the early reading and *hmt* as a later one (though solely based on the Coptic *chomnet*). The old sign with which *bi3* is written is a hemispherical pot, later in the Middle Kingdom often the "tooth" is added and still later the hemispherical pot is substituted by the "basket" sign (GARDINER, W, 10) or even the "incense pot" sign (GARDINER, R., 7) (XVIIIth and XIXth dynasties). On the other hand the old hemispherical pot is often

exchanged for the "red earthenware pot" sign (GARDINER, W., 13). In some Wadi Maghara inscriptions it is clear that the original pot was a picture of the melting crucible, as sometimes the small spout is still visible. The "hemispherical pot" sign is exactly like the crucibles found at Badari and in Sinai, who have the shape of a tobacco pipe without its stem. It is possible that the word *bi3* means "molten metal" and was depicted by the crucible in which it was obtained. This also means a terminum post quem for the origin of this word, as a crucible means knowledge of the reduction of ores and the melting of metals. WEILL suggested that the word *bd* (later *bt*) for crucible is related to *bi3* and was originally its nisbe-form *bi3.j* (117).

SETHE derives his reading *bi3* from the Coptic *barot*, "grown metal", "pure copper" against the Coptic *benpe*, iron, the sky-metal. From the Coptic *chomnet* he also derived the reading *hmtj* for the sign for smith or artisan. In the earliest texts the word *bi3* is determined by the small sign in the form of a drop, usually interpreted as a picture of a "loaf of bread" (GARDINER, X, 3) but in this case probably a lump of metal or a copper axe-head! It is always followed by the small circle, the determinative of metals in general, or materials in the form of grains or small rounds particles. From the Middle Kingdom onwards it is usually exchanged for the "ingot" sign (GARDINER, N, 34) to which often a luniform determinative is added in Ptolemaic times. The "harpoon" determinative occurs when the harpoon of Horus is written with the *bi3* sign.

VON LIPPMANN is wrong in connecting the Coptic *chomnet* with the Greek *chyma* ("casting") because the latter is derived from *choanein*, "to melt" and "to cast". RICKARD's supposition that the word *bi3* first meant "stone", then "copper" and then "metal in general" is unwarranted.

Two other words connected with copper were formerly translated "iron" by LEPSIUS (65). The first, *hsmn* (ERMAN-GRAPOW, II, 163), is the word for bronze that occurs since the Old Kingdom. Another word for a copper-alloy, possibly bronze or brass is the Late Egyptian *ih3.t* (ERMAN-GRAPOW, IV, 396). The following kinds of copper are mentioned, in later texts after the XVIIIth dynasty): *bi3 3tt* or Asiatic copper (brought to Egypt as tribute of booty) and *bi3 km* or black copper which is probably exactly the same as our Schwarzkupfer, black copper, which was imported in Egypt and refined there. The copper ores known to the Egyptians, that is those ores mentioned in connection with copper, are *h3bd*, lapis lazuli (which is

a semi-precious stone) or azurite (a copper-ore) and *mfk3t* (later *mfk*), malachite or turquoise, which the Egyptians do not seem to have distinguished properly.

It would seem from the texts that the home-production of Egypt began to decline or could no longer supply the growing demands of the copper industry of the New Kingdom. Hence since the XVIIIth Dynasty more and more mention is made of imports of copper from different parts in Asia sometimes as booty, sometimes as real (or may be fictitious!) tribute, but also as an object of trade. All paintings show us the Keftiu bearing hide-form slabs of copper as a tribute (or probably a well paid article!) to Egypt and the store-houses of El-Amarna show rooms full of these bars and also of bricks and cakes of copper. The Amarna letters bear witness of a lively trade in copper between Asia (Isy) or Cyprus and Egypt to which we shall revert later on. The annals of Thothmes III mention "vessels of copper and bronze" brought from Zahi (AR, II, 459, 460, 462, 490), the western coast of Phœnicia where from times immemorial a copper- and bronze-industry seems to have thrived. In a text on the tribute of Isy (Cyprus) Thothmes mentions that he received "108 blocks of pure copper weighing 2040 deben" which if taking the deben at 93 grammes gives a mean weight of about 1.75 Kgrs per block (AR, II, 493). Taking this average weight as a standard the tribute from Retenu (Syria) in general amounts to 70 (AR, II, 471), 140 (AR, II, 491), 6257 (II, 509) Kgrs. and Amenhotep II says that he took no less than 500.000 deben or 46.500 Kgrs.! Part of this booty were vessels of copper and bronze, part blocks of copper. They were used for weapons and tools, but also for architectural purposes. No less than 200 doors are mentioned in these texts and are said to be "mounted with real black copper" or to be erected of copper made in one sheet (AR, II, 45). Asiatic copper is also often mentioned (AR, II, 45, 614; III, 217, 537). Much of this copper must have originated in Asia Minor or Armenia to be worked in Syria but there is no proof that copper came from Mycene and Crete to Egypt as ERMAN claims unless in the form of objects of trade not as a mineral product of the country. In this same period bronze comes into general use and part of the copper will have gone to its manufacture. The Tomb of Rehmire shows us the "bringing of the Asiatic copper which his Majesty captured in the victories of Retenu, in order to cast the two doors of the temple of Amon in Karnak" (AR, II, 755). The great Abydos inscription of Ramses II mentions "import of God's

Land in copper" (AR, III, 274), wherever that may be. And the god Ptah blesses Ramses II on the Abu Simbel temple saying: "I have wrought thy limbs of electrum, thy bones of copper, thy organs of iron" (AR, III, 403).

Enormous quantities of copper are mentioned in the Papyrus Harris amongst Ramses III's benefactions to the gods. Over a period of 31 years Amon received no less than 2437 Kgrs. of copper, Re 291 and all the gods 15.645 or a total of 18.373 Kgrs. as "black copper, copper in vessels and scraps, black copper for balances, copper in beaten work, copper in vessels or simply copper" apart from statues in copper, doors of cedar mounted with copper and other gifts!

The story of Ramses III's expedition to the land of '3 . ii . k3 is the last reference to Sinai as a copper producing country, if we may identify this land with Sinai (AR, IV, 408): "I sent forth my messengers to the country of Atika to the great copper mines which are in the place, their galleys carried them, other on the land journey were upon their asses . . . Their mines were found abounding in copper, it was loaded by ten-thousands (of blocks?) into their galleys. They were sent forward to Egypt and arrived safely. It was carried and made into a heap under the balcony (of the palace), in many bricks of copper like hunderd-thousands, being of the colour of gold of three times (thrice refined gold)."

The Piankhi stèle mentions stores of copper at Memphis.

The smith was not a highly honoured person in Egypt, if we may judge from the Papyrus Sallier, and in the records of the Royal Tomb robberies under Ramses IX several copper-smiths are mentioned among the robbers! Still the Egyptian copper-smiths were the equal of their fellow-craftsmen in other countries and even in Roman times produced good work. In Ptolemaic times Egypt had a copper standard and the value of copper as compared with that of silver was 1 to 400 or 500 or better (in view of the high price of silver in Egypt) if compared with gold the value was about 1 to 1000. If Egypt ceased to be an important copper producing country in these late times, this was due to its gold production which enabled it to buy Asiatic copper as it did procure its silver from the north. Therefore the statement of IBN ALFAQIH (about 902 A.D.) that copper came from Egypt must be wrong unless he meant to say that Egypt had a copper-working industry.

If we now turn to *Syria and Palestine* we find that though they mined copper in the Lebanons and the Wadi Arabah, both countries

did not belong to the important copper producers of Antiquity though Syria could boast of an ancient copper industry for was not Hiram of Tyre "cunning to work all works in brass"?

Even very early remains in Palestine show the knowledge of copper. Thus for instance the cavedwellers of Southern Palestine between Hebron and Ashdod used a little copper. Between the Natufien and the Canaanitic period both bronze and copper appear together and the Early Bronze Age of Palestine may be dated about 2500-2000 B.C. The flint axes and chisels were gradually superseded by copper and bronze ones of types mostly Mesopotamian and with some Cyprian analogies. Petrie found plenty copper rings and beads in Gerar from 2000 onwards and the metal remains of ancient Lachis before 1500 are mainly made of pure copper. It is even probable that most of the "early bronzes" are really copper objects, but here further analytical material should be produced. At any rate by the Amarna Age copper and bronze had come to dominate.

There is little to guide us in the *Bible*. From the first the evidence therein is complicated by the fact the term *nēchošeth* (possibly connected with *nabāš*, to glisten) is used for copper, bronze, and brass, and thus is as ambiguous a term as *aes* and *chalkos*! Copper is said to be "dug in the mountains" (Deut. 8 : 9) or "molten out of the stone" (Job 28 : 2), but there is no further information about the art of metallurgy, which the inhabitants may have learnt from Egypt though influences from Mesopotamia have always been very strong. Furnaces were known, probably several types for some texts have the word *kur* (Deut. 4 : 20; Jsa. 48 : 10; Prov. 27 : 21), but Gen. 10 : 28 has *kibšan* and they differ from the furnace used for lime-burning mentioned in Dan. 3 : 6, the *attūn*. The bellows (*mappūab*) were known, as was the crucible (*masrep*) and the art of casting in open and closed moulds was known in later times, core casting being mentioned in Bel and the Dragon 7, where Bel is called "clay within and brass without". Though "copper" is a natural metaphor for indestructible or strong (Ps. 107 : 16; Isa. 15 : 2; Job 6 : 12) it is doubtful whether the early Hebrews worked copper mines themselves as Deut. 8 : 9. and Isa. 51 : 1 would imply. It is of course known that Israelites worked in the Sinai mines and they may have brought their knowledge to Palestine. But then, though the smith is said to work both copper and iron (Gen. 4 : 22), the Israelites were not capable of making large pieces (1 Ki. 7 : 15, 46) and at the time of the conquest we read that "there was no smith found throughout all the land of Israel"

(1 Sam. 13 : 19-20). It has been stated that "the repeated references to the purification of metals and refining from dross in the Bible are probably of Persian origin (REITZENSTEIN)" and though Mesopotamian and Syrian tradition may have played a large part too, we should not concede too much metallurgical knowledge to the Israelites. On the other hand it goes too far to suppose with BENZINGER that the Israelites never smelted themselves. Copper was abundant in Solomon's time and tradition has it that this king opened mines in Lebanon. We can not prove this but he certainly started mines in the Arabah as the recent explorations of GLUECK (50, 51) have proved. His publications contain much valuable information on iron and copper metallurgy in Edom which substantiates Deut. 8 : 9. Of the many sites we mention Ghor eṣ-Şâfi, where copper slags of the Early Iron Age were found, Khirbet el-Yâriyeh with many ruins of houses, smelting furnaces and heaps of copper slag (probably Nabatean), a large smelting site at Khirbet en-Nahaş with great quantities of cuprififerous sandstone in the neighbourhood, other smelting plants at Khirbet Nqeid Aseimer, etc. The furnaces may be ovals of 2.9 by 2.6 M. or square, sometimes with an upper and lower compartement, but most of them too far damaged to distinguish details. Most of these sites are enclosed and though GLUECK supposes that they were inhabited by forced labour as they were in Christian times, that may not hold true for earlier times and the sites may have been just protected against robbers as were the Sinai camps. At Ezion Geber (51) GLUECK found smelting of copper as one of the main activities. A plant in the North-West corner of the mound contained five small rooms with pottery crucibles still half immersed in charcoal, while the walls had flues and these "chamber" furnaces profited from the ruling strong north wind to obtain sufficient draught for the smelting.

GLUECK's story of this mining district boils down to the following lines. The region around Pheinan and down the Arabah was occupied from the Early Bronze Age to the Middle Bronze Age, the mines were worked, but this stopped from the Middle Bronze Age to the Early Iron Age and the sites seem to have been uninhabited just at the time when the exploitation of Sinai under the XVIIIth and XIXth Dynasties was in full swing. After this gap from the 18th to the 13th century B.C. the region was occupied by the Edomites and Kenites and David exploited the mines after enslaving the Edomites (1 Ki. 11 : 15; 5 : 27; 9 : 20). The exploitation was intensified under the reign of Solomon and his Tarshish ships exchanged copper for gold. Then the

copper mining languished until the country was again governed by a deputy of Jehoshaphat (1 Ki. 22 · 49-50) but the trade declined. After the revolt of Edom under Joram, it was again subjected by Ahaz but succeeded in obtaining its freedom until the disintegration of Edom in the eighth century starts a new gap in the archaeological remains which lasts until the third century B C, when the Nabateans after occupying the country start the old mining of copper, which flourishes until after the reign of Trajan, when the Arabah was no longer an important trade highway with Ezion-Geber as its port at the head of the Gulf of Akabah, but the trade was shifted from Petra

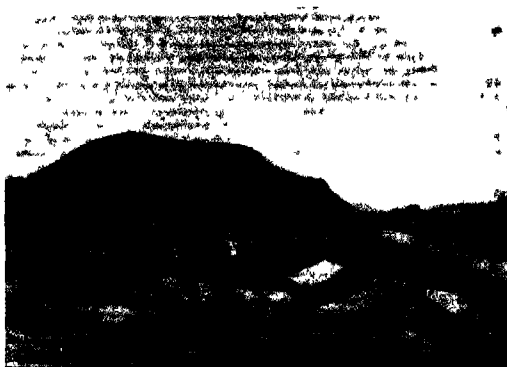


Fig 74 Smelting furnace at Kherabit en Nahas (after N GLUECK, *Explorations in Eastern Palestine*)

to Bosrâ Still the mines were also exploited by the Byzantines and the Arabs, for ST JEROME mentions the copper mines between Zoar and Petra, the mines of Phaeno in Idumea, which were worked by Christian slaves in the time of Diocletian, when the Christians were condemned to work in the metallae Still these slaves had certain liberties in the seventh century (EUSEB, *de mart Palest*, XIII, 1). More details on the methods of smelting should, however, be published after a new inspection of the remains by some expert.

Copper was imported into Palestine from the North, from Kurdistan (according to EUSEBIUS) and from the mines at Chirbet es Sawra in North Arabia. Damascus seems to have had a local copper industry of some importance (2 Ki 16 · 10). Copper is mentioned as the third metal in series of metals such as given in Num. 31 · 22 and Ezech. 22 · 18.

The importance of *Phoenicia* as an ancient centre of copper industry

has already been stressed. Copper occurs in the earliest strata at Byblos and it is common in Qatna from 1800 B.C. onwards. The ancient Ugarit (Ras Shamra) was an important centre of copper and bronze working, importing its copper from Asia and Cyprus and selling its products to the South and West, perhaps also to the East. There is no site in Syria or Palestine where so many tools and weapons have been found (38), a hoard found in 1929 contained no less than 74 pieces. From the fourteenth century onwards the influence of Mycenaean metallurgy is sensed in this international trade-centre. Though the importance of Phoenician trade has been greatly exaggerated by earlier generations (Movers!) it remains true that the North Syrian ports played an important part in bringing together the Mediterranean world and the countries around Mesopotamia, though the high-days of the true Phoenician civilisation of Sidon and Tyrus are now estimated not to have lasted longer than about 1100 upto 800 B.C.

The importance of *Cyprus* as an copper producing centre is obvious to any student of ancient history. The isle of Aphrodite is even said to have lent its name to our term for copper. It is the *Isy*, *Asy*, or *Alasia* of the Amarna letters, the *i3-r3-š3* of the Egyptian texts, the *Iainana* of Assyrian documents. Though WAINWRIGHT contented that *Asy*, *Isy*, was the Orontes and *Alasia* the coast between Arvad and the Orontes (113), the grounds for the identification of *Alasia* with Cyprus are numerous (18) and it has been proved beyond doubt by the bilinguis found at Tamassos mentioning the *Apollo alasioteas* (40) as SCHACHRMAYR showed. Some like CONDER and HÜSING identify Cyprus with the *Elīša* of Gen. 10 : 4, but this is probably Carthage (Klio, 1921, p. 230).

This would already constitute sufficient proof against the contention of DAVIES that the Cyprian mines were hardly worked in the prehistoric period (28). He mentions that Early and Middle Cypriot copper is sharply separated from Late Cypriot copper by the presence in several cases of considerable amounts of arsenic which might point to contacts with Egypt. There are plenty of signs of exploitation from the classical period onwards. But archaeology has provided the counterproof. CASSON has already pointed out that Temesa mentioned in the *Odyssey* (I. 184) is the Tamassos in Cyprus as was stated by DIODOR (V. 55) and STRABO (XIV. 2. 7). Furthermore the ingot of Enkomi with its Cypriot sign is certainly preclassical and then the large Skouriotissa mines were worked in the Bronze Age as is proved by the Mycenaean settlement of Katydhata partly over these older remains.

The early Cypriot metal forms are very primitive up to the Mycenaean period and it is thought that the island was peopled by chalcolithic tribes from the mainland of Anatolia. Metallurgy did not come to Cyprus prior to Egypt and though there were probably contacts between the island and Egypt in the third millennium B.C., there is no question that Cypriot metallurgy did influence Egyptian metallurgy as HALL formerly supposed. It is doubtful whether any true Neolithic civilisation existed in Cyprus. GOWLAND stated that the earliest copper worked there was native copper, but he brings forward no substantial proof for this statement except that the copper is very pure, which is quite in line with early smelting wasteful though it was.

Though classical tradition credited the Cyprian king Kinyras with the discovery of copper (PLINY, *Nat. Hist.* VII, 57; HOMER, *Iliad* XI, 20) we may now conclude from the variety of copper objects found that copper mining began at least in the second half of the third millennium B.C. (96). There were mines near Lithrodóna (Larnaka district), at Marion (Arsinoë) which may be the Aimar mentioned in the Medinet Habu inscriptions, and at the now largely exhausted mines in the hinterland at Tylliria. The richest mines are said to have been near Soli (GALEN, XII, 214, 219 K) (PS.-ARISTOTLE, *Mir. Auscult.* 43), Tamassos (of which STRABO says (XIV. 6. 5. c. 684) "there are abundant mines of copper in which are found chalcantite and also the rust of copper which latter is useful for its medicinal properties. . . The mines helped against the thick forestation since the people would cut down the trees to smelt the copper"), Amathus (OVID, *Metamorph.* X. 220, 531), Kurion (PLINY, *Nat. Hist.* 34, 2, 94) and Krommyon. In the opinion of Myres Marion was the headquarters of copper trade to the West from Geometric to classical times.

The earliest mines drove irregular galleries into the rocks looking for malachite and azurite and leaving the pyrites in place. But soon the sulphidic ores were worked too. Early slags contain from 0 to 3.6 % of copper, the ores worked upto 60 %. There is a great similarity between the slag of Enkomi (with 5.8 % of copper) and that found at Ugarit (with 1.9 %) and also between the by-products found at these two sites. It would seem that ores and black copper were exported from Cyprus to Ugarit and worked there as well as at Cyprus itself by the same processes (96). Chalcopyrite was worked according to local geologists, roasted and smelted. A piece of matte found at Ugarit contains 35 % of copper, the blue metal contains 84.1-87.2 % of copper, 12.7 to 14.1 % of iron and 0.2-0.5 % of

sulphur and the refined copper 98 % of copper and traces of iron, tin, lead, zinc and sulphur (0.3 %). Further analyses have proved that the same processes were used at Skouriotissa, Enkomi, and Ugarit, and that the working of sulphidic ores was therefore understood well before the sixteenth century B.C. This is very important in view of our conclusion that the working of sulphidic ores (our stage V) was well understood by the Amarna Age and then gradually became general practice until it superseded the working of oxidic ores by the Roman period. Possibly this smelting of pyrites was indeed started in Cyprus aided by the earlier smelting of galena in Asia Minor which always stood in close contact with Cyprus.

When geologists of the Cyprus Mines Corporation were prospecting (107) they found, apart from Roman galleries, shafts and slag heaps, open cast trenches in the northern hill near Apliki dated by Late Bronze Age pottery. In the houses nearby sherds, tools, tuyères and silicious rock used as flux were found. The remains of another house of the same Late Cypriot II period (1350-1300 B.C.) contained a furnace of the type found in Iron Age Megiddo, as well as slag of the common Cypriot type. A Boghaz Keui text of the same period states that "from the city of Alasia from Mount Tagatta (*alua-la-ši-ia-šum har-sag tag-ga-la-šum*) copper had been brought", which points to copper exports to the Anatolian mainland too, and a bronze stand found at Kurion shows a man carrying a hide-form ingot on his shoulders.

The Egyptian records first mention Cyprus in the annals of Thothmes III, but by the Amarna Age contacts are very frequent. The Amarna letters contain the correspondence between the king of Cyprus and Amenhotep IV (62). The earliest letter (KNUDTZON, No. 33) contains a message to the Egyptian king on account of his coming to the throne mentioning a gift of ten talents of copper already sent and promising some 200 more. The next letter mentions 100 talents of copper sent to Egypt in exchange of gold, horses, dresses, oil and timber (No. 34), and in letter No. 35 the Cyprian monarch regrets that he could not send more than 500 talents of copper but "the hand of Nergal has killed all the men of my country and so there is none who prepares the copper". The Egyptian king is asked to send the Cyprian envoy together with his and he will send everything that is wanted and pay the timber. Silver and oil should be sent to Cyprus. Fragments of another letter (No. 36) mention 80 talents already sent, 70 ready for export and 30 to be expected soon. "Now I have pre-

pared much copper for my bróther and I will collect scores of vessels." Later on the copper transports seem to have languished, but the Cyprian king assures his Egyptian friend that this is due to the Lukki, the pirates who attack the Cyprian coasts too, which goes to prove that they are not conspiring with him against Egypt (No. 38).

Since these days Cyprus remained an important centre of copper production exporting to Egypt, Syria, Anatolia, Crete, and the Aegean world. Earlier attempts to prove that this copper industry was initiated by the Phoenicians tried to derive the word *Tamassos* from a Phoeni-



Fig. 75. Cypriote bronze stand with man carrying an ingot (after CASSON, *Ancient Cyprus*)

cian *temes*, to smelt, *Tainaron* from *tannûr*, oven, and *Seriphos* from *zarphat*, to smelt, but these attempts are absurd in the light of modern archaeological evidence. The exploitation of the mines was a monopoly strictly guarded by the native kings and the Ptolemies. The Roman Emperors continued this tradition. The mines were worked under Augustus as a gift or lease to king Herod (JOSEPH., *Antiq.* XVI. 4. 5), but Imperial officials are in charge during the Empire (GALEN, XII, 226 K, 234; XIV, 7). ARISTOTLE calls the copper ore of Cyprus *chalkitis lithos*, that is copper pyrites. The earliest methods used salts as fluxes, but very early the use of ferruginous fluxes was appreciated. PLINY mentions (XXXIV. 2) that "copper was prepared from cadmea. It is prepared also from another mineral called chalcitis in Cyprus where copper was first discovered. Cyprian copper soon be-

came very cheap". But in his time already this copper was replaced in Rome by Spanish copper, where the production soon outran that of the older production centre. Still Cyprus remained important though we hear little of these mines after the fourth century A.D. though mining was continued under Byzantine rule. After a long period of neglect under Frankish rule (1192-1517) and afterwards under the Turks the mines have been reopened by modern industry.

We know nothing about early copper mining in Arabia and our knowledge from pre-classical *India* is scant too. In Mohenjo Daro and kindred sites copper and bronze occur from the lowest levels (71) (73). As copper ore is unknown in Sind it must have been brought from other regions, the nearest of which are the mountain ranges of Baluchistan, where Sir AUREL STEIN found civilisation related to the Indus civilisation, often in an earlier stage but all using copper and bronze freely, at least in the explored surface strata. The amount of lead in the copper would point to Baluchistan and Afghanistan, but such ores do occur in Rajputana too. Because the copper also has an appreciable nickel content DESCH concluded that the ore was imported from Oman, but then nickel occurs in Chota Nagpur ores too! Sometimes 2 to 4.5 % of arsenic is found probably from the working of local löllingite, a copper-arsenic ore. At Mohenjo Daro and other sites ingots, slags and remains of by-products have been found which lead us to believe that the furnace consisted of a circular brick-lined pit with a hole for the introduction of blast air, while the molten copper was run into a fore-hearth, a semi-circular depression in the ground. The ingots weighing upto 2½ lbs have a puckered surface, probably due to unequal cooling. The copper was either cast or hammered into sheet copper, the *cire perdue* process was known. Still the Indus tools and weapons show an exceptionally primitive character if compared with Mesopotamian forms of the same date. Copper axes were cast and then the cutting edge was sharpened by cold hammering. Copper plays its part in the Vedic Age even in ritual. At the dedication ceremony of a Kshatriya king the *adhvaryu* put a piece of copper into the mouth of a long-haired man sitting beside the king's hut, in order to remove evil spirits. It has often been supposed that copper objects mark the route of Indo-European invaders who had adopted earlier the civilisation already existing in the country (76). Though MITRA claims that there is no native copper in India but many places where copper and iron ores are associated, there are abundant signs of a Copper Age in Northern

India. In Southern India the Stone Age is immediately replaced by the Iron Age. The Chetri living on the foothills of the Awali Mountains of Rajputana and other primitive Asura tribes in Chota Nagpur still use their primitive methods of smelting copper from pyrites. They pound and wash the ore, mix it with cowdung and roast it, the roasting product is then resmelted with charcoal (5) (76). Still it seems that the home production of India even in Hellenistic times was insufficient, though copper was required for coinage by the Indians and ancient Indian inscriptions frequently occur on that metal. That copper often came from Rome or its dominions by the way of the Red Sea (114). The copper which the *Periplus* (28, 36, 56, 49) says was exported from Barygaza to Ommana and Apologos in the Persian Gulf was perhaps surplus European metal exported to Malabar and Barygaza and thence re-shipped by the Indians to the Persian Gulf, probably when Rome and Parthia were at war. *PLINY* too has iron, copper and arsenic as products of Carmania shipped to the Persian Gulf and Red Sea ports for marketing.

Tradition gave a very early date for the introduction of copper in *China*. The Emperor Huang-Ti (2704-2595 B.C.) was said to have opened the first copper mine, the Emperor Yü cast nine bronze tripods (2200 B.C.). But a careful archaeologist like *LAUFER* put the introduction of copper in China at about 1500 B.C. and his opinion was largely confirmed by *ANDERSON*'s excavations in Kansu where the earliest three strata were free of copper though the metal occurred in the three later stages Hsin Tien, Ssu Wa, and Sha Ching. The earliest finds are small copper objects, then more numerous objects such as winged arrow heads follow. These copper objects are dated about 2200-1700 B.C. and the whole Yang Shao painted pottery civilisation is thought to be a cultural migration from the West. *CREEL* proved that after this Copper Age the Shang culture introduces copper and bronze in general use shortly after 1400, the true Bronze Age starts after the Shang or Yin period which is the transitional period (34) as *DONO* proved by a series of analyses. As for Japan though the dolmen builders used native copper, there is no true Copper Age and copper and bronze do not come into general use before the ninth century A.D. (56).

Very little is known about the history of copper in *Persia* except for the sites that have been excavated in the last decennia. Anau I yielded copper and lead but no gold, silver or tin. *Pumpelly* states that because of its antimony and arsenic content the copper was of

Central Asian origin, but then the local ores contain the same impurities! Upto Anau III copper is found together with bronze of a variable and low tin content, very often just impure copper and no true bronze at all. Tepe Hissar I had copper, daggers, etc. have been found, Tepe Hissar II has much more copper tools or poor tin bronze, and the Tepe Hissar III objects resemble those of the Kuban valley as well as those of Mohenjo Daro. At Tepe Giyân early copper was found too, with gold and silver. It seems as if the AIObeid culture coming down along the northern coast of the Persian Gulf thrust far northwards into Mesopotamia while a wave of a similar metal bearing civilisation reached out north from the same central eastern source to Anau, Chisme Ali and other sites along the Caspian. Later these two branches of Sumerians(?) met at Tepe Giyân. In the early strata at Susa gold and copper are frequent, thin copper mirrors, axes and blades have been found. Casting was so well understood in ancient Susa that many centuries afterwards Ur-Nina sent to Susa for metal workers to carry out some work in his country. It is interesting to remember that Persia remained famous for copper and bronze work for not only have we the famous Luristan bronzes but after the Arabian conquest of Persia the Persian copper-smiths travelled far away and they are now found all over Syria, Asia Minor, along the South coast of the Black Sea in Armenia, Kerman Maghreb and Transoxania and Ferghana.

Copper ores were plentiful in Persia and even at the present time there is an important native copper industry at Kashan as there was one at Mosul at the time of the Chalifate. But even in early times ores travelled easily. Darius is said to have taken ores from Egypt and for the Persian metallurgists there were plentiful supplies in the Afghan mountains. Such long distance transports are testified by archaeology for instance in the case of lapis lazuli, the *uknu* dear to the Sumerians and Babylonians which could only be got from Badakshan or the region of Lake Baikal. But little is available as to the ores and methods of early Iranian metallurgists and this point should be given more attention by future excavators in these regions.

This brings us to copper in *Mesopotamia*. The sources of ancient Sumerian copper were the object of an investigation by the Sumerian Copper Committee. Prof. DESCH made many analyses of ores and objects for the Committee and at the outset he thought that the nickel content of most Mesopotamian copper or bronzes would lead him to the source of the ore. Most Egyptian copper objects did not contain

nickel or gold, but were very pure though sometimes they did contain iron and arsenic. As nickel is no invariable constituent in copper ores, therefore the Committee made a search for nickel-bearing copper ores as the impurity might indicate the source of the ore. Native copper does not contain nickel. Ore from Oman has the relatively high nickel content of Mesopotamian copper, but the veins are thin. Still the slag found in Oman contains no nickel which points to correct smelting. Ores from Persia, the Black Sea region, the Sea of Marmora, Cyprus, Egypt, and Sinai were shown to be free of nickel. In later reports, however, the Transvaal bronzes and ores with a high nickel content cropped up though this source is impossible for supplies to Sumer. But the sulphidic ore at Singbhum (India) has sufficient nickel and its outcrops were probably worked early. Again the Abu Seyâl ore from Egypt was found to contain nickel and though copper objects from Palestine were clearly derived from different sources than Mesopotamia, arsenical copper ores sometimes containing nickel were found in Armenia south of Lake Van and in Anatolia at Yenekoi south of the Sea of Marmora whilst the ore of Kastamouni was known to contain nickel. Such mixed ores seem to form a long band through Anatolia, Armenia, and Azerbaijan. Native copper was shown to contain no nickel but usually iron, gold, and silver. Thus after all the original theory that the Sumerians could only have got their nickel-bearing copper ore from Oman, which was supported by PEAKE (81) and BELAIEW (7), was disproved by further data, which left the whole problem as it was. The Sumerian Copper Committee now continues its work as the Ancient Metals Objects Committee (1939), but the values of its work is hampered by the fact that only short yearly reports were printed and even the Sumerian Copper Committee never published its full results with a discussion of the data to the benefit of science. Others have considered the nickel theory most hasty as most sulphidic ores are known to contain nickel and when desulphurization was known metal contaminations were produced which might have come from any ore or flux as far as modern research would be able to conclude. On the other hand it is not at all impossible that copper ores came from Oman, for as we pointed out lapis lazuli came from Badakshan and amazonite was fetched by traders from Central India and went from hand to hand until it reached Sumer. Oman also seems to coincide with the elusive Magan which was said to produce copper, diorite and dolerite as Oman does and from Magan Sargon was said to

take his copper, but then the copper mountain of Magan occurs in a late VIIth century text only (II, R, 51, No. 1, 1, 17). On the other hand the import of copper ore from the North and West was logical, the rivers offered splendid possibilities for the transport of ores from these regions. And ores were indeed imported too, not only black or refined copper, as finds at Ur and Tell Asmar show. Gudea mentions that he got his copper from Mt. Magda (probably up the Zagros river in Elam), from Abullat in the mountain of Kimaš ("from the depths of the mountains near the town of Albadh") and from Dilmun on the Persian Gulf. It would seem from the texts that in later times the eastern sources for copper ores dried up or were superseded by the mines in the mountains nearby. Sargon II, for instance, mentions mines in the mountain Ba-il-sa-pu-na, which may be Mount Segend near Lake Urmia. At any rate it proved impossible to find the sources of Sumerian copper by analytical data only for even the evolution of metallurgy is not yet sufficiently known and before this is cleared by series of analyses there is little hope to solve the other problems such as the sources of the copper ores. We must remain content with the few texts on this question.

When the Sumerians entered the valleys of Euphrates and Tigris from the East in the AIObeid they found there marshdwellers who used a few copper objects probably imported. The Sumerians were then well acquainted with copper, at Susa true metal forms are found immediately, objects were made from very pure malachite (probably selected by handpicking) and "teemed" into open moulds. Weapons and tools have been found and a tholos-shaped pottery kiln from Karkemiš indicated that the Sumerians had at this time conquered the difficulties of smelting ores and melting copper and possessed the apparatus required for such work. In the south of Mesopotamia copper objects are still rare but then excavations have not always reached this level. Still copper occurs in graves of AIObeid itself, and in the earliest remains of Lagaš, Kiš, Nippur, Eridu, etc. It is probable that Western Iran got its metallurgical knowledge from these early Sumerians whose influence spread far West and North and that this movement finally met another movement (at some later period!) which went from the original home of the Sumerians to the North-West and reached Anau and Chisme Ali first.

