UNIT 14 METAL & MINERAL RESOURCES

Structure

14.0 INTRODUCTION

Metal is a solid material which is hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity. Similarly mineral is defined as an inorganic substance of natural occurrence that is usually obtained by mining. The term mineral itself is derived from the term mine, i.e. excavation. Minerals are important inorganic substance needed by the human body for good health. There are very few metals and minerals available independently in the nature. The significance of metals and minerals is that they have a variety of applications for the humans. The social significance, since the ancient past, has been clearly brought out by Gordon Childe in the book, *Man Makes Himself* . He argues that the implications and consequences of developments in metallurgy meant four major discoveries: the *malleability;* the *fusibility*; the *reduction* from ores; and *alloy* making. Metal 'seemed a superior sort of stone that can not only be sharpened to cut like flint, but can also be bent, shaped by hammering, and even beaten out into sheets which can be cut up'. Secondly, 'when heated metal, especially copper, becomes as plastic as potter's clay; nay it will become liquid and will assume the shape of any container or *mould* into which it is poured. Yet on cooling it not only retains this shape, but becomes as hard as stone and can be given as good a cutting edge as flint. For tools copper possesses all the virtues of the older materials –stone, bone, wood– with other superadded. The possibilities of shape became unlimited as sole limit to shape was the mould.

The utilisation of these advantages required in practice a complex of ingenious inventions– a furnace with a draught fusion to produce the relatively high temperature requisite for fusion, crucible to contain the molten metal, thong to lift them with, and above all moulds to confer upon the casting the desired shape'.

The sciences applied in metallurgy are more abstruse than those employed in agriculture or even pot-making. The chemical change affected by smelting is much more unexpected than that which transforms clay into pottery. The change from the solid to the liquid state and back again, controlled in casting, is hardly less startling. Hence, it is not surprising that in the earliest historical societies, metallurgists are always *specialists*. Probably from the beginning metallurgy was a craft as well as a technique. The operations of mining and smelting and casting are too elaborate and demand too continuous attention to be normally conducted in the intervals of tilling fields or minding cattle. Metallurgy is a full-time job.

The most important consideration for the spread and extensive use of any metal would have been its availability. The spread of bronze age civilisation was very limited compared to later civilisations using iron as base metal. The limited availability of copper and tin had restricted extensive use of the metal by the common man/peasantry in particular. Even in the field of agriculture, it was not extensively used. Almost all the bronze age civilisations were located on the banks of rivers as flood plains sustained the agriculture. Corollary to this was the limited utility of bronze in the process of forest clearance. Therefore, expansion of civilisation in the thickly forested areas was restricted and the change in the landscape would have been limited.

The situation changed dramatically with the introduction of iron. Iron is one of the commonest elements in the earth's crust and with continuous experiments the production of iron became relatively cheap. Cheap iron democratised agriculture and industry and warfare too. Any peasant could afford an iron axe to clear fresh land for himself and use iron ploughshares to break up ground. The common artisan could own a kit of metal tools that made him independent of the household of the kings or nobles. Thus in the Iron Age civilisation not only spread over a wider area than in the Bronze Age, it also spread deeper.

The purpose of this Unit is to familiarize you with the use of metal and mineral resources and the complex process of their appropriation. The pattern of appropriation and consumption has marked a definite stage in the evolution of civilizations in the world. The consumption of metal and mineral resources to a great extent depended upon the stratification in the society and the availability along with accessibility of these resources. Our focus is on the significance of metal and mineral resources for humans, the broad spatial distribution of metal and mineral resources in India, and the historical evolution of methods of appropriation and patterns of consumption especially in India.

14.1 METAL RESOURCES

Metallurgy is one of the oldest applied sciences. Its history can be traced back to 6000 BC when its form was rudimentary. However, to gain a perspective in Process Metallurgy, it is worthwhile to spend a little time studying the initiation of mankind's association with metals. Currently there are 86 known metals. Prior to nineteenth century only 24 of these metals had been discovered and, of these 24 metals, 12 were discovered in the eighteenth century. Therefore, from the discovery of the first metals - **gold and copper –** until the end of the seventeenth century, only 12 metals were known. Four of these metals, **arsenic, antimony, zinc and bismuth**, were discovered in the thirteenth and fourteenth centuries, while **platinum** was discovered in the sixteenth century. The other seven metals, known as the Metals of Antiquity, were the metals upon which all early civilisations were based. These seven metals in the descending order of their discovery from the earliest, are:

- Gold, (ca) 6000BC
- Copper, (ca) 4200BC
- Silver, (ca) 4000BC
- Lead, (ca) 3500BC
- Tin, (ca) 1750BC
- Iron, smelted, (ca) 1500BC
- Mercury, (ca) 750BC.

