Man, Metals and Magic: The Ancient History of Metallurgy

500 B.C. - 500 A.D.

Chapter IV

Ancient Greece

Ancient Greece was not a nation in the modern sense, but was composed of a number of city-states, some of which possessed several external colonies. Neither the geography of Greece nor the temperament of its peoples encouraged national unity, nor perhaps was the time sufficiently advanced for it. The mountains and the sea provided natural obstacles between scattered communities, and the independence of the Greek showed itself in his desire to rule his own city rather than to elect some one else to govern his own country. Athens, Sparta and Corinth are perhaps the most familiar names among the city-states. Colonies existed along the north coast of the Black Sea, in southern Italy, and along a vast stretch of the North African coast between Egypt and Carthage.

Silver Mines and Ships

It was this Greece that the Persians sought to subjugate in a great empire building campaign. Under Darius I their territory included Egypt, Asia Minor and Syria in the west, and stretched eastward as far as India. Then in 490 B.C. after the Persian fleet had conquered islands in the Aegean, the Persian armies landed in Attica where, at the battle of Marathon, the Athenians defeated them. Nevertheless, Athens was still threatened and the Persian fleet, although it had sailed out of Aegean waters, remained a serious menace. Themistocles, a Greek statesman, had for many years insisted that without adequate sea power Athens could not be safe from attack. At last his persuasive arguments were heard. But the enterprising shipbuilding program he suggested needed vast financial resources. Fortunately, it was at this time that a rich vein of silver was struck in the mines at Laurium, near Athens. The ore was mined and the silver extracted and sold, and ships were built. In 480 B.C. they fought and destroyed the Persian fleet in the Bay of Salamis. Athens was no longer in danger, and many Greek cities that had previously been conquered were liberated. But without Themistocles wisdom and without the silver mines at Laurium, the story of Greece might have been a very different one.

The mines, leased to citizens by the state, were worked in a way that shows considerable technical development from the primitive scrapings of 1000 years earlier. In the mines at Laurium, shafts were sunk to depths of nearly 400 feet, and cutting steps in sloping shafts gave access to the underground workings. While fires helped ventilation, conditions were severe so slave labor was used. The slaves were usually prisoners of war – frequently inhabitants of conquered Greek cities – who were freely bought and sold in the slave market. But the conditions that were imposed upon them, although unpleasant enough, were generally not so horrible as they were under later Roman rule. A slave might, for instance, be directed into a business house, eventually acquire property, be set free, or even be the beneficiary under his master's will. In the mines, however, such liberties were not common. Chains and brands were often the fate of these unfortunate people, whose lives were made more awful by the poisonous atmosphere that was produced at the mine surface by roasting the sulphide ore there preparatory to smelting it.

By the light of oil lamps, the slaves hacked with iron hammers for long shifts and their produce was carried in sacks to the surface. There it was hand-sorted and crushed in crude mills or mortars. The crushed ore was then subjected to a stream of water, which carried away the light, sandy material and left the valuable mineral to be roasted and smelted to produce a lead-silver alloy. This process of concentrating the mineral has remained in principle unchanged. So,

too, has the method used by the Athenians in extracting silver from the lead by a process of "cupellation."

This involved heating the molten alloy in a shallow clay basin, known as a cupel, and blowing air over the surface. Lead oxidizes preferentially to silver and so lead oxide was produced, which was removed from the surface of the melt, while a proportion was also absorbed in the material of the cupel. After sufficient oxidation, only pure metallic silver remained in the basin. The separated oxide and discarded cupels were heated with charcoal to recover the lead. In more modern times, the process used remains much the same, except that it is made more efficient by a preliminary process that effects a concentration of the silver by simpler means. Cupellation is the same; it is only the conditions under which it is used that have altered. If gold occurred with the silver and lead in the original alloy, the cupellation process produced the gold-silver alloy, electrum. When it became possible to separate gold and silver is high controversial, but it was certainly before the Christian era, and may have been as early as 300 B.C.

The rich resources of the mines allowed the introduction of silver coinage at Athens, and this uniform currency together with the power of the Athenian fleet, brought Athens into a predominant position in trading with the rest of Greece and Asia Minor. The Athenian silver mines played an important part in history.

The Greeks were also capable iron makers. While the Egyptians knew the hardness conferred upon a carburized iron by plunging it hot into water, it is believed that by 400 B.C., the Greeks had learned that a subsequent tempering operation -- involving heating the metal to a fairly low temperature -- relieved it of its brittleness. Iron heads to lances and arrows, scythes, sickles, chain links, files, chisels, swords, razors – all these in iron (and what many would call steel) were made by the Greeks. Archimedes is said to have constructed a ship whose sides bristled with iron spikes and other devices to discourage a boarding party. Iron was becoming important in man's life and culture.