In the following Uruk period influences, perhaps invaders, from the North for a while thrust back AIObeid civilisation, which after a short while reasserted itself as the so-called AIObeid 2 culture, to

be subdued again by stronger forces from the North implanting a firm and strong domination of the Uruk civilisation on the Sumerians. There is a strong development of copper industry and copper now comes into general use, more difficult castings like that of the socketed transverse axe are attempted with success. On the whole the number of types of copper objects grows quickly. In this period the



Later erû = bronze and siparru = copper (Sargon II)

URUDU. SAĤAR. ĤU. LAĤ. ĤA	= si-It ĥur-ri	= native copper
(copper+dust+washed)	(what comes out of the mine)	
URUDÚ. ĤU. LAĤ. ĤA	erû mesû	= refined copper
	ZABAR ruššu	= red copper
URUDU. SAĤAR. LAL (KI, ŠU) =		= ingot or lump copper
	erû šipku (šapku)	= cast copper
ZABAR. KÙ. PAD. DA	= siparru šibirtu	= new, black, copper
URUDU. NIG. KALAG. GA	= erû dannu	= "Hartkupfer"
	gur-gur-ru = coppersmith	ti-bi-ra = his god

Fig. 76. Cuneiform signs for copper

cuneiform script was invented in its pictographic phase and as we find already signs for copper and gold in this script which was invented in the Uruk IV c stage, copper must have been a common thing in the earlier Uruk V period at least. It is also significant that these signs are written with a simple pictogram, that of copper being the picture of a copper vessel, of which there are several types mentioned already in the very early Fara texts. For bronze (ZABAR written *ud-ka-bar*; the Accadian *siparru*) a complex sign is used. It is astonishing to remark that later in Assyrian times the word *siparru*

comes to be used for "copper" while the old word *êru* (Sumerian URUDU) then denotes bronze. We can not see the reason, but it certainly confuses our translation of later texts, but in the earlier texts there seems no reason not to adhere to the strict separation of the two words. The Sumerians were much more formal in the use of names for natural objects and would hardly use a word in a loose sense like the Greeks used *chalkos*. They were well aware that bronze was an alloy, even if they did not know tin and bronze is called "what was made by the smith as an alloy" by the time of Sargon I. We can not understand LUTZ' reason for stating that ZABAR originally meant shining ore and then copper, for which URUDU was used later and ZABAR was transferred to the alloys of copper and lead (RICKARD (92), p. 165).

DE GENOULLAC (49) mentions that at Telloh copper is as common as at Susa or Uruk and as the analyses show that the copper contained some iron and tin he supposed that mixed pyrites were already worked. This is, however, not probable, as there were no traces of sulphur found and the working of small surface deposits of complex ores might easily lead to the curious analyses that are sometimes found, but there remain exceptions to the general rule of fairly pure copper. Copper, however common already, still remained a luxury good and copper implements coincide with stone and polished stone tools. Some think that a scene picturing a man blowing into a furnace with a blow-pipe is depicted on seals of this period (LEGRAIN, DP, vol. XVI, p. 31)

The following Djemdet Nasr period might well be called a Sumerian Renaissance. Copper metallurgy produces copper picks, double-axes, bowls, rings, tubes, mirrors, fishhooks, forks and socketed axes. Intricate casting of copper in animal form are attempted. This movement more or less culminates in Early Dynastic times. Then bronze seems to have come in general use as copper was already for some time. Early objects from Ur are as pure as native copper, but DESCH considers them manufactured from pure malachite. The melting and refining of copper must have been carried out with skill. No absorption of oxygen and embrittlement of the copper by the copper-oxyde formed could be proved and the floating layer of refining slag must have covered the copper in the furnace upto the right moment of casting. Not only is open mould casting known, but also closed moulds casting and the *cire perdue* process which was used for many of the elaborate copper reliefs of Ur. It often causes astonish-

ment that these early metallurgists so freely cast copper which is still considered at present a difficult job especially in closed moulds as the molten copper is so viscous that it does not flow readily into all the ends of the moulds and often sticks to it on cooling. However, natural impurities of early copper often made casting much easier than would seem at first sight. Early Dynastic finds at Tell Asmar include statuettes of 99 % pure copper cast by the *cire perdue* process and welded most professionally. RICKARD states that the casting of copper had only just begun and says that the inequality and variability of the skill displayed in castings like the recumbent Ur bulls suggest an undeveloped art, but archaeology has by now disproved his statement. Hammering cold and annealing was practised on some of these reliefs like the Im-dugud relief (86) of Ur as was found by C. ELAM and A. SCOTT. Hammering thin sheets of copper over a core was also practised. Filigrain, granulation and point-technique were well known and the skill of Sumerian metallurgists of the Early Dynastic is better and more widely developed than in Early Dynastic Egypt. Copper was already used in payments in the forms of bars, rings and bricks. Copper helmets were worn by the Sumerian army.

This highly developed metallurgy left little traces in religious texts. Apart from such poetic expressions as "Your fame may shine like glistening copper" or "Your sorrow may flow like molten copper" we do not find direct associations between metals, colours and planets as often supposed even in Babylonian times! A special god of the copper-smiths as an emanation of Ea is mentioned and though the text is late (*Bab. Misz.*, XII, 4), the legend is probably very old. The old fire-god Girru is mentioned as "the refiner of gold and silver the mixer of copper and *siparru*". A special god of copper, Nindara, who shone like it, came out of the earth where the metal is found "covered with solid copper like a skin".

In the period of the Sumerian Renaissance of the Ur III Dynasty (2300-2200 B.C.) the ensi Gudea imports copper from *kà-gal-ad*, the mountain of Kimaš (in the Zagros region), where it was dug from the mountain side (*ba-al*) and the ore was concentrated by sieving (*imi-bi mu-na-ab-pad*). After smelting the cakes of copper were transported in baskets (*ušub*). Other texts of his reign mention *urudu-lu-lah-ha*, that is copper refined by fire which serves to make bronze by alloying it with NAGGA (accad. *anaku*), a work of the smelter or SIMUG. It is possible that tin was already known and that the Sumerians mistook it for lead (*anaku*), as the Romans much later often

mistook antimony for lead. In other texts (RTC, 19 & 100) NAGGA-ZABAR (tin-bronze?) is mentioned. Three specimen of Ur III copper contained 0.78 % of lead, 1.50 % of iron and traces of arsenic, which experts considered to have been smelted from pyrites though the smelting was carried out quickly and the copper had not long remained in the furnace. This is of course most important and should be confirmed by further analyses. We have tentatively said that the smelting of sulphidic ores (our stage V) had become more common in the Amarna Age but it is quite possible that so intricate a process was developed only by many experiments and trials and that the foundation of the art was laid much earlier in imitation of the smelting of galena, which as we saw was invented in the early half of the third millennium B.C. Connections between Anatolia, where this art was developed, and Mesopotamia are particularly tight in this period, when the Cappadocian letters testify that black copper and refined copper were exported from the inland of Asia Minor to Mesopotamia, to which correspondence we shall revert presently.

Texts from Umma belonging to this period throw some light on the organisation of metallurgy in these Sumerian cities. The metal is delivered to a central storehouse (97) (AZAG AN), the purpose of which is defined in the texts by the addition "where is kept . . .". Here the copper-smiths get their orders and their material for which a receipt is written and kept. Here also the city's imports are stored. These texts range from the 34th year of Dungi to the ninth of Bur-Sin, and comprise amongst others a receipt for 1 talent of imported copper, a delivery to the smith Ur-nigin-gar, a receipt for 0.6 talent of forged copper (URUDU-KIN) and a receipt of a present of 26.5 minae of copper for the ensi. From the latter text it would seem that quantities of 10 Kgrs of copper are still worth mentioning and this warns us again not to overrate the copper production of these early times.

Trade connections with Capadocia and Syria were firmly established and Mesopotamia was then already a flourishing and well-known centre of copper and bronze industry, the Sumerian craftsmen were as famous as their Syrian brethern. In fact copper was now much cheaper than in Egypt, copper served as a medium of exchange, often in bar form and weights of metal in animal form are common too. The texts of Mari (about 2000 B.C.) mention the construction of a war chariot for the king, for which no less than 18 minae of crude copper were used. 27.8 minae of copper were used for the "statue of the king

that is to be sent to Aleppo", this copper belonged to Dagan of Terqa. Four passages in these texts refer to *erû misû -ala-šû- u*, that is refined Cyprian copper used in the palace refineries. These imports of refined Cyprian copper become very common in the fifteenth century, exports of copper and bronze to Syria are common in Mesopotamian texts since the sixteenth century.

We do not yet quite know the part played by the country of Subartu in the foothills of the Armenian mountain and the region of Lake Van, Urartu, but this is certain that these mountain regions, rich in metals, must have played a large part in the evolution of metal craft in the alluvial Mesopotamia (111). Possibly the Subarians and the inhabitants of Urartu were not only trading in metals and ores but also worked as metallurgists in Assyrian and Babylonian towns. A text of the end of the Hammurapi Dynasty (CT, VI, 25) mentions "25.3 minae of copper (ore?) that they have added for the Subarean".

Subartu, Urartu and all the Armenian mountains kingdoms play a large part in the supply of Assyria. In Assur there was a special gate and a quarter of the metallurgists. The copper of the North and West were often brought back as booty by the Assyrian armies. The Assyrian records (70) mention that Tiglath Pileser I took 180 vessels of bronze and 5 bowls of copper from the Muški and Kutmuhi (Commagene) (ARL, 222) and from Urratinaš 60 vessels of bronze, bowls of copper and great cauldrons of copper (ARL, 223). Tukulti Ninurta II received 130 talents of copper as a tribute from the Lakéan Hamataia, 30 copper pans from Harâni the Lakéan, 40 copper pans from the city of Sirku and 50 copper vessels from the city of Katni (ARL, 412). Assur-nasir-pal took vessels of copper from the land of Kutmuhi, the city of Katni and vessels, cups, dishes and a great hoard of copper from BitAdini (ARL, 443), vessels of copper from the land of Hanibalgat and the land of Nairi (ARL, 447) and bowls, cups, copper utensils and a copper wild-ox from the land of Zamua (east of the Tigris (ARL, 454). Also "at that time I received copper, tabbili of copper and rings of copper from the land of Sipirmena" (ARL, 456), from the land of Kirhi in Kutmuhi (ARL, 460) and as a tribute of Ahuni of the land of Adini (ARL, 475), whilst the tribute of Sangara king of the land of Hatte (the Hittites!) consisted of wild-oxen, vessels, bowls and a brazier of copper together with 100 talents of copper (ARL, 476).

Shalmaneser II received a tribute of copper from Hattina, from

Sûa the Gilzanite and Karparunda of Hattina (ARL, 585, 589) and again "from . . . of the Hattinites 300 talents of copper and 1000 copper vessels, 90 talents of copper from a prince at the foot of Mount Amanus, and from Sangara, prince of Karkemiš 30 talents of copper" (ARL, 601).

The booty of Sargon II taken from the temple of Khaldia in Musasir was no less than 3600 talents of crude copper, 25.212 shields of bronze, great and small, 1.514 lances, 305.412 daggers, 607 basins, all of bronze" (ARL. II. 173) together with many undefined objects of bronze.

These few quotations will go to show the enormous importance of these regions for the copper supply to Mesopotamia. The Assyrians themselves were as skilled in bronzework as the Sumerians, from the monuments we know that they were able to run vast quantities of molten bronze into a single mould.

The importance of copper trade is also shown by the records of a Babylonian banking-firm, which deals in gold, silver, copper, bronze and lead, but not yet in iron (1395-1242 B.C.) (CAH, I, 566).

Here again, though bronze and iron are available, the use of copper weapons continues into the Persian period.

A few data are also available on the prices of copper in different periods. We have mentioned that it served as a medium of exchange in the form of rings, blocks or cast animal figures which were at the same time weights. In the Sumerian period Telloh texts give a silver-copper ratio of 1/240, Singašid states that he fixed this ratio at 1/600-700, which is too good to be true (2000 B.C.), as the ratio of Hammurabi's period is 1/120-140. The earlier Dynasty of Agade (Sargon I gives a ratio gold/silver/copper of 1/8/200. The Cappadocian tablets distinguish different qualities of extra refined copper for which the silver/copper ratio of 1/25 and 1/55 is given, but the ordinary copper is usually sold at an average ratio of 1/45-60.

In the Assyrian period a ratio of silver-bronze is given at 1/185 and therefore Sargon II's statement that silver and copper had equal value in his time is undoubtedly a boast, as is Shamsi Adad I's low price. In the sixth century B.C. the silver/copper ratio was about 1/80.

The regions south and east of the Upper Zab seems to have played no part in the copper supply of Mesopotamia. But as the mountain region of Armenia which is practically unexplored further excavations will undoubtedly throw a wealth of light on this question as we are practically certain that even from prehistoric times onwards a metal-

lurgical centre existed here, the influence of which can not yet be estimated.

Another region yet insufficiently explored (though several unobtainable but recent publications in the Russian language are announced) is Transcaucasia and Caucasia. *Transcaucasia* is a region particularly rich in copper ores. JESSEN counted no less than 418 outcrops of some extent especially in the Middle Caucasus, Araxes and the adjacent Pontic regions. The ores contain an average of 10 to 20 % of copper and native copper is quite common; nuggets of upto 4 lbs have been found. Both fuel and water are plentiful and make these mountain ranges the ideal centre for metallurgy. In the Northern end of the Caucasus range there are but few mines. Most early copper objects found in these regions contain the same impurities arsenic, lead, antimony, silver and nickel in about the same proportions, which suggests that the ores of the Araxes region were those exploited in Antiquity.

It has been observed that Mesopotamian metal types have greatly influenced Caucasian types, which is quite clear when we remember that Transcaucasia is situated on important crossroads from east to west and from north to south and that Mesopotamia has always tried to dominate these important mountain regions and their valuable ores by more or less successful inroads and conquests. Sumerian and Assyrian rulers were ever engaged in breaking any growing power in these regions.

The archaeology of Transcaucasia has been discussed by HANČAR who distinguished three phases. In the earliest Načlik period (from 3300 to 2400 B.C.) the inhabitants were mainly engaged in hunting and primitive agriculture; they imported their copper from the south. In the following Kuban period (CHILDE's Kuban period) (2400-1800) contemporary with Troy II and Tepe Hissar III the import of copper objects seems to cease and a local copper industry starts which has connections with the south, the west (Troy II) and the east (Hissar III). This industry rapidly grows in importance; casting and hammering are learned and copper, either pure or with 0.25-1.25 % of tin (no intentional alloy!), is used. The connections with the Near East are then suddenly cut short at the end of this period.

In the following period (CHILDE's Middle Kuban period) (1800-1200) the metal industry develops quickly, casting in valve or closed moulds is learnt and the local smith already admitted to the ranks of the barrow builders in the former period now attains the

height of his skill. Caucasian metal industry now greatly influences the tribes of the Caspian steppes and at a time trade with the Danube valley seems to have existed!

Metal forms of Transcaucasia and Armenia have always exerted a great influence on the metallurgy of the Near East and especially on *Asia Minor*. Though HERZFELD is probably exaggerating when he says that Khaldic metal objects are found from the Oxus to Etruria, it is quite certain that metal objects from these regions were found in Byblos, Cyprus and the Balkans at an early date (HUBERT). The influence of Transcaucasian and Pontic metallurgy on Troy is obvious and FRANKFORT has proved that metallurgy had a bad influence on the quality of the pottery in that town.

Very early sites of *Asia Minor* like Sakcegözü (11) yield copper even in the deepest strata and in the 1b period of that site bronze is already found. It seems that the earliest invaders of *Asia Minor* were already acquainted with copper and by 3000 nearly every site in *Asia Minor* shows copper that has been reduced from ores and casting is well understood. Still native copper occurring in *Asia Minor* too is used, as some contend even in Phrygian times (87). Though VIRCHOW has ascribed the invention of copper metallurgy to the Pontic tribes, the famous Chalybes and Tibareni, this statement is not true as we have seen. Nevertheless the Pontic region is a most important secondary centre of metallurgy, where many other important discoveries were made. It seems certain that an important copper production existed in this regions by the time of the Cappadocian letters at the end of the third millennium B.C. These letters mention especially the towns of Haburata, Tišmurna an Wašhania. The Assyrian merchants engaged in metal trade in Anatolia had trade communities of local branches in several of these towns and did not engage in private trade but each merchant seems to have delivered periodically certain fixed quantities of copper to the central office and storehouse of his particular town. In this *bīt karim* his merchandise was received and he was credited for his deliveries on a special personal account (*qātum*) for the amount of refined copper equivalent to the amount he had brought in. Other accounts in silver, etc., were run to his name. There were two qualities of copper, the "bad" (probably black copper) and the "good" copper (refined copper), for one text gives a clear definition of the two kinds: "You wrote as follows: Tell me how much good and how much bad copper there is. Bad copper there is, I am waiting for the good kind and how much will be won by refining."

Again of the "good" copper there were two qualities distinguished by their price. The cheapest kind was the *erûm haburatai*, valued at a silver-copper ratio of 1/55, and then the better *erûm šikum* valued at 1/25, the average of the prices mentioned for refined copper is 1/45-60 and the amounts mentioned in these letters are 130, 40, 180, 78, 100 minae, etc. (CCT, 43). Another letter mentioning the refining of copper runs: "Make good copper, so that they buy it from me" (Clay 4, No. 35). The copper was probably traded in bars or cakes. These cakes had not as is often stated the form of a double-axe in honour of the thundergod but they are in the form of a hide, probably they were used as money and the connection of early forms of money with cattle is well known from Rome and other countries. There is no question that a hide is represented and not an axe for the edges are not convex but concave!

Still very little more is known of these highdays of copper metallurgy between 2400 and 2000, except that it would seem that attempts were made to work sulphidic ores as the sulphur content of some copper objects would go to prove. This should, however, be confirmed. Tools or furnaces are not mentioned in the excavations, but then these have still been carried out very spuriously in the Pontic region and any careful investigation is sure to bring further evidence. A second apex of mining and metallurgy was reached between 1500 and 1200 B.C. By then the demand had reached such proportions that import of copper from Cyprus ("from Mount Tagatta") was growing. A ship found on the bottom of the sea near Anatalya dating from the earlier part of this period had a load of bars of copper on board which seemed to have served as money too. The Hittite law-book (1300) gives a copper-silver ratio of 1/240, which is higher than that in Babylonia. Much old metal was recast in this period as is proved by the many hoards found. By 1500 all the aspects of copper metallurgy were perfectly understood in Asia Minor and when the copper industry revived after the troubled times between 1200 and 800 A.D. to flourish in the Iron Age between 800 and 550 there were no new technical discoveries to be made (87).

QUIRING states that the types of shafts with a circular descending staircase as found at Kedabeg and Arghana Ma'den (where Assurnasirpal II got his ore) date from the Assyrian period, but then his typology of early mines is still rather theoretical and remains to be proved. That the copper mines of Western Asia Minor were exploited in late Babylonian times is proved by the fact that Nabonidus imports copper from Jamana (Ionia) in 550 B.C.

In *Troy* the earliest settlement has yielded some copper (very hard through accidental impurities) and even bronze, but the true metal culture starts in Troy II when the town becomes an important trade centre between Asia and Europe. Though they practise open mould casting, spinning of copper vessels, hammering and other techniques the Trojan metallurgists were not very skilled or advanced, but then Troy was a trade centre not a metallurgical centre though there are plenty ores in the neighbourhood which were certainly exploited in classical times. The analyses of the copper objects from the different strata of Troy are still very discordant and they should be corrected at the earliest opportunity as Troy is an important link in the relative chronology of Europe! Contrary to some statements the local smiths were trained in Asiatic rather than in Nilotic schools as CHILDE correctly remarks (19).

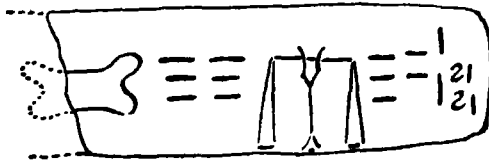


Fig 77 Tablet from Knossos, Crete, showing typical copper (or bronze) ingot (after HEAD, *Coriollo Numismatica*)

Crete received its first metallurgical impulse from the Anatolian mainland. Copper becomes common at the beginning of the Early Minoan I period about 300 B.C. before gold and silver and remains the most important metal until replaced by bronze about 2000 B.C. There is no doubt that Crete itself could not but supply a secondary copper industry. There is a little copper ore in the west coast eparchies of Kydonia and Selinos and on the island of Gavdos in the south-west (58). The supposed copper mines described by Mosso on the mainland over this island at Chrysokamino do not contain ores, but were probably smelting places. But even the Curetes would have found the methods described by Mosso impracticable. The slags, ore, pieces of crucibles, etc. are of Middle Minoan date (42), their real source is the East, probably Cyprus.

There is a close connection between Egypt and Crete, a flat copper axe of late Neolithic date indicates this, but the connection is broken at the end of the Old Kingdom to be resumed under the XIIth Dynasty, to be interrupted again by the Hyksos invasion and resumed in the XVIIIth Dynasty. Small specimen of votive axes (*pelekis*)

may have been used as weights or currency or probably both. Nineteen large bars in hide-form of Late Minoan date (1600-1250) have been found, each weighing 28.8 Kgrs, that is a Babylonian or Cretan talent. FORRER supposed that the Babylonian mina was the basis of Cretan weights but the supposed relations are doubtful and the Minoan weight system still obscure. These ingots punched or incised with Minoan signs are found in Sicily, Sardinia, and elsewhere in the Mediterranean, and they were imported in Egypt as Egyptian wall paintings prove. They were also found in Dalmatia, Mycene, and Euboea, and thus prove the extent of Minoan trade relations. We have already mentioned that their form has nothing to do with the Homeric *telekeis*, but that they are blocks of copper in the form of a hide, cast in an open mould. They also occur on account tablets found in different sites of Crete.



Fig 78 Tribute from Punt and Crete shown in the tomb of Rehmire abt 1400 B.C.) The ninth man from the left, under row, carries an ingot (WRESZINSKY, *Atlas*, I, 315)

The smiths of Crete were famous in Antiquity, as the Curetes were said to be their ancestors, and their art had its influence on the Greek mainland and the Cyclades, where copper occurs on Paros, Syria, and Siphnos, but most metal objects are ostentably imports.

In Greece chalcolithic *button* seals have been found but in the Early Helladic period copper was mined or imported, distributed and worked. Anatolian settlers probably brought their knowledge to Early Macedonia, as is proved by a crucible found at Saratse, but long after the metal still remains rare. The Mycenaean civilisation derived its knowledge of metallurgy from Crete. An axe found near Saloniki and dated about 1300 B.C. (118) was proved to have been made from cast copper and hammered cold. The sources of slags at Mycenae and other prehistoric sites have not been discovered, they were possibly derived from small local deposits now exhausted. The copper mines of Euboea gave out in STRABO's time, but copper seems to have been exploited in the Othrys range in Hellenistic times. Still in the Homeric world metals formed a valuable part of private property

(Odys. XIV, 321). Axes do not only figure in hoards, they are given together with other copper objects as prizes in contests (Iliad, XXIII, 830). Then in the Mycenaean period Cyprus was colonised by the Greeks no doubt in view of the supply of copper.

In the classical period there was a strong tendency towards specialisation in metal industry, factories of special weapons are known to have existed. Special markets and hours of sale were fixed for the producers of metal objects and among the famous centres of copper and bronze industry we mention Corinth, Delos, Chios, Samos, Cyzicus, Rhodes, and Pergamum. Under Roman rule the "Romans gave order that gold and silver were to be worked by the state only, but iron and copper remained free. The charges imposed were only half of what the Macedonian kings imposed formerly" (LIVY, XLV, 29, 4-14).

In Italy many mines of copper, silver, and lead have been located in the Campagliese (1), though copper furnaces have not yet been identified. The Etruscans have also exploited mines in the Locrian Temesos and in other places in Italy. Many of these mines were taken over by the Romans who succeeded in lowering the limit of exploitation from an average of 125 m to about 200 m by proper draining.

In Middle Italy blocks of copper of a specified weight (*aes rude*) were common since the ninth century B.C., which gradually developed to bars or blocks well shaped with pictures of a ox or pig stamped on. "King Servius was the first to coin copper, uncoined copper being used at Rome before that time according to Timaeus. The device employed was the figure of an animal (*pecus*), from which it is called *pecunia*" (PLINY, Nat. Hist. XXXIII. 43). In Etruria copper bars were in circulation very early and continued to be used for judicial and religious purposes after coinage was in use, finds of over 10,000 pieces are known (REGLING, PW, XII, 294). "We have shown for what a long time copper was the only material used in coins by the Roman people and the fact that, in a distant past, a guild of copper-smiths was third among those established by Numa, proves that their importance dated back to the foundation of the city" (PLINY, Nat. Hist. XXXIV, 1). The gradual reduction of the bronze as from 1 ounce in 200 B.C. to half an ounce in 100 B.C. may indicate a corresponding rise in the price of copper as against silver, because of the heavy indemnities of the conquered countries. The ratio of silver-copper rose from 1/110 in 200 B.C. to 1/70 in 150 B.C. when it was 1/60 in Egypt!

Under the Republic copper mines were still worked between Populonia and Volterra, so that Etruscan bronze is more or less a home product. However, after CATO organised the newly acquired mines in Spain, which were far richer in metals, Etruscan mining began to decline. This may have been due to disfavour of the Spanish equestrian contractors with private mining in Etruria (FRANK) or the Senate wished to preserve Italian copper supplies. A *Senatus consultus* was imposed on mining in Italy in the second century B.C.

In the Early Empire the old copper mines at Tempa were abandoned. Roman copper coins were exported as bullion to Silezia, East Prussia, and the Baltic States (UNDSSET), and there is a connection between the copper alloys of these countries and Roman coinage (BEZZENBERGER). Exports of copper from the Roman Empire to the East developed at the same time.

The manufacture of bronze and copper ware seems to have developed a real factory system at least in Capua at the end of the Republic and in the Early Empire. Great quantities of this ware, quite uniform of workmanship, are found throughout Italy and everywhere in Germany, Sweden, and even in Finland. Gaul was another province where certain quality wares were produced. Capua was the centre in CATO's days (*de Agri Cult.* 135) and in PLINY's time (*Nat. Hist.* XXXIV, 95-96). The metal was alloyed with proper proportions of tin and zinc and cast, polished, carved or forged. Copper nails of the Nemi ships are equal to the best quality of refined copper now available (41). They are rather brittle but hard and forged hot after annealing.

The old copper producing centres lost their importance to Baetica, Lusitania, Narbonensis, and England. The Italian copper industry shows a generous investment of capital and far-reaching division of labour. Plain kitchen utensils and farm implements required the service of many individual shops. These coppersmiths combined the functions of craftsmen and salesmen, often melting down articles of stock to supply materials of immediate need.

In Rome itself we find some individual *aerarii* as well as a guild of copper-smiths and at Milan there was a very large *Collegium Aerariorum* with 12 centuries of members.

There were different mining laws for gold, silver, and copper mines, who ranged together, and iron mines, where the different metallurgy and greater production required a different form of organisation to produce at the lowest cost.

Spain was the most important copper-producing province, and the metal was produced since prehistoric times. Though QUIRING gives very early dates judging by his theory of the analogy of architectural and mining details, SCHULTEN is of the opinion that regular copper production in Spain is not earlier than 2000 B.C. (PW, VIII, 2004). The ore bodies of Murcia and Almeria contain small quantities of native copper which were collected by the aborigines in the Copper Age (El Garcel). Like its counterpart in Sicily the Spanish Bronze Age was due to the impact of influences on the peninsula from the Eastern Mediterranean which gave rise to a copper industry in the south-east (Algarve, Los Millares, El Agrar). Malachite and azurite are mined to depth of 125 M. Gradually the mines of Cerro Muriano (Cordoba), Villaneuva del Rey, Rio Tinto, and Huelva, are drawn into the process, and flint tools prove that this exploitation took place at least at the end of the Bronze Age and in the Early Iron Age. The Huelva district and Eastern Portugal contain no less than 30.000.000 Tons of slags, of which at least one tenth is of the pre-Roman type and derived from the reduction of oxide ores. Gradually the knowledge of copper metallurgy spread from Almeria and Portugal northwards, though during the Bronze Age long distance trade with the East languished and was perhaps totally interrupted during part of the period. As tin was rather scarce the smith had to be content with both copper and bronze objects. In the Iron Age an intense exploitation with the accompanying deforestation set in. Tartessian copper reached Greece in the VIIth century B.C. On the North-western mountain divide of Asturias and Leon most mines belong to this period, though many just like those in Galicia were mainly worked in the Roman period.

Though the Romans still worked malachite in the first two centuries B.C., they exploited the large sulphidic ore-bodies under the Empire which had been worked for precious metals only before that date. The copper ore of Baetica contains up to 25 % of copper and the Huelva outcrops contain gold and silver. There is little evidence of Roman exploitation south of the Guadalquivir, the distribution of the more important Roman mines coincides with the ore bodies worked today. Roman technology was not afraid of difficult problems, chalcopyrite and grey copper were treated, liquation practised and the purified copper refined. PLINY and STRABO were not the only classical authors to wax enthusiastic over the rich copper ores, they are also mentioned by JUSTIN (XLIV, 3.4-5) and FLORUS (II. 33. 60). Roman

conquests were often economic acquisitions and Roman policy had a good eye for mining prospects.

The rich mines of the Sierra Morena fell to the state when Tiberius had the proprietor of the Aes Marianus, Marius, murdered (TACIT., Ann. VI. 19.1). We have a wealth of details on the rich Metallum Vipascense at Ajustrel because of the Lex Metalli Vipascensis which contain mining regulations for taxation purposes. Mining dumps and rock piles were taxed. The laws distinguish the following phases of mining: mining, cleaning, crushing, smelting, preparing, breaking up, separating and washing.

Though there may have been some exploitation of malachite in the Midi (dépt. Hérault) in the Bronze Age (112), Gaul was not rich in copper ores and even in Roman times there were no mines worth mentioning.

When discussing *Brittannia* CAESAR says: "They use imported copper or bronze (Bell. Gall, V. 12)" but then he must refer to imports of copper objects for pre-Roman mining of copper is proved by the finding of rilled hammers and many other signs. Pits sunk in the sandstone impregnated with copper on Alderley Edge (Cheshire) contained most primitive tools very similar to those found near Lake Superior. Other pre-Roman mining sites were in North-west Wales, Carnavon, Anglesey and Shropshire. The Romans have continued many of these mines, large quantities of bun ingots, flat round cakes of copper, have been found about 11-13" in diameter and 2-2½" thick (120, 121) weighing about 30-50 lbs and many were inscribed with abbreviated personal names (conductores of company?). The copper is mostly 98.5 % pure, but often over 99 %.

In Central Europe there are small Roman prospects of poor impregnations of malachite and azurite in Baluberg (Wallerfangen) and Kordel, both in Rhineland, worked for a short period only.

Apart from other prehistoric copper mining sites the mines of the Eastern Alps may have played some part in the Mediterranean World (47) (61) (127). In the Early Bronze Age between 1700 and 1300 open cut workings with small shafts were worked. The highdays of the exploitation lay between the Late Bronze Age and the Early Iron Age (1300-800 B.C.); QUIRING suspects Etruscan influence. Shafts and galleries were sunk into the strata and most of the total of 20,000 Tons of copper for the field were then produced. The remains of smelting sites have been found and studied (127) and they proved that sulphides were smelted in two stages at least. There existed some

trade with the regions south of the Alps at the end of the Bronze Age. Between Hallstatt and La Tène (800-400) the mines decayed and gradually stopped working. Other copper mining sites well studied include those of Velem St. Veit (75).

A few words remain to be said on the *ancient nomenclature* of copper. Our word *copper* is derived from *Cyprus*. The earlier Latin authors speak of *aes rubrum* or *aes cyprium* (PLINY). VITRUV, SCRIBONIUS and LARGUS have *aes cyprinum*, POLLIO and PALLADIUS *cyprius*, VEGETIUS *cuprinus*, the Edict of Diocletian *cuprum*, SOLINOS

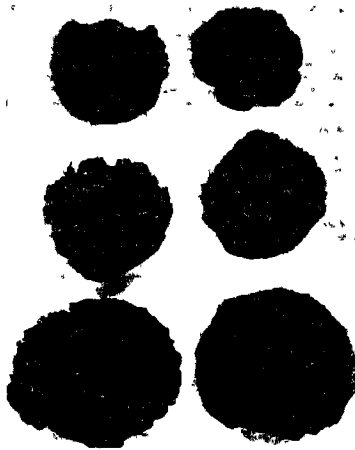


Fig 79 The typical round bronze (and copper) ingots of Middle Europe
Specimen from Ittersee in the Salzburg Museum (FRANZ)

cyprum, and there is the Byzantine *koupron*. Since Spartian (IVth century A.D.) *cuprum* is the general term, whence our words *copper*, *civre*, *Kupfer*, *koper*, etc.

The Italian *rame*, Spanish *alambre*, French *airain* are all derived from the Latin *aeramen*, *aeramentum* (copper ware).

The Sumerian and Accadian languages are the only to possess separate words for copper and bronze from the beginning. The Hebrew *nehôšet* (63), the Greek *chalkos* or the Latin *aes* may denote copper as well as bronze or brass! The Hebrew word has been connected with *Nubašše*, the country of the Amarna letters without much reason.

The Latin *aes* is derived from one of the Indo-European words for

copper 'ayos. Both this word and 'raudba or 'roudhos are probably words used by the Aryans only and not by all the Indo-Europeans (100) (20). POKORNY has suggested that 'ayos may be derived from *Alašia*, the copper land Cyprus (Z. vergl. Sprachwiss., 49, 128). In the different Aryan languages, however, the words derived from this original acquired widely varying meanings. The Latin *aes* was used for copper, bronze, and brass, but the Gothic *aiz* (Old High German *êr*, German *Erz*) meant both ore and later metal especially iron, the Old Slavonic *âr* came to mean *ore*, the Sanskrit *ayas* is used for iron only! (5) (12). There are no archaeological proofs for POKORNY's contention, no direct connection between Cyprus and the early Aryans.