Some of these metals were known to the Mesopotamians, Harappans, Egyptians, Greeks and the Romans. Of the seven metals, five can be found in their native states, e.g., gold, silver, copper, iron (from meteors) and mercury. However, the occurrence of these metals was not abundant and the first two metals to be used widely were gold and copper.

In metallurgy it was important that the metal deposit must be identified. In the case of the first metals color was the most important factor as it allowed the metal to be recognized in surrounding rock, stones, gravel and dirt and separated from these. Separation was then the next problem followed by concentration. These three steps are very important and the economics of these steps usually defines whether it is viable to produce the metal from a deposit or not. In the early days all three steps were carried out simultaneously. In the following pages we will take a brief account of the early metals, their nature and their availability to understand their significance as resources of value to the man.

Gold

Gold articles are found extensively in antiquity mainly as jewellery. Early gold artifacts contain significant silver contents. Man learned to convert gold into jewellery and ornaments, on the basis of knowledge that it could be formed into sheets and wires easily. However, because of its malleability, it has little use value except for decorative purposes. As gold is a non-corrosive and tarnish free metal, it served this purpose admirably.

Gold is widely dispersed through the earth's crust and is found in two types of deposits: lode deposits, which are found in solid rock and are mined using conventional mining techniques, and placer deposits which are gravelly deposits found in stream beds and are the products of eroding lode deposits. Since gold is found uncombined in nature, early goldsmiths would collect small nuggets of gold from stream beds etc., and then weld them together by hammering. The scarcity of gold and its value, due to mankind's fascination with its color, have resulted into gold becoming one of the more important metals in daily life.

In the early stages of the development of metallurgy all metals were reduced by either carbon or hydrogen, however, the majority of the metals once smelted were not available in a pure state. Refining of gold, that is the separation of silver from gold, has a very old history. During the second millennium BC, an amalgamation process using molten lead was used to separate the metal from crushed quartz. The lead then being cupelled (refine in a small flat circular vessel) to separate the gold and the silver. Purification was then carried further (but not until the first millennium BC) by a cementing process where a mixture of the alloy was closely mixed with common salt. The silver reacted, formed a chloride which was soluble and easily rinsed off. The cementation process was used until about 1100 AD when other refining processes became popular. One method used sulphur addition to the molten bullion to form silver sulfide which was removed as "black" during gentle beating. Mineral acids were developed by the alchemists. Nitric acid was used to dissolve silver as a purification technique. By the end of the fifteenth century, stibium (antimony sulfide) was also used in the cementation process. Generally, a mixture of salt, stibium and sulphur was heated with the gold foil. Amalgamation processes were also popular. The gold was dissolved in mercury. The amalgam was coated onto the piece and then heated to drive off the mercury leaving a gold coated piece.

Copper

The use of copper in antiquity is of more significance than gold as the first tools, implements and weapons were made from copper during the Chalcolithic period. By 3600 BC the first copper smelted artifacts such as copper rings, bracelets, chisels were found in the Nile valley. By 3000 BC weapons, tools etc. were widely found.

Malachite, a green friable stone, was the source of copper in the early smelters. Earlier it was thought that the smelting of copper was the result of a chance dropping of malachite into campfires but that was found improbable due to low campfire temperatures. It is more probable that early copper smelting was discovered by ancient potters whose clay firing furnaces could reach temperatures of 1100^0-1200^0 C. If Malachite was added to these furnaces copper nodules would easily be found. Although the first smelted copper was found in the Nile valley, it is thought that this copper was brought to Egypt by the Gerzeans and copper smelting was produced first in Western Asia between 4000 and 4300 BC.

Although copper can be found free in nature the most important sources are the minerals cuprite, malachite, azurite, chalcopyrite and bornite. Copper is reddish colored, malleable, ductile and a good conductor of heat and electricity.