In subsequent years, the Peloponnesian Wars saw supremacy pass from the Athenians to the Spartans and eventually to the Macedonians. Throughout these seemingly disturbed times, the foundations of philosophy and scientific thought were being laid.

Archimedes of Syracuse

Of the great men that studied a wide diversity of subjects in that first rational endeavor to understand the nature of things, it is Archimedes of Syracuse who has the distinction of taking the first step towards an appreciation of metallic structure. The story of his discovery -- that for equal weights different materials displace different amounts of the fluid in which they are immersed -- is well know, but colorful enough to be retold.

King Hiero, suspecting that his goldsmiths had alloyed silver with the gold he had given them to make his crown, asked Archimedes to demonstrate whether this in fact was so. We shall never know whether an inspired guess or an involved process of logical thought led Archimedes to realize while bathing that a body displaces water according to its volume and not accord to its weight. So for equal weights, a light metal would displace more water than a heavy one. The gold-silver alloy of the crown should displace more water than pure gold of the same weight.

Archimedes jumped from his bath and ran down the street shouting "Eureka! Eureka!" – which means, "I have it! I have it!" No doubt the citizens were inclined to believe him. The king's suspicion, by the way, was eventually proven. So the weight per unit volume, or density, of a metal was discovered to be something characteristic of the metal. This applies to all substances, of course. A facetious mind cannot help reflecting that the course of science might have been substantially delayed had the Greeks used shower baths, rather than tubs.

If the story of Archimedes is a true one, then it is difficult to accept the Greek accounts of the touchstone, which was used to estimate the purity of gold. Touchstones, which were black pebbles of a certain kind usually taken from the river Tmolus, had been described and their use well known before the time of Archimedes.

On rubbing gold across them, a streak was produced whose color depended upon the purity of the metal, or if a gold-silver alloy were used, upon the amount of silver in it. According to the writings of the time, the test would allow a quantitative estimate to be made of the purity of the gold. This is rather difficult to believe, however, for it was not until the 15th century that the test

was systematized so that by a comparison with streaks made by alloys of known composition an estimate could be made.

The repercussions of Greek thought were felt after the lapse of more than 500 years, first by the Arab alchemists who, as we shall see, based their hopes of the transmutation of metals upon misapplied Greek philosophy, and later, more effectively by the 18th and 19th century thinkers and scientists. The wisdom of the Greeks cannot be said to have had an immediate or wide effect, but the effect was there, an influence in the next two millennia.

In their writings, the Greek philosophers often mentioned metals, describing methods of mining and extraction, occasionally with amazing clarity but more often with annoying vagueness. In either case, their records are valuable in that they provide firsthand evidence of contemporary practices. Their descriptions include the earliest account of the production of mercury from its sulphide mineral, cinnabar. It involved rubbing cinnabar with vinegar in a brass mortar with a brass pestle – an experiment that, on account of its complete futility and absolute safety, might well be included in home chemistry sets. That mercury was known, however, is quite apparent and because of its liquidity at room temperature, it was not regarded as a metal. This peculiar property of mercury resulted in mystical properties being ascribed to it – a belief that lingered into the early 20th century.

While Greece demonstrated its intellectual capacity during the 500-odd years before the Christian era, India, which was as far removed culturally as geographically, had begun the first real production of steel. Wootz steel, as it was to be called, was produced by a development of the carburizing process that was known to the ancient Egyptians.

The Indians produced a sponge iron in a furnace that was remarkably like the earliest blast furnace (which was not to be generally introduced until the 14th century). About four feet high, a blast was applied at the bottom while the charge was made at the top. Apparently, the temperature reached was not sufficient to yield a liquid product. The sponge iron so made was hammered to expel the slag, broken up and packed tightly with dry wood chips into a clay crucible. The metal was then covered with green leaves and the crucible sealed with clay to prevent the ingress of air. A number of these crucibles were piled up and put into a stone furnace, and packed around with charcoal, which was kept burning with the aid of an air blast. After a few hours, the crucibles were taken out and cooled. The pieces of iron had absorbed carbon throughout their section, producing the alloy, steel, which had such superior properties of strength and hardness. The steel pieces were then heated and hammer welded into bars.