The derivation of the other word 'roudhos from the Sumerian *urudu* is more firmly established. We should remember that the Sumerian *urudu* is a very early word for copper, being written with a simple pictogram and occurring in the oldest texts in Sumer. It is also used in the Sumerian language to determine copper vessels or metal vessels in general (DEIMEL, *Šum. Lex.*, 132, 1). Then we must remember the early Sumerian influence on Transcaucasian metallurgy and the influences which the latter had at a later date on the tribes of the Northern steppes and which we can find even in the Danube valley. The Hero-smith of the Kalevala, Ilmarinen, has copper weapons of the type which the Finns believe to have brought to their country from the "Ural mountains", but which show affinity to Transcaucasian models. In this case at least a chain of archaeological evidence goes to support IPSÉN (*Sumero-akkadische Lehnwörter*. Indo-Germ. Forsch., vol. 41, p. 417). The root 'roudhos is said to mean "red" and the name "red metal" would suit copper perfectly. The Sanskrit *rudhira*, the Old Persian *ruad*, *rôdb* (New Persian *roy*), the Greek *erythros* (refined copper is called *chalkos erythros*) (9), the Lat. *ruber*, Gothic *raudo*, Old Norse *raudbr*, Finnish *rauta*, *ruda*, and the Basque *urreida* all mean either copper or red or both. The connection between the Basque *urreida* and the Sumerian *urudu* or its Indo-European equivalent is not clear. It is not impossible that the Sumerian word or a derivative reached Spain by the way of the Mediterranean. SPENGLER has correctly remarked (104) that the names of materials and objects of trade are apt to be adopted by those who come in contact with them, trade names easily form part of some "pidjin" language. *Urudu*, the oldest word for copper, may easily have passed into the lingua franca of the Mediterranean.

The third word, *chalkos*, has been the subject of much speculation.

Many philologists has contended that this word was a loan-word from some Asiatic language and that the "Greeks as the most advanced Aryans were ignorant of copper" (9). LENORMANT connects *chalkos* with the Phoenician *halaq* (to polish, to work), EISLER with the Aramaic *halbi* ("belonging to the heaven") (a rather illogical connection for copper, as gold is the sun metal and there is no meteoric copper!), DUSSAUD (37) derives it from the Khaldi, the inhabitants of Urartu! KRETSCHMER believes it to be a third Indo-European word for copper, connects it with the Greek name of the murex *chalkè*. But the Greek for murex is *kalchè*! Still he points to other words like the Lithonian *gelezis* and the Slavonian *želežo* which mean iron and therefore he says that the word originally meant copper or "red metal" and then came to mean iron. CURTIUS at a time connected *chalkos* with the Semitic *halaga* (to work) and said that *chalkeus* first meant "a worker in copper", then "one who casts copper", then "copper-smith" and finally "(iron)smith". LIDDELL-SCOTT give a later view of CURTIUS comparing *chalkos* with the Sanskrit *brik-us*, *blik-us* (tin), Slavonic *zel-ezo*, Lithaunian *gel-eziz* (iron) and thinks that the Sanskrit *ghar* (lucere) has the same root. *Chalkos* has the specific sense "copper and metal in general" in Greek only! F. MULLER derives the word from a root *ghel(âx)*, yellow, blonde (compare the Latin *helvus*, *gilvus*, *flavus*, the German *gelb*), and he therefore supposes that the original meaning was "yellow metal" and that *chalkos* is really the third Indo-European word for copper.

We can not enter the battlefield of philologists but the last two authors seem to give serious links worth pondering over. We must add that the Greeks used the word *chalkos* in the general sense of "metal" fairly often, but we should hesitate to join some authors in believing that this was the original meaning. This might of course be true for a civilisation in which apart from copper and copper alloys no other useful metal was known. The knowledge of gold and silver would not prevent such a terminology as the precious metals do not serve any practical purpose in such a community. But we know of no passage in which this word *chalkos* alone means metal in general, however, several places give *chalkos* with some colour determinative added to denote some variety of copper. Thus we find *chalkos melas* for "black copper", *chalkos leukos* and *chalkos erythros* for refined copper, the latter expression occurring only once (HOMER, Iliad, Book IX).

But these matters of philology must be left to competent authorities,

though may be these riddles are as dark of the properties of lapis lazuli about which AL MUSTATRAF says:

“Aristotle says that wearing it in a ring enhances a man’s dignity in the eyes of the people and that it is useful in cases of sleeplessness — but Allah knoweth best”.

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CHAPTER ELEVEN

THE EARLY STORY OF IRON

“Our next subject must be the ores of iron, a metal which is at once the best and the worst servant of humanity, for to bring death more speedily to our fellow-man, we have given wings to iron and taught it to fly”

(PLINY, *Natural History*, XXXIV, 138)

To this passage of PLINY we could add the words of the Prophet: “Dire evil resideth in iron as well as advantage to mankind” (Koran, Sura 57, 25), but PLINY adds: “Let the blame for such death be brought home to man, and not to nature!” and he continues: “Several attempts have been made to enable iron to be guiltless. In the treaty which Porsenna granted to the Roman people after the expulsion of the kings, we find a specific clause forbidding the use of iron except for agriculture. According to the most ancient authors the ordinance that a bone stilum should be used for writing dates from the same period. An edict is extant promulgated by Magnus Pompeius in his third consulship at the time of the tumult occasioned by the death of Clodius forbidding the possession of any weapon in the city of Rome” (XXXIV. 139).

The myths and magical practices of many peoples show clearly that iron was a comparatively late metal. By many peoples iron seems to have been received with much suspicion. Celtic folklore has many references to this. Some of the African tribes have objections against iron hoes which they say keep away the rain. Among the Caribou Eskimos iron, a new material, was not worked during the season of the musk-ox hunting.

It would be easy to multiply these examples. In PLINY's writings iron figures in magical recipes (Nat. Hist. XXX, 17; XXXVII. 60), in some cases he forbids the use of iron implements in cutting herbs (XXIII. 81) or in killing animals (XXIV. 17; XXV. 106).

There are many quaint recipes for the correct solutions in which to temper or quench iron. Thus the *Mappae Clavicula* states that urin of a he-goat or a red-headed boy should be used and BANDINI's *Fons memorabilium* says that a sword tempered in the juice of a radish mixed with the juice of earthworms cut up and strained through a cloth will cut all iron as if it were lead.

Many other legends centre in the magnet and its properties. PLUTARCH states that iron rubbed with garlic does not respond to the magnet and the *Causa Causarum* of the eleventh century says that onions are similar damaging substances. The legend of the magnetic mountain in the Indian Ocean, well known from the Arabian Nights, figures in earlier writers such as CONSTANTINUS AFRICANUS, who also holds that the magnet comforts those who are afflicted with melancholy.

Iron transfers its magical potencies to other substances. Thus the water or milk in which iron was quenched was said to be a good cure for diarrhoea. Iron will also protect against the baneful influences of evil spirits and such beliefs had a very long life. SOCINUS OF SIENA (1450 A.D.) states that one should put a key, sword, or any other object of iron between one's teeth when the bells are first heard on the Saturday of Passion though he himself considers this to be a superstition.

CELSUS calls iron the metal of Hermes "because it is busy, loving labour and bearing all fatigues like him", but Hermetic tradition gives the series Mars-haematite-red-iron and the alchemists' symbol for iron seems to have been that of the god Ares (Salmasius). Astrological writings of the third and fourth century A.D. say that Mars is the planet of red-headed men, people busying themselves with iron and fire or giving wounds by iron and fire or receiving them, and this finds its sequel in the medieval tradition that Saint Barbara is the patron of "all those who work with fire or iron". From the fourth century onwards iron is no longer the metal of Hermes but that of Mars (PIBÊCHIOS).

Iron plays a part on the colouring experiments of DEMOCRITOS, who is said to have written "a book on iron", and it belongs to the Tetrasomy of base metals which the early alchemists sought to transform into gold. It can only be worked "by the assistance of the gods" (ZOSIMOS) and it forms part of the "bones of copper" or "Persian bones" (iron, copper, lead and tin burnt) which figure largely in the alchemical writings of ZOSIMOS and AGATHODAIMON.

In the technological treatises of the eighth century and later we find many semi-magical recipes of the hardening of iron by tempering and quenching it in oil or certain "waters" and of "colouring iron to Indian steel".

These few examples will go to show the important part which iron played in early magic and chemistry.

We must postpone the story of its discovery until we have discussed its production but first we must review the ores of iron and the most important deposits.

I

The ores of iron are probably the most widespread ores on earth. No less than 4.2 % of our earth is formed by iron or its compounds! Though not the most important source of modern iron production the small quantities of meteoric and terrestrial iron are prominent in the history of iron.

Meteoric (celestial) *iron* is fairly widespread. It is interesting to note that the density of the recorded meteorites can be correlated with the density of the population of the regions mentioned and therefore many arid and unpeopled regions may hold far more meteorites than we know. Again in the Ancient Near East the natural stock of meteorites will have largely disappeared in the course of history. The celestial origin of meteoric iron was noted early though it was often disregarded. The possibility of collecting or detaching pieces from larger lumps is abundantly proved by the records about Eskimos and other primitive tribes. This meteoric iron contains 5-26 % of nickel (with a rough average of 7.5 %) and 0.3-5.0 % of cobalt.

Iron occurring as a metal of non-celestial origin is called *telluric iron*. It occurs in basalt and other rocks as grains and nodules, generally too small for practical use and mostly hidden in the rock. It often contains upto 65-75 % of nickel and generally it is unworkable. In far north-western Greenland there is one of the few large deposits of telluric iron. This native metal, with a lower nickel content was also used by the Eskimo of that district and fashioned into knives and points. But we can state that in general telluric iron must be ruled out as a possible source of the ancient metallurgist.

There are some natural nickel-iron compounds of rare occurrence in New Zealand, the Ural mountains and the Piedmontese Alps, in Oregon, British Columbia and California, but in general iron ores and the iron produced from them will not contain nickel or only to a possible maximum of 2.5 %. Nickel has not to our knowledge been recorded in specimens from the Near East, save in case of meteorites and objects fashioned from them.

Apart from the nickel content there are other sure proofs to fix the meteoric origin of ancient iron objects.

Not all iron compounds are *iron ores*, for we know that the criterion is economical production of iron from the compound. Generally speaking we now consider iron compounds with at least 20-30 % of iron to be iron ores. The most important of these ores are:

	Theoretical iron content (in %)	Practical iron content (in %)
Magnetite (Magneteisenstein)	72.4	60—68
Haematite (Roteisenerz)	70.0	40—66
Limonite (Brown iron ore, Brauneisenerz)	59.9	25—58
Oolitic iron ore (Minette)		24—46
Bog ore (Limonite, Raseneisenerz)		35—55
Spathic iron (Siderite, Spateisenstein)	48.3	30—44
Sphaerosiderite (Sphärosiderit)		25—40
Blackband (Kohleneisenstein)		36—40

All these ores are oxydes of iron except the types of siderite which are carbonates and therefore contain carbon dioxide and water which should be removed by pre-roasting before the proper reduction can take place.

All these ores occur in many forms; compact, crystalline or amorphous and earthy forms, too many to be described in this short space. It is certain that they were worked in Antiquity too, though the limit of economical production may have been higher than at present and the ores will have been specially selected pure ores or perhaps hand-picked. We have already mentioned the considerable knowledge which the Sumerians had of the different iron compounds and ores and THEOPHRASTUS gives quite a good description of the most important iron ores (Lapid.): "A dense stone is the haematites which is dry and resembles its name "bloodstone", it looks like condensed blood. Excellent minerals some of which have an earthy nature, like ochra and miltos are very common in many mines. The workability of some large ores is very different, some can be sawn, others can be chiselled and even turned, like the magnes which has a peculiar appearance and which looks like silver as some say, though there is no affinity. Miltos and ochra occur in silver-, gold- and copper-mines, mostly forming veins or even heavier strata as in the case of ochra. They are often mined, for instance in Cappadocia and in large quantities. The best kind is that of Ceos. One type comes from mines, as miltos occurs in iron mines too, there is also the Lemnian kind and the so-called

Sinopian which is non but the Cappadocian kind which is brought to Sinope! It occurs in three qualities, red, white (chalk?) and one in between. A further quality is made by burning ochra. This is an invention of Kydios who is said to have observed during the fire of an inn, that ochra was coloured red when half-burnt." PLINY has many scattered remarks on iron ores, "which occur in greater quantity than those of any other metal. Where the ocean washes the coast of maritime Cantabria there rises a lofty mountain which is entirely composed of iron ore" (*Nat. Hist.* 34. 149). The following passage refers to bog ore: "In Cappadocia only the question is raised, whether iron is to be placed to the credit of the water or the earth, for the earth yields iron to the smelter only where the water of a certain river has flooded it" (3. 142). And on the magnetite he says: "The common folk call the lodestone "quick iron" and wounds made with magnetic iron are worse than ordinary wounds. This mineral occurs in Cantabria also, not as a massive rock but in scattered pebbles called bullae, but its influence on iron is the same" (34. 147-148), but his further description of magnetite is rather confused: "Passing to other stones with striking properties, who would hesitate to deal first with the magnet? For iron, the tamer of all substances is drawn by the magnet. So the magnet is given another name, sideritis, while some call it Heraclion. Nicander is our authority that it was called magnes from the man who first discovered it on Mount Ida and he is said to have found it when the nails of his shoes and the ferrule of his staff adhered to it, as he was pasturing his herds.

Sotacus classifies magnets into five varieties, the first found in Aethiopia, the second from the Magnesia which has a common boundary with Macedonia, the third found at Hyettus in Boeotia, the fourth in the neighbourhood of Alexandria in the Troad and the fifth from Magnesia which is in Asia. The first point of distinction is whether the stone is male or female, the second depends on its colour. Magnets found in Magnesia near Macedonia are of a reddish-black colour, while the Boeotian magnets are more red than black. The magnets found in the Troad are black and of the female sex and therefore without magnetic power, but the worst of all come from Magnesia in Asia. These are white and have no attraction whatever for iron. It is an ascertained fact that the more blue they are the better magnets are likely to be. Those from Aethiopia bear off the palm and sell for their weight in silver. They are found in Zmiris, for so they call the sand covered district of Aethiopia. In the same district

is found the hæmatite magnet which is the colour of blood and which gives, when powdered, a material of a saffron hue. Haematites has not the same power of attracting iron as the magnet, though the Aethiopean variety attracts other magnets" (36. 126-130). It would seem from this passage, that PLINY's *magnes lithos* does not imply magnetism and his account is rather muddled when he contrasts *haematites* and *magnes* and even speaks of *haematites magnes*! Other classical writers also mention the *magnes lithos* but refer to the magnetic properties only and not to this ore as a source of iron production, for though it was probably little worked in Egypt and Macedonia, it was certainly treated in Noricum. Just as *magnetites* or *magnes lithos* does not always cover our magnetite, the *haematites* of the ancients had a wider meaning though it refers to our haematite in the case of Elba and Cantabria. But in the case of *haematites* too, its working for iron is not mentioned. The *schistos* mentioned by PLINY (36. 145) is probably a form of limonite, and the *schistos* of THEOPHRAST is clay ironstone. The *hepatites* of the ancients is certainly limonite, which "when burnt yields miltites". PLINY's *schistos* is probably a fibry variety of limonite. The *aetites* or "eagle stone" (PLINY, *Nat. Hist.* 36. 149) is probably a type of concretions of clay ironstone. The ochre varieties (also called *sil*) hail from Laurion, Cappadocia, Cyprus, Lydia, and the neighbourhood of Rome. The ore of Noricum is the spathic iron ore (Bohnerz) still worked in Styria and Carinthia. It is doubtful whether the ancients ever worked iron pyrites which they can not have failed to observe as they are very similar to the copper pyrites both in colour and form, possibly the word *chalcitis* is sometimes used to denote iron pyrites instead of copper pyrites, but the descriptions of the *chalcitis* are not very clear (PLINY, *Nat. Hist.* 34. 117). PLINY also knew the celestial origin of meteoric iron (2. 147) and he mentions that the quality and composition of the ore is important in smelting (34. 143). He also mentions that iron ores "are recognised without difficulty by the striking colour of the soil" (34. 142) a remark repeated centuries later by AGRICOLA who says that "iron rust is an indication of good iron ores" (Book II). It seems that oxydic ores of an earthy or of a loose structure were preferred by the ancients and their disciples for even BIRINGUCCIO says that good iron ore is brown and that the black ores or those of the colour of pyrites should be avoided. The earthy iron ores of the ochre class were used as pigments from times immemorial, limonite, goethite and haematite are all found in a soft form, rich in

iron, and well adapted to rudimentary smelting operations. Magnetite, though a compact crystalline ore and rather difficult to work, may have been among the earliest iron ores to be worked when gathered as a byproduct of gold-washing and treated in a crucible process. Still with early metallurgical methods only the more reducible ores were utilizable and the first-comers must have gathered unique harvests of native meteoric metal and ores accumulated during previous ages near the earth's surface and in streambeds, "the sluice-boxes of nature".

It seems certain that the washing and roasting of certain iron ores was an old standard practice in the Near East. In some cases as that of the working of spathic iron and other carbonates it was imperative to drive off the carbon dioxide by roasting, but many other ores profited from pre-roasting by losing water and slight amounts of sulphur from admixtures or by obtaining a more loose structure. Roasting was for instance standard practice in the iron mines of Elba (DIODOR, V. 13). The washing and crushing of iron ores did not differ from that of other ores.

Some iron ores were used in ancient medicine (PLINY, *Nat. Hist.* 34. 151-155; DIOSKURIDES V. 93-94).

It would be impossible to enumerate all the *deposits of iron ores* in the Ancient Near East, we shall confine ourselves to a rapid survey of the most important ones, which have been marked on our map (fig. 80).

In *Egypt* there is haematite, pyrolusite, and psilomelane in Wadi Baba and other valleys of the Sinai peninsula, but it is doubtful whether these deposits were ever worked. As they contain iron ores holding titanium and manganese, they would have yielded an excellent iron!

In the eastern desert Wadi Araba contains ferruginous limestone, and red ochre is found to the north. In Wadi Dib there is haematite, in Wadi Marwat limonite, and on the road to Qosier near Abu Gerida there is haematite just as near Ranga (near Ras Benas), where the haematite is titaniferous. Near Wadi Halfa there are banks of oolithic ironstone and between Assuan and Shellal there is magnetite. The alluvial Nilesand contains much magnetite, often worth washing and the oases of the western desert have strata and concretions of ochres and limonite. There is a good quality of brown ochre in Dâkhle Oasis and red ochre near Aswan. The Egyptian red ochre is mentioned by VITRUV (VII. 7. 2). In Gebel Rassa, north of the Fayyum there is psilomelane and west of Cairo there is yellow ochre.

Though BURTON reported exhausted iron-mines in Wadi Hammamat, no inscriptions were found and no iron mine of Egypt can be ascribed with certainty to Antiquity. It is doubtful whether the iron mines of Meroë mentioned by STRABO (XVII. 2. 2. c. 821) were exploited as early as some writers contend.

Palestine and Syria have a few deposits of rich iron ores, though poor ores are very common, for it was a country "whose stones were iron" (Deut. 8 : 9). The deposits of the southern Lebanon are poor and can hardly have been worked by the Phoenicians and Hebrews as some claim. Still there are a few deposits of limonite and weathered haematite near Nahr el Kelb and Beyrout which may have been worked in Antiquity, and there are a few deposits worth exploiting near the sources of the river Jordan. There are traces of old mines near Merdjiba (Nahr el Kelb) but their date is uncertain. Other old mines are situated near Ikzim on Mount Carmel.

East of the Jordan there are deposits near Ain Tab, Resheya (north of the Hermon mountains), Birma and Mogharet el Warda south of Adjlun, where red and yellow ochre and marcasite abound. These are probably the deposits mentioned in the Letter of Aristeas as situated "in the neighbouring mountains of Arabia". They were probably exploited in Roman times like some ores near Jericho. There are several other deposits in the mountains bordering Moab and in north Edom. JOSEPHUS mentions an "iron mountain and mines" in Transjordan (Wars IV, 8. 2). Other deposits occur near El Kura and in the neighbourhood of Pheinan. Midian is very rich in deposits of haematite and magnetite, and in Yemen there are deposits in the neighbourhood of Usala and Sana.

In Syria there are richer deposits near Alexandria and mines were exploited near Germanicia north of the famous town of Doliche, "where the iron was born".

In *Cyprus* there are deposits near Soli, Paphos, and Tamassos, mainly haematite and limonite, and there are many traces of ancient mines.

The deposits of *Crete* are poor and few; they were probably never worked or produced for local consumption and all the Greek legends about iron working daemons or heroes in Crete are probably untrue. The foundation of these myths is probably the confusion of the Cretan and the Phrygian Mount Ida and it seems that these myths were originally told about the Phrygian mountains and other sites in Asia Minor where there was indeed a very old iron industry.

There are many deposits on the islands in the *Aegean*, for instance on Syros, Cythnos, Ceos, Seriphos, Siphnos, Gyaros, where there is chromite, an excellent iron ore, though it is not known whether it was used in Antiquity. Other deposits are found on Andros and Skyros. Iron ore is found on Samothrakè, Samos, Rhodes and Cos.

On the mainland of *Asia Minor* there was the magnetite of Mons Ida near Andeira (PLINY, *Nat. Hist.* 36, 4, 128) (STRABO 13. 1. 56. c. 610), which is probably STRABO's "stone which when burnt becomes iron". APOLLONIUS OF RHODES mentions "the iron-bearing land of the Mariandynians" in Bythinia (Argon., II. 141). To the south there is magnetite near Magnesia (PLINY, *Nat. Hist.* 36. 128) and further south there are several deposits in Caria near Latmus and the famous Cibyra "where the easy embossing of iron is a peculiar thing" (STRABO 13. 4. 17. c. 631), which are probably the haematite deposits near the present Corancež. The legends of the Telchines (STRABO 14. 2. 7. c. 654) and the Dactyloi (STRABO 10. 3. 22. c. 473) mentioned by STRABO and many other classical authors probably belong to these ancient mining centres in Phrygia and Lycia. In the centre, in Phrygia Maior, there are several deposits of high-grade haematite.

The Taurus range is very rich in iron. Near Alaya and Silinti (Adana) there is much haematite and iron pyrites. The iron mines of Amaxia in Upper Cilicia were given to Cleopatra by Antonius, and the last Armenian king Archeläus had scores of *mettaleuti* (miners) working in iron and other mines of Galatia. Near Jünik Tepessi in the Taurus range there are mighty strata of iron ores which contain upto 53 % of iron.

Very important deposits are centred in the north, in Pontus and the neighbouring districts. Near Amasia, Tokat, and Sivas there is magnetite and iron pyrites. HAMILTON saw many traces of ancient mines west of Trapezus. The Cappadocian iron and the iron-working Chalybes were famous in Antiquity (XENOPHON, *Anab.* V. 5. 1) (STRABO, 12. 3. 19) (PLINY, 34. 142). There are many deposits in Pontus up to Kighi near Erzerum. There are bog-ore deposits in the valleys of the Thermodon and Iris. Other deposits are scattered on the lower slopes and foothills of the ranges between the modern Yeşil Yarmak upto Batoem.

In *Caucasia, Transcaucasia and Armenia* the iron deposits are particularly rich. In Kuban on the banks of the Kotscharka river there are 30 M. thick magnetite strata (62-68 % of iron), which were worked

from the Persian period onwards. There is haematite near Damyrtash on the river Bolnis and near Tamblut and Tshatash, near Sizimadani and along the Dyblaki pass near Miskan. Very pure haematite is found in the valley of the Bojan and near Elisavetpol. Magnetite and ilmenite occur in the eastern Karabagh district. Iron pyrites and other iron ores are found near Talori and Karadagh. Other iron ore outcrops are found near Lake Urmia and north of Tabriz, smaller outcrops occur in the Tiyari mountains and near Chorsabad.

In *Persia* there were mines and smelting sites near Tabriz, which ROBERTSON saw and which he ascribes to very early periods. The Elburz mountains have old mines near Resht and Massula, where the inhabitants are still mainly blacksmiths. West of Teheran and near Kazwin there is much haematite, to the east near Firuzkuh and on the foothills of Mount Demawend there is haematite and limonite. The mountains near Damghan, Semnan, and Sharud have rich strata of haematite, and deposits of limonite and yellow ochre. Near Kashan and Kohrud there is magnetite and haematite, and in the Kuh-i Benan region and in Carmania there is yellow and brown ochre and limonite. Remains of early iron workings have been found in the plain of Persepolis and between Kerman and Shiraz and the islands of the Persian Gulf have red ochre and other iron ores. Carmania was long time famous for its iron and steel, though the mines were not worked after the Arabian period. In Chorassan there are several deposits near Semende and Ilak and in Afghanistan near Juwain, Herat and Bamian. The old mines of Alexandria and Caucasum in Kohistan are now abandoned.

Several other ancient mines will be mentioned in the course of our story and it would be impossible to include in this survey all the deposits of Europe which were known to the ancients. The principal iron deposits exploited by the Romans were those of Noricum (Tyrol, Styria and Carinthia), Bosnia (STRABO, V. 1. 8. c. 214) (Sana valley) and the deposits of Gallia had great importance in the Celtic wars of Caesar, though their importance dwindled in later periods (STRABO, 3. 4. 17. c. 164; 4. 2. 2. c. 191). Britain had several deposits which were worked in Roman times and perhaps earlier (STRABO, 4. 5. 2. c. 199), but the importance of the iron mines of Spain (STRABO, 3. 2. c. 146; 3. 4. 6. c. 159) is rather exaggerated by the ancients.

The most important sources of Italy were the mines of Etruria and above all those of Elba (STRABO, 5. 2. 6. c. 223) (DIODOR, V. 13).

All these mines belong to the classical period except the Celtic

Illyrian mines of Noricum and Gallia and the local industry of Central Europe which though exploited in prehistoric periods had little influence of the development of iron metallurgy in the Ancient Near East. Their slight connection with this evolution will be discussed in the following lines, it is very probable that the impulse to exploit them came from the East.

However, before tracing this story of the discovery of iron and the rise of the manufacture of iron, it is imperative to discuss some of the processes used in its production and to define some of the terms denoting these processes and the apparatus used as they will recur in our arguments, because the production processes are intimately linked up with the story of iron.

II

We shall have opportunity to prove that the ancients always produced iron in the form of a *bloom* and that they could not make cast iron. A *bloom* is a rough ingot of iron or steel as produced directly from iron ores in a bloomery. This word *bloma* (bloom) occurs in English texts before 1000 A.D.

In this most primitive form of direct extraction of iron from its ores a mixture of the ore was treated either in a "hole-in-the-ground" furnace or a hearth-fire with charcoal. The impurities formed a *scoria* or slag which was fluid and ran out of the fire or collected outside the furnace and the remainder of the ore was reduced to a tough, pasty, spongy mass of iron. This mass was withdrawn in the form of porous blocks after cooling, and these blooms were put into another furnace and strongly heated. The iron was there taken out and hammered into a compact mass as to drive out any scoriaceous matter.

The earliest bloomery furnaces had a natural draught and they seem to have been generally erected on high grounds in order that the wind might assist combustion. This was not only the common method of building furnaces in prehistoric Europe, etc., but many Negro tribes still build them thus. But as soon as bellows became known, blast air was used to supplement or to replace natural draught. Thus the Roman smelting furnaces of Populonia and those reconstructed from the remains at Wilderspool (Warrington), which both belong to the best examined remains, consisted essentially of a cavity with a wall and covering of clay with holes at the base for admitting a draught and for withdrawing the metal. They were usually built on sloping ground and the remains show that both coal and charcoal were used for

smelting. There is no proof that bellows were used, nor is there any proof that cast iron was produced in one furnace and converted into malleable iron or steel in another. The entire plant of a bloomery

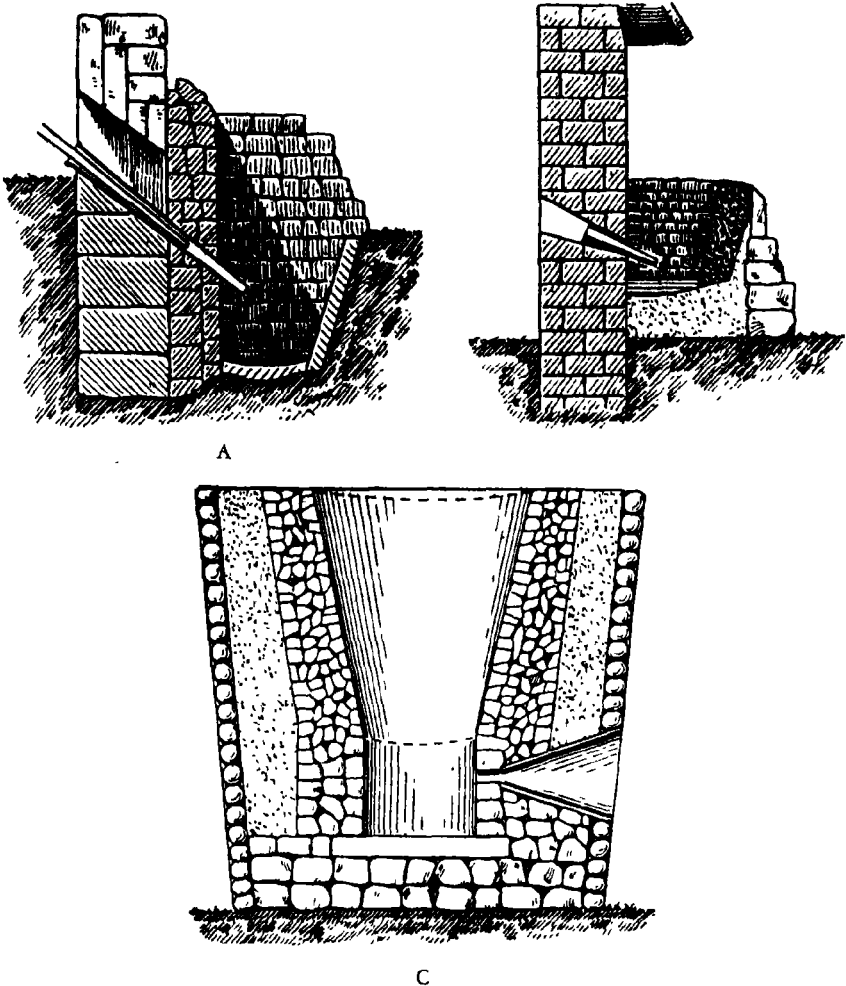


Fig 81. The Catalan (A), the Corsican (B), and the Osmund (C) furnace (after NEWTON FRIEND)

consisted of a kiln for roasting the ores, a smelting furnace, as described above, and a smith's forge. Minute samples of metal collected on the furnace bottom in a fluid state, but the smelting furnace yielded blooms of spongy iron. The fusion of the iron in the furnace must occasionally have occurred when the temperature was

higher than usual, especially in those cases where bellows were used, as can be proved in the case of other ancient bloomery furnaces.

The definite adaption of blast air in the manufacture of iron led to the invention of more suitable furnaces. One of the oldest of this type is the *Catalan process* of extracting iron which was formerly practised in Catalonia and also around Ariège (France). The furnace was still used in the seventeenth century in Spain in the provinces of Navarra and Guizpuzcoa. It consisted of a shallow, oval cavity or hearth forming a kind of inverted truncated cone. A *tuyère* or pipe, through which the blast air is forced into the furnace, projected downwards and inwards over the middle of the long sides of the oval. The blast is supplied by two bellows working alternately. Later a continuous blast was obtained by a *trompe* (a mechanical device to supply blast air by means of falling water) where a fall of water was available. A Catalan forge consisted of a furnace, a blowing-machine and a heavy hammer.

The so-called *Corsican furnace* is hardly more than a smith's forge.

The *Osmund furnace* was a primitive bloomery smelting furnace formerly much in use in Sweden, Finland, and Norway, called *osmund* after the bloom (*åfsumd*). The furnace was an oblong, rectangular cavity to receive the lump of reduced iron; there was a large opening at the side through which the lump of iron or bloom was extracted and which during the working of the furnace was temporarily built up with stones. The inner lining of the furnace was a refractory rock and the space between this and the timber casing on the outside was filled up with earth. The calcined ore was smelted with charcoal and the resulting bloom was forged as required. The blast was obtained by two bellows worked by a treadle.

BIRINGUCCIO stated that this was the pre-Roman smelting furnace of the time of HESIOD, and indeed remains of fairly similar furnaces were found by QUIQUIREZ in the Jura, though their date is by no means as sure as this author claims. This type of furnace was usually built anew after each smelting and fired with wood. Many older furnaces must therefore have disappeared as links in the chain of evidence.

The so-called *Stückofen* was a bloomery furnace consisting of two Osmund furnaces, one inverted above the other. They were at a time worked in Carniola, Carinthia, Styria, Hungary, etc. The larger furnaces were 10' to 16' in height and the blast was operated by bellows worked by a water-wheel. The product was a lump of unfused malle-

able iron upto about 6 cwts. This was cut into pieces or "Stücke", which were then hammered in the usual manner. This bloomery furnace must be considered to be the forerunner of the modern blast-furnace. The conditions in the Stückofen were far more favourable to the formation of that highly carburised ("containing carbon"), relatively fusible product known as cast iron, that when obtained had to be decarburised before it could be worked under the hammer. Indeed, the carburised metal was virtually a new metal, which could readily be cast into any desired shape and size.

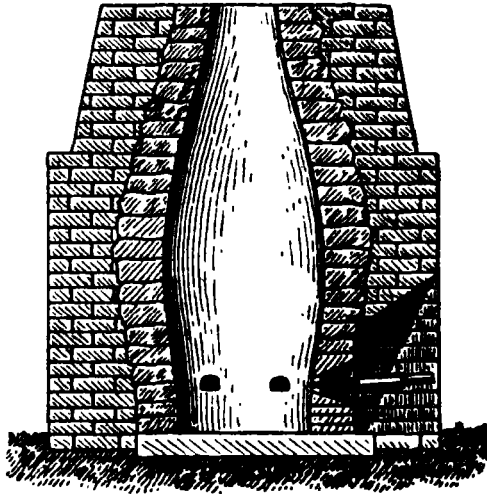


Fig 82. Stückofen (after NEWTON FRIEND)

Up to that moment the production of iron had been a *direct process* which yielded the malleable wrought iron, now the trend became to produce a crude cast iron and to work this up to steel, wrought iron or whatever form of iron was required, thus iron came to be produced by the *indirect process* that is to say no longer in one operation directly from the ore.