Bronze (Tin and Copper Alloy)

Smelted copper was rarely pure. In fact, by 2500 BC the Sumerians had recognized that if different ores were blended together in the smelting process, a different type of copper could be made which flowed more easily, was stronger after forming and was easy to cast. An axe head from 2500 BC revealed that it contained 11% tin and 89% copper. This was of course the discovery of bronze. Bronze was a much more useful alloy than copper as farm implements and weapons could be made from it. However, it needed the discovery of tin to become the alloy of choice.

Native tin is not found in nature. The first tin artifacts date back to 2000 BC. However, it was not until 1800 BC that tin smelting became common in western Asia. Tin was reduced by charcoal and at first was thought to be a form of lead. The Romans referred to both tin and lead as *plumbum* where lead was *plumbum nigrum* and tin was *plumbum candidum.* Tin was rarely used on its own and was most commonly alloyed to copper to form bronze. The most common form of tin ore is the oxide casserite. By 1400 BC bronze was the predominant metal alloy.

Silver

Although silver was found freely in nature, its occurrence was rare. Silver is the most chemically active of the noble metals and is harder than gold but softer than copper. It ranks second in ductility and malleability to gold. It is normally stable in pure air and water but tarnishes when exposed to ozone, hydrogen sulfide or sulfur. Due to its softness, pure silver was used for ornaments, jewellery and as a measure of wealth. In a manner similar to gold, native silver can easily be formed.

Galena always contains a small amount of silver and it was found that if the lead was oxidized into a powdery ash a droplet of silver was left behind. Another development in this process was the discovery that if bone ash was added to the lead oxide, the lead oxide would be adsorbed and a large amount of material could be processed. By 2500 BC the cupellation process was the normal mode of silver manufacture.

Iron

Iron was available to the ancients in small amounts from meteors. This native iron was easily distinguishable because it contained nickel. There is some indication that man-made iron was available as early as 2500 BC, however, iron-making did not become an everyday process until 1200 BC. Hematite, an oxide of iron, was widely used by the ancients for beads and ornaments. It is also readily reduced by carbon. However, if reduced at temperatures below 700^0-800^0 C it is not suitable for forging and must be produced at temperatures above 1100^0 C. Wrought iron was the first form of iron known to man. It is interesting to note that in the early days iron was five times more expensive then gold and its first uses were as ornaments.

Iron weapons revolutionized warfare and iron implements did the same for farming. Iron and steel became the building block for civilization. Interestingly, an iron pillar dating to 400 AD., remains standing today in Delhi, in Qutab Complex. It is made of forged iron and corrosion to the pillar has been minimal. Iron is rarely found in its native state. The only known sources of native iron are in Greenland where iron occurs as nodules in basalt that erupted through beds of coal and two very rare nickel-iron alloys.

Lead

Lead is not found free in nature but Galena (lead sulfide) was used as an eye paint by the ancient Egyptians. Galena has a very metallic looking appearance and was, therefore, likely to attract the attention of early metalworkers. The production of metallic lead from its ore is relatively easy and could have been produced by reduction of Galena in a camp fire. The melting point of lead is 327 C, therefore, it would easily flow to the lowest point in the fireplace and collect. At first lead was not used widely because it was too ductile and the first uses of lead were around 3500 BC Lead is highly malleable, ductile and non-corrosive making it an excellent piping material. Lead pipes bearing the insignia of Roman emperors can still be found.

> The ability of lead to flow and collect at the bottom of the campfire is an important concept in process metallurgy as reduction reactions to be useful must cause a phase separation between the metal and the gangue. Also, the phase separation should also enable the metal to be cast into a desired shape once concentrated.

Mercury

Mercury was also known to the ancients and has been found in tombs in Egypt dating back to 1500 and 1600 BC. Pliny, the Roman chronicler, outlined purification techniques by squeezing it through leather and also noted that it was poisonous. Mercury, also known as quicksilver, is the only metal which is liquid at room temperature. Although it can be found in its native state, it is more commonly found in such ores as calomel, livingstonite, cordierite and its sulfide cinnabar. Extraction is most simply carried out by distillation as mercury compounds decompose at moderate temperatures and volatilize. Mercury was widely used because of its ability to dissolve silver and gold (amalgamation) and was the basis of many plating technologies. There is also indications that it was prized and perhaps worshipped by the Egyptians.