It was steel of this kind that later was to be used in Damascus, in making the swords for which that city became famous. The swords were made by using a hammer to weld together a pile of alternate bars of iron and steel, which were then reheated and hammered until their thickness had been appropriately reduced. The sword that was shaped from this material had a structure consisting of alternate wafers of iron and steel, and these produced the typical damask pattern when they were suitably corroded. The corrosive agent used is not known, but it was perhaps a dilute acid, which would discolor the steel sections, leaving the iron comparatively bright.

The Roman Contribution To Metallurgical Progress

During this pre-Christian period, metallurgical activity was not confined to the heads of the Greeks and the hands of the Indians. The small city of Rome in Italy had shaken off its imposed monarchy and was struggling for freedom at home and an empire abroad. She attained both. By 100 B.C. the Roman Empire included all the countries at the north of the Mediterranean Sea, and during the next century or so it acquired the North African coastal countries as well as Gaul and Britain.

The Roman contribution to metallurgical progress was not so much a gain in knowledge as an improvement in organization – an efficient administration but no back-room boys. The earliest Roman republic, near the mouth of the Tiber, had no ore deposits and was of necessity an agricultural community. The Romans made pottery, hewed stone and mixed mortar. As their territory was extended into Italy, mines were acquired by the state, although many remained in private hands. In either case, Rome became richer.

The first mines to contribute to Roman Wealth were in those parts of Italy that came under early rule. Prospecting was prohibited and soon the existing Italian mines were closed.

Perhaps this was because the Romans felt their own soil was too sacred to be exploited, or they may have wished to conserve their resources. Further, as there was initially so great a production of gold at Aquileia, in the north, that its value was considerably diminished and prices rose alarmingly. Some control had to be exercised. There was the popular belief, too, that minerals grew as crops did, and that a mine, which had lain fallow, would prosper on being re-opened. For reasons of this kind, the Italian mines remained unworked until the conquest of Spain made gold, silver, lead, and bronze so plentiful that home produce became unimportant, and the order was widely ignored.

Usually the mines that the Romans exploited throughout their empire were either leased to the highest bidder, or controlled by a state administrator, who may have worked them himself or sublet them for a rent proportional to the number of employees. There were other controls as well, and the inevitable restrictions bound up with a state enterprise of this kind produced fixed prices and stipulated markets. This was most particularly so with respect to the metal that had to be produced for the imperial mint. Chief among the contributors to the wealth of the empire was Spain, whose mines, like all Roman mines, were worked by slaves. From the accounts one reads it appears that the slavery of Imperial Rome was far more brutal than that imposed earlier by the Greeks.

While the Athenian mines had become poorer, the mines in the south of Spain were worked to greater depths and produced vast quantities of gold, silver, copper, lead and tin. The workings were unhealthily similar to those in Greece. At lower levels water was frequently encountered and the mines had to be drained. This was accomplished by using the Archimedian screw pump, which was not the new invention that its name implies. Archimedes is said to have seen it in the Nile valley in 200 B.C. where it was used for irrigation. This, however, was its first appearance in mining techniques. It may represent the first application of a machine to mining operations.

The Romans made no extraordinary metallurgical discoveries. By this time lead was beaten into sheets and pipes – an industry presumably stimulated by the Roman habit of bathing. Silver was extracted from argentiferous lead ores by the methods known to the Greeks and already described. Tin was known as a metal by this time, not merely as a something, which was the difference between copper and bronze. The Romans were the first to use it as a lining for food containers. In Spain, the Romans made no improvement to mining conditions. The shafts and tunnels were small, the tools used were primitive, and working conditions were pitiable. What the Romans did, however, was to organize their mining so that it benefited and enriched Rome. It did this, of course, at the cost of continued slavery, but in those days slavery was not a matter of social abhorrence.

The Spanish mines were usually leased to contractors, and each mining district was under supervision of an imperially appointed office (*procurator metallorum*). The contractor sold his metal, or used it in manufacture, according to the restrictions imposed upon him. Additionally, he collected taxes from all members of the local community. On the debit side, the contractor paid his employees, and was responsible for the upkeep of the public baths. This is not so peculiar as it may seem at first glance, for the local community depended upon the mine for its livelihood, and upon the baths for the only social life which a mountainous country could offer in those days.

Spain also possessed rich deposits of cinnabar (mercuric sulphide), which have been worked at Almaden, in the south, from times before the Roman occupation. The first distillation process for producing mercury, by heating cinnabar and condensing the vapor, was described about 370 B.C. Mercury's property of amalgamating with other metals was also known. Much later, at an unknown date but probably not before 1500 A.D., the powers of amalgamation were used to extract metallic silver and gold from sandy materials. It seems fairly conclusive that the Romans did not practice this application.