The size of the furnace for making iron was gradually increased to save fuel and reduce the cost of manufacture; at the same time it was noticed that the accidental production of cast iron became increasingly frequent because the iron remained a longer time in contact with the fuel or charcoal and it thus became more highly carburised. For a time the Stückofen was used for the production of both malleable iron blooms and molten cast iron. The furnaces gradually

replacing it were called Bauerofen, Blaseofen, Blauofen, etc., but the furnace first remained exactly as it was in the Stückofen and the name referred to the product only not to the construction.

Eventually cast iron was the only direct product; and, as is the case at the present time, it was obtained in the *blast furnace* (Hochofen, haut fourneau), which originated in the Rhine province in the beginning of the fourteenth century or perhaps somewhat earlier.

Just as the crude metal was extracted from the ore by fire, so it was found that by another application of the purifying agent the crude metal could be converted into malleable iron. In the modern method of extracting iron from its ores, cast iron is therefore first



Fig 83. Models of a primitive blast furnace (courtesy of the Science Museum)

produced and this crude product is subsequently employed for the manufacture of iron and steel. What was formerly an accidental and abnormal freak in the bloomery furnace is now the regular and normal product of the blast furnace. As the ore came to remain longer in the furnace it could reach a higher temperature and it was also in contact with more fuel. There are several zones in the blast-furnace, in which specific processes take place. First of all the ore is preheated by the rising gases from the burning fuel, then the oxide is reduced by the charcoal or coke, in a still lower and hotter zone carbon particles can penetrate the iron formed and carburize it to form cast iron, which melts in a still lower zone and can be drawn off together with the molten slag.

The process in the bloomery furnace was much simpler. The earlier furnaces could contain but a few Kgrs. when compared even with the earlier blast furnaces of the Middle Ages which "Stückofen" still

working intermediately produced about 100 to 150 Kgrs per charge. In general only rich ore, poor in sulphur, with a silicious gangue could be worked when only charcoal and no flux was used. The yield would not be more than 30-50 % of the iron present in the ore, the rest would be lost in the slag. In the furnace the slag had a decarburizing influence on the drops of molten iron formed from the ore and thereby their melting point was raised and the drops solidified. As the furnaces developed the blast was intensified and higher temperatures were necessary to reduce the growing masses of ores. This led the development of the furnaces towards higher types such as the Stückofen and the later blast furnace. Longer lasting reduction at higher temperatures gave a total reduction of the ore and iron which had time to absorb carbon at high temperatures and to become cast iron. When smelting this again with charcoal wrought iron could be

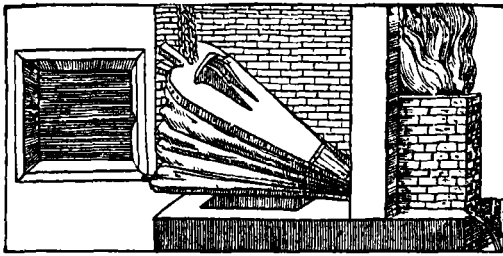


Fig. 84. BIRINGUCCIO'S blast furnace

produced at pleasure. Once the blast furnace was evolved its advantages were so obvious that this type spread very quickly. The earliest blast furnace in the Rhine-country dates back to about 1311 but it reached Sweden as early as 1360 (101)!

But elementary as the early furnaces were, they would produce blooms of quite sufficient size to be handled by the primitive smiths. Furnaces of the types found near Tarxdorf were capable of producing a semi-fused bloom of about 50 lbs in eight to ten hours with some 200 lbs of charcoal and another 25 lbs of charcoal were necessary for the subsequent heating and forging. However simple this operation may appear, it presupposes quite a lot of skill developed by long experience. Both excess carburization and incomplete reduction imperil the process. Neither is handling the bloom a simple task with primitive tongs, anvil and hammer.

All in all starting with a charge of about 300 lbs of ore the metallurgist would obtain something like 25 lbs of fairly good iron.

Furnace reactions were not understood neither was the chemistry underlying these processes and this was the reason why primitive forms of furnaces survived until well into the eighteenth century. The necessity of oxygen and the effect of the presence of carbon which determine the furnace reactions were unknown. Medieval furnaces were merely better because they were larger and the bellows were more efficient, but now they are better controlled. From the remains of the Roman furnaces of Noricum it is clear that the Romans did not produce more than 100 lbs per unit. The quality of their iron improved when they smelted the manganiferous spathic iron of Noricum with bellows, where they could now produce steel at will. If "hard

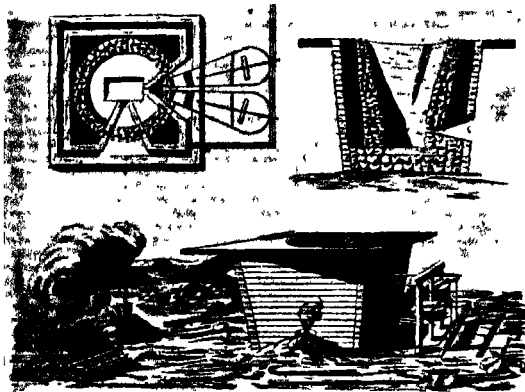


Fig 85 Simple Swedish blast furnace (SVEDENBORG, *de Ferro*, 1734)

iron" or steel was desired, more and thicker charcoal was added and the process continued longer and reducing the draft until the carburisation had proceeded to the desired amount. Reversing the process would give the "soft iron" or malleable, wrought iron as produced of old. With iron as in other activities mere quantitative superiority seems to have been the goal of the Romans and few new inventions in the field of iron metallurgy can be put to their credit. Greater masses were simply produced in small bits and welded together. Still the Romans had different smelting furnaces, each being suited to special phases of iron metallurgy, such as carburising, welding, etc. They very skilfully adapted types that had been developed by the Celtic smiths or those of the Ancient Near East.

The main product was the bloom or *spongae*, as the Latin texts have it, but they had already noticed the occurrence of the "massa" or

flatum ferri on the bottom of the furnace and retreating this regulus would yield a fairly pure piece of wrought iron, which could be broken up and sold to the smith.

When by the tenth to thirteenth century water-driven bellows allowed the development of the blast furnace the cast iron "pig" became more common and soon a standard product. Thus we read in BORBONIUS' *Ferraria* (XVIth cy.) that the miners dig a reddish-yellow ore and crush and wash it. It was then reduced by the *fusor* in a square blast-furnace, the slag drawn off with an iron hook and the remaining iron molten and tapped into the fore-hearth. The "pig" is then smelted in a second furnace by the *fabri* to a bloom which is forged by water-driven hammers.

The production of cast-iron was still a very difficult one, and the

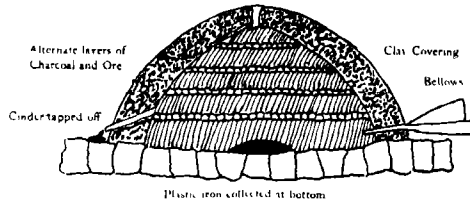


Fig. 86. Diagram of a bloomery hearth (after STRAKER, *Wæalden Iron*)

production of wrought iron from the pig-iron was still more intricate. Often the iron remained too brittle, for PARACELSDS says: "The illness breaks the body as snow-water breaks iron!"

It seems from the texts that the Romans some skill in producing iron and steel by the direct process. For PLINY mentions the effect of the quality of the ore and the metallurgical process on the quality of the iron produced: "There are many different kinds of iron, the chief factors being the nature of the deposits and the climate. Some deposits furnish only an iron which is nearly as soft as lead, others a brittle and coppery kind, quite unsuitable for making wheels and nails, for which the first kind is excellent. The permanency of one variety brings it in favour for shoes and nails for military boots, another has a greater liability to rust. All kinds are called *stricturae*, a term not used in case of other metals and derived from "*stringere aciem*". (*Strictura* would mean a lump of metal from which instruments with sharp edges can be made). There are considerable differences in furnace practice too. What we may call the "nucleus of iron" is smelted here into the hardness of steel, there into the compactness of anvils and hammer-heads. The greatest difference, however, is due to

the nature of the water into which the glowing steel is plunged from time to time. Widely-divided localities, such as Bilbilis and Turassio in Spain and Comum in Italy, renowned for their iron, owe their glory to the excellence of the local waters, although they themselves possess no iron mines.

Among the varieties of iron, that of the Seres carries off the palm and it is exported by them together with garments and pelts, while the second best comes from Parthia. No other kind is made of sheer steel, for the rest contain an admixture of iron of a softer character. Within our empire, excellence such as this occasioned in place by a first-class ore, as in the Noric country, in others by processes of manufacture, as at Sulmo, and in the localities mentioned above by the water.

Strange to say, when ore is smelted, the iron flows like water and breaks up on solidification into spongy masses." (*Nat. Hist.* 34. 143-146).

Whatever difficulties this rather garbled text written by a layman presents, it is certain that he recognised that the facility with which a metallurgical process is carried out depends almost entirely on the character of the ore employed.

Many authors forget that the production of iron is rather difficult for primitive smelters who did not possess good tongs to handle the heavy bloom at red-heat and the reduction process requires a lot of trained intelligence. One of the main difficulties is the gangue of iron ore. This gangue is mainly siliceous and the silica of this component of the ore combines in the furnace with part of the ferrous oxide of the ore to form a fusible silicate or slag. The mass of iron becomes pasty and the slag drips aside, leaving a spongy bloom, which after removal is hammered to cause the unreduced slag or ore to fall apart and thereby the bloom becomes a compact mass of iron. This is a tedious process which requires frequent re-heating of the bloom and much of the ore is wasted in the slag. At present fluxes like lime are added to bind the silica to a far more fusible slag, which separates readily and thus a far greater percentage of the iron from the ore is saved!

Now the primitive smelter did not use *fluxes* in smelting the easier type of ore. Still in Populonia the very siliceous Elban ore was mixed with lime and also the more clayey Monte Valerio ore. In Erzberg the slags show signs of greater liquidity in several cases and as a rule the slags of a particular smelting site richest in iron can be said

to be the oldest. Perhaps older slags were reworked in Roman times, but this should be confirmed by further analyses. THEOPHRAST mentions the "fire-fighting stone" which was used in Pontus as a flux. PERSSON quite correctly identifies this *pyromachos lithos*, which LIDDELL SCOTT translates by "resisting fire, fire-proof stone", with limestone. The furnace used in those regions probably was a rectangular stone furnace with low walks covered with slabs of limestone. In close contact with fire this limestone liberates carbon dioxide and the stone appears "to be fighting fire" but the disintegrated limestone acts as a flux which is useful as the limonite type of ore is generally phosphoric. If the temperature is kept low enough the phosphorus combines with the lime and is slagged away. ARISTOTLE (*de Metereol.* IV. 6. 11) says of the same stone that "it melts and solidifies again", which could be taken as an unscientific interpretation of the disintegration of the limestone. Another flux which was added in Antiquity to form a *scoria* or slag was the *melias lithos* (THEOPHRAST, *de lapid.* 9) which is probably lava. But lime seems to have been the most generally applied flux of Antiquity. However, few analyses of ancient slags are available though STRAKER has shown what important results can be obtained from the direct process, which does not subject the ore to a very high temperature (600-700° C is sufficient to reduce the iron ore!) and does not bring it in contact with charcoal for a very long period, produced a very pure iron, which is malleable and which we call *wrought iron*. But if kept at higher temperatures and when in contact with charcoal for a longer time the iron is formed by reduction of the ore but it subsequently absorbs carbon upto over 86 lbs/Ton (2.5-4.0 %) and the melting point is lowered from that of wrought iron (1530° C) to a minimum of 1170° C as the amount of carbon augments. This carburised iron liquifies more readily and flows out of the furnace as *cast iron*. The carbon which is absorbed by the iron, combines with part of it to form iron-carbide or cementite, a hard but brittle compound, crystals of which form part of the structure of the solidified iron. This cementite imbues the brittleness to the iron, wrought iron which is free from carbon and therefore from cementite is tough and malleable. The cementite, however, is unstable and if the iron is very slowly cooled, a texture of iron with graphite (carbon) particles is formed; if cooled more quickly or even rapidly (quenched) the cementite structure remains with all its inherent properties.

Steel is an iron with much less carbon than cast iron. It is now made

by decarburizing cast iron, but formely when wrought iron was made by the direct process, this method was impossible and steel had to be made by carburizing wrought iron, that is by imparting carbon to it. This *carburizing* was probably not achieved intentionally but simply by the repeated heating of the wrought iron bar in charcoal between the hammerings, for as PLINY says (*Nat. Hist.* 34, 149): "Iron which has been heated deteriorates, unless it is hardened by hammering; iron can not be forged when red-hot, nor indeed until it reaches incipient white-heat" at which temperature it more readily absorbs the necessary carbon (0.3-2.0 %) to form steel. In steel again the cementite stable at high temperature forms the component that imbues it with the hardness proper to steel. If slowly cooled this steel would either

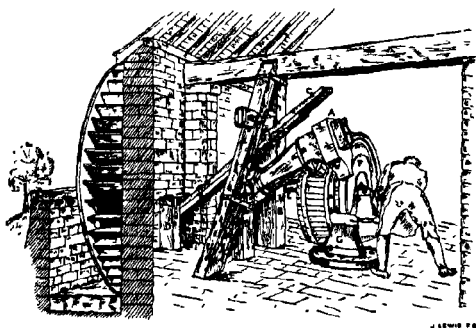


Fig. 87 Working drawing of a hammer forge (after STRAKER, *Wealden Iron*)

lose its cementite straight away or fairly quickly after cooling and the iron-graphite structure stable at normal temperatures would be formed. But by *quenching* or rapid cooling for instance by dipping the white-hot steel into water or oil the cementite structure is rapidly carried through the danger-zone of disintegration and more or less stabilized at low temperatures. However, for certain purposes the steel would be too hard and too brittle and it is necessary to find a means to give the steel a certain amount of toughness and take away some of its brittleness. This can be achieved in two ways. By *tempering* (*Anlassen*) the steel was first hardened to the limit and then "let down" by heating it again until a certain colour is shown on the polished bright steel when it is quickly quenched again. Thereby we impart the steel the exact structure that belongs to the temperature to which it has been heated for the second time. A second method was

that of *annealing*, that is reheating the brittle steel and cooling it, regulating both operations very carefully. Hereby the structure is rearranged and any degree of mildness can be imparted and brittleness taken away from the steel. At present this process is carried out in carefully controlled annealing furnaces, but in Antiquity it depended entirely on the skill of the smith, who hampered by the lack of proper means of temperature control, often missed the effect he desired.

Apart from this very simplified explanation of the structural differences of wrought iron, cast iron and steel, many further complica-



Fig. 88. Smithy with bellows, hammer, and quenching pit (after AGRICOLA, *de re Metallica*)

tions arise in practice because during the smelting of iron ores such impurities as silica, etc. from the gangue may react and form silicium, manganese, phosphorus, copper, arsenic, nickel, etc., which are absorbed with the carbon by the iron and impart the cast iron and steel with different properties. Much depends nowadays on the skill of the smelter who adds fluxes and other compounds to the reaction taking into account the composition of the gangue and thereby regulating the final composition and the amount of impurities of his end-product. The ancient metallurgist must often have been baffled by the result of the smelting operation and only long experience could guide him towards the correct smelting and the kind and amount of fluxes necessary to obtain a good product. Here again it would be very dangerous to judge

from the analysis of a few pieces of ancient iron and statistical-chronological series of analyses are the only means that will show us how the ancient smelter overcame his difficulties and when he first mastered them. There is of course the difficulty that terrestrial iron rusted away as it is not as resistant as the natural meteoric iron-nickel alloy. As PLINY says (*Nat. Hist.* 34. 141): "The foe of iron is the customary benevolence of nature which decrees that which inflicts most loss on short-lived humanity shall be of all materials the most short-lived"; but on the other hand iron-rust is a most stable product and could be easily noticed if archaeologists had payed more attention to it formerly as they do now. Therefore, the abundance of any metal in a particular district now does not stand in a sure relation to its utilization in earlier times. Not is it often clear what ores have been smelted in the earliest periods. The earthy ochres have been used as paints from times immemorial and haematite was early used as a seal-stone. Both limonite and haematite are easily reduced in bloomeries, magnetite is more difficult to attack because of its compactness, but we have evidence that it was also among the earliest iron ores smelted. Probably in the earliest periods local pockets and lake- and bog-iron ores were worked until a definite iron industry arose with its own technical code and tradition, which gradually mastered the different techniques of smelting the various iron ores.

When iron production became an industry there was already considerable differentiation among the metallurgists, as we have seen; and we need not wonder that at several places the ore was not treated at the deposits but only mined and traded to the smelting centres, as excavations show.

It may be that smelting was sometimes a home-industry as it still was in Sweden and Finland in the last century and perhaps in early Caucasia too. But often the crude iron was produced on the mining site as with many other metals and traded to special metallurgical centres. Thus iron was produced at Noricum and worked in Aquilea and the surrounding district, at least in the earlier period of Roman domination. But the combination of mining and smelting with the smith's forge was still very common in Antiquity, for instance in Asia Minor, as it is still with such primitive smiths as the Asura of Chota Nagpur. As APOLLONIUS OF RHODES expresses it in his *Argonautika* (II, 1001-1007):

"That folk (Chalybes) drive never the ploughing oxen afield:
No part have they in planting of fruit, that is honey-sweet to the heart;

Neither lead they the pasturing flocks over meadows a-glitter with dew:
But the ribs of the stubborn earth for treasure of iron they hew,
And by merchandise of the same they do live: never dawning broke
Bringing respite of toil unto them, but ever midst of mirk of smoke
And flame of the forge are they toiling and plying the weary stroke."

RICKARD and ZIMMER have proved beyond doubt that the earliest form of iron used by mankind was *meteoric iron*. Of course there were many peoples who remained either ignorant of iron or used meteoric iron without recognizing its metallic properties and working it as a kind of stone. For even finding pieces of iron will not teach its metallurgy! The Andaman islanders when they obtained iron from wrecks (130) did not employ heat in making it into arrow-heads. They simply broke off a piece of metal and ground it into shape exactly as they were accustomed to do with a piece of shell.

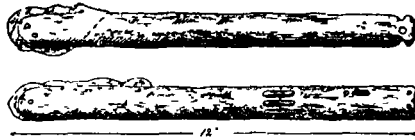


Fig 89 Eskimo knives found by Capt J Ross at Cape York, West Greenland (after RICKARD, *Man and Metals*)

As far back as 1889 HENSOLDT stated that when Cortez completed the conquest of Mexico the Spaniards were struck by the fact that the Aztecs possessed certain implements such as knives, daggers, etc. made of iron, but it seemed that only the most distinguished possessed such. Iron was a great rarity prized higher than gold. No smelting site was ever found and the Aztecs were unacquainted with the smelting of iron ores, which they did not consider akin to the valuable metal that they called *tepuztli* or "copper". Their iron was, in fact, of meteoric origin, like that of the Mayas of Yucatan and the Incas of Peru, of which many weapons are still preserved in the collections. Nor did later excavators like JOYCE succeed in finding any terrestrial iron in the New World.

To primitive man who knew native copper the rough shaping and polishing of meteoric iron must have been a great success. He must have gone on to search dilligently for this stone which enabled him to fashion tools that were definitely better than the older stone tools, for the nickel-iron alloy has the properties of steel. Now smaller meteorites rarely fall alone and more likely there are many others to

be found in the same locality. The siderites and meteorites have sizes that range from a few ounces to 50 Tons, but they were undoubtedly wrought into objects according to their size and shape. Less than 300 Tons of meteoric iron are known at present most of which occurs in the New World. But we have already pointed out that the amount of meteoric iron observed correlates with the density of population and perhaps primitive man in the Old World used up an equal amount which would explain the preponderance of the American continent. Many types of meteorites can be flaked when slightly weathered and only detachable parts or small masses could of course be used. This is clearly showed by the finds of objects fashioned from meteoric iron such as rings, amulets, images, daggers, etc. It is possible that the lump of iron which Achilles offered as a prize at the funeral games (Iliad, XXXIII) was of meteoric origin. PLINY certainly knew the celestial origin of meteorites (*Nat. Hist.* II. 147) and the ancients possessed in the natural nickel-iron alloy a type of steel that was not manufactured by mankind before 1890 (86). Nearly all the people of Antiquity use such words for iron as "heaven metal" or "something hard (stone) from heaven".

There is one well-known example of the occurrence of telluric iron. At Ovivak in Greenland metallic iron is found in a basalt that has erupted through beds containing coal, which may explain the reduction of the iron. The Eskimos have used it for making knives and other implements without the aid of any suggestion, as far as known, from any sophisticated foreigner. But they also detached pieces from meteorites, treating the iron as a malleable stone by hammering. On an island in Melville Bay there are three famous meteorites, one called "the Tent" weighing 36.5 Tons, another "the Woman" of 3 Tons and finally "the Dog" of 960 lbs only. Pieces were detached by laminating some slight prominence on the surface, pounding repeatedly until a small ridge of metal was formed which they worried apart in the same manner which the Indians used to separate fragments from the copper masses of Lake Superior. In the Turner mounds there are also several pieces of worked meteoric iron. The Eskimo metallurgy is very different from that of the Norsemen who lived in Greenland. The latter reduced iron ores with charcoal in pot-bowl furnaces and forged it. They also knew the art of tempering (98) in fact, they had brought with them the art as it was practised in their times in N.W. Europe. There seems to have been no contact with the Eskimos close enough for passing on this knowledge.

It seems pretty certain that as soon as the process of melting native copper was known the same operation must have been tried with meteoric iron, but as the furnaces could not yet attain such high temperatures except in crucible smelting, this experiment was doomed to fail. Even the reduction of iron ore in simple furnaces of the "hole-in-the-ground" type using blast air will only succeed when using good ores, but for copper the conditions are far more favourable and therefore metallurgy proceeded first along the line of the development of copper metallurgy. The smith was not yet ready for the intricate treatment of the bloom, in which but few would suspect something that could be hammered into a piece of metal.

It is still a puzzle what the earliest iron ore was, that mankind tackled. Probably this is rather a local problem and not open to some general solution. Several authors have speculated on this problem (74) (115) (102) and RICHARDSON has presented the case for each type of ore very clearly. Limonite is rather siliceous and contains a lot of water, its iron content usually wavers between 30 and 40 %, while the limit of efficient treatment is something like 35 % of iron. Spathic iron though an excellent ore of generally more than 50 % of iron has no striking, metallic appearance, it requires pre-roasting and there are but few deposits in the Ancient Near East. Haematite is a wide-spread ore there, it contains over 50 % of iron, but it is often very manganiferous and its surface is often weathered to limonite, thus changing its striking appearance. The only ore that had both a very high iron content (upto 72 %) and a striking metallic appearance that would attract the primitive metallurgist would be magnetite, that is quite common in the beds of mountain streams and the mountains of Armenia and Egypt. It would appear that though magnetite was probably the earlier iron ore to be worked, it was not treated directly in a bloomery furnace with blast air, as the ore is very compact and requires fairly high temperatures for disintegration, but it is suggested by several authors (originally by QUIRING) that this direct treatment of the ore began only when the metallurgy of iron was already rather developed in the Near East and that iron was originally produced as a *by-product of the refining of gold*. The Nile sand and especially the gold gravels of Nubia (74) contain grains of magnetite of high specific gravity and an iron content of over 65 %. About half the residue of goldwashing is magnetite, the grains gathering with the gold dust and nuggets in the residue of the pan. Now the gold was smelted in Egypt in crucibles in a reducing atmos-

phere using chaff of clover and straw as the texts tell us. After the smelting a slag rich in iron would collect on the top of the mass in the crucible, a layer of pasty iron would form the middle course directly over the liquid gold. If this pasty iron were extracted, it would be immediately ready for forging. It is clear that the quantities of iron produced in this way were small only. This method of iron manufacture as a by-product of gold would not only account for the peculiar association of small pieces of iron with gold in early jewelry but it would also explain the pygmy character of the early iron objects, such as the small models(?) of tools, amulets, etc. found in the grave of Tut-anch-amun, etc. The Nubian gold production became a regular industry after the incorporation of these lands in Egypt by the dynasties of the Middle Kingdom and the fact that this iron jewelry and the small iron objects begin to appear after 2000 B.C. add to the probability of the early reduction of magnetite as a by-product of gold refining.

Of course this early manufacture of small quantities of man-made, nickel-free iron can hardly be called an industry and it would seem that the earliest ores to be worked on a larger scale were the *lake- and bog-iron ores* of Cappadocia, and the process seems to have been a kind of Osmund process. The account of this industry in PSEUDO-ARISTOTLE (*de mirab. ausc.* 25-26) runs as follows: "Iron is obtained in large quantities from the ironstone of Elba and from the mines of the Chalybes near Amisus on the southern shores of the Black Sea. The ore is difficult to smelt on account of the quantity of clay contained in it, and it is softened only by raising it to a great heat. Iron is of great strength and very hard, though it is said that in Cyprus there are mice which are able to gnaw it. The best and hardest of all kinds of iron known is that of the Chalybes, that is chalybs (steel) and it is obtained from iron by melting it repeatedly together with certain stones in a furnace, during which process much slag is formed and a great loss in weight occurs on account of which the process is very costly. The finished steel is hard with a glittering surface and resists rust, but it is not applicable to all purposes for which the less pure iron is used. The quality is judged by the sound given out in working it on the anvil". The earlier part of this text is not as clear in all versions and HULME after careful study of the available evidence proposes to render it thus: "The matrix of the Chalybian and Amisenian iron ore is peculiar to the locality, for it is made up from the silt brought down by the rivers. This they smelt

in their furnaces after simple washings, and they superimpose on their furnace the fire-fighting stone which is plentiful in their country. This steel is superior to other forms of iron and closely resembles silver, if not smelted in one furnace (only). It alone is not subject to corrosion but the output is small", an interpretation which is technically more sound. The ore mentioned in this passage reminds us of PLINY's account of the Cappadocian ore (*Nat. Hist.* 34. 141), "where the earth yields iron to the smelter only where the waters of certain rivers have flooded it." This passage certainly refers to typical lake-iron ore deposits. For limonite and other carbonates of iron are broken down in the presence of carbonic acid and water (73) to hydrated sesquioxide of iron which is soluble in water and deposited by bacteria in the form of silt in the presence of vegetation and still water. Bog-iron requires prolonged roasting, whereas lake-iron needs only washing and drying, but on the other hand the ores are phosphoric and contain greatly varying quantities of manganese. Therefore the smelting requires careful adjustment of the temperature to slag the impurities and to prevent them from alloying with the iron. In Europe where the Germans treated similar ores green wood was used instead of charcoal. The deposits mentioned by these ancient authors seem to be those of the Pyramus river, and this smelting of lake-iron would account for the excuse in the Hattusil letter which mentions that "no iron is available at present", as we shall see, but they may just as well refer to the Iris in Pontus. Further research should be directed towards the distribution of lake-iron deposits, the methods of their deposition and their utilisation in ancient Asia Minor before these questions can be solved.

In Roman times the German tribes worked bog-iron ores but the wrought pure iron obtained at low temperatures was soft and the iron swords were of little use against the superior bronze weapons and stood far behind the iron and steel weapons of the Celts, who had obtained a steel-like iron from the special ore of Noricum and had learned to obtain steel from others. This lake-iron industry does not seem to be a separate phase following the magnetite-phase but merely one aspect of the general *working of iron ores in bloomeries*. The beginnings of the iron industry are still very dark from the technical point of view. All we can say is that the earliest bloomeries must have consisted of very simple clay-lined pot-bowl furnaces or simple bloomery fires (Rennfeuer) both worked with blast air and smelting ores of the limonite and ochre type or weathered haematite. We have

seen that these simple furnaces developed into the peculiar shaft furnaces called "Stückofen" by the way of the Catalan hearth and how these Stückofen permitted the smelting of ores of the haematite and magnetite type. But the early iron industry will remain dark as long as the history of the smelting furnace is not known better in detail. It is certain that many types of furnaces were evolved according to local needs and their evolution and spread may prove to be as inextricable as the story of the African smelting plant seems to us now. It seems that by 500 B.C. the normal bloomery was used in most of the then existing iron-smelting sites. The evolution of shaft-furnaces had already begun, as we have several types of prehistoric furnaces from Central Europe which look like the first steps in this direction; but the Stückofen did not succeed until better blast air production was achieved. Here the Celts seem to have led the way and the Romans took over their water-driven(?) bellows and forges and developed them but little. Ancient iron production was always that of a semi-soft iron mass or bloom which by forging was turned into wrought iron, but sometimes by fortitious admixtures or special treatment into steel or harder types of wrought iron. It received little stimulus from the general type of the wandering iron-smith of those days who either worked bar-iron or produced his own iron from the local sources on his way. The iron industries of Noricum and other sites developed their local technique but there was of course no binding research to guide them all and once the most efficient way of working the local ore was found the industry settled to use such methods and no further progress was achieved. Ancient iron technique differed considerably from that used for other ores in Antiquity, because the iron was not liquified like copper and other metals but a bloom was produced and the heated mass had to be hammered on an anvil until the iron was welded into a solid lump and all the impurities were expelled. If larger pieces were required a number of such blooms were reheated and welded into a single mass by forging as the special re-heating furnaces of Corbridge and Cedworth prove.

Gradually such higher types of shaft-furnaces were evolved which allowed a better separation between slag and bloom. We often find the bloom wedged half-way the narrow Roman furnaces or the Silesian "hour-glass" furnaces. On the other hand we have no proof that the earliest pot-bowl furnaces were all equipped with blast air, no attention has often been paid to the clay-nozzles of the bellows, and they may have been worked with natural draught as some types

undoubtedly are. As long as the fundamental reactions were so little understood and so much was left to chance we find the most primitive pot-bowl furnace together with the better Stückofen in a welter of types, the history and spread of which only careful research will be able to disentangle. This medley of methods and apparatus continues to thrive for many centuries. Thus THEOPHILUS mentions only the primitive bloomery furnace for the production of iron and does not mention the Stückofen, which was quite well-known in his days (Cap. XC): "Iron is formed in the earth as stones. When it has been mined it is crushed in the same way as copper ore and smelted together into lumps. Then it is brought to higher temperature in the furnace of the black-smith and it is forged to be ready for work. Steel gets its name from the mountain Chalyps where it is found in large quantities and it is prepared in the same way." Even BIRINGUCCIO mentions both the bloomery furnace worked with blast air and the shaft-furnace (I. 6), though he also gives a bad description of the blast furnace (III. 3), and AGRICOLA (1) seems quite content with the production of iron in a bloomery fire combined with a smith's forge and hammer, while he approves of the Stückofen for smelting iron pyrites and advocates crucible smelting for the production of good steel. Thus even in the sixteenth century primitive and more sophisticated methods were used side by side and different forms of smelting furnaces adapted to the peculiar characteristics of local ores. No wonder that our picture of Roman and pre-Roman iron smelting is far from clear. Only further research in that very neglected field of smelting furnaces and their products (ores, slags, etc.) will help to clear it. In several furnaces of the Stückofen-type the temperature might rise to a point at which iron is fused and *cast-iron* is produced, but this metal was far too brittle and hard to be used for industrial purposes. In order to produce a cast-iron suitable for making castings a much higher temperature is required which only the blast-furnaces of the fourteenth century could reach.

Cast-iron must be considered unknown to Antiquity according to most authors, and there is no certain reference to it in ancient literature. Still there is the possibility that some knowledge on cast-iron reached the Roman Empire from the country, where cast-iron was invented, from China by the way of the desert route. But cast-iron seems to have been known to the Graeco-Roman world as an accidental and useless product formed by raising the temperature, but as its nature was not recognised it was thrown away. Even at Halstatt sites, for

instance at Byčiskala near Brno, cast-iron pieces were found in the slag-heaps. The frequency with which pieces of cast-iron have been found at Roman bloomery sites has led some writers to suppose that its production was intentional. Thus MAY claimed that it was produced in coal-fired furnaces as a bloom which was then purified with charcoal in crucible, but the best metallurgical opinion is against it. Still the Warrington piece found by MAY in 1904 seems to be true cast-iron (WYNDHAM HULME, *Antiquity*, vol. VII, 1933, p. 363) and further analysis of this piece is an urgent matter. But the claim that a "Roman" blast-furnace was found at Colsterworth has been denied by STRAKER. Some Roman objects like the head from Beauraing are definitely stated to be cast but the final proof is mostly lacking, as frequently such "cast-iron statues" have proved to be figures of pure wrought iron which had been chased! We have the statement by PAUSANIAS (III. 12. 10) about "Theodorus the Samian who invented how to cast (*diacheai*) iron and to fabricate statues from it", but most authors consider this sixth century invention very doubtful or, like READ, suppose that PAUSANIAS mixed up the casting of bronze and iron. Another passage in PAUSANIAS' account (X. 18. 6) runs: "The working of iron into statues happens to be the most difficult work and a matter of the greatest labour. The work of Tisagoras (whoever he was) is wonderful", but this does not imply the casting of iron and may well refer to chasing or even hammering into a mould (swaging), which LUCAN (VI. 403) mentions, though this passage is also read to mean welding pieces of iron into a bloom.

Yet there is a passage in PLINY's *Natural History* (33. 30), where he discusses the use of pine logs for the melting of iron and copper and in this text he uses the word *fundo* instead of the *excoquo* of other passages, but there is nothing in this text to indicate that the manufacture of cast-iron is meant. A similar case is the passage from HESIOD's *Theogony* (864-868), which may refer to the fusion (*tekethai*) of iron, but this does not imply casting. On the other hand the "ponderous mass of iron as a quoit" (*Iliad*, XXIII, 826) (*sólos autochionos*) is considered by some to be a meteorite but RICHARDSON thinks that it was a bloom described by one who was contemporary with the beginnings of iron-working. The passage in ARISTOTLE's *Meteorologika* (IV. 6) refers to "weak, malleable iron".

The direct production of cast-iron in blast-furnaces was impossible, the only other possibility was smelting with a flux in crucibles. Certain prehistoric furnaces like that at Rudic (near Brno) are well adapted

to crucible-smelting, which is unusual and uneconomical for the production of a bloom. In Gradišče (Carinthia) many fragments of crucibles impregnated with iron have been found. But these are probably crucibles used for the production of steel by the cementation process, during which iron may have occasionally absorbed excessive carbon and liquified. There are no further indications that cast-iron was manufactured outside the Roman world except in China, to which fact we will revert in due course.