In 315 BC, Dioscorides mentions recovery of quicksilver (which he called hydrargyros, liquid silver) by distillation, stating *"An iron bowl containing cinnabar is put into an earthenware container and sealed with clay. It is then set on a fire and the soot which sticks to the cover is quicksilver"*. Methods changed little until the eighteenth century.

14.2 HISTORICAL EVOLUTION OF METALS

We give here a brief account of the use of metals in different regions of the world and follow it up with details regarding the use of metals in India in the historical context.

14.2.1 In World

The Sumerian city-states are considered as the first major metal-using civilization. They navigated the Euphrates river for commerce, including the transportation of copper from Armenia to the north. At Gerza on the Nile river just south of the modern site of Cairo, the Gerzeans developed a civilization based on the metallurgy of copper which they had learnt from Mesopotamia, in about 3200 BC.

The pyramids and other great buildings of the Egyptian civilization were built of stones that had been quarried and shaped using copper tools. While the rock used in the buildings was found nearby, the Eygptians mined copper in the Sinai Peninsula. The scale of copper mining in the Sinai reached a size that made it the first real industry of the ancient world. The Egyptians mined deposits of the green copper mineral **malachite**. Malachite, a copper carbonate, was prized because it was the easiest copper mineral to reduce to copper metal. The closely related blue copper carbonate mineral **azurite** also was discovered. Near these two copper ore minerals, the early prospectors often found another copper mineral, blue-green turquoise. Turquoise is still prized around the world as a gem stone. Ruins of the old mines, the miners' huts, and inscriptions to the Goddess Hathor, the Lady of the Turquoise, can be found to this day in the Sinai.

Copper reached the island of Crete from Egypt. A copper axe from about 3000 BC was found on the floor of the ruins of a house. Egyptian barges carried copper to the western coast of Asia Minor, where they traded for the famous cedar wood from what is now Lebanon. Ruins of the Cretan civilization hold artifacts with Egyptian influence, such as fresco painting, pottery, and stone statuettes. However, the form of the metal objects is more like that from Asia Minor.

Metallurgy from Asia Minor reached Cyprus about 2600 BC. Egyptians traded fabrics and gold for copper from Cyprus. Myceneans settled near the copper deposit sites in Cyprus.

Early metal-smiths of Sumer, Babylon, and Egypt were highly prized members of their society. Often they were not free, owing their obedience and livelihood to temple priests and authorities. They were so valuable that invading armies made a special effort to carry them off in captivity. Metalsmiths transmitted their secrets to their children. Their guilds may have been the first trade unions in history.

Bronze, came into use at about the same time in Asia. Bronze artifacts dated at 3600 BC have been found in Thailand. Copper is found scattered around East Asia. Tin is found in the peninsula of Malaysia. Chinese written records date the first copper mining at about 2600 BC. and the first casting of copper vessels at about 2200 BC. The Shang dynasty's capital of Anyang in northern China had a bronze-casting industry in 1400 BC.

14.2.2 In India

India witnessed a long sequence of cultures using both stone and copper tools known as Chalcolithic cultures. The innovation in the Chalcolithic cultures was the use of the new technology of smelting and crafting bronze artefacts. The most prominent has been Harappan culture also termed as Bronze Age culture. We shall take up discussion on the use of metals in the historical sequence in which some of the early metals were used by the people.

Copper/Bronze

The copper workings in India have an antiquity dating back to the second millennium BC. They are reported from Barudih in Singhbhum. We also have a small finger ring discovered at Babri, Birbhum, West Bengal which has been formed from the chalcolithic levels and is dateable to about 1000 BC. It seems the copper mines at Chhotanagpur plateau were in use at that point of time and tin as an alloy was being used to obtain bronze.

In the Harappan culture copper tools were used to help cut stone tools in a more fine manner. The Harappans practiced alloying of copper and tin so that a more strong metal, bronze would be available. "Whereas 70 percent of analysed copper artefacts from Mohenjodaro and Harappa have been found to contain one percent tin (probably the same as found in the natural ore), the remaining 30 per cent had tin ranging from 8 to 12 per cent, which indicates that tin was here deliberately mixed with copper. The proportion of bronze within copper artefacts increases significantly with time at Mohenjodaro, and this was probably the case in the Indus civilization generally. Nickel, arsenic and lead were also used as copper alloys (Irfan Habib, *The Indus Civilization, A People's History of India 2*, New Delhi, 2002, p. 29).