Just as the Romans prized Spain for its metals, so to a large extent they were prompted to occupy Britain for its expected mineral wealth. In fact, they seem to have considerably over rated the potentialities of the country. However, they came to Rye in 44 B.C., strode out to the Severn and beyond, opening up and commandeering mines that in modern times are pretty well worked out. They exploited with hungry efficiency the deposits, which before their arrival had been worked reasonably and unhurriedly. Britain's mineral wealth was diminished considerably during the Roman occupation, and the native Britons benefited only very indirectly. The copper mines in Cumberland, North Wales and in the Isle of Anglesey were soon put under Roman rule.

The tin mines of Cornwall were unimportant in comparison with their Spanish counterparts. However, in the 3rd century A.D. the Romans occupied the extreme southwest to mine tin when the value of the pure metal for lining food containers was discovered. But, most strikingly, they unmercifully exploited the lead mines, for lead was particularly needed for water pipes and was even more important for the silver it contained. The mines in Flintshire, Shropshire, Derbyshire, Yorkshire and Somerset were easy to work, for the upper deposits were still rich. All these swelled the imperial Roman purse during the 400 years of occupation.

Although the Romans contributed little to the natural progress of metallurgical knowledge, minor improvements were inevitably made. The first furnaces used in lead extraction were simple hearths built upon hillsides. Later, they developed into something more furnace-like, with stone-walls and hearths made of clay and clinker above ground level. Even so, it was still necessary to ladle out the metal, for the structure was not sufficiently robust to allow a tap hole to be spiked and prodded for the metal to run from.

To the Romans' credit, however, is the first purposeful manufacture of brass, which they used for coinage and which, for many years, had a higher value than bronze. They were aware, too, that with a lower content of zinc, the alloy could be beaten into thin foil. Accordingly, they used a brass containing 11-20% zinc for decorative purposes where thinness and a good color were needed. In subsequent years, brasses of this composition became known as gilding metal, or Dutch leaf, because of their similarity in appearance to gold leaf. The brasses, which the Romans used for coinage, contained more zinc (21-28%).

Although there was an understanding of suitable compositions for appropriate purposes, there is no evidence that zinc was known as a metal, to be added to copper in varying proportions to make different varieties of brass. Simply, we presume, suitable combinations of copper with zinc ores were known to yield a metal that had more or less definite uses.

The Romans were also responsible for a wider use of existing materials. Bronze was employed not only in making statues, implements and weapons, but also for furniture, cooking pots, and razors. Even an artificial leg has been unearthed, dated about 300 A.D. Lead was given an additional use new to Europe, but first known in Egypt, as a constituent of bronze. Presumably this was only to cheapen the alloy, for the mechanical properties were bound to suffer. Although the Egyptians knew that corroded leaded bronzes produce a pleasant green patina that looked well on statues, the Romans often used the alloy where strength was more important than appearance, adding as much as 10% of lead. One might believe that the measure was an economic one, but in view of the great resources of copper and tin, this is not a very adequate explanation.

The iron production of England during the Roman occupation was not as remarkable as that of Spain, whose manufacture was indeed renowned throughout the world until the 18th century. However, iron was known and used before the Romans came to England, although only in very small quantities. Its uses were confined, and its rarity is indicated by its use in bar form for currency. During the years of Roman rule, foundries and furnaces were set up, at first in the south and always in wooded areas, where charcoal could be readily available. Iron production increased to an extent where export was possible, and this trade continued until the Romans left England. It may not have been very large for the comparative scarcity of iron ensured a high price, as the Romans were quite well aware.

The Romans did not use their wealth as coldly or efficiently as they had gained it. Much of it was used to buy luxuries from the East. Pliny estimates that the equivalent of about 1 million pounds in coinage was sent to India and Arabia each year to pay for silks, spices, and other extravagancies. The Romans worked out the readily available metal, paying it to foreign countries and even to their enemies, while internal coinage had to be debased.

The resulting economic disorder contributed to the break-up of the Roman Empire. Europe was still weak after the plague of the late 2nd century A.D., the Roman rulers became more autocratic, and the people they governed grew more discontented. In the early 5th century the whole of Europe became prey to the barbarian invaders, and the Roman Empire, largely inspired by the lust for metals and built by their exploitation, was at an end.

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