The passage in Daniel (II. 31 : 41) which some hold to refer to cast-iron seems to combine clay and iron only as a simile illustrating the impossibility of combining the weak and the strong.

In contrast to this negative result we are sure that *steel* was produced in Antiquity. Steel is called *chalybs* but also *adamas* (untamable) or *kyanos* (the dark-blue). By *acies* or *stomoma* the sharpness or the sharp edge of a weapon or tool was meant, but these words were never used for steel itself, though they may denote "steeled" portions of an implement.

It is doubtful whether the ancients knew any direct method of producing steel, but they produced it accidentally when they treated suitable ores. If working manganese-bearing iron ores, free from phosphorus, arsenic or sulphur, there was a possibility of obtaining steel in the bloomery furnace. Care should be taken not to decarburize the bloom fully and thus a good malleable steel would be obtained. This fact was probably discovered by the Celts in Noricum around 500 B.C. though of course not understood. The specific shaft-furnaces, about 1-2 M. high, found in this field would suit the *production of such "natural" steel* excellently. Such a fortitious composition is not limited to spathic iron ore only and the possibility of a direct production of "natural steel" may have existed in several other ancient metallurgical centres, but this point can not yet be settled for the lack of proper analytical data on ores and products.

A second possibility would be a crucible process of preparing steel, a *fusion process*. It is uncertain whether the Romans ever produced steel or iron by the fusion process, but in the light of present evidence it seems very unlikely. They may have occasionally produced amorphous iron carbide if we may believe RICHARDSON's interpretation of PLINY's passage (*Nat. Hist.*, 34. 141), but a sure proof that they did not know the fusion process seems to be the fact that all their best steel was imported from the East. PLINY wrongly believes Seric iron to be Chinese steel, but it was in reality Indian steel from the

Hyderabad district, known at present as *wootz*. Wootz is produced from black magnetite ore, bamboo-charcoal, and the leaves of certain carbonaceous plants sealed in a crucible of native clay. Smelting the contents in a charcoal fire with blast air yields a button or regulus of metal, which is alternately melted and cooled again four or five times until round cakes of 5" diameter and $\frac{1}{2}$ " thick, weighing about 2 lbs, are obtained. These were the *wootz* cakes exported in Antiquity to Damascus and later to Toledo and other Arabian metallurgical centres for the manufacture of so-called "damascened steel". This was a high quality steel with a certain pattern dictated by taste. Such damascened blades were forged from wootz cakes by flowing the metal in two or more directions by blows of the hammer. After prolonged annealing the blades were then quenched and drawn to the desired hardness, polished and etched. The last operation brings the "damask" pattern to the surface. Pattern and colour largely determine the quality of this Oriental steel. There are different methods of preparing this steel, one of which we have described. Another consists in forging and working the steel at dark-red heat without quenching (135), but whatever method of forging is used, the general characteristic of the damascened steel is a structure with small particles of globular cementite, which is easily identified under the microscope (30). The Persian steel seems to have been produced by carburising and smelting wrought iron with charcoal in a crucible and this "Parthian steel" was inferior in renown to Seric iron only! The fame of this Oriental steel lasted until present times and we often find references to it in literature, mostly without intimate knowledge of this secret process of which we will have more to say. Thus THOMAS OF CANTIPRÉ (147) tells of an oriental iron called *andena* or *alidea* which is very good for cutting and which is fusible like copper and silver but is less ductile than iron from other parts of the world! Of course this excellent steel was soon imitated and even in Antiquity similar products were attempted. Thus the Celtic smiths of the first century A.D. have invented a process of welding steel strips or wire onto an wrought iron bar and falsely damascening it by cross forging as proved by the Nydam find. It is very probable that this "damask" pattern was adopted from meteorites (75). Siderites when passing through the atmosphere to the earth get covered with a thin film of magnetic iron oxide. When forged at low temperatures a crystal pattern, the so-called Widmanstätten figures, show up, a pattern that is destroyed at white-heat. It seems very probably that the "wootz" pattern, a contrast between carbon-rich and car-

bon-poor particles in the steel is an imitation of this "damask" pattern of meteorites.

Such direct steel by the fusion process depends upon high furnace temperatures, much charcoal and the proper clay and other ingredients for refractory crucibles. At present "cast steel" is still largely prepared in such crucibles by a fusion process, but often crude iron is carburised to "blistersteel" and forged directly into tools (59). Cast steel is of course a modern invention, though BIRINGUCCIO hints at the direct production of cast steel from Stückerofen-iron. But the true development of the process was the work of the generations of metallurgists between Réaumur (1722) and the early nineteenth century (77).

RICHARDSON maintains that the Chalybes also used a fusion process in crucibles for their famous steel, but there is no direct evidence.

However, most of the ancient steel was made by a third process, by *cementation* or *carburisation* of wrought iron. The ancient wrought iron is not always very pure, it often contains small particles of slag, and above all the carbon content varies throughout the object (20). In other words the purified bloom is partially and unevenly steeled. Now the gradual conquest of this "steel-making" process was the real impulse of the rise of iron metallurgy in Antiquity. For wrought iron objects could of course be used for many a purpose, but it was generally inferior to bronze, the production of which was already well in hand for centuries before iron came to the fore. The modern process entails the heating of wrought iron or mild steel in a powdered mass of carbon-rich material. It is generally called *case-hardening* and the surface of the piece is carburised to a depth depending on the length of the treatment. It is commonly effected by cementation with charcoal, powdered horn, dung or similar carbonaceous matter, though by modern processes with potassium cyanide a mere skin of steel can be formed at will. It is probable that this cementation which is very common among the analysed steeled tools was an accidental discovery. When forging the bar of wrought iron, the primitive smith had to reheat it often and if he achieved this heating by embedding his bar in the heart of a charcoal fire and maintained the temperature by using a blast insufficiently strong to penetrate the heart of the hearth, he would have ideal conditions for the process.

We have some inkling of the gradual development of this process in the Near East from the researches of CARPENTER (20). When analysing several iron objects from the period between 1200 B.C. and Roman times, all hailing from Egypt, he discovered, that the earliest

objects were only carburised, than about 900-700 B.C., quenching is added to the operations and tempering is introduced by the Romans. The latter, probably the most difficult of heat treatments, was not yet properly understood and some of the objects were overheated. If therefore Negroes often produce crucible steel nowadays, we must remember that these black smiths were vastly sophisticated when compared with the classical smith who seems to have used case-hardening as a general rule, however difficult he could control the operation without instruments like ours. Carburisation or decarburisation was long the bane of the Roman metallurgists and it remained

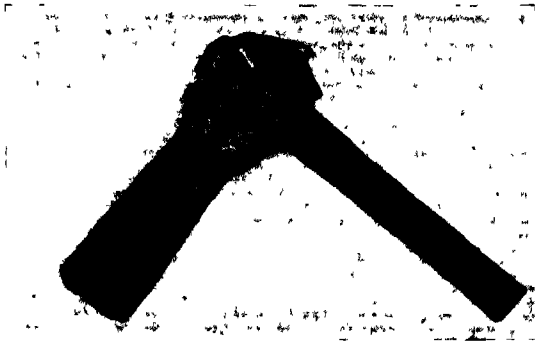


Fig. 90 Ornamental "steeled" battle ax from Ugarit (SCHAEFFER, ILN of Jan 6th, 1940)

a difficult problem how to retain or restore a cutting edge of an implement. Very often, therefore, the Romans resorted to other means and annealed part of the tool or carburised only its blade, so that it should not be too brittle. If a combination of strength and toughness was required for a tool, this could be attained by the false method of damascening, by welding together plates or strips of softer and harder iron and steel by forging. The Celtiberians were greatly hampered by the varying properties of their home-produced steel and according to DIODOR (V. 33) they buried it for some time and then reformed it. The softer iron rusts more quickly than steel and thus by re-forming the iron rust is expelled and the remaining steely parts are welded together. Thus they were able to repair the insufficient mastering of the smelting process in their primitive furnaces.

The heat treatments like quenching and tempering were certainly no Egyptian inventions for the tools analysed by CARPENTER fall in a period when iron was still far from common in Egypt, which enters

the Iron Age not earlier than 700-600 B.C. They must have been imported objects or perhaps the work of foreign smiths in Egypt. Tempering was a Roman achievement as it seems. A Roman chisel from Chesterholm, for instance, has a steely portion in which the carbon content varies widely. The edge of the tool was heated to 900° C and quenched in water, but only the cutting edge (103)! This is but one of the examples of implements hardened by tempering and quenching, which now can no longer be denied as JOHANNSEN did several years ago (77).

It is, however, a wrong idea, that heating a steel tool to red-heat and quenching it would harden the tool, without forging it with a hammer this operation would only soften it. The tool is heated to be able to hammer it properly but unless keeping it at white-heat any other temperature would only cause the loss of the "steel" structure acquired at higher temperature and formation of the iron-graphite structure, stable at lower temperatures. Copper is softened by the heating not by quenching. Quenching was well known to the ancients. We not only read in the Odyssey (IX. 459): "As when the smith an hatchet or large axe tempering with skill, plunges the hissing blade deep in cold water (hence the strength of the steel) . . .", but the term *baptein*, *baphé* occurs in several passages (SOPHOCLES, *Ajax*, 650, etc.). The Latin expressions are *tinguere* (VIRGIL, *Georg.* IV. 172), *restinguere* (PLIN, *Nat. Hist.* 34, 146), *temperare* (PLIN. 34. 145; ISID., *Orig.* XVI, 20.1; Mart. IV. 55, 15). Quenching in water or oil was the recognised method in Antiquity, but of course the actual process was not understood. As late as 1370 the Quodlibeta of Oresme put the following problem: "Why does cold water harden ignited iron or steel and why does it soften when put in the fire again?" Cooling in oil was generally advocated to avoid making the steel too brittle (PLIN. 34. 146; HIPPOCR., *coic. praenot.* 384; PLUT., *de prim. frig.* 13, p. 950 C) and in the case water the contents of the cooling trough or *lacus* was considered of the utmost importance, for certain waters were said to be most effective. We have already cited PLINY on this matter and others (JUSTIN, XLIV. 3. 8) also believed in the special properties of the waters of the Jalon at Bilbilis, etc. Later special solutions were manufactured. An encyclopaedia of the fourteenth century even mentions quenching in honey to get a steel that is readily softened and easily liquified in the fire (147)! These tales are not all myths, as some solutions seem to have an effect indeed. Possibly these stories also served to conceal the essentials of

the tempering methods at Como, etc. as RICHARDSON suggested. Of course some of these stories may have ascribed the properties of the local steel to the wrong factor, whereas the true reason of its quality lay in the absence of harmful impurities and the presence of manganese or titanium.

The ancients recognised many qualities of steel. The Chinese had only "natural" and "artificial" steel, but the Greeks of the age of Alexander had many qualities according to DAIMACHUS. There was the Sinopic steel used for carpenter's tools, the Chalybic kind, Laconian steel for files and borers, and Lydian steel for swords. In Roman times we find the Spanish and Noric steel prominent together with the Seric and Parthian steel imported from the Orient.

Technically speaking we must, therefore, distinguish the following phases of iron industry. First a period of the use of meteoric iron, then iron produced as a by-product of gold-refining, followed quickly by the evolution of the reduction of iron ores in bloomery and shaft-furnaces, which rose to prominence when methods of cementation allowed the manufacture of steel. For only steel is definitely better than bronze for tools and weapons and only the invention of steel could herald the Iron Age. This is an important fact which we must keep in mind, if we want to trace the discovery of iron.

III

The production and working of iron spread more widely than that of copper and bronze had as it ousted them as the main materials of the metal workers. In Africa where iron came first copper is used almost entirely for ornamental purposes. Both the agricultural and pastoral peoples of the Old World know iron but in the New World and Oceania it remained largely unknown. Nor could the simple exchange or trade in this new metal start an Iron Age. As we have proved the technique of the Iron Age is built up of an entirely new set of methods and processes, which differ fundamentally on many points from those used in the manufacture of copper and bronze. Therefore even if the Polynesians lost their earlier knowledge of iron metallurgy during their wanderings from Hinter India to their new island empire (125) they could not recover it or learn it from the iron which reached them from driftwood, wrecked ships, shipwrecked Europeans or simply by trade. The knowledge of iron metallurgy was carried through the ocean by travellers, it could not be learnt by casual finds (126).

No Iron Age could start from the knowledge of meteoric iron alone. It is true that ZIMMER showed that meteoric iron is practically always malleable, more than 99 % of the known meteorites consist of a malleable iron-nickel alloy and only 0.56 % is definitely non-malleable. Even the rare natural nickeliferous iron is mostly malleable. But the Iron Age could be initiated only by a people who knew how to reduce iron ore and had acquired the special knowledge of working the bloom obtained from the ore, a most unmetal-like substance for a generation which had all the lore of copper-, lead- and other metal-craft. The iron-smith is the real smith in our sense of the word, the Iron Age is the period in which the first smithies are built, with their characteristic equipment.

Now the craft of the black-smith is fundamentally different from that of the copper metallurgist, iron metallurgy is coupled with its typical furnaces, bellows and apparatus, tongs, crucibles, etc.; the arts of hardening, carburising, quenching, annealing and tempering are new acquisitions of several generations of smiths.

The fact that iron metallurgy spread relatively quicker than copper and bronze has misled many authors to believe that this complex of operations was not diffused from a certain centre and that it could be and was indeed re-discovered in many regions of the earth (VON LIPPMANN, etc.). But this special set of techniques and the knowledge of other techniques of other metals which iron working presumes, do not only dub it a late comer, but are strong arguments for its diffusion from a certain centre.

That iron is a late metal no one can deny in the face of evidence. The history of folklore and religion favours the comparatively late origin of the Iron Age. The superstitions attached to the use of iron some of which persist upto the present day and the taboos possibly imposed on it by religion, all point to the fact that iron is a newcomer and an importation in older civilisations.

GOWLAND, DAY, BECK and others considered the assumption that meteoric iron was the earliest source of mankind quite unnecessary, because iron ores can be so easily reduced to metallic iron in an ordinary wood-fire or charcoal fire. But there is no reason why iron should be the first from a technical point of view. Many authors like PERCY underestimated the difficulties that would attend the manufacture of iron by primitive smiths. For if the bloom may be easy to obtain from the ore, the transformation of this bloom into good wrought iron or steel remains a difficult operation and one which

can not be performed by a people unless it possesses some degree of trained intelligence and is well acquainted with the pitfalls of metalcraft (56).

Secondly, as soon as man learnt how to obtain iron from its ores, of which large deposits are widely distributed, he would begin to use it for industrial purposes if he could produce a "steel-like" quality from his local ore. If he knew how to produce one pound, he would proceed to produce five, ten, fifty pounds. If therefore we find iron rare and costly, if it was valued as highly as silver and gold during a certain period, we are justified in concluding that at that time and place the inhabitants had not yet learnt to extract it from its ores, in short that their iron was celestial and no terrestrial. If we find a piece of man-made iron in the pyramids it is more probable that this iron is not contemporaneous with the building of the pyramid than that it is man-made iron. It is improbable that a religious taboo would be operative for so long a period of say 2000 years and that the possession of the secret of its manufacture could be kept by those in power. Nor is it probable that these early "accidental" smeltings would have taken so long to be rationalised by peoples who were conversant with the metallurgy of copper, bronze, gold, and lead!

Thirdly, Sir JOHN EVANS has pointed out long ago that early iron objects have "bronze" forms and not those for which it is best adapted, as we can see in the case of the earlier Hallstatt swords (139)!

What we see in the Near East is the early appearance of iron in jewelry, amulets and the like or statues, then the use of iron as an ornament of bronze implements, the gradual use of iron for parts of these tools and weapons, until iron ousts bronze from its place and is used for the principal part of the implement, while bronze serves as an ornamental material. Finally the entire tool or weapon is made of iron, which gradually acquires its specific "iron" form.

Long after gold, copper and silver meteoric iron was collected and worked by hammering. Primitive man may have attached magical importance to this meteoric iron when he discovered that it fell from heaven. Many ancient terms for iron are of the type "heaven-metal", etc., Hittite texts speak of "black iron" or "black iron from the sky". It is, however, still a matter of doubt whether this recognition of its celestial origin was as early as many authors suppose, for the observation of the fall of meteorites coupled with the finding of these pieces is not as common as silently implied in their statement. Probably it

was first held to be a kind of native copper until the real origin and its specific nature was learnt. Meteoric iron certainly was believed to have magical properties in later times, but whether this was already the case in prehistoric and early historic times remains an attractive hypothesis, but it is still to be proved.

However, as early as the first half of the third millennium B.C. pieces of man-made iron appear in Mesopotamia (Tell Asmar, Tell Chagar Bazar, Mari) and Asia Minor (Alaca Hüyük), and possibly Egypt too. It is still uncertain what ores were worked first. Such brilliant, "metallic" ores like magnetite, haematite, iron pyrites and some striking forms of limonite may have attracted the attention of primitive smelters first. The use of haematite for seal-stones was widespread in Sumerian times and fragments of specular ore, a hard metallic variety of haematite, were found on the smelting site near the ziggurat of Ur (Ant. J., vol. V, 1925, p. 391). On the other hand the ochres were used as pigments in prehistoric times, they are found in a soft form, rich in iron and well adapted for rudimentary smelting operations. Probably the natural inquisitiveness of the primitive smith led to the "trial by fire" of these ores and he discovered that he could obtain a lump of malleable metal from them. LUCAS thinks that the first production of iron was almost certainly an accident due to the use by mistake of iron ore in the place of copper ore and that there can be no doubt that when iron was first obtained it was treated as copper and bronze to shape it. But hammering iron cold was found useless. This experiment must have been repeated many times before it was realised that complete command over this new metal could only be obtained by hammering it red-hot. By the aid of heat the smith could weld the small pieces of iron together into a larger piece. But the new metal represented no improvement over copper and bronze tools, it was much less easy to work, the forging demanded much expensive fuel and the cutting edge made by hammering blunted quickly. Then he discovered that repeated hammering and heating in a coal-fire followed by plunging in cold water gave the iron a hardness superior to bronze. The delay of the discovery of quenching was due to the fact that copper when heated softens but is not affected by quenching at all. Only if heating the iron to white-heat and hammering it patiently followed by quenching the smith would accept the new metal as something of practical use for tools and weapons. In fact, not before the discovery of steel or case-hardened iron could the metallurgy of iron rise from the status of a tentative experiment. The

difficulties of slagging the ore, working the bloom and forging at white-heat combined with quenching delayed the Iron Age. It would seem from the archaeological evidence that the earlier stage of iron-working, the production of wrought iron from the bloom obtained from ores, was an achievement of the mountain-region of Armenia (between Taurus and Caucasus).

From 1900 to 1400 we see the spread of iron ornaments and ceremonial weapons, which remain precious. It is probable that some of the knowledge of wrought iron working spread too from this same centre in different directions. The earlier attempts (before 1900), which probably were also made in this centre are still too isolated, but some finds as small smelting sites at different places, for instance at Ur (of Ur III date, that is about 2300 B.C.!) show that even then the smelting of iron was known and slowly spread. However, RICHARDSON is right in saying that these rings, beads, amulets, etc. are only the heralds of a coming dawn. Iron was still a costly and precious metal, though probably its identity with meteoric iron had been recognised in the early second millennium B.C., there was no special stimulus to improve its manufacturing methods as the metal was quite useless for tools and weapons, which determine the career of a metal or alloy.

Weapons and tools of iron appearing and growing more and more frequent, that is the Iron Age! For the objects mentioned in early Hittite and other texts the ore smelted is quite immaterial, meteoric iron would do too and some of these objects could even be made of haematite without difficulty. When, however, the smelting of iron became an industry there was a demand for good and pure ores in large quantities.

It would seem from the available data that the "steeling" of iron was discovered in the same centre around 1400 B.C., thus giving the Hittites a monopoly of the manufacture of "true iron" or steel for another 200 years. Iron objects now appear more frequently as objects of trade, even in northern Europe of the thirteenth century B.C. (Seeland and Bornholm!). An early Italian smelting site at Nevigata near Manfredonia, Apulia, must be dated before 1200! But whatever progress iron trade made, the new metal was still subordinate to copper and bronze. It is even doubtful whether steel was more frequent in Asia Minor itself than say in Palestine and Syria, where iron begins to penetrate between 1400 and 1200.

The invasion of Thrako-Phrygian and other peoples in Asia Minor around 1200 B.C. and the subsequent destruction of the Hittite Empire

had an enormous influence on the spread of iron-working and the knowledge of case-hardening processes. Between 1200 and 1000 there is a quick growth of the iron industry in Iran, Transcaucasia, and Syria and Palestine, while Cyprus, Mesopotamia, Caucasia, and Crete follow closely. In all these countries some knowledge of iron-smelting had penetrated in earlier periods. Now the new processes which made steel an equal or better material to bronze found their way prepared and local industries could prosper quickly as the foundations of the craft had already been laid. This is probably the reason why iron-working spread so much quicker than copper-working, but the latter did not find its way prepared and had to be introduced as an entirely new craft.

Now the centre of origin of these iron-working processes was long hotly debated. RICHARDSON made out a good case for an European origin and his arguments were these. China and India are too far removed from the stream of civilisation in these early days, the latter country has an iron industry which was but a few centuries old in the days of Alexander. To Palestine iron was brought by the Philistines from the West. It is certain that there was an iron industry in the Armenian mountain region and in Central Europe (Styria) around 1000 B.C. Precedence of the West can be claimed as this region fulfills more nearly the combined premised conditions of available ore, metallurgical knowledge and economic necessity. Both bronze and iron Hallstatt forms, though the same, are well-advanced shapes.

In the fifteenth and fourteenth century B.C. the stream of European immigrants begins to move southwards and it is not coincidence that the earliest references to iron-working in Asianic-Egyptian texts correspond so nearly with the invasion from Europe! That the use of iron was forced upon Asia by conquering races is implied by the widespread taboo of this metal. This is quite natural for peoples at a disadvantage of securing raw materials or working them, for from the Upper Nile to the Caucasus there are no deposits comparable in quantity and quality to the spathic iron of Europe, the best ore adapted to the groping technique of iron-working. Again Hallstatt forms have a long history behind them, as the metallurgical progress of Central Europe was quickened between 2000 and 1500 by the trade with the East. The claim of the "Caucasian" region is nothing but an epic tradition without tangible proof. The earliest hoard of iron work mentioning is that of Sargon II, even among the Hittites iron was only common after 1200, their ores being only low grade haematite and some magne-

tite. The "ancient times of the Chalybes" fall between HOMER (ninth century) and AESCHYLOS (fifth century), by which time the Chalybes were the producers of famous steel. The Celts of the La Tène period have spread the iron weapons over the main part of Europe.

RICHARDSON was violently attacked by HERTZ (70), WRIGHT (156), HARLAND (67), and others, who held that the Chalybes were the discoverers of iron-work (113) (140) (24) (114) (83) (131) (152) (102) (19). Now PREZWORSKI is quite correct in stating that some of the protagonists in this battle, like QUIRING, PERSSON, RICHARDSON and WAINWRIGHT, have given little attention to archaeological proof. Thus WAINWRIGHT held that the Hittites used iron freely as early as the twentieth century B.C. (152). Neither can we believe HERTZ who claims that the Sumerians were the inventors of iron metallurgy (70) though she quite correctly refutes several of the claims of RICHARDSON. Nor is it possible that iron was a Cretan invention as MONTELIUS believed (96), mainly on account of the Parian Marble, for to take one argument, Crete has no iron ores worth while working!

However, RICHARDSON's hypothesis is still very much in the realm of speculation as there was certainly iron in Palestine and well developed and specialised furnaces at Gerar at least a century earlier than the earliest possible date for the Hallstatt cemetery (156)! Also the Indo-European peoples in Greece and the Balkans used bronze at least upto the Aegean wanderings if not later, and iron spread back on the way of the invaders (131). The famous Thracian swords were probably obtained elsewhere, just as the Damascene blades came from India or Parthia! In the Mycenaean Age iron was used for ornaments only and the Homeric Age was a Bronze Age though of course the passages on iron can not be explained away. But HOMER makes iron common only among the Trojans (Iliad, VI. 58; XI. 146): "For ample stores I (Tydides) have of gold and brass and well-wrought iron" (Iliad, X. 425) or among the Achaeans after they had plundered Asiatic towns. Whether we believe the Chalybes already a famous tribe of metallurgists of Pontus or whether they were late-comers in this region from the Armenian highlands; whether iron-working was first discovered by the Khaldi of Lake Urmia and Lake Van and then went westward (114), or whether it was a development of the Chalybic-Pontic-Chaldic peoples under the stress of their Hittite masters as HEICHELHEIM believes, it is certain that iron-working as we have learnt to understand it, the "steeling" of man-made iron, which

alone made it superior to bronze, originated somewhere in the Hittite realm of Asia Minor, probably in the Armenian mountain region and not in Europe. The possibility of the transmission of the knowledge through the Balkans to Noricum must not be overlooked and should be thoroughly investigated (140). On the other hand the sea way is quite possible too. We have mentioned early smelting sites in Southern Italy, whence it was brought to the Umbrians round Bologna quickly, may be by Greek or Illyrian traders and thence northwards to Noricum, to be stimulated by the Etruscans (102). It is difficult to support WITTER who claims that the Philistines were Illyrians, who brought the secret of iron from Noricum! Even an authority like KOSSINNA, who is no apt to post-date Central European events, admits that the invention is due to Asia Minor in the fourteenth century B.C. even if he dates the earliest iron finds at Seeland and Bornholm in Northern Europe as early as 1400. He also believes that it spread quickly to Noricum and finally reached the German tribes of Central Europe by 750-700 B.C. (83).

We must leave the problem of the exact location of the earliest "steel manufacture" to future research, it may turn out to be the region of Doliche "ubi ferrum nascitur" or it may even be true that the Chalybes were the aborigines and did for iron what they did for other metals.

At any rate from 1200-1000 B.C. iron-working spread from the Armenian mountain region. Now not only weapons but more and more agricultural implements were manufactured though "bronze" forms were usually adapted. The same can be observed in Central Europe where since 1000 iron is first used for ornamental purposes then quickly for weapons and tools, but long iron and bronze objects co-exist and even in the later phases of Hallstatt civilisation combinations of bronze and iron are frequent in weapons and tools. Then from 800 onwards iron is supreme here and the centre of gravity of iron manufacture wanders from Asia Minor to Carinthia and later in La Tène times to the Celtic dominions and to Spain. This extensive Noric industry led to important conquests and tribal migrations which moved European politics.

Thus after a long evolution and series of experiments parallel in the Near East and the Eastern Mediterranean countries the original centre Armenia again found the solution the "case-hardening" of iron, and passed it on quickly to the other countries where the foundations for a quick rise of the iron industry were already laid. But still for

many centuries when intricate objects had to be made, bronze was used, as casting was immensely superior to the hammering technique which dominated iron metallurgy long after the eighth century when in Muşasır (near Lake Van) lamps, vases and kettles were still swaged (hammered in moulds) and even in other fields such as welding, etc. the methods used for bronze were long in use for iron too, before more specific methods were discovered.

IV

We must now discuss the evolution of iron metallurgy in the different countries in further details, and we shall deal with *Africa* first. Here we find an ideal field of study of ancient metallurgical methods,

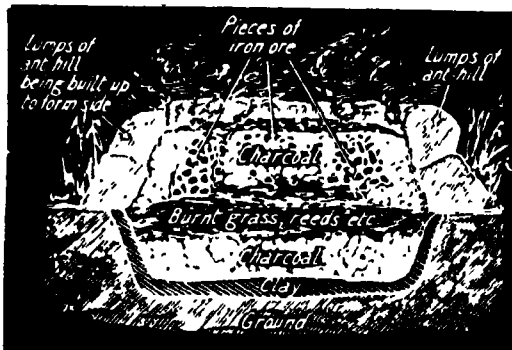


Fig 91. Primitive Uganda iron furnace (from a drawing in the Graphic)

for there is a great variety of smelting methods, furnaces ranging from pot-bowl types up to well-built shaft-furnaces using, clay, termite cones, etc. as building materials, working with or without blast air. Generally a bloom is produced, but occasionally it has a steely character. Large masses are easily obtained but many Negro tribes do not know how to make steel and rely on chance production of this valuable form of iron. They are as helpless as the Vikings who knew how to make iron anchors but who could not make steel swords with good cutting edges! The bloom is generally produced by smelters who break it up and sell the pieces to the smiths in the neighbourhood.

We can obtain an idea of Negro technique from BELLAMY's description of iron smelting in Lagos (J. Iron Steel Instit., vol. 66, 1904, p. 99). The siliceous haematite is roasted, pulverised in a wooden mortar and washed in a water-filled hole in the ground. Then it is

conveyed to the furnace in the smelting shed. This furnace is a 7' circular space built of clay and about 3' 9" high. A depression in the floor gives access to the bottom of the furnace, the dome of which is bound by ropes of twisted vine. In the centre of the bottom there is an aperture 3" in diameter, which communicates with the tunnel entered from a pit in the shed. There is also a small kiln used for firing the tuyères. The smelting lasts 36 hours and blast air is given by nine pairs of earthenware pipes. The selected slag from each successive smelting is used as a flux. The slag is run off by opening the orifice in the bottom of the furnace. For removing the bloom six clay-sealed apertures are opened, the earthenware tuyères are removed and the doorway of the furnace is opened. The contents of live charcoal is raked out and the 70 lbs bloom is removed red-hot with a loop of green creeper. It is then broken up with stone, pounders to convenient sizes and sold to the smiths. This natural steel is brought down by the smith to tool steel with about 1 % of carbon. This one example must suffice, we must refer the reader for further details to CLINE's monograph (25).

Iron was certainly the first metal to reach the Negroes, thus Kaffir tribes use *tsipi* (iron) as a basic word for metal and call gold "yellow iron", silver "white iron" and copper "red iron". Many tribes reckon values in terms of bars of iron. VON LUSCHAN (93) and after him BALFOUR (J. Inst. Metals, vol. 43, 1930, p. 350) have claimed the invention of iron metallurgy for the African continent on the following grounds:

- 1—The high antiquity of iron-working among the Negro and Bantu tribes is evidenced by the wide-spread dispersal and high degree of skill of the native smiths.
- 2—Iron ores are very abundant in Africa, and can be collected with ease on or near the surface.
- 3—Some of these ores are easily reduced even by an open fire.
- 4—The full evolution of pot-bowl furnace to kiln and shaft-furnace can still be seen observed in the different African regions. If they had been introduced by advanced metallurgists, these crude methods would not have been adopted. There is evidence for the early stages in the progression from simple to complex.

But such early dates for African iron-working as 1500 B.C. as VON LUSCHAN claimed remain without any proof! There is plenty evidence that Negroes did not know iron until historic times. Agatarchides states that copper or bronze chisels were used in the

Nubian gold mines because "iron was then still unknown" and the *Periplus* states that iron for spear-heads and weapons was exported in the first century A.D. from Alexandria to Aethiopia. PROCOPIUS even says that the Romans forbade the sale of iron to the Aethiopians who had none, but this may refer to steel. If "Meroë" used iron fairly early, this is because the Aethiopians had to import both iron and copper from the Graeco-Roman world. Nor is it likely that the Negroes learnt iron-working from the Egyptians early as ROEDER claimed, for the Egyptians themselves did not enter the Iron Age before the seventh century A.D. at the earliest.

Indeed, Cline, who has carefully sifted the available evidence (25), reached the following conclusions. The beginning of iron-working in East Africa between the sixth and twelfth century A.D. can be ascribed to the stimulus of trade with India, Arabia and Aethiopia. This would allow a century or more for the growth of the metallurgy at Zimbabwe. From folk-tradition in the Northern Congo and Central and Western Sudan these regions form together with parts of Northern Rhodesia a relatively old iron-working centre, that probably received its stimulus and traditions from Aethiopia. Still it is more probable in the face of present evidence that the Negroes of the Western Sudan learnt to smelt iron from the first waves of camel-riding Berbers who put them in touch with northern civilisation about 400 A.D. At first only the bare elements of northern technique came in and the Negroes developed some crude methods of their own.

The art of smelting did not reach the forested coast-lands of Guinea until late and then only in certain districts, but it spread quickly through central Sudan into the Congo basin carrying with it a simple technique (though very effective!) of forging with drum-bellows, nail-shaped iron anvils and a straight unshafed hammer, that could be used as an anvil as well. This technique diffused further through the Congo to Rhodesia and Nyassaland, eastwards to the Upper Nile and the Lakes and even on a few points to the Indian Ocean. It spread in divergent and interlacing streams which left a few Neolithic islands. Over most Negro areas the smelting technique is roughly the same and remained so. Fine wrought iron is produced under a hand-forced draught in a simple pit or hearth. Sometimes the smelters increased their yield by building over the pit a small clay furnace two or three feet high charged with alternate layers of ore and charcoal, but still they had to work the bellows through out the smelting and produced only small quantities of wrought iron. In two widely

separated areas, the interior of West Africa (west of the middle course of the Niger) and the interior of South-east Africa (from the Congo-Zambesi water-shed to Lake Nyassa and the Kafuo river) iron smelting became a big industry, the furnaces grew taller and free ventilating tubes were substituted for bellows.

Natives of the Southeast coast first learned of iron from Arab or Indian traders about 600 A.D. and passed the knowledge on to the south and west to inland groups who had not yet received knowledge of ironworking from the north-west. It filtered into East Africa from the North-east as well but more slowly for the Aethiopians and their neighbours lacked the adventurous proclivities of the Arabs.

The Yoruba resmelting of selected iron clincker imitated Northern Nigerian tin working and in the South-east the use of crucible smelting and fluxes were taken over from copper working to iron metallurgy! KNAFF analysed African iron blooms under the microscope and found them identical with blooms and bloomery iron of Europe from the early seventeenth century, which need not be surprising as the methods were alike.