The ore for smelting copper in the Harappan culture was most likely obtained from Rajasthan and Baluchistan, though Afghanistan and Persian sources too would have made the supply (Cf. D.P. Aggarwal, 'Archaeometallurgical Studies in India : A Review' in *Archaeology and Interactive Disciplines*, ed. S. Settar, Ravi Kovisettar, New Delhi, 2002, p. 426). "Copper was smelted in brick-lined pits, and wax-and-clay moulds were probably used to cast whole or parts of copper and bronze artefacts. These included tools such as razors, knives, chisels, hooks, sickles, saws and axes... Smaller copper tools include awls, nails, needles and tubular drills.... A considerable number of copper and bronze utensils (pots and pans) suggests that at least richer households could now use metalware in addition to the breakable pottery" (Irfan Habib, *op. cit*, pp. 29-30).

The Chalcolithic cultures, other than the Harappans, also used copper for making different artefacts. A content analysis of these artefacts reveals that the chalcolithic metallurgical traditions and the Harappan tradition had distinct identities and the probability of any direct transmission is precluded (Cf. D.P. Agarwal, *op. cit*, p. 431).

Iron

The studies focusing on the history of introduction of iron in India had earlier believed that iron was introduced between 600 and 700 BC (cf.D. H. Gordon, *Prehistoric Background of Indian Culture*, Bombay, 1950). But the discoveries made at Painted Greyware (PGW) sites has now settled this date around 1000 BC. D.K. Chakrabarti has written a comprehensive work dealing with the discovery and use of iron in India (*The Early Use of Iron in India*, Bombay, 1992). Some of his main findings may be given here to understand the use pattern of iron:

- The probable date of production of iron in India is c 800 BC;
- The use of iron in India is earliest reported from Central India and South India;
- These production centres were located close to the areas from where ore was found;
- There was a continuity in tradition of iron metallurgy upto the pre-industrial period; and
- Any correspondence between the Indian iron tools of the earliest period and the West Asian tools was lacking (Also see D.P. Agarwal, *op. cit.* p. 433).

Zinc

India provides the earliest evidence of metallic zine. "There are references to burning a metal, *rasa*, to produce an eye salve, which should refer to zinc, placing it use in the last centuries of the first millennium BC. The *Rasaratnakara*, ascribed to Nagarjuna, the great Indian scientist who lived in the fourth century AD, describes both the production of brass by the familiar cementation process, and of metallic zinc. Furnaces (*Koshthi*) have been found at the ancient mines of Zawar in Rajasthan (D.P. Agarwal, *op. cit*, pp. 434-35).

The Zawar mines from where zinc was extracted are located at about 35 kms. to the south of Udaipur in Rajasthan. The ore is mainly a mixture of zinc and lead and is obtained in dolomite formations. Agarwal suggests that “zinc and some lead was being mined between the sixth and first centuries BC” (*op. cit*, p. 435). This trend then continued further and as we come to medieval India we find evidence of zinc distillation process on a fairly elaborate scale. P.T. Craddock (*The Early History of Zinc*, 1987) specializes in the study. We give an extract from him explaining the process (as quoted in Aggarwal) : “at first glance the Zawar industry is the most unusual phenomena, a fully fledged technology with neither antecedents nor successors—and apparently no contemporaries either, for even within India it seems unique.... Zinc required a much higher temperature and the total exclusion of air. The form of the Kosthi furnace for holding the retorts seems to have been inspired by the common spottery kiln. The arrangement is of course totally different, instead of a fire beneath to heat the pots stacked above through the perforated floor, in the Kosthi, the fire and retorts were in the upper chamber and the zinc was collected beneath… the Zawar process was certainly one of the most sophisticated and technically exacting process developed in the mediaeval world, one hesitates to use the term ‘pre-industrial’, for surely this process, with its appreciation of scientific techniques and learning towards mass production, should properly be considered as an early example of an industrial process in the modern sense’’ (p. 435).

It is evident from the description given above that metals as a resource had come to grip the society firmly by the time state formation in India began. Thereafter, it was a question of controlling the resources. It is not without reason that the Magadhan state grew in and around Rajgrih which area was a significant iron ore area.

14.3 MINERAL RESOURCES

To be classified as a “true” mineral, a substance must be a solid and have a crystal structure. It must also be an inorganic, naturally-occurring, homogenous substance with a defined chemical composition. Mineral-like substances that do not strictly meet the definition are sometimes classified as mineraloids. A crystal structure refers to the orderly geometric spatial arrangement of atoms in the internal structure of a mineral. This crystal structure is based on regular internal atomic or ionic arrangement that is often visible as the mineral form. Even when the mineral grains are too small to see or are irregularly shaped the crystal structure can be determined by x-ray analysis and/or optical microscopy.

Chemistry and crystal structure define together a mineral. In fact, two or more minerals may have the same chemical composition, but differ in crystal structure (these are known as *polymorphs*). Similarly, some minerals have different chemical compositions, but the same crystal structure. Crystal structure greatly influences a mineral’s physical properties. For example, though diamond and graphite have the same composition as both are pure carbon, but graphite is very soft, while diamond is the hardest of all known minerals.

A mineral is a naturally occurring, inorganic substance with a definite chemical composition and a crystalline structure. A rock is an aggregate of two or more minerals. (A rock may also include organic remains). The specific minerals in a rock can vary a lot. Some minerals, like quartz, mica or feldspar are common, while others have been found in only one or two locations worldwide. Over half of the mineral spices known are so rare that they have only been found in a handful of samples, and many are known from only one or two small grains.

There are currently just over 4,000 known minerals. according to the International Mineralogical Association, which is responsible for the approval of and naming of new mineral spices found in nature.

Minerals may be classified according to their composition. The list below is an approximate order of their abundance in the earth's crust.

- *Silicate Class* **–** the feldspars, quartz, olivines, pyroxenes, amphiboles, garnets, and micas;
- *Carbonate Class* – lime, dolomite, stalactites, and stalagmites;
- Sulfates – anhydrite (calcium sulfate), celestite (strontium sulfate), barite (barium sulfate), and gypsum (hydrated calcium sulfate). The sulfate class also includes the chromate, molybdate, selenate, sulfite, tellurate, and tungstate minerals;
- *Halide Class* – The fluoride, chloride, and iodide minerals;
- *Oxide Class* – hematite, magnetite, chromite, rutile, and ice;
- *Sulfide Class* – selenides, tellurides, arsenides, antimonides, bismuthinides, and sulfosalts;
- *Phosphate Class* – phosphate, arsenate, vanadate, and antimonite minerals.

One of the common use of minerals by humans has been in dietary form. They are inorganic compounds necessary for life and good nutrition. Some of these are minerals such as salt; others are potassium, calcium, iron, zinc, magnesium, and copper. These can be naturally occurring in food or added in elemental or mineral form. For a considerably long period the minerals in dietary form were used by man through experience.

14.4 SUMMARY

The inclusion of metal technology introduced some complexities into the patterns of living, for instance determining who was to control the new technology, since those who were producing the artefacts were not necessarily the same as those in authority. In most of the cultures bronze technology was accompanied by the script, beginning a new chapter in the process of historical evolution. If bronze marks the beginning of the new chapter in the social relations/stratification, then introduction of iron provided tools to colonise the newer terrain, not inhabitable until then. The process of expansion of agriculture received a new and potent tool. It provided tools to not only clear the forest tract but also to exploit the hidden potential of land other than the river denuded ones. Similarly minerals played an imporant role – as dietary supplement and in jewellery.

14.5 EXERCISES

1) The introduction of metals changed the life-style of man in a major way. Comment.

2) Discuss the introduction of bronze in Indian history and assess the significance of this process.

3) Compare the changes introduced in Indian history by bronze and iron.

4) Write a short note on minerals as a resource.

14.6 SUGGESTED READING

Bridget and Raymond Allchin, *The Birth of Indian Civilisation*, India and Pakistan before 500 BC, Penguin, 1968

Alan W. Cramb, *Short History of Metals*, Department of Materials Science and Engineering, Carnegie Mellon University