If we now turn to *Egypt* we enter a field where the story of iron has given rise to many unfounded statements and speculations. HADFIELD (59) stated that the Egyptians could make steel tools and harden iron. This knowledge was obtained from India. GSELL (58) contended that they made wrought iron and also steel by the "wootz crucible process". Iron was, however, not found in early graves because of religious taboos, but iron-working was introduced by the Egyptians in Syria and thence found its way to the rest of the Near East. Bronze remained long in vogue because it could be remelted and because of aethetic ideas. Finally the Hyksos reintroduced the worship of Seth and since his metal, iron, became common in Egypt. It took, however, a long time to reach the Aegean and Europe.

BURCHARDT (19) is quite right in warning the reader against GSELL's dissertation which all Egyptologists know to be worthless. The idea that iron was known in Egypt 2500 years earlier than in Europe and kept a tradesecret or did not spread as the other metals, is sheer nonsense. It is now generally considered impossible that iron objects were common in Egypt before say 1500 B.C. For though these tools and weapons may have been reused and reformed as some say, they must have been rejected at some time or got lost. If they rusted away, some trace of them must have remained for rust is chemically a most stable product and only acid water could have washed it away without

leaving a trace. As nothing is perhaps better for the conservation of antiquities than Egyptian desert sand and even such tender objects as pieces of cloth have been recovered from it, it is impossible that iron objects, even if rusted could have escaped our attention. These theories of early Egyptian iron descend from statements by WILKINSON and LEPSIUS, who considered the working of Egyptian granite impossible without iron tools! Formerly many authorities believed these statements when BELZONI brought the earliest polished granite objects to the British Museum, but afterwards similar objects were produced from Aberdeen granite first with modern tools later with simpler ones. Abrasive powders, perhaps obsidian and emery, copper grinders and cutters but above all almost infinite patience were the agents employed by the Egyptians. No trace of iron tools was ever found in the Sakkarah temple but plenty stone and copper ones. Again these ancient authors forgot that iron tools would certainly not do the work but that steel was necessary in this case and hence the insistence by later authors who upheld the "granite-theory" that the Egyptians knew how to make steel. Again we must point out that the knowledge of iron does not imply that of steel. The Cordofan negroes who make excellent soft iron from poor ore do not know to make steel, and many other similar examples could be quoted from Africa.

SOLDI, as early as 1881 (142), rejected early iron in Egypt and modern authorities now agree with him, though FLINDERS PETRIE wavers and thinks that iron may have come from the south as a tribute Aethiopians, Nubians and Negroes either in the form of ore or as weapons, but the date of iron metallurgy in Nubia is now put much later than formerly by common consent. Not until 2000 B.C. the blue-coloured implements appear on monuments (122) which may imply iron, but the true Iron age is the Saitic and Roman period (122) (37), and as far as we know there was no religious taboo of iron in Egypt.

It is certain that the appearance of iron is curiously sporadic and not until 800 B.C. we find an iron knife with a bronze handle to show us that iron was getting cheaper than the older alloy (105). PETRIE who knew that the Egyptians never exploited the Sinai iron ores believed that they may have used occasional pockets of native iron in Sinai. He quotes RIDGEWAY's theory of the origin of the Greenland telluric iron and states that strata of carboniferous sandstone and black haematite may have been attacked by eruptions of thick basalt, which covers it partly in Sinai, and that here telluric iron may have been formed to serve as a source to the Egyptian but there is no proof forthcoming that telluric iron was ever found in these regions.

Since Predynastic times iron was used for charms, amulets and other small objects of hammered iron or meteoric iron were found. Now iron is at present still considered unlucky for certain ceremonies by the natives of Egypt, but it is said to dispell demons. PLUTARCH and DIODOR both state that the Egyptians not only hated red hair, one of the attributes of the god Seth but also his metal, iron, which is called "bones of Seth", just as magnetic iron oxyde is called "bones of Horus". PLUTARCH's *de Iside et Osiride* speaks of "a hook of iron, of the iron which came out of Seth" (cap. 62). Amulets of magnetite were also used in ancient Egypt. Many statements of the religious significance or taboos of iron centre around the meaning of the Egyptian word *bi3*, which we believe to mean "copper, black copper".

The *Book of the Dead* mentions a wall of heaven made of *bi3* and also a chain of *bi3* put around the neck of the serpent Apep. The dead man is said to conquer heaven and to split its *bi3* (Pyr. 305). Since Hyksos times we encounter the expression *bi3. n. pt.* "iron from heaven" (?) (or perhaps better "metal, copper from heaven"). Other religious texts say that the sky is made of *bi3*, though ZIMMER's conclusion that this idea arose from its blue colour and from the fact that meteoric iron occasionally fell from the sky seems putting our ideas into these ancient texts. WAINWRIGHT thought that *bi3. n. pt.* originally meant haematite, which can cut into statuettes, etc. like marble, then later "iron" (46). WAINWRIGHT set out to prove that *bi3* always had meant "iron" (150, 151) and he started to show that the ceremony of the Opening of the Mouth, originally performed with a stone instrument, was later always executed with one made of *bi3*. All the magic instruments used in these ceremonies the *nw3*, the *mihtyw*, and later the chisel called *mdtft*, were all said to be made of *bi3*. A Roman text speaks of the "instrument of *bi3* of the sacred shrine" which represented a thunderbolt. The small chisels of iron found in Tut-anch-amun's grave and other instruments seem to represent these magical instruments. The metal *bi3* is connected with heaven, with the waters of heaven or the wall around heaven, it is intimately linked with meteorites, which were probably the forms under which Amun and Seth were worshipped. The Theban fetish of Amun looks like a meteorite and so does the sacred object of the Cabasite nome. *Bi3* is not as SETHE thinks "metal in general", but a quite specific metal and as copper seems impossible it must be iron. *Bi3* is mentioned as offerings in the very early texts of the Unas and Pepi II pyramid (70). The man-made iron, the *bi3. n. t3* is first mentioned in a Denderah

text of Neronic date (DÜMICHEN, *Hist. Inscr.*, II, 1869, 56). These data of WAINWRIGHT have been discussed by COOK (Zeus, vol. II, 1940, p. 885), who quite aptly points out, that the equation thunderbolt: meteorite: omphalos is far from universally valid. Also we have no adequate proof that Min or Amun or Seth had any connections with meteorites and therefore WAINWRIGHT's reasoning stands only as an attractive hypothesis. WAINWRIGHT also never brought forward one text in which *bi3* must have meant iron, the old and recognised translation copper fits in just as well. If we take *bi3* to mean "copper, black (unrefined) copper" and if we remember that the Mexicans, for instance, call iron *tliltic teputzli*, that is "black copper", there is no reason not to suppose that the Egyptians thought their meteoric iron just a form of black, unrefined copper and that they recognised its celestial origin much later and dubbed it *bi3. n. pt*, that is "copper from heaven". Only when they had attained the full Iron Age and iron was smelted and worked in Egypt itself copper and iron were distinguished as separate metals and the expression *bi3.n.t3*, that is "iron from the earth", was coined. As long as there is no positive proof of another meaning and as long as it fits the translation without "technical impossibilities", we must translate *bi3* as "copper, black copper" and not as "metal (in general)" as SETHE proposed.

The oldest iron object from Egypt were predynastic beads from El Gerzeh (S.D. 72) found in a grave with an undisturbed mud layer covering it (149). GOWLAND still believed them to be man-made smelted iron, but DESCH reported a nickel content of 7.5 % which proves their meteoric origin. They were treated like other metal objects made from native metals and therefore have no special significance for the story of metallurgy (23).

The earliest man-made object of iron was formerly thought to be a piece of iron found by Vyse between the stones of the Great Pyramid, which many now believe to have been dropped by Vyse's own workmen (152), though his story of the discovery is remarkably complete and precise. Some think that it can not be explained away as a fragment of an excavating workmen's tool, as it is "a thin film of metallic iron with a more or less thick coating of its oxides" (68). But RICKARD strongly doubts it and LUCAS thinks that it is a recent piece of iron lost in the cracks when removing the outer facing of the pyramid for modern construction. A better attested piece is the Abydos lump found by PETRIE in a hoard of copper objects in a VIth dynasty pyramid at Abydos (64). This lump of oxide is certainly of Old

Kingdom date but there is no proof whether it was a tool or implement of any kind and we do not know why it was placed in this foundation deposit. It may have been a piece of iron produced accidentally.

Several other finds mentioned in literature can be traced back to writings by Maspéro, but his statement though apparently precise will not stand scrutiny, they are mostly cursory footnotes entirely written from memory and even the description of the same objects varies in his different works (152).

A thin blade of meteoric iron (containing 9 % of nickel) inserted in a silver amulet in the form of a sphinx's head (Cairo Mus. No. J. 47314) may be of Old Kingdom date.

Another fiercely contested piece is the Buhen spear-head which RANDALL MACIVER found at that site in Nubia opposite Wadi Halfa

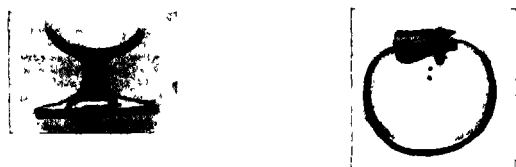


Fig 92 Small iron head rest and ring with *ud3*.1-eye of iron, both found in the grave of Tutankhamen (CARTER, *Tutankhamun*)

and which he assigns to the XIIth dynasty (at the latest XVIIIth dynasty). However, this socketed spearhead, one foot long, which certainly is man-made iron, looks very modern and is quite like the weapons still used by the natives of Nubia. Both shape and size make the find extremely doubtful, the more as Sudanese iron smelting proved much later than GOWLAND originally believed it to be and it is either a late intrusion in the grave where it was found or it belongs to a later date and is an import from the north.

PREZWORSKI mentions texts of the XIIth dynasty which are said to state that Egyptian ambassadors were sent to Nubia to get gold and iron ore, but these can not be traced. The oldest text which may mention iron is the Abu Simbel text of the XIXth dynasty!

All the finds before the XVIIIth dynasty (and the New Kingdom), therefore were proved to be meteoric iron or else stand in grave doubt. But the contact with the Hittites and the Amarna Age mean a great change for Egyptian metallurgy. GRIFFITH found at Tell el Amarna a lump of oxidised iron firmly stuck to a bronze axe-head (1924)

and there is a pair of iron bracelets roughly worked with dog's heads in the collection of Mrs. J. H. REA (XVIIIth dynasty). Then there are the iron objects found by CARTER in Tut-anch-amun's grave, a small amuletic iron head-rest, a gold bangle with a *w . d3t* eye of iron and an iron dagger, all made of wrought iron according to LUCAS (21). The small implements found on the mummy are too slight to be used as tools and have some magical intention, perhaps for the "Opening of the Mouth" as WAINWRIGHT proposed, though there is no certainty whether the metal iron itself had a magical meaning in those days in Egypt. These iron objects may have been presented to Tut-anch-amun (as some others were presented to Amenhotep III according to the Amarna letters) by one of the kings of Western Asia. In Syria and Palestine iron, however, must still have been quite a new discovery in the early part of the XVIIIth dynasty as it is not included in the tribute lists from these parts.

Iron is said to be mentioned twice in the Ebers papyrus, but the *bi3 ksj* of Ebers 48.19 is not iron from Qesi in Upper Egypt (VON LIPPMANN) but magnetite (EBBELL), and the *ir . pt* (JOACHIM's art-pet and translated "heaven-made iron") of Ebers 92.16 is some medicine (EBBELL).

By the end of the XVIIIth dynasty blue objects on the monuments are generally thought to represent iron implements, but no Egyptian text tells us of the introduction of iron and hair and eyebrows are also coloured blue. LEPSIUS has contended that wrought iron was coloured brown and "pure, true iron" or steel blue, just as the Homeric Age distinguished grey and violet-blue iron.

The slight imports of iron objects from the Hittites and from Mitanni, perhaps, also from Palestine have no great effect on the use of bronze, iron remained scarce for many centuries. In the battles against the Lybians only bronze weapons are taken and no iron object nor any trace of rust was found in the town of Gurob. Still there are the military forges of Gerar near the Egyptian frontier and in the papyrus Anasasi I a royal messenger has his chariots repaired in Joppa by iron-workers. An iron halberd was found in the sand foundation of Ramses III's temple at Abydos and an iron sword of Cretan type dates from the reign of Seti I, all about 1200 B.C. A century later are iron knives found in the bright arches of the Ramesseum. CARPENTER's researches pointed out that between 1200 and 900 B.C. iron objects were carburised and quenched in Egypt, probably by foreign experts.

Perhaps by this time iron ores were worked in the eastern desert and near Aswan, though the former deposits are generally said to have been worked by the Romans only. The new methods of treating iron and the possibility of making steel were of course important, but bronze remained superior as a base material as it could be cast.

The first real set of iron tools dates from the Assyrian domination. They were found together with an Assyrian helmet at Thebes and they have a quite modern appearance, and may be of Syrian manufacture. They are probably remnants of Assurbanipal's expedition (666 B.C.).

By Saitic times iron becomes more common and we can say that Egypt entered the Iron Age in the course of the seventh century B.C. A scale of armour found in the palace of Apries (XXVIth dynasty) is probably of Persian manufacture. But even the Carian and Ionian invaders of Egypt in this same century still carry offensive weapons made of bronze (85)! HERODOTUS finds iron quite common in Egypt. He tells us that the priests engaged in mummification "take a crooked piece of iron and with it draw out the brain" (II. 86) and in his discussion on the pyramids he sighs: "If this then is a true record, what a vast sum must have been spent on the iron tools used in the work and on the feeding and clothing of the labourers" (II. 125). The latter passage is often taken as a proof that iron tools were used in building the pyramids, but of course HERODOTUS just talks in terms of his age, when iron tools were common even in Egypt. The Assyrian tools which we have mentioned are partly made of mild steel since the tools have been given an edge and they can be permanently magnetised. The source of this steel seems to be Assyria or Syria.

Iron statues are mentioned in the Harris papyrus (40. b. 11), but it is very doubtful whether cast iron is meant, they were probably chased from wrought iron or may even have been cut from haematite.

In the meantime an extensive iron industry developed on the rich deposits of ore mentioned by STRABO in the "island of Meroë" in Nubia. GARSTANG and SAYCE have dated the beginnings of this industry in the ninth century B.C. (AAA, 1911/1912, p. 45), but they are now generally thought to be later than 700 B.C. Great mounds of slag enclose the city walls and by the "Birmingham of ancient Africa" this country passed from the Stone Age to the Iron Age. Perhaps this was the source from which the Sudan got its early iron-workers. Iron slag and crucibles have been found at Kerma, Kawa and the islands of Argo too. Formerly it was thought that

this was the centre for the early iron in Egypt, but this can no longer be maintained now the chronology of the earlier remains in Nubia is placed on a better footing. The Roman-Nubian remains of Karanog contain plentiful iron anklets and bracelets, etc. Thin sheet iron was cut into the shape of rounded arrow-heads about 3" long, these objects are still used for money in Cordofan and called *hasbisb*. Iron chisels were also found in the abandoned gold-mines of Aethiopia.

The Ptolemaic Age brings us the first proofs of local working of iron ores. At Memphis, Daphnae and Naukratis slags and crucibles have been found. Papyri tell us that iron tools were served out to the quarrymen in this period (255-254 B.C., record in the Flinders Petrie Papyri II. 7). A grave-yard of the reign of Ptolemy II yielded a considerable quantity of iron. This local iron industry flourished in Ptolemaic and Roman times to disappear in the Late Empire and Byzantine period. The iron-smith is called *chalkous* in the papyri and later *siderourgos*, or *sidero-chalkers* (IVth cy. A.D.). Specialists as nailsmiths (*helokopoi*, *kleidopoioi*) (119) and also weapons-, knives- and strigil-smiths are mentioned. Every village seems to have had at least one smith, in larger places there were guilds who bought their bar-iron collectively. The work is paid by the weight! Tools and weapons are the earliest iron implements, such objects as vases, etc. long remained bronze. The prices of iron objects are known in the first three centuries A.D., also the taxes paid by a *siderourgos* or ironmonger, who pays 20 drachmae and 2 obols a year and iron figures in the lists of customs due on imports, for instance in the Fayum district (A.D. 104).

Palestine and Syria have yielded no objects of the third millennium, but the earliest finds date of the reign of Amenemhat III (about 1825 B.C.). This is a small inset of iron in a gold ring used as an amulet and found in a royal grave at Byblos. Next in age are seven iron objects mentioned in the temple inventory of Qatna in the days of Tothmes III (about 1475 B.C.). The Annals of Thotmes II mention under the booty of the seventeenth campaign in Syria "tribute of the chief of *Tyn'y* a silver vessel of the work of the *Kftiyw* together with vessels of *bi3*", which latter may well be iron objects, though there is no proof. Still Syria has yielded further early iron objects. Thus at Ras Shamra (*Minet el Beida*) the excavators found a large ceremonial axe dating from the fifteenth or fourteenth century, though later finds are all ornamental, either beads, or rings of iron (152). Later Phoenician finds at Rachedieh and other places include arrow-

heads, rings and nails, but these are believed to be of later date (1000 B.C.).

In Palestine there is the Late Bronze Age ring found at Gezer, two axe blades from a watertunnel at the same site (about 1500 B.C.) and an implement with an iron shaft from Tell et-Mutesellim III (1500-1200).

We already discussed the iron workers at Joppa which are mentioned in the Papyrus Anastasi I about 1250 and certain proof of iron-working in Palestine was found at Gerar, Tell Džemme, which was occupied from the Hyksos period (perhaps later by the Philistines) onwards to Persian times. A broken steel dagger of 1350 was found there and another steel dagger (before 1300) in the neighbouring Beth-Pelet. Around 1200 iron is quite a common metal in this post on the Egyptian frontier and the period from 1200-1100 shows large objects, hoes, picks, plough irons, adzes, etc. One pick weighs about 7 lbs.! The earliest of these tools dates from about 1180-1170, as do the furnaces found in this place. Petrie thought that they were metallurgical furnaces smelting the ore from the Beersheba basin, but the absence of slags is fatal to his theory. More probably blooms or bars of iron were imported here from the north and reheated in the furnace, for proper fuel supplies for smelting are also far to seek. The large furnace was probably for forging and case-hardening weapons and tools. HULME aptly compared them with the military *fabrica* of the Romans. The later furnaces are certainly just smith's hearths.

A structure at Lachiš formerly thought to be a blast furnace, proved to be a pottery kiln, but iron was found here in the Fourth City (1400 B.C.). From 1200 B.C. onwards, therefore, more iron objects begin to appear in Palestine like the lance-heads, knives, daggers and tools of Tell Džemme rings from Tell el-Fara, knives from Gezer, agricultural implements, adzes, axes and knives from Tell Beit Mirsim B, Tell et-Mutesellim IV (together with a smithy, iron slags and lumps of ore), Tell Ta'annek III and an iron knife from Jericho.

Then by 900 iron is very common at all these sites and the Iron Age can therefore be said to begin at least as early as 1000 B.C. with a transition period running from 1300 to 1000 B.C.

Now it is an interesting question whether the early smiths at Gerar were Philistines or whether they occupied the site at some later date. These Philistines either formed part of the Sea-peoples, who invaded Syria and Palestine and were held by Ramses III on the Egyptian

frontier in 1194 B.C., or they came in their wake. At any rate they occupied the coastal plain between 1190 and 1160 and their power was not broken before the reign of Saul (1020). Though some like Witter have of late stated that they were of Illyrian stock and that they learnt iron-working from the Mitterberg people in their home country and then introduced iron into the Near East (155), it is now generally believed that they came from Western Asia Minor and that they were kinsmen of or befriended to the Cretans. The question of their superiority in iron-working is still difficult to solve for we have no archaeological traits of Philistine civilisation to guide us, in fact, we know next to nothing about their material culture. As they came from Asia Minor they may well have had contacts with this region and imported bar iron which they worked in Palestine. They certainly did not smelt it as their territory contained no ores worth mentioning. But we think that the finds at Gerar solve the question (if Petrie is right in supposing Philistine occupation there). The Philistines were blacksmiths as so many other peoples from Asia Minor. They certainly could not have worked the mines of the Lebanon, not yet exploited then, as this region was outside their control! Still according to Scripture they had a "corner" in iron which was not broken until the reign of Saul (2) (156) if we may believe I Sam. 13 : 19-22.

The Israelites were certainly unacquainted with iron at the time of their wanderings and they seem to have learnt the art from the Philistines and other pre-Israelite people by the time of their settlement (II Sam. 12 : 31; I Ki. 6 : 7; II Chron. 26 : 14; Is. 44 : 12; 54 : 16) though many of the iron tools may have been bought or imported from the North or from the Philistines. In David's time the Hebrews had iron tools and weapons which his conquests in the north made familiar and which must have been advertised by the Hittite warriors in his service. Was not his friend called Barzillai, that is "man of iron" (II Sam. 19 : 31), like the famous Swedish chemist BERZELIUS?

The Israelites, however, retained a strong religious feeling against iron forbidding the use of hewn stones for the altar (Jos. 8 : 31) and though by the time of Amos (760) iron is in regular use even by the poorest and local smelting is quite common, there was no change in this taboo. JOSEPHUS says that not only was the altar in the Temple formed without iron tools, but this held too for the stones of the first temple. The Samaritan Pentateuch has an eleventh

commandment prescribing the erection of two stones inscribed with the ten commandments on the plaster surface but "thou shalt not lift any iron thereon".

Still bronze must have remained in use quite long, the Bible mentioning it 83 times against iron weapons only four times. Iron ore is mentioned as plentiful (79) and the iron smelting furnace rather than that of other metals is mentioned figuratively for great oppression (Deut. 4 : 20; I Ki. 8 : 51; Jer. 11 : 4). Iron is often used as a metaphor for unbreakable, strong, not to be pierced by arrows, hard, unyielding and unploughable earth. Of the objects manufactured from iron we are told of the sledge-hammer (*pattish*), anvil, knife, sharpening steel, cooking griddle, bars of the city gates, fetters and iron points for the threshing sledge. Armour was also made or imported (Job 20 : 24; Is. 41 : 7). It appears in the lists of metals after copper but before lead and tin. Hellenistic treatises of Jewish-Egyptian origin refer to iron and steel as "*ballabhà* of the Jews" (DIETERICH, ABRAXAS, p. 191), "steel" in the Authorised Version should often be read bronze or copper. The *paldàb* occurring in Nahum 11 : 3 is thought to mean the flashing steel scythe of the Assyrian war chariot.

The "northern iron" of Jer. 15 : 12 though given in the Vulgate as *ferrum ab aquilone* is probably Chalybian steel and the "bright iron" taken with cassia and calamus from the merchants of Dan and Javan (Jer. 27 : 19) may refer to Ionian steel though others say that the Phoenicians got these materials from Uzal (S. Arabia) and that it might be Indian steel! The *ferrum infectum* in the stores of Masada (JOSEPHUS, Wars, VII, 8. 4) is certainly not cast iron but unworked wrought iron, nor should we read "cast iron" for the *sideros chytós* of the Septuagint version of Job 40 : 18, but bars of iron or blooms are meant.

The "iron bedstead of Og" (Deut. 3 : 11) is probably a basalt sarcophagus, as the peasants east of the Jordan often call basalt iron, and this makes it probable too that the iron teeth of the threshing sledge (Amos 1 : 3) are really pieces of basalt which are still used for these instruments.

SIRACH describes a blacksmith's shop in details (Eccl. 38 : 28) and also the cutting of the conduit to the pool of Siloam under Hezekiah with iron tools (Eccl. 48 : 17). The temple of Solomon is said to have contained no less than 100,000 talents of iron (I Chron. 29 : 7) (JOSEPHUS, Ant., VII, 14. 9). The blacksmith is generally

called *charaš barzel* but also *nappach* (user of bellows) or *pechami* (user of charcoal). He must have been a familiar figure in the reigns of the later kings, for Nebuchadnezzar sent thousands of smiths in exile (II Ki. 24 : 14).

Iron-working was also well established in the north. PHILON OF BYBLOS states on the authority of SANCHUNIATHON, the Phoenician historian (1200 B.C.?), that his people were the inventors of iron working guided by a magician called Chrysor Chorosh and the Chronos of the Phoenicians (Melkart) shaped himself a spear and sword of iron on the advice of a goddess "Athene". In later times North Syria was famous as an iron-working centre. An Aramaic dedication of a Nabatean *faber aerarius* was found at Puteoli and Diocletian established large imperial armament factories in Antioch, Damascus, and Edessa, which must have had some connections with such private workshops of earlier centuries.

If we now turn to *India* we find that it is difficult to fix an exact date for the beginning of the Iron Age. There are strong proofs of the existence of iron in the R̥gvedic age (5) (6) (7). Iron is described in these sacred writings as *ayas*. The *asi* or sacrificial knife, the *svadhiti* (sacrificial axe), the *ṣura* or razor and the *kbādi*, the quoit ring worn traditionally by every Hindu woman on the left hand, are all made of iron. The metal serves as a metaphor for the legs of strong horses, weapons are tipped with *ayas*, etc. It is smelted by the *karmāras* or smiths. Both the *karmāra* and the *dhmāṭṛ* (literally "blower") are iron-smiths. *Ayas* is said to be hard, tough, strong, tenacious, ductile, and malleable. BANERJEE believes that steel was also already manufactured in this period by the well-known "wootz crucible process", using the leaves of certain plants and bird's wings as carburizing matter.

It is certainly used and mentioned in the period when the Yayurveda and Atharvaveda were composed, its name is often given as *ṣyāma ayas* (dark copper). From other, later developments between this period and that of Alexander it seems pretty certain that iron was introduced in Northern India by 1000 B.C., perhaps somewhat earlier, but in Southern India the Iron Age does not begin before 500 B.C.

Between 500 and 200 B.C. iron weapons became general. Iron swords and daggers were found in early graves at Tinnevely (300 B.C.) and at Buddha Gaya. The earliest examples of wootz steel were weapons found in early graves of the seventh and sixth century B.C., for instance in the tombs of Wurri-Goan, Central India. However,

most of the famous iron pillars and beams are much later than originally claimed, all of them date of the first century A.D. or later. By this time there was a flourishing iron industry, often practised by wandering iron-smiths and there are many references to their craft in the Upanishads, where for instance the production of a bloom is described as "a mass of iron overcome by the fire and hammered by the workmen takes numerous shapes and forms." The size of these pillars and beams points to a settled industry as well which in later centuries was able to copy European models very quickly. Stories have been circulated about the secret composition of the iron of these



Fig. 93. Primitive Indian blast furnace, Nagpur (after BEGBIF, *Iron Industry*, 1908)

pillars and beams, because they have not rusted in the places where they were erected. BRITTON cleared this problem by proving that it was only the climate that made them resistant to corrosion (17) not the composition. Samples taken to Europe rusted just as quickly as modern ones. They were all hammered, welded together of smaller pieces of iron produced directly from ores, and remain a marvellous example of the possibilities of primitive technique.

There are of course different readings of the wootz process and Ure gives one which differs slightly from that which we have discussed, but which adds some interesting details (*Dictionary*, vol. III, 1867, p. 764): The bloomery is pear-shaped, 5' at the base and 1' at the top, built up of clay in a few hours and ready the next day after firing to dry it. The front opening 1' wide is opened up after every smelting. The bellows are simple goat's skins. Bamboo nozzles end in tuyères of clay. The furnace is first filled with charcoal and lighted. The moistened ore is then filled on top of the coals without flux and

covered by charcoal, and these are then supplied constantly during three to four hours. The furnace is then stopped, opened and the bloom is removed with a pair of tongs from the bottom of the furnace. The bloom is then cut up into small pieces to pack the crucible better. These crucibles are made of refractory clay. Mixed with the charred husks of rice, the leaves of *Asclepios gigantea* or *Convulvulus laurifolia* and the wood of *Cassia auriculata* they are packed tightly. The charge is seldom over one pound mixed with the proper amount of wood chopped in small pieces. The mouth of the crucible is stopped with a handful of tempered clay, which is rammed closely to exclude air. When the plugs are dry, 24 crucibles are built up in a furnace arch and kept covered with charcoal and now subjected to a fire aided with blast air for about 2½ hours. Then the furnace is allowed to cool and the broken crucibles yield the wootz in the form of a cake. The whole process though seemingly simple is one of long standing and the result of considerable experience. The magnetite usually worked contains about 72 % of iron, the yield is about 15 %.

If not exported but worked on the spot, the steel, a mixture of carbon rich and carbon poor iron is forged many times and etched with acid to obtain the "damask" design. It is then glowed, not over 700° C and carefully cooled.

The resistance to rust of certain kinds of iron and steel did not escape the ancients, for we find PLINY telling us (*Nat. Hist.* 34. 150): "Iron is protected against rusting by white lead, gypsum and pitch. Rust is called by the Greeks the antipathy (natural opposite) or iron. It is said that rusting may be prevented by a suitable religious ceremony too and that an iron chain still exists, at the town of Zeugma on the Euphrates which was used by Alexander the Great in bridging the river there. Those links which have been renewed are a prey to rust, from which the original links are quite free." It is not stated whether this was Chalybian or Indian steel.

HERODOTUS tells us about the Indian contingent in the Persian army, that "the Indians wore arrows also of cane with iron at the point" (VII. 65) and indeed ten such arrow-tips were found on the battlefield of Marathon and now reside in the British Museum.

CTESIAS mentions two wonderful swords of Indian steel given to the Persian king, and QUINTIUS CURTIUS (IX. 24) says that a present of 100 talents of Indian steel was given to Alexander by Porus, the Indian king. The matter of some 30 lbs. of steel would hardly have been considered a present worthy of the conqueror of the world if

this had not been a speciality not manufactured by any other nation in the world in his times. This has led many authors to exaggerate the antiquity of Indian steel and to claim, as we have seen, that the ancient Egyptians imported and used it. Another source of difficulties is the word *adamas* which does not yet always denote steel in these times. PTOLEMY'S *adamas* for instance may be steel, but it is more probably the diamond from Sabaræ, Cosa and the Sankh branch of the Brahmani (153).

The fine swords made of Indian steel had been famous since the days of CTESIAS and Roman trade in India steel and iron was important. We must take the Seres mentioned by PLINY as being the Cheras of the Malabar coast, though China had an early industry, which however, is localised in Shantung (136). But Indian is the epithet applied by the Periplus and other authors and by the Digest-list. Now the Periplus gives Indian iron with sword blades at Adulis and other African ports and the author knows that "likewise there are imported from the inland regions of Ariaca Indian iron and steel", yet he did not see any metal at Indian ports. So Indians sent their ships with steel to the Axumites, who kept it secret, perhaps allowing the Romans to attribute the metal to remote China. Today the Indians make steel at Madras, Mysore, Punjab, Kashmir, Bengal, Rajputna, Assam, Burma, but especially at Hyderabad, and it is no wonder, therefore, that the Greeks attributed it to Ariace and the Chera kingdoms. SAUMAISE points out that a special Greek treatise was written in Antiquity on the tempering of Indian steel and CHWOSTOW may be right in supposing that the bulk of the Roman imports consisted not in large quantities of ore or steel but of objects fashioned from iron and steel. They worked them into fancy cutlery as CLEMENS shows (Alex. Paed. II, 3, 189 P) and perhaps into armour in Damascus, whither Indian steel was sent and at Irenopolis. The iron and steel attributed to the Seres, therefore, comes from India, not from the Sind town of Haiderabad but from the central district and it was exported solely from North-West India (PLINY, *Nat. Hist.* 34. 145; OROSIUS VI. 13. 2; APULEIUS, *Flor.* 6; PERIPLUS 6, 39, 49, 56, 64). *Ferrum Indicum* figures on the list of articles subject to duty at Alexandria. Later the cakes of wootz, called *kus*, were exported in large quantities to Syria, Persia, and Arabia. Damascus continued to be a centre of the working of Indian iron since Diocletian founded his armament factories there, until these were carried off to Samarkand and Chorassan by Tamerlane in 1399. The Damask steel is

therefore an Indian product, which is still appreciated by the tribes of Assam, who work the imported iron rods into swords, etc. The value of these weapons depends upon the number of the welding lines on the blade (36).

The antiquity of the iron industry of *China* has been greatly exaggerated, the father of Confucius is said to have been strong enough to lift an iron door, the Iron Age is said to date from the Chou dynasty and to have been introduced into Japan by 500 B.C. It has been proved lately that the transition stage is the Ts'in dynasty (255-209 B.C.) and the early Han dynasty (209 B.C.—25 A.D.) (35).

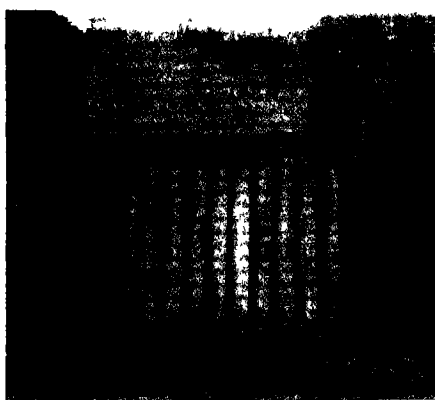


Fig. 94. Iron reduction furnace, Shansi, China (after READ, *Geogr. Review*)

Bronze and iron then still occur together, but the later Han dynasty (25—220 A.D.) China is in the full Iron Age (87); the graves now contain many objects of cast-iron such as stoves, etc. Wrought iron, steel and cast iron are known early and the latter metal can be said to be a Chinese invention. READ has devoted several studies to this early Chinese iron industry (116) (117) (118). In Shansi iron is still made as of old. Limonite and haematite are mixed with 50 % by volume of coal in crucibles and burnt in furnaces. The bloom is sold to wrought iron smiths, smaller pieces go to the manufacturers of cast iron. These mix them with coal in crucibles and heat them in small furnaces heated with hand-bellows. The contents of several crucibles are poured into one, which is then used to fill the mould. The high phosphorus content of the coal makes casting easy, the cast-iron melts at 980° C that is lower than copper! Crucible steel is not made by the Chinese, they always resort to case-hardening. PINEL

(109) examined nine specimens of Chinese cast iron ranging in date from 502 to 1093 and found that they had a remarkable low phosphorus content taking in mind that of the coal used. Three pieces were cast in a single piece, but in most cases the composition varies largely even in the piece itself. Sand moulds were used in the earlier periods. The five M. high Buddha from Tsinanfu dates of the sixth century; the biggest piece is a cast iron lion of 953 A.D. which is 20' high and 18' long! But even the early Han pieces are already large for a young technique. Iron bells were made early as they are said to chase spirits!

There is a remarkable document on the importance of early Chinese iron manufacture in the form of a treatise by HUAN K'UAN written



Fig 95. Chinese crucible furnace opened (after READ, *Geogr. Review*)

in the later part of the first century B.C. and containing a discussion held in 81 B.C. on the salt and iron monopolies exploited by the state (49). Already two early Chinese industrialists, I-tun and Kuo Tsung, had amassed princely fortunes in the production of both commodities and other families are recorded as prosperous iron workers under the early Han dynasty. But after favouring agriculture under the early emperors the later princes had to resort to various expedients to replenish the treasury which was depleted by the reduction of the land tax. The Yen-T'ieh-Kuan offices were instituted in 119 B.C. under Han-Wu-Ti's reign to control the iron and salt industries and to sell these product at a high rate yielding a large profit. In the year 115 "officers to equalize distribution," were appointed and a "bureau of standardisation and equalisation" was set up in the capital (110 B.C.). Though the treasury deficits disappear soon, great discontent followed and the iron implements in use standardised by the state were greatly criticised. The discussion recorded in this document was commanded by the Emperor and was held between the Crown officers and representatives of the Literati and Worthy classes, which showed up all

the defects of state monopolies. In this document castings are mentioned as *jung-chu*, that is "melt-fuse".

STANISLAUS JULIEN says that the secret of casting iron was brought to Ferghana by Chinese deserters in the second century B.C. but he states no source for this contention. Anyway this was the route by which the process reached the West and the Arabs had adopted it from China long before Mohammed. Chinese iron and steel was exported both to the West and to the South. I—TSING says that the inhabitants of the Eastern Ocean valued it very much (680 A.D.) and

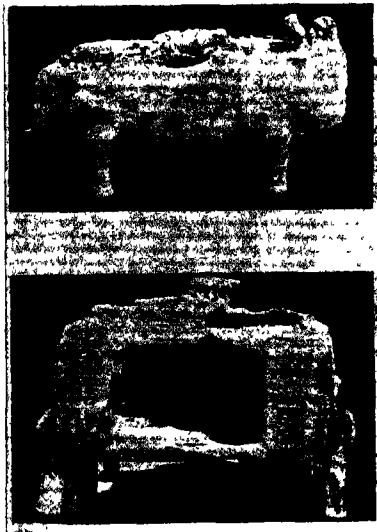


Fig. 96. Chinese iron stove (150 B.C.), probably the oldest cast-iron object still extant (after LAUFER, *Beginnings of Porcelain*)

that the Malaysans were afraid of its "poison". MARCO POLO mentions the Chinese iron industries which in later centuries were mainly located in Shantung.

However famous Persian and Parthian steel was, the birth-date of the Iron Age of *Persia* is still uncertain, though it is quite close to the original centre of iron-working in the Armenian mountains. The excavations of Tepe Gyan I (1400-1100) showed that iron was still scarce in this site; a few daggers, spear- and arrow-heads, rings and bracelets were found, but no tools! At Susa a lump of iron, an iron bar, an oxidised ring, iron nails, etc. were found, but they can not be earlier than 1100 B.C. Many iron finds come from the Talyš region,

but iron weapons are still partly of bronze! Their date is certainly not 2500 B.C. as some would have it but probably 1200-1100 B.C. Syalk A (1100 B.C.) yielded only a dagger and a spear-head, but in Syalk B (850 B.C.) there is a great variety and quantity of iron objects. In Luristan though bronze still prevails, many objects dating of 1000-750 B.C. have useful parts of iron and decorative parts of bronze and gradually the objects are entirely fashioned of iron. In the necropolis of Ab-i-Zal (eighth century) the adzes and axes are of iron as the greater part of the fibulae, though the bracelets are mainly made of bronze. These few data go to show that the Iron Age begins about 1000 B.C. The iron industry of north-western Persia is said to be very old. A century ago ROBERTSON reported (127) on the iron mines of Caradagh near Tabriz. Magnetic iron predominates with haematite and a mixture of the two is used by the smelters. The furnaces contain two hearths, the smaller 14" square and 9" deep, the larger sunk 3' more into the ground, and with walls 2-3' high covered with stones capable of resisting fire. These are supposed by HULME to be a natural draught furnace coupled later with the second blast-driven hearth. The packing with a central dam of charcoal recalls the Corsican method of smelting. The blooms produced are marked. Were these mines already the sources of supplies of Assyria? ROBERTSON calculated that one mine with a production of 200 Tons a year might have produced 2857 years from the area excavated.

It is certain that Iranian steel was famous early. Artaxerxes (about 450 B.C.) is said to have given Ctesias a sword of Indian steel, but the Roman authors praise Parthian steel second only to that of the Seres. This was even exported to China in later days under the name *pin t'ieh* or *ki-pin* (Kashmir) as a product of Sassanian Persia (LAUFER, *Sino-Iranica*, p. 515). The Ko-Ku-Yao says that its surface exhibited the patterns of the winding lines of a conch or that it was like "sesame seeds and snow". The price of swords inlaid with gold threads and polished to make the pattern visible was higher than that of silver. It was said to be so hard and sharp that it could cut stone. The term *pin* is probably derived from the Iranian *'spaina* and the Pamir *spin*. The Iranian *pûlâd* occurs in Tibetan, Armenian, Ossetic, Grusian, Turkish and Russian and the Mongol is *bolot!* In the Ts'in period Chinese writings mention *hu t'ieh* (iron of the Hu in Turkestan) (265-419 A.D.).

As early as the Han dynasty; the Chinese modelled their scale and chain armour on Parthian examples. The Persian troops of 480 B.C.

had scale armour as in the time of HELIODORUS, but the Parthians and later Persians had true mail with links rivetted together (SUIDAS), which was still famous and often praised by medieval writers. The Arabs borrowed the coat of mail from the Parthians and spread it. Thus the Sudanese names of weapons are all Arabic (9) and the thousand years of feudal Arabic domination had a great influence of the art of war of the Sudanese and other African tribes.

The Turks were also famous weaponsmiths who worked the iron ores of the Altaï for the Avars until their fall (552 A.D.). Their name seems to mean "iron helmets" (71).

The country of the largest iron output in Arabian time was Persis, but Beirut, Kabul, and Kerman had important mines too. Of the latter province MARCO POLO tells us (I. c. 14): "In the kingdom of Kierman there are also veins of steel. They manufacture here in great perfection all articles necessary for warlike equipment" and he also mentions the mines of Kabul (I. c. 39). The mines of Ferghâma were famous for a very ductile kind of iron which they produced. A yearly tribute of 1300 iron vases or pieces of sheet iron were sent thence to Baghdad.

In Arabia (Bahrein, Oman and Jemen) there was a very old iron industry working with iron and steel imported from India, Persia and China. Bahrein was the centre of the manufacture of lances, Jemen and Muta specialised in damascened steel. Syria and especially Damascus remained an important centre and in the West the Arabs worked iron mines of Sicily and even Africa, whence iron was exported to India for further treatment.

The desert warriors were always in need of iron. In 964 the Carmates sent to Saifeddaulah in Tiberias to demand iron and this prince took the iron gates of Raqqah and even the weights of the merchants and surrendered them. Then the Carmates sailed down the Euphrates to Hit and took this iron into the desert.

There are several references to iron in the Koran and more particular the fifty-seventh Sura called Iron, but as it is a gift of Allah, the Mohammedans have never tabooed iron like other peoples.

ALKINDI (873) wrote a book "on the properties of swords" in which he distinguishes female iron which can not be hardened (*Mer-mahâni*; that is *nermâben*, soft iron) and the male kind which can easily be hardened (*Sâburqâni* probably: "iron from Shaburan"). Magnetic iron can be made by adding certain substances to wrought iron, certain others produce the silverwhite steel (*fûlâd*), sometimes

green and blue-tinted steel, also the "damask type (Firind) looking like veined malachite", which is used for needles and bells. The best iron is *al-hindî* (*al-hinduwânî*), which comes from Qalah, Ceylon, Jemen, Basrah, or Damascus, but above all from China.

ALFAQIH (eighth century) says that iron is produced in Egypt and his contemporary IBN HAUQAL (902-968) states that "in Tûs they win a red-brown ochre like the Egyptian haematite, which sometimes gives the male, at other times the female iron."

In the Arabian Nights huge walls of iron are mentioned and also the old story of the magnetic mountain in the Indian Ocean. Iron also figures largely in Persian epic literature. FIRDUSI tells that Shah Dshemshid made iron weapons and Feridun had a banner made of the apron of his smith Kawe. Special weapons are made by hardening Indian and Chinese iron and steel with blood.

The story of iron in ancient *Mesopotamia* is still fragmentary too. Black pigment used on pottery at Al Ubaid and Tell Halaf proved to be magnetic oxide of iron, and haematite appears quite early as a seal-stone. An iron object found in a grave at Al Ubaid was examined by DESCH and proved to have 10.9 % of nickel. It is believed to have been forged from meteoric iron at a comparatively low temperature (31) (110). Next come three early pieces of man-made iron all dating from the early dynastic period (3000-2700 B.C.) and all found quite recently. There is the fragment of iron found in grave G. 67, Tell Chagar Bazar, by MALLOWAN (94) which was analysed by DESCH and can not possibly be of meteoric origin. PARROT reports fragments of iron found at Mari near the remains of the pre-Sargonic temple of Ishtar (AfO, vol. 12, 1938, p. 310). Then there is the bronze open-work handle of a dagger found at Tell Asmar which contained the remains of an iron blade, that was certainly of terrestrial origin (32). FRANKFORT suggests (42) that this knife is very likely an importation from the north and that iron was occasionally produced and used during the third millennium in Transcaucasia and Armenia but was not exported as it was less servicable than well-hammered copper or cast bronze. The spread of iron in the later second half of the second millenium is due not to the discovery of the smelting of iron ores but to new methods of working the metal ("steeling").

As no smelting sites of this early date were found near these pieces or in the rest of *Mesopotamian* sites, it is suggested that they were imported pieces, probably from the highlands as FRANKFORT suggested.

It is unknown to the author whether the word *parzillu* (iron) occurs in any text of Gudea's reign as BOSON claimed (95), but the earliest use of this word is found in a fragment of a tablet of the first dynasty of Susa from that town, which mentions along with gold, silver and ivory a *hullam pa-ar-zi-li*, an iron helmet, and it would seem from this text of the early second millennium that iron was still rare (133). Mostly *parzillu* is not spelt out but written with the Sumerian signs AN·BAR, the pronunciation of which is unknown in Sumerian, though it possibly reads *bar·gal*, a word adopted from the Accadian *parzillu*. This word has itself been lent from a non-Semitic language, for HALL, DUSSAUD, and ZIMMERN point to the non-Semitic but Asianic ending *-ill*. AN·BAR can be translated "heaven-metal" or "star-metal" and thus would point to the meteoric origin of early Sumerian iron according to some. In the famous epic of Gilgamesh there is a reference to a "meteor falling from heaven" (2. i. 6), but not as some state to "death by iron", as the relevant passage reads "death during battle".

Even during the Sumerian Renaissance of the Ur III period iron seems to have remained scarce. At Telloh iron objects such as beads, hooks, a bracelet and a lump of ore were found and though said to belong to the Ur III or Larsa period, they are loosely catalogued among the objects which are "not Graeco-Aramean", an indication which makes them useless to archaeologists. Iron weapons and tools appear in the Kapara stratum at Tell Halaf together with a movable hearth with bars of iron, perhaps a brazier (2000 B.C.). But in Mesopotamia proper a few years later under the reign of Hammurabi iron is still valued at one-eighth of its weight in silver (CT, VI, 25a).

The excavations of Yorgan Tepe yielded a dagger blade of bronze in a haft of iron dating from the Churrite period (1600-1375), and an iron foundation tablet of Tukulti Ninurta I (1280-1261) was found, at Assur.

The Amarna letters mention iron rings covered with gold and ceremonial daggers, but the tablets of a big Babylonian banking firm a century later (1395-1242) mention all metals but iron! Still at this period more art objects appear with bronze and iron parts. In Assyria there is certainly no iron industry by the thirteenth century and it is suggested that Mesopotamia had still to turn to the west or the north for supplies. In northern Syria the iron-using culture is suddenly introduced in the twelfth century. It is possible that the migrations of the "Peoples of the Sea" are connected with the changes wrought by

a more prevalent use of iron from this period onwards. The Assyrians certainly adapted the "harder" way of fighting like they previously had learnt the lessons of horsemanship and organisation from the Hittites (141). They adopted iron weapons, possibly importing them or bars of iron from the north and west and their use of the new iron weapons enabled them to start their extensive military conquests.

Shalmeneser I (1276-1257) records "foundation tablets of iron" buried when rebuilding the temple Eharsagkurkurra (ARL, I, 120). Tiglath Pileser I (1115-1103) tells of his hunting expedition "with my mighty bow, with my iron spear and with my sharp darts" (ARL, I, 247).

With Tukulti Ninurta II (890-884) we enter the full Iron Age. This king mentions that he took "iron" from the inhabitants of the Nairi (Khabur) region (ARL, I, 405) and that on a later expedition he cuts his way through the mountains upstream of the Euphrates with axes and "iron pickaxes" (ARL, I, 411). But still 1 talent (60 Kgrs.) are assessed at sixteen shekels of silver (about 120 grammes) and a slave at 30-40 shekels (70). Assur-nasir-pal II (883-859) very often refers to iron in his inscriptions. He takes iron from the city of Sûru (ARL, I, 443) and the tribute of Sangar the king of the land of Hatte was 250 talents of iron (ARL, I, 476), that of Kunulua the royal city of Lubarna of Hattina 100 talents (ARL, I, 477). Iron was placed among the spoils in the new palace of Qalah (ARL, I, 492) where it was found by LAYARD in 1867! Hatchets of iron were used to pave the way of the troops and from the Nairi lands he takes no less than 300 talents of iron (ARL, I, 498, 501). It will be observed that this iron always comes from the mountain highlands to the north and the west of Assyria.

Shalmaneser III (858-824) receives iron as a tribute of the Cilician cities and from Hattina (ARL, I, 583, 585) and later he takes 400 talents of iron from the Hattinites, 30 from Haianu of Mount Amanus and from Sangara of Carcemish 100 talents (ARL, I, 601).

Adad Nirari III receives iron as a tribute from the town of Mari and no less than 5000 talents from Damascus (ARL, I, 740).

Sargon II (721-705) uses iron on a lavish scale. He takes it from Khaldia near Lake Van, not only in the form of bars but iron ovens, lamps, etc. (ARL, II, 213). In his palace large quantities of weapons, armour, rings, nails, picks, and tools were found, together with bars of unworked iron nearly 150 Tons, of good soft iron (not steel!) free

from nickel and manganese according to DESCH. When used by a native smith it proved as good as modern Persian iron (152). The rough bars are 12 to 19" long and $2\frac{3}{4}$ - $5\frac{1}{2}$ " thick, roughly tapered on each end and pierced by a single jagged hole, weighing from 8 to 44 lbs. Similar bars and pieces are common in Roman times and the type of ingots survived in Sweden and Finland until 1870.

Sennacherib receives iron daggers from the king Hezekiah and under his reign hard stone is quarried with iron picks (ARL, II, 178).

There are several interesting texts relating to iron from these days.

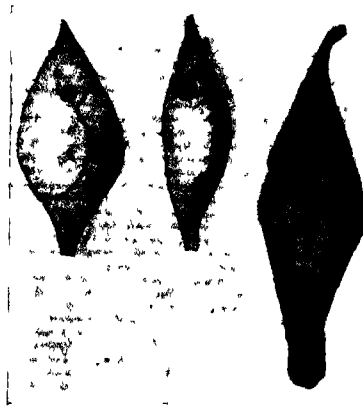


Fig 97. Pieces of wrought iron, found in Sargon's palace of Niniveh
(after V. PLACE, *Niniveh et l'Assyrie*, 1867)

Tablets from Niniveh edited by JOHNS give the names of 17 smiths, always called *nappachu* and never *gurguru* or smelter, they are therefore real blacksmiths working with imported iron. One tablet (JOHNS No. 812, K. 954) mentions purchases of iron in Commagene, Harran, Khalhi, and other districts to the north-west of Assyria. In Harran 75 talents of iron are bought for sixteen shekels of silver through the intermediary of a smith, and the price of the iron goes down as iron tools become quite common. A central storehouse for iron is mentioned in a tablet (HARPER 91, K. 620) which speaks of a "wooden building wherein the iron is stored at Assur" that needs repairs very badly. And another text gives details on the theft and recovery of "iron which the king my lord gave to the smith" (HARPER 1317, K. 5397) (108).

The Neo-Babylonian king Nabonidus (550) got his iron from Mount Amanus and Mount Lebanon. A text of this Neo-Babylonian

period (625-538) refers to different qualities of iron which have varying prices accordingly (YOS, 6, 168). One weight of silver can buy 240 units of iron from Iamana, but 361 to 406 units from Labnana. Therefore the iron from Mount Amanus seems to have been of better quality than the Lebanon iron. In another text of the above-mentioned king silver is valued at 225 times its weight in iron (STRASSMEIER, Nab. 428), in a further text (BIN, 1, 162) at no less than 624 times its weight. This points to the identification of different qualities of iron on the market in some way or other. Iron was then already common as a building material, for instance iron clamps were used in the bridges of Babylon (HERODOTUS, I, 186).

Very little is known of the story of iron in *Armenia and Caucasia* for the lack of proper archaeological data from these countries. From the Assyrian data we have seen how important this country must have been as a source of supply to Mesopotamia. The big city of Tušpa in Urartu (known under Shalmeneser I (1250)) was founded about 840 by new invaders in this region who were formerly thought to have brought the knowledge of iron from their original home Thrace (SAYCE, CAH, III, pp. 19, 172). This is now generally rejected, for iron is very plentiful in these regions as soon as it is mentioned in Assyrian texts. The inhabitants hewed out rock dwellings with iron tools. Their gods, the Khaldi, from whom the region takes its name, are associated by some with the Chaldeans of Pontus, and they are perhaps borrowed from the Hittites as they included their god Teshub. It is not known whether the aborigines of this country, HERODOTUS' Alorodians, had any connection with iron-working or with the metal culture of Pontus. It has been suggested that much of the metalwork attributed to Assyria was actually made in Van, the artistic traditions of which were transmitted by the Medes to Achaemenid Persia (HERZFELD). The introduction of the Iron Age in Mesopotamia is certainly due to the extensive booty of iron taken from these highlands. In classical times iron from these regions was shipped in Sinope and Trebizond.

In Transcaucasia a few ornaments of iron appear in the thirteenth century in the Gandža-Karabeg region, then in the next two centuries iron weapons which do not differ typologically from the bronze ones. In Georgia and Armenia iron appears in the same period. The earliest finds in the Kuban area are mostly incrustations and it looks as if iron is much later here than in the south. Iron then grows common in the ninth century, the Kasbek, Georgian and Lelvar region yielded

plentiful iron weapons but the full Iron Age is the Scythian period. In Southern Russia iron penetrates by 800 and grows common in the sixth century B.C.

We must now turn to *Asia Minor*, where we find information as to the occurrence of early iron in Troy very confused and doubtful. Useful iron does not seem to appear before the destruction of Troy VI in the twelfth century (MYRES, CAH, I, 109).

The only early objects are small ornaments and a needle from Alaca Hüyük III (about 2500 B.C.), but many pieces formerly dated 2000 B.C. and earlier are now considered to be considerably later.

The Kültepe or Kaneš business letters of the end of the third millennium mention a metal *amutum* which is five times as expensive as gold and 40 times as expensive as silver. GOETZE considers this metal to be iron, but we must await further proofs, as the only data are the price and the fact that it is used for ornaments. SAYCE has stated that iron was mentioned in two letters of this collection, but the KU·AN of Clay No. 50, 1.9 read by SAYCE *parzi-ili* should be read *kaspu* and refers to silver, the same signs occur in lines 18, 25, and 26 of the same letter. Again in letter Clay No. 92. 1. 12 SAYCE read *barzi* to mean iron, but this word means impost (it reoccurs in CCT, III, 37, 8).

We have mentioned that the word *parzillu* is first found in a tablet of the first Susun dynasty (2200-1962) and that it is probably of non-Semitic origin on account of the suffix *-ill*. The Hittite signs for iron are AN·BAR or AN·BAR·GE, though here again as in Sumerian the pronunciation is unknown. The earliest document in which this word occurs in Asia Minor is a text from the Boghaz Keui archive (KB, IV, No. 1), in which Anittaš of Kuššar (1950-1920) says that he brought it as booty from Hattušaš: "Then the man of Purushkanda was commanded before me. He brought an iron throne and an iron sceptre as commanded." Between 1850 and 1400 several ceremonial weapons of iron were made and exported as it seems. Boghaz Keui texts mention iron statues and iron foundation tablets or tablets for treaties. Thus BK II, No. 1, Rs. IV, 5, mentions 10 gold objects and 11 wrought iron ALAM (*salmu*) probably tablets for a temple. No reference is yet made of iron as a trade object but only objects fashioned from iron are mentioned. RICHARDSON may be right in stating that the texts of the Teshub temple may be as late as the reign of Hattusil III (1283-1260), but he is wrong when he says that there are no earlier texts (120) (121). We have already given

the Anitaš text edited by HROZNY (*Orientalni*, 1929, p. 281) and further texts are sure to appear as the documents from Hittite sites are published. There is another text BK, IV, 1, 35-40 (about 1300 B.C.) which runs: "They cover the wooden beams with plates of silver and gold, the gold they bring from the city of Bi, the silver from Kuzza . . . , black iron of heaven from the sky . . ." (128). CAMPBELL THOMPSON thinks that this meteoric iron came with the copper from Mont Tagatta mentioned further on in the text. Therefore the evidence is now overwhelming that iron was known earlier than RICHARDSON thought. "Black iron" is mentioned in several texts of different date (BK, XII, 1; III, 8; XII, 24, I, 8; XV, 9, III, 3).

Next comes a much debated letter (KB, I, 14, 20 ff): "As to the good iron (AN · BAR *damqu*) about which thou hast written to me. There is no good iron in my "sealed house" in Kizzuwadna. It is a bad (time) to make iron, but I have written (ordering) them to make good iron. So far they have not finished it. When they finish it, I will send it to thee. Behold, now I am sending thee an iron dagger blade . . . which thou hast sent, have no blades . . . (I have ordered) blades to be made, but so far they have not finished them" (See also LUCKENBILL, *AJSL*, vol. 37, p. 206). MEISSNER's opinion that the letter is written by the king of Kizzuwadna to the Hittite King of Kings Hattušiliš III (1283-1260) is now generally accepted, but formerly it was thought that it was sent by the latter to Ramses II or the king of Assyria (CONTENAU, WEIDNER, etc.). The second point of the debate was the exact situation of Kizzuwadna, which GOETZE and S. SMITH placed in Cilicia in the Taurus mountains, WINCKLER, ED. MEYER, BILABEL, and others in Pontus and WAINWRIGHT in the north-eastern corner of Cilicia, as it was later called Tabal. This name goes back to the Sumerian TIBIRA (smith) and Naram Sin already refers to a mountain Tibar apparently near Aram in the far north-western corner of Mesopotamia. Later we find in Pisidia the city of Seleucia called "Sidera". We, however, still follow SCHACHRMEYR and say that at the present time the exact situation of Kizzuwadna is unknown but it is enough for our story to know that it is some part of the mountains between Taurus and Pontus (104).

This letter certainly proves, that at this time iron weapons were still rare, that the king of the Hittites had no easy access to the supplies of smelted iron and that the iron was smelted and worked in the region that had already produced copper, gold and silver for many centuries (141). Thus even in the later Hittite Empire iron

was not yet very common and iron weapons were certainly not used by the Hittite armies in general before 1200 (14). Though there are iron objects at Tell Halaf around 2000 B.C. there are still scarce in Carcemish nearby eight hundred years later. But gradually more and more iron tools and weapons appear in the years between 1400 and 1200. In this period the bronze production seems to have run short and much old material was remelted and reused and this was a stimulus to the growing iron industry. Necessity to have a good new material gave the impulse and overcame the objections of more fuel and greater skill that iron metallurgy demanded. Time taught the right processes of "steeling" and gave iron its superiority over bronze. The unrest following the fall of the Hittite Empire by the onslaught of the Peoples of the Sea stayed this evolution for a time, though it spread the knowledge of the smelting and working of iron. Afterwards trade and traffic had found new roads and the copper imports in Asia Minor ran still more short, which gave a new impulse to the iron industry especially after 1000 B.C. Then we first find iron objects imitating bronze types, then equal amounts of bronze and iron copies of the same objects in every site as well as iron ornaments on bronze objects followed by the use of bronze for the ornamentation of iron and the repairing of bronze with iron parts. Then finally iron fully takes the place of bronze. Thus iron and iron wire are still used for the decoration of bronze weapons in Alishar Hüyük II and iron is still used for ornamental purposes in Koban and Thespiat around 1000 B.C. But between then and 800 there is a strong growth of the production of iron and we find many iron objects in such sites as Kerkenesdagh, Göllüdagh, Gordion, Gâvurkalesi, Gözlu Kule, Pazarli, Alishar Hüyük, and Toprakkale, though bronze objects still form the majority. Still combinations of both metals run scarce and by 700 iron is absolutely supreme. Therefore 1400 to 1000 B.C. must be recognised as the transition from bronze to the full Iron Age. We also point to the Sword god of the Hittites pictured at Yasili-Kaya. CUISSIN pointed out that this sword is entirely different from the Bronze Age types and that it belongs to typical iron-workers. This line is worth following up and we must remind the future student of this problem of the Scythians "who sacrificed to an antique sword, an image of Ares" (HERODOTUS IV. 62) like the Khonds of Hindustani who have a god of iron, Loha-Pennu, who also is a god of war and who is represented in each village by a buried piece of iron.

The picture we gather from Northern Syria, later occupied by a

Hittite state, Mitanni, and by smaller successors after its downfall is this. The list of the temple-treasure of Mishrifé-Qatna before the conquest of Thotmes III (1500) mentions seven objects of iron, six of which are set in gold, and it is possible that the *Ty. n'. y* of his seventeenth campaign was on the confines of Asia near Qatna, and that the *bi3* mentioned as a tribute is really iron. There are many iron deposits in Northern Syria and the later Doliche on the road between Cataonia and Tabal to Mitanni may already have played a part in the history of iron of those early times.

Anyhow, in the Amarna letters Mitanni figures as an iron-exporting and perhaps iron-producing country. The presents sent by Tušratta of Mitanni to Amenhotep III of Egypt embrace a *mittu* of *parzillu* covered with 15 shekels of gold (XXII, I, 38), two "handrings of *parzillu* sheeted with gold" (XXII, II, 1-4) and a "dagger the blade of which is made of *parzillu* and the haft of which is covered by lapis lazuli set in gold" (XXII, II, 16). Again the presents sent by Tušratta to Amenhotep IV or Akhenaten consist of "ten thin handrings of iron covered with gold, using 30 shekels of gold" (XXV, II, 28). The first letter also mentions "a dagger made of *ha-bal-ki-nu*" (two more mentioned in the same letter) and also "ten *giakātu* of the same material" (XXII, I, 32; III, 49, III, 6). This *habalkin(n)u* is tentatively supposed to be steel for no more reason than that it is a dagger blade. At the same time it comes from a state not far from the Chalybes and there is a certain possible "merchant's garbling" in *habalkinnu* and *chalibikós*. It is therefore permissible to leave the translation as it stands and take this unknown word to mean steel. Possibly the further decipherment of Hittite documents will one day show up the origin of this word.

This brings us again the problem of the Chalybes, those smithing tribes, about which we possess so many classical references (AESCHYLOS, *Prom. Vinct.* 714) (APOLL. *Rhod.*, *Argon.* II. 1002) (VIRGIL, *Georg.* I, 58) (AMMAN. *MARC.*, XXII. 8. 21) (DION., *Per.* 768) (AVIEN., *or. mar.* 947) (VAL. *FL.*, 611). These *siderotektones* living in dens and caves on the Black Sea coast between Samsun and Trebizond are said to be "a Scythian tribe, living where the iron was born" (*Etymologicon Magnum* and *SUIDAS*). SAYCE derived their name from *Kbale-wa*, that is "dwelling in the Khale or Halys basin", and he contends that their axe-hammer was not only a battle-weapon but served in smithing as well (102). We do not know whether they lived in Pontus already before the wanderings and invasions of 1200

B.C. Possibly they are related to the Alorodians or they may be remains of the Khaldi of Lake Van dispersed over a larger area. But whatever their story may be, it is certain that the Pontic region played an important part in the history of metallurgy long before 1200 B.C. and we have dubbed the aborigines of Pontus Chalybes as long as no other data are forthcoming. Relations between the Chalybes and the inhabitants of the Kuban area and diffusion of iron to Europe by the way of the Russian steppes remain entirely hypothetical. It is certain that after 1200 B.C. the Chalybes were working for their new masters, the Mushki and the Tibareni, and therefore it seems more probable that they were the original inhabitants of the country. The classical reports which make the Chalybes Scythians has led HULME to suppose possible connections with India, not only because of the connections of the magnetite process of the Chalybes with the Indian wootz process but also because of the curious story of mice nibbling iron, which also occurs in Indian tales and may denote the finely divided state of the magnetite worked. This legend given by PSEUDO-ARISTOTLE is, however, more common in the West than usually supposed. AELIAN reports the same peculiar taste of the mice of Teredon in Babylonia and THEOPHRASTUS (*De natur. animal.*, V. 14), who adds that the mice devoured the iron and steel of the forges of the Chalybes! Further study of this problem, comparing the classical reports with the role of mice in the legends of the Near East will probably throw more light on this question.

The Greeks had some faint ideas on the invention of iron in Asia Minor for the Parian Chronicle on the marble slab now in Oxford records as item 11: "From the times when Minos the elder was king of Crete and built Apollonia, and iron was discovered in Ida, the discoverers being the Idaean Dactyls, Kelmis and Damnameneus, in the reign of Pandaion of Athens" (1462-1423 B.C.). Though the Cretan Mount Ida is wrongly mentioned instead of the Phrygian mountain of the same name, the report contains a vague indication that the Greeks believed iron metallurgy to have been evolved in Asia Minor somewhere around 1400 B.C., which fits in quite well with the archaeological data for the rise of iron industry in these regions. Apart from the sword-god already mentioned the Hittites possessed a god of the thunderstorm, Teshub, who is also closely connected with iron. In the troubled years around 1200 B.C. a group of Chalybes immigrated to Doliche, bringing their god Teshub of the double-axe with them and thus they started the cult of the "Baal of

Doliche", who invented iron and who was still worshipped in Roman times as the "Jupiter Optimus Maximus Dolichenus natus ubi ferrum nascitur". His cult spread in the Roman Empire and we find him as the god of the tree-fellers for the Roman troops in Germany!

The wanderings and invasions of the Peoples of the Sea broke the Hittite monopoly of iron and steel manufacture and iron spread quickly over the Near East. The Shardana forming part of these peoples are shown on the Egyptian monuments as carrying blue (steel?) weapons, and in Asia Minor the production of iron and steel was taken over by the Traco-Phrygian invaders and spread all over Asia Minor. Thus the industry of Phrygia, Ionia, and Lydia started. Iron tools and weapons are now very common the post-Hittite and Phrygian strata of Alishar Hüyük IV and V contain no less than three times the amount of iron as compared with the older strata. Phrygian slag from working haematite was found in the tumulus of Bos-hüyük (Lamunia). Iron working spread to Europe between 1300 and 700 and we find the Dipylon, Villanova, and Hallstatt civilisations, practically continuations of the Bronze Age, using both iron and bronze weapons. There are typological proofs of the influence of Anatolian bronzetypes of the first quarter of the first millennium in the Aegean up to Italy and as there are close trade connections with Thrace and the Middle Balkans, there are possibly the lines along which the knowledge of the new metal was carried to Europe (113). Though the iron industry in Asia Minor suffered greatly by the new invasions of Cimmerians, Scythians and Assyrians about 700 and the ores of Central Europe and Spain became more important, partly because of their natural steel production, the industry in Asia Minor still survived and remained important even in classical times. Pontic iron was still most favoured, the best iron for building purposes was Sinopic and Chalybian, while the Lydian iron was favoured for rasps, swords, razors and graving tools. This difference was probably due to both chemical composition and to different methods of tempering, a point which deserves further research. Possibly the difficulty of producing iron made local industry less prevalent than that of copper or bronze and certain great centres remained the producers for the civilised world.

Still there was a blacksmith or two in every town and one must naturally assume that few objects in ordinary use were imported in finished form but that they were made by the local smith in the form or shape desired by the customer from bar-iron. Bronze and iron lay

in the workshops of the Cilician pirates (APPIAN., *Mith.* 96) and Vespasian had arms made in the most important cities of Asia Minor (TAC., *Hist.* II. 82). Cyzicus and Rhodes were famous for weapons probably on account of their trade with the Black Sea. In Late Republican times Cibyra was especially noted for its chasing and embossing of iron (STRABO, XIII. 4. 17; CICERO, *Fam.* XIII. 21; HORACE, *Ep.* I. 6. 33) and the Roman publicani exploited the products of the province and also the iron work of Cibyra.

The iron industry of *Cyprus* had no great importance but the constant contacts of this island with Anatolia introduced iron there. POCOCKE saw iron mines at Paphos, Soli, and Bole. The iron working areas were concentrated at Tamassos and Soli. Brown iron ore of some richness is found in the pyritic masses of the igneous regions. Magnetite and specular haematite are also found on the northern slopes of Mavrovouni (22), so there was no need for the islanders to import the metal (PLUT., *Alex.* 32; DEMETR. 21) (CELM., *Alex. Strom.*, 1, 16, 75) (EUSEB, *Praep. evang.* X. 6. 5; PLINY, *Nat. Hist.*, 34. 121; 36, 137). There is the legend given by STRABO that the Telchines invented copper and iron working in Crete and came to Cyprus by the way of Rhodes, but the archaeological data show quite clearly that iron penetrated Cyprus from the Anatolian hinterland.

Iron figures as a precious metal in jewelry since 1400 B.C. There is the agate sceptre of Kurion now in the Cesnola collection, the sockets of which show traces of iron. An iron arrow-head was found in an old grave of Tamassos and a plated ring at Salamis and also two iron knives with ivory handles in a 1200 B.C. tomb. After 1000 B.C. it is generally used for knives and swords though other objects are still mostly made of bronze, and both metals continue to be used side by side very long even in the Geometric period when there are plentiful types of weapons and tools.

Crete is not very prominent in the story of iron notwithstanding the classical traditions which localise its invention in Crete instead of on the Anatolian mainland. Though MEYER mentions traces of old mines, there are no notable deposits in Crete and Mount Ida is covered with timber but there are no signs of smelting sites! There is no doubt that iron was a foreign metal in the early Aegean. Mosso's lump of unsmelted iron of Neolithic date (Phaistos) turned out to be magnetite (65).

In a tholos of Hagia Triada slags of iron working were found (2000 B.C.) and there is some meteoric iron of the same date in a

tholos of Platanos. The Grotto Mavro Spelio at Knossos yielded a cube of iron of MM II date (1800 B.C.). Eight finds of iron finger rings from the Aegean from the period between 1500 and 1200 B.C. are listed by PERSSON (102). But the metal becomes more plentiful after 1200 in the transitional period before the Geometric age. Iron weapons from Muliana, Kavusi, and Knossos are still "bronze types", and bronze tools and weapons continue to be used long side by side with iron ones. Iron gradually becomes supreme in the eighth century and a hundred years later iron was used for all kinds of utensils and art objects as the excavations of Olympia show. The Doric invasions brought iron to Crete as is shown by the affinity of the early weapons with Central European types.

Meteorites were known and worshipped in ancient Greece. The Iliad describes Athena darting from heaven like a meteor and in the Hymn to the Pythian Apollo the god is represented as having reached Krissa in the same meteoric form. Many meteorites were worshipped in Antiquity for instance the stone of Elagabalos and the stone of Chronos.

Still no objects fashioned of meteoric iron have been found in Greece. The earliest iron workings (slags of Vardarovca C) dates from the twelfth to eleventh century B.C. In Thracia they are hardly older than the ninth (Swords of Alexandrovo and Popovo of typical bronze forms). The general spread of iron in the Aegean in the twelfth century B.C. may be actually connected with the Dorian invasion. Iron may well have spread across the Aegean back along the paths travelled by the Aiolian, Ionian, and Dorian colonists. The last invaders, traditionally the Dorians, may have introduced it in Hellas, which previously received it from Anatolia via Thrace and Macedonia. They merely popularised what was already in use in southern Hellas.

In the Mycenaean period iron was still as costly as gold. We have already mentioned the finger rings catalogued by PERSSON and at Mycenae Tsountas found some iron chains along with gold chains in late tombs. Iron is used with strips of gold, copper and bronze inlay. Iron did not come from Egypt to Greece as some supposed, for the earliest iron types of Daphnae and Naukratis are definitely Greek or European forms.

From the Geometric period upto the sixth century iron became more and more common. The metal was possibly smelted at Tyrins, Athens and in the Dorian plain from the tenth century onwards.

The Greeks knew very well that mankind had passed a period in which iron was unknown. HESIOD (*Days and Works*, 151) speaks of a period "in which there was no dark iron" and HERODOTUS (I. 68) says that "iron had not yet been discovered to the hurt of man." But in the Homeric Age iron though well-known was still on its probation (85). Men of the sword preferred bronze and Sir JOHN EVANS thought that even in 600-500 B.C. steel and iron were common but had not yet superseded bronze entirely. Though in the Homeric poems the *chalkeus* is already a blacksmith, the prizes set by Achilles are a bloom or piece of crude iron (*Iliad* 23. 825) or implements but not iron weapons! The further references to iron in the *Iliad* and *Odyssey* merely indicate what HOMER thought of the use of this new metals and they prove little of its production. The iron which Mentès brings to Temesa in Cyprus (or Tempsa in Bruttium as WILLAMOWITZ believed) is thought by some to come from the Illyrians!

The Greeks were never prominent in metallurgy and imported their iron mostly in semi-finished condition. It is doubtful whether the Greeks of the epic were very familiar with its production, but the generation of Hesiod already possessed a considerable knowledge of "the softening of iron in glowing mountain fires" (*Theogony* 862-866). The earliest exploitation of ore deposits after 1000 B.C. was probably in the islands rich in ores such as Samothrakè and Euboea and in Sparta and Boeotia. Here the sagas later bring figures from Pontus, Colchis, Syria, and Cyprus, but above all from Phrygia. We have pointed out several of them and, therefore, refer only to HELLANIKOS' Phronikos which tells of the Dactyls.

The earliest smelting seems to have been of a simple kind, smelting in small pits with charcoal and forging the still glowing white *mydros* (mass) to wrought iron, a sight still new and wonderful to the man in the street in Croesus' time (HERODOTUS, I. 68). This iron was not always very good and contained many bits of slag and holes (*diplôe*). It was often traded in the form of bars like the Spartan *obeloi* or *obeliskoi* which may have also served as "roasting-spits" as some contend, but which surely served as money in Sparta and other Peloponnesian states before the earliest coinage. Some cult-ceremonies still forbade the use of iron or the touching of iron was taboo for the officiants.

The blacksmith hardened his iron and quenched it, using a *pharmakon* or secret remedy, in cold water. The steel weapons and tools were described as *ioeis* or violet-coloured, common iron being *poliôs*

or grey, but both remain *polúkmetos*, difficult to work. The word *adamas*, untamable, for steel, first appears in the writings of HESIOD. Chalybian steel was probably introduced after the colonisation of the Pontic coast. Periclean iron is often loosely classified as steel, but it should be remembered that the carbon content of ancient iron is often entirely fortitious and tempering remained a difficult art. Therefore the word "steel" should only be applied if an analysis has shown it to be such. By the end of the seventh century Glaukos of Chios had invented *kóllesis* (welding) and the Samians are said to have discovered (or borrowed) the process of hollow bronze casting, not iron

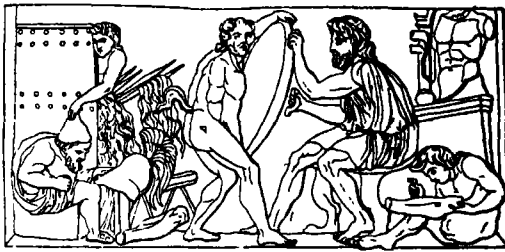


Fig. 98. Hephaistos, the lame Greek god of the smithy

as the texts claim. ARISTARCHOS OF ALEXANDRIA (220-145) says that "iron is not cast as bronze" and this remains true for Greek metallurgy certainly.

Laconia later famous for its steel may not have begun industrial production before 550 B.C. from the deposits of Portokalio and Kulenda. Lesbos and some of the Cyclades (Cythnos, Seriphos, Siphnos) contain iron ore but there are no certain traces of ancient workings, neither was the splendid chromite ore of Rhodes worked by the ancients.

In the Athens of Pericles iron was worked by foreign residents. There were armour factories at Pasion and Kephalos and Sophocles' father is said to have been a blacksmith. The patrimony of Demosthenes includes a sword factory. PSEUDO-ARISTOTLE in his passage on Chalybian iron tells us that a fourth-century Sicilian banker made a nice little "corner" in iron "recognizing that iron was an indispensable commodity he once succeeded in buying up the produce of all the smelters of iron and made a profit of 200 % when a scarcity arose".

The iron mines of Macedonia were worked in Roman times too, when the charges imposed were half of what had formerly been paid to the kings (LIVY, 45. 29. 11).

In *Italy* the transition to the Iron Age starts between 1100 and 1000, but until 1000 B.C. bronze is still supreme in Etruscan necropolises. In Bologna and its Villanovan civilization iron was quite common about 900 B.C. It is this Villanovan civilisation in its Etruscan form that created Rome, it started the Elban and Tuscan mines. The early history of Rome can certainly be seen as Rome striking out for the Etruscan ore deposit. But until the closing years of the Republic iron working remained rustic in its simplicity as we can see from VARRO's report on the travelling smiths of his days (*de re rustica* I. 16. 4).

Early Rome had its iron-smiths and Porsenna forbade the use of iron except for agriculture (PLINY, *Nat. Hist.* 34. 139). The Fratres Aravales had a strict taboo on using iron in many ceremonies and a similar taboo held good for other cult-ceremonies. Iron was said to destroy the work of the spirits who hated it, then it was used to counteract the influence of base spirits.

The people of Populonia furnished iron (LIVY, 28. 45. 13-21) for the levy in 205 B.C. for Scipio's invasion of Africa, probably from the Elban mines. In the period of 200-150 B.C., the war period, the manufacture of arms must have been extensive. Probably Rome and the municipalities between Rome and Capua supplied most of the weapons needed. Many implements and tools were also in demand if we compare CATO's equipment for his olive orchard (*de Agric.* X).

When by senatorial decree Italy was closed for private mining, this did not apply to the iron mines of Elba, the product of which was of the highest importance to the army and the agriculturists. PLINY calls the decree old and we may assume a second century date. Later references prove that the Elban mines continued their operations, at least they were worked throughout the Gracchan period (150-80 B.C.) and well into the Empire. Elba was one of the earliest Greek places in Italy. DIODOR reports on this Elban mining (V. 13): "Near the town of Etruria called Populonia lies the island of Ilva. It abounds in siderite which they mine for smelting and making of iron, since it contains much of this metal. Those engaged in the work crush the rock and roast it in furnaces skilfully made for the purpose. When it has been melted in a strong fire, they cut the matter into parts that look like large sponges. Merchants buy these with money or an exchange of goods and carry them to Dicaearchaea (Puteoli) and other ports. Men who engage the labour of smiths buy these masses of ore and make all kinds of implements of them. Some parts they

hammer into weapons, others into hoes, sickles and other useful implements and the merchants carry these everywhere and they are used in every part of the world." It is possible that the iron industry did much to support Puteolian shipping and had already begun in the second century, since Cato finds some of his implements in the Campanian region. The forests of the islands and the mainland coast nearby were not very abundant and the factories of Puteoli (where there was timber and a good harbour) had taken up the work of producing wares from the blooms produced in Elba.

DIODOR's report is confirmed by VARRO (quoted by SERVIUS on Aen. X, 174) and by STRABO (V. 2. 6).

The State had armories of its own before 100 B.C. (CICERO, *pro Rabir. Perd.* 20, *In Pis.* 87). Military necessity leads to concentration of the industry in Puteoli, Syracuse, Rhegium, Venafrum, and other centres like Populonia, Volterra, and Minturnae. Thus the way was paved for later government control. Then gradually the industry was transplanted to the provinces in the neighbourhood of the mines. In general there was only a broadening field of industrial application, no technical progress, for there was abundance and the ruling classes had only contempt for industry. The Roman Empire possessed mines of all metals used anciently and was selfsufficient, though certain quality products such as Seric steel might be imported occasionally. State organisation was applied to the largest deposits, but iron was still normally produced by independent labour in many forest regions. Furnaces of itinerant smiths were usual in the Weald, the Jura, Loire Inférieure, and Yonne. In Bosnia, Chalcidice, and England slag derived from smelting is frequent on both Roman and pre-Roman sites, showing that the ore was collected locally and reduced as needed, just like the bog ores of Germany. Gaul supplied itself and the armies on the Rhine. Only in times of war in towns like Beuvray or when the ore was abundant and of good quality, especially if it occurred in massive formation and not in thick beds which could be attacked by shallow pitting, the Romans confiscated the mines, as in Aude or Carinthia, and entrusted the management to imperial lessees.

The blooms from forest furnaces were welded together into large blocks as current in Roman trade in such installations as found in Corbridge, Cedworth, and Sarmizegethusa. They were often bought by the military, who had a smithy in every important station, which thus accounts for the slag so frequent in Roman forts in England and elsewhere. It was also common in Roman villas, where the

ordinary tools, required locally, were manufactured or repaired as had been usual even in Homeric days. The magnetite sand from Avellino, east of Naples may have fed part of the iron industry of Southern Italy.

Iron slag found in association with small brick-lined furnaces under St. Saba church proves that forges existed in the capital.

In the Early Empire there was a very large guild of fabri at Milan and also an unusually large number at Brescia (Brizia). Como was famous in PLINY's days for its iron industry. Aquilea was probably deeply interested in the famous iron mines of Noricum; Roman state-contractors who handled the mines lived there but very few fabri! Populonia has still a few ironworkers but most of the iron trade had gone to Puteoli. Since inscriptions there mention no guilds of fabri, it is probable that slave-labour manned the numerous smithies of the town.

Still to a far greater extent articles were made and sold in small shops. It would seem that the making of iron tools was partly in the hand of individual smiths, partly in the hands of firms who produced articles in large amounts under a system half-way advanced towards factory production. Even at Capua where silver-plate was more or less a factory product, iron utensils were made more often in small shops and Rome itself had many individual iron-workers.

The Romans of the Imperial Period understood to make different kinds of steel having adopted many methods of the Celtic smiths. Roman swords of the Nydam find were analysed by NEUMANN (97) who found that three methods were followed: *a*) welding on damask-strips on both sides of a hard steel blade; *b*) cutting edges of hard steel welded on iron and *c*) case-hardening and forging iron. He showed that some of the typical structures changed into more stable forms in these old samples buried so long in the soil.

During the conquest of Roman *Spain* direct State exploitation was no doubt rule notwithstanding DIODOR V. 36, though modern exploration does not bear out the classical reports on "richness in iron", except in the Basque provinces which were hardly explored before the middle of the first century A.D. But the Early Empire found iron in the large area stretching from Baetica through Dianium, Bilbilis, and Cantabria to the coasts of Gallaecia (PLINY, *Nat. Hist.* 3, 30; 4, 112; 34, 149) (STRABO, III. 2. 8; 4. 6) (MARTIAL, IV. 55; XII. 18) (JUSTIN, 44. 3) (SOLINUS, 23. 2) (SILIUS ITALICUS, 1. 228) though it was best known to the world in its manufactured form. Arms and

cutlery were the articles ordinarily exported. The fame was mostly due to particular manufacturing methods such as steeling by burial (PLUTARCH, de Garr. 17) or to the special quenching qualities of certain waters (MARTIAL, JUSTIN, PLINY). The importance of this industry to Rome is attested by a wealth of records of societies, officials and private individuals connected with the extraction, manufacture or distribution of the iron. Certain alluvial beds like those of Catalonia and Alicante and also Toledo were worked in the Later Empire and the Middle Ages.

Roman *Gaul* contained the relics of many older smelting sites and enormous masses of slags have been found which can not be dated precisely. Many blooms of Celtic date have been found spread all over the country, though there is possibly some connection between the bloomeries and the rise of some towns. Some oppidæ like Bibracte had an important iron industry and CAESAR mentions the ingenuity of the Bituriges and their iron mines in the country surrounding the present Bourges.

In Roman *Britain* the important phase of the Roman industry falls between 250 and 360 A.D., when iron slags were also used for road repairs. Iron was mined in many places especially the Weald and the forest of Dean in Roman times. CAESAR's "coastal regions of Britain" (Bell. Gal. V. 12) probably refer to the former. These deposits were, however, inconsiderable when compared with the central iron deposits exploited by the Romans. The slag heaps of the forest of Dean range from the first to the fourth century in date, traces of smelting also exist in Glamorganshire. Pre-Roman smelting sites were found in the Mendips and near Glastonbury. Other Roman smelting sites were found in Lincolnshire, Nottingham, North Wales and on the Lancashire-Cheshire border. In the forests of the North iron slag is not infrequently found in circumstances which prove that iron was produced locally for the use of the garrison. Iron-smelting was done at some villas (At Ely near Cardiff, etc.). The use of malleable iron by the blacksmith in making various kinds of objects is attested by vast quantities found at different sites. But often they have not been analysed owing to their rusty condition and their bulk and variety have been overlooked. Here and there we can trace blacksmith's work which seems to have been done commercially, the Wroxeter finds were hardly meant for local shops only. Again some iron objects especially knives and centre-bits bear the maker's name!

In *Central Europe* the Iron Age begins with the Hallstatt period

(1000 B.C.) and is usually said to end in the La Tène civilisation (400 B.C.). The bearers of the Hallstatt civilisation were the Illyrians, but the La Tène period is that of the Celts who were the clever smiths making tools, weapons and bars of iron for trade purposes with whom CAESAR had to contend." Their steel is hard and pliable" says PHILON when telling of the method of burying the wrought iron before the forging of steel. Carinthia, Carniola, and Styria, as well as Tyrol abound with useful iron ores such as magnetite, haematite, limonite and above all the famous spathic iron. The furnaces are either of the simple pot-bowl type or the more complicated shaftfurnace and primitive forms of Stückofen seem to have been used in the Later La Tène period. The Hallstatt civilisation knew case-hardening only, but the Celts had various methods of "steeling" such as the false-damascening which consisted in welding harder and weaker strips together. Some of the natural steel quite free of sulphur and phosphorus must have been difficult to forge as it was liable to form cracks. As the hardening can be easily found under the microscope it is proved that we can still analyse the ancient methods of working iron and steel on the excavated samples though sometimes the structure is slightly changed by time (66).

The bog-iron industry of Europe has the character of village iron-smelting. In Noricum much smelting is done in the hill-top settlements, the mines being worked from Hallstatt to well into Roman times. The Romans controlled the Noric fields directly just like the Sana valley in Bosnia; local workings were gradually concentrated into larger fields. The slag found in Noricum amounts to some 100,000 Tons which may be equivalent to 30,000 Tons of iron; lime was the usual flux as proved by finds at Eisenberg. In Noricum most traces of the older workings disappeared where the Romans started exploitation (Hüttenberg) only the Romans do seem to have preferred the wheathered yellow and white ores, while rejecting the spathic iron. Some of these ores contain titanium, an excellent component to make steel with. The bars or blooms of iron were probably no longer worked on the spot but exported to Aquilea. Iron was also mined on the Styrian Erzberg between Eisenerz and Vordernberg, where coins prove exploitation upto at least 316 A.D. Further north there were many Roman workings in Central Jura, North-Eastern Gaul, Luxemburg, Northern Alsace, near Trier, and in the Eiffel. In Central Germany the bog-ore was exploited locally.

The Romans adapted not only the methods but also many of the

tools of the Celtic smith (99). Only the form of bars of crude iron do not seem to have been imitated for the Celts used a peculiar double-pyramid form. There are two types of Celtic bars (154), the short ones from the south about 30 cms long and the longer ones of the north ranging from 40 to 60 cms. They weigh about 3-10 Kgrs. Both belong to the Illyrian-Celtic civilisation as they are found in Germany inside of the Limes. As many of these bars are adjusted to a certain weight and sometimes bear stamps of guarantee they also seem to have served as precursors of money like the currency bars and "Schwurschwerter" of prehistoric Europe.

The Germans originally did not know iron but began to work it in the fourth century and produced iron and steel locally mainly from bog-ore. The smelting was conducted in forest-smithies which form remained popular in Germany until well in the Middle Ages (TACIT., Germ. 6). In Siegerland both the primitive pot-bowl furnaces and small Stückofen are found (52). Good manganese-holding ores and oak charcoal produced iron and steel of widely varying composition. It seems that the Stückofen were introduced in this region as early as 300-100 B.C. (83). Earlier types include shaft-furnaces.

The Finns, at least the West-Finns, are said to have learnt iron-working from the Germans, calling the new metal *rauta* (copper), but by the fourth century A.D. they were already good blacksmiths. From the Kalewala which treats of the origin of iron (Runo IX) we learn that the Finns smelted bogore.

Again we must devote a few lines to the ancient *nomenclature of iron*. The etymology of many ancient words for iron is far from clear. The Sumerian AN . BAR is generally interpreted as "heaven-metal" or "star-metal", but CAMPBELL THOMPSON believes it to mean "heaven-flash (of the meteor)". But these explanations would infer a very early knowledge of the celestial origin of meteorites. Possibly there is some colour-association in the element "heaven" in this word. It certainly does not mean "foreign metal" as KIRSTEN contended (80).

Since HOMMEL (ZDMG, vol. XLV, 1891, p. 340) gave his etymology of the Semitic forms *parzillu*, *barzel*, etc., the word *parzillu* has been the subjects of many speculations. Though some still believe that it is derived from a Sumerian BAR . GAL (CT, 18, 29. 51a; ŠL, 74, 316), it is now generally believed to be a non-Semitic, Asianic word on account of the ending *-ill*. BORK and GAERTE (OLZ, 1922,

p. 19; AOF, vol. 8, 1933, p. 310) believed in a Caucasian origin and mention a Caucasian *varkil* for iron as the ancestor of a series of terms for this metal, to which belong both *parzillu* and *ferrum*! In Pehlevi steel is called *pulafat*, New Persian *pûlâd*, Russian *bulatu*, Mongol *bolot*, while similar words are found in Tibetan, Armenian, Ossetic, Grusian, and Turkish.

Another Iranian expression for steel is *al-hindî*, *al-binduwânî* (the Indian) which occurs in later writings as *bindiab*, *andaine*, *andun*, or *ondanique*, the latter four especially in books by European medieval writers on Oriental subjects.

MAX MÜLLER (*Lectures on the Science of Language*, London, 1882, vol. II, p. 255) suspected that *ayas* originally meant copper in Sanskrit and that as iron took its place the meaning of *ayas* changed and specified iron. In passages of the Atharva Veda (11.3) and the Vâgasaneyanshitâ (18. 13) a distinction is made between *syâman ayas*, dark-brown metal, and *lobam (lobitam) ayas*, bright metal; the former meaning copper, the latter iron. This shows that the exclusive meaning of *ayas*, iron, was of later growth and renders it probable that the original Aryan '*ayos* meant the metal par excellence, copper. In Old High-German a new word for metal in general was formed *ar-uzi*, the modern *Erz*. The present *Eisen* seems to have descended from *ayas* too. These conclusions are confirmed by SCHRADER (137) who finds that there was no general Aryan term for iron and that a new word for this metal was formed in each of the Aryan languages separately, which originally had words for gold, silver, and copper only!

In the Avesta *ayah* is permanently used for iron, like the later Sanskrit use of *ayas*.

Sideros has been connected with *sidus*, star, by POTT and LENORMANT in analogy with such expressions as AN·BAR, etc. But TOMASCHEK and SCHRADER have derived it from a Caucasian or Udic *zido*! Others again consider *zido* to have been derived from *sideros* (102) and PAULI thinks that the latter goes back to a Cretan-Etruscan word(?) and cites a similar Lycian term, the Etruscan *sethala*, *seth-lans* (Vulcan) and the names *Hanthalia*, *Saithalia*, *Aithâleis* used for the islands Lemnos and Elba. On the other hand modern writers such as MÜLLER derive it from '*suidē-ro-*, compare the Lithuanian *svidēti*, glittering, thus giving it the meaning "glittering metal", a name associated with its colour like that of the other metals.

Chalybs is connected by the scholiasts with Chalyps, son of Ares, but it is probably born in the trade between the Greeks and the Chalybes!

The French *acier*, Italian *acciajo*, Spanish *acero* have been derived from the Latin *acies* (PLINY, *Nat. Hist.* 34, 141, etc.) but others connect it with the Middle-Latin *aciarium*. It certainly first meant the sharp edge, then the steel itself!

The etymology of *ferrum*, the Latin for sword, is still doubtful. The links forged by BORK between *ferrum* and the Semitic *parzillu* or *barzel* remain very weak. HINTNER connects it with *videdhrti, ferrum*, and says *ferrum* means "the solid"!

Neither is the origin of the modern German *Eisen* fully explained. POKORNY (111) connects *Eisen*, Gothic *eisarn*, *isarn*, Celtic *isarnon*, with an Illyrian *'eisârno-m*, which means "the strong" (as compared with bronze) and therefore connected with the Greek *hierôs*, strong. The Celts may have taken this name from the Illyrian Veneti who were the bearers of the iron-working Hallstatt culture! The compound-names with the Celtic *isarâ*, strong, are very frequent in place-names or the names of rivers. GRIMM, SCHRADER, and others, however, consider the Gothic *eisarn* as a derivative form of *aiz*, *'ayos*, the Aryan term for copper. *Eisarn* was then later changed in Old High-German to *isarn*, then to *isan*, the modern *Eisen*, while the Anglo-Saxon *isern* leads to *îren* and *iron*. It would seem that the latter derivation is the most probable of all.

Having run with seven-league boots through the story of iron we have detected many weak points and many blanks. It would seem to us that exact data on smelting sites and furnaces of iron-workings are possibly still more scarce than in the case of other metals and unless this is repaired by future students we can hardly say with the aged Ilmarinen, the supersmith of the Kalewala:

"Now I know whence comes the Iron
And of steel the evil customs."

(*Kalewala*, Runo IX, lines 269-270)

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CHAPTER THIRTEEN

OLD METHODS AND NEW TOOLS

And, strange to tell, among that Earthen Lot
Some could articulate, while others not!

(OMAR KHAYYÁM, *Rubáiyát*)

It is only a fitting epilogue to our ramble through the history of metallurgy to devote a few pages to future research in this field. The reader will have remarked that only too often we had to report that details on some archaeological, historical, or philological point were missing or that experts should re-examine the evidence already reported by others. It is no use repeating these jeremiads of which these pages may have seem already too full. It is more constructive to devote our further space to a discussion of the methods of examination of metallurgical finds and their possibilities.

Only too often little attention is given to the metallurgical finds apart from the archaeological and typological descriptions in reports and handbooks. Some striking objects find their way in handbooks of art and other works, but for the main part they linger in the museum storerooms or in the museum showcases. Little is often done in the way of the preservation and restoration, though we possess excellent handbooks on this subject (9) (19) (23) (24) (25) (30), and at present several of the larger museums are equipped with a good laboratory which is fully competent to tackle this job. But alas, only too often money is not available for the preservation of finds which cost relatively large amounts to recover from different archaeological sites. The cleaning and preservation of the exhibits is often necessary as malignant patina is apt to destroy the entire object within a few years or to transform them into unrecognisable masses of oxidised metal (23) (28). But a strong force counteracting the cleaning and preservation of these objects is the beautiful patina on many of these objects the aesthetical effect of which is such that many museum directors object to the necessary treatment of their relics. Still apart from the fact that many objects should be cleaned lest they are destroyed by the malignant patina which is more frequent than generally though, we must remember that the patina, whatever its aesthetical effects are, is by no means an intrinsic part of the metallurgical product. When it was used in ancient times it was certainly kept free

from rust and oxidation and it is our task to restore its ancient appearance. The author has had the opportunity to examine several cleaned objects which did not only profit by their cleaning, but which yielded important inscriptions on cleaning and thus became more useful to the archaeologist. Whenever the object is not hopelessly broken or destroyed by oxidation it should be cleaned and its life lengthened by the appropriate treatments to be found in the handbooks mentioned. The electrolytic treatment has been developed by many scientists to become a safe routine method even in the hands of those who are not fully acquainted with this kind of work (15) and a long and safe life can now be guaranteed to properly treated metal finds.

Proper cleaning and restoration can also in many cases lead to the correct identification and recognition of the materials used in making these ancient objects. The proper description of the material and the correct labelling of museum objects are still subjects which leave much to be desired and especially the smaller museums do not pay much attention to them. The author once came across the oxidised remains of a tin ring described as "ivory" and the material from which the famous statue of Pepi I so important in the history of metallurgy, was fashioned, was once described as bronze and at the same time as copper in contemporaneous handbooks. The terms bronze and copper and even brass are still used so loosely in catalogues and handbooks that any attempt to establish a chronological spread of the alloy bronze is greatly imperilled by these statements and only very careful authors can avoid slips in this important matter.

This often very loose identification of the material may be partly due to the fact that many archaeologists are not fully aware of the possibilities of new methods of analysis of metals and still think that the *chemical analysis* is the one and only panacea of all ills. This is of course far from true. The chemical analysis of metal objects reveals their compositions and identifies the constituents of metals and alloys and their quantitative relation, but nothing else! Its great disadvantage is that it destroys part of the object at least, though modern methods of microanalysis allow full figures when using a minute fraction only, but this destruction of archaeological matter has withheld many to use it. In fact, there is a great resemblance between criminal and archaeological investigations in that the matter to be analysed can be produced only once and if possibly should not be destroyed in the course of analysis as it will be lost irretrievably. We have already argued often

in the course of our story that the essential element in ancient metallurgical objects is the technique or treatment to which they were subjected during their production and though this treatment may be of less importance in the case of the older copper alloys it is of foremost importance in the case of the types of iron produced in Antiquity. No chemical analysis is able to give an idea of this treatment if not correlated with other data and therefore no modern investigation should be based on chemical analysis, or on these figures alone. We possess far better methods which use up only a fraction of the object or even none at all.

Metallographical methods permit us in polishing, etching and observing a small part of the object under the microscope to draw conclusions on the treatment to which the metal was subjected before its use and at the same time we get a rough impression of its composition, in most cases quite sufficient to determine what kind of metal or alloy was used and what its main impurities were. Only too often much attention was given to impurities found by chemical analysis without remembering that such impurities might be due to the crude metallurgical methods of the ancients and that they were not intentional additions as they might be in modern metal objects, because now we know the effect of these impurities. It is too often forgotten that the ancients did not appreciate the ins and outs of metallurgy as they were unable to correlate the special properties of metals and alloys with the amounts of different constituents for the lack of proper analytical methods. What they achieved was knowledge by trial and error and though they mastered many of the main rules of metallurgy such niceties must have escaped them. Even for this reason chemical analysis is not always necessary as it may merely lead us on the wrong track if the figures obtained are not handled by persons who are well acquainted with ancient metallurgy and its achievements. As metallographical methods give us the details on the treatment of the metal, a rough insight into its composition and as they damage the object but slightly and cost very little money and time if applied to a series of objects; they are greatly to be preferred over chemical methods, which should be applied, only as a confirmation of the results obtained with the former methods, to broken and valueless metal finds of the same series.

Now metallographical methods have been applied more and more in the last fifteen years and the results are such that they have proved their merit without doubt. We have quoted a few examples in our

bibliography (2) (5) (6) (7) (11) (17) (22) (32) (33) and these were selected to prove that these methods are equally informative for all kinds of metals and alloys. Many other investigations of this kind have been mentioned in the different chapters of this book.

Again chemical analysis, should it prove necessary, can be replaced by microchemical or by spectrographical methods which demand only minute portions of the object. Especially the *spectrographical methods* have of late proved of great value to prehistoric research in Central Europe and the methods developed by a series of chemists are now foolproof (12) (16) (34) (35) and should be applied everywhere when only a few valuable objects are available for examination and no broken or valueless metal finds can be spared.

This combination of metallographical and spectrographical (microchemical) analysis will give all the data necessary for a proper understanding of ancient metallurgical methods. What can be achieved in this way is not only proved by the exemplary investigations of ancient ores, slags and metals by WITTER and his collaborators (35) but also by the valuable work of the Sumerian Copper Committee and its successor, the Ancient Metal Objects Committee. It is only to be hoped that the results of these two Committees will soon be published in more details than the preliminary reports in the papers of the British Association for the Advancement of Science, Annual Meeting Section H, have given since 1928. It would also be very important if the Committee could publish the analytical methods used so that they were available to all concerned.

For what we need most is a thorough investigation of all the metal remains now buried in our museum storerooms. The analysis of a few metal finds may give us some valuable figures but there is always a chance that we are misled. Ancient metallurgy was far from foolproof and lack of proper temperature control and other modern apparatus often delivered the ancient smith in the hands of the fickle goddesses of Fortune and Chance. It may, therefore, be that some object analysed by us is just such a chance product, an unusual result produced unwillingly by the ancient smith, which might lead us to draw entirely wrong conclusions as to his skill and technique. To make sure we should apply statistical methods, that is we should analyse a series of objects belonging to the same find and date and take the average result as a picture of the technique of that time, using the unusual, exceptional figures to complete this picture of the average. If these investigations are repeated with other series of

dated finds, we will in due course gather the results of chronological-statistical series of analyses of well-dated metal objects, which will permit us to draw certain conclusions on the development of metallurgical technique.

Though this be the only way of obtaining certainty it may seem a most expensive one to the reader, but this is not so, if these investigations are properly handled. For not only are modern analytical methods far less expensive than the old full chemical analysis, but if such work were concentrated in a central laboratory in each country these results could be achieved with relatively little money. In England we have a core of such a central laboratory in the Ancient Metal Objects Committee, the work of which could be done in any well equipped museum laboratory or at some university. It will not be difficult to achieve a similar concentration of work in any other country. A second advantage of this concentration of archaeological-chemical investigations is that it could be put in the hands of the few experts that should handle this kind of matter, that is in the hands of chemists and scientists who are at the same time interested in archaeology and have studied ancient metallurgy. Only these would know how to attack the problems and what to look for, they only would be able to draw all the hidden information from these metal objects which can not be replaced without losing any datum. Only too often the analysis of these objects was entrusted to experts, who however clever, were not interested or initiated in the mysteries of ancient metallurgy, and thus they have unwittingly destroyed valuable evidence. What remains to be done is, therefore, not only expert examination and re-examination of ancient furnaces, smelting sites, mines, etc. but also further information of ores and deposits in the Near East and chronological-statistical series of analyses of ancient ores, slags and metal objects.

We began this book by saying that it was a collection of facts and fancies. In short, what we want is re-examination and amplification of the facts and demonstration of the fancies.

As to the present evidence on the story of metallurgy as collected in these pages, we could hardly find fitter words to describe it than the closing lines of ROBERT BOYLE'S *Sceptical Chymist*:

"As unsatisfied as the past discourse may have made you think me with the doctrines of the chymists, about the elements and the principles, I can yet so little discover what to acquiesce in, that perchance the enquiries of others have scarce been more unsatisfactory to me, than my own have been to myself."

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