CHAPTER III

Techniques Employed in Smelting Copper During the Chalcolithic Period.

From the archaeological evidence and the spectroscopic study of the selected artifacts and the sample of chalcopyrite ore obtained from the ancient mine of Khetri, it has been possible to indicate, in the last Chapter, that the copper ore deposits of the Aravalli region were probably the raw materials for smelting copper during the Chalcolithic Period.

Economic aspect of the Chalcolithic Period copper metallurgy.

For the purpose of producing copper from any copper ore, the proportion of copper in the ore should be sufficiently high, so that, the ore may be mined, concentrated, roasted, smelted and the useful object produced from the extracted metal and sold, at a profit.

This economic aspect of metallurgy was probably true even during the Chalcolithic Period. However, as will be seen from the forthcoming pages, the ores employed for extraction of copper during the Chalcolithic Period contained a small proportion of the metal. According to the present standard of copper metallurgy, the chalcopyrite ore deposits of the Aravalli region are not highly economical.
During the Chalcolithic Period, apart from employing poor ore deposits, the economic aspect of the metallurgy had to contend with rudimentary resources of metallurgical techniques. Nevertheless, it is possible to observe that, the Chalcolithic Period copper metallurgy was profitable. Had it not been profitable, it would have ceased in its early childhood. On the other hand, the industry had not only survived for centuries, but also progressed. It had supplied the metal to the communities settled far and wide, over an area of more than 150000 square miles. The production of the artifacts had progressed from impure copper castings to comparatively purer metal objects and further on to objects of bronze. The bronze specimens studied below will clearly indicate that tin was deliberately fused with copper to produce an alloy, capable of giving implements of greater hardness and keener cutting edge, than that of unalloyed copper. Copper objects were, therefore, in great demand during the Chalcolithic Period.

The vast demand for the metal that prevailed during the period can only explain the economics of the Chalcolithic Period copper metallurgical industry of India. It is not without interest to note in this connection that, the number of copper metal objects recovered in all the Chalcolithic sites is very small. This small number of artifacts probably accounts for their high cost, during this period.
Owing to the great demand for the metal, copper ore mining and metallurgy, started in the Aravalli region, right from this very early period, continued until very recently.

Brown has noted that copper ore mining and smelting was in practice, in the region, until the last quarter of the nineteenth century.

Eighty or ninety years ago the industry was carried on on a very small scale. In the great majority of the cases, the miners were unable to cope up with the water that flooded the mines, once they attained any considerable depth. That apart, in spite of the availability of cheap labour, the Indian copper metallurgy, towards the end of nineteenth century, could not compete, even within the home markets, with the metal brought in by the European traders. This is what happened to ancient Indian iron industry as well.

Iron ores were smelted in India, in many parts of the country, in substantial quantities, as has been shown by archaeological evidences, right from 6th century B.C. There is hardly a district away from the great alluvial tracts of the Indus, Ganges and Brahmaputra in which, remains of iron metallurgy in the form of slag heaps are not observed. The primitive iron smelter in India finds no difficulty in obtaining sufficient supplies of iron ore from deposits that no European iron metallurgist would regard as worth his serious attention. The author has observed the nomadic iron working tribe of Western India, the Loharias, selecting
small bits of iron ore schists, breaking them, concentrating the ore by winnowing and smelting the metal in a primitive furnace, (fig. 11). But the industry is carried out to-day in a very limited scale. Introduction of cheap iron by European traders has almost completely destroyed this indigenous industry.\textsuperscript{2} It may be noted that the Indian iron was famous in antiquity. Pliny\textsuperscript{3} records that the Romans imported a very superior 'Seric iron' from India. This metal was produced in the Hyderabad district of Andhra Pradesh.

Reverting back to the Chalcolithic Period copper metallurgy, it has been noted above that, a number of copper ore deposits in the Aravalli region are delineated with ancient mining and metal-workings. But, how actually the ore was mined during these early periods, has not been so far studied. A detailed study of ancient copper ore mining techniques is a desideratum. It will be complementary to the metallurgical study included in this work.

The remains of metal-workings, observed near the mines are slags. But they are mostly observed on the surface and therefore, cannot be attributed to a particular period. In this connection, the slag like material excavated from the Period I levels at Ahar is of great importance. An analytical study of this slag like material is bound to provide with useful clues regarding the Chalcolithic Period copper metallurgy, if it is a copper metallurgical slag material.
Analytical Study of the Slag like material recovered from Ahar

During the excavation of Period I levels at Ahar, large heaps of slag like material was recovered alongwith copper artifacts like flat socketless axes, a piece of sheet of the metal and fragments of bangles. As pointed above, the Period I at Ahar is attributed to the Post-Indus Chalcolithic Period in India, circa 1800 B.C. to 1200 B.C., by C-14 method. The slag like material was observed in the trench, in specially made round pits of about one and a half feet in diameter. It is not known whether these pits are a part of a furnace.

For the purpose of this metallurgical study three samples of this slag like material, collected from three different layers, were kindly made available by Professor H.D. Sankalia. All the three samples were massive, heavy and dark blue in colour.

The samples were thoroughly washed in distilled water, dried in air, powdered separately and then dried in oven at 110°C for twenty-four hours. The dried samples were subjected to quantitative chemical analysis. The percentage composition of the samples is given in the Table of Results - 2.
### Table of Results - 2.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Details of the sample</th>
<th>Sr</th>
<th>FeO</th>
<th>MgO</th>
<th>Al2O3</th>
<th>MnO2</th>
<th>CuO</th>
<th>SO3</th>
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<tr>
<td>1.</td>
<td>Reg.No. 921 Trench J</td>
<td>Sr1</td>
<td>38.16</td>
<td>45.32</td>
<td>3.02</td>
<td>5.96</td>
<td>1.89</td>
<td>0.91</td>
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<td></td>
<td>Depth 29 1/6″, Chalcolithic Period, Phase-B.</td>
<td>FeO</td>
<td>4.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2.</td>
<td>Reg.No. 1035 Trench D</td>
<td>Sr2</td>
<td>35.18</td>
<td>48.26</td>
<td>2.39</td>
<td>5.25</td>
<td>1.16</td>
<td>0.67</td>
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<td></td>
<td>Depth 24 1/6″, Chalcolithic Period, Phase-C.</td>
<td>FeO</td>
<td>6.08</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Reg.No. 1487 Trench J</td>
<td>Sr3</td>
<td>37.12</td>
<td>43.89</td>
<td>3.61</td>
<td>7.79</td>
<td>2.15</td>
<td>0.86</td>
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<td></td>
<td>Depth 31 1/6″, Chalcolithic Period, Phase-C.</td>
<td>FeO</td>
<td>3.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the analytical data above, it is possible to observe that the samples are of copper metallurgical slag. Therefore, it is possible to indicate that, Ahar was a copper smelting centre of the Chalcolithic Period. The fact that the slag was recovered from more than one trench at three different depths, in the course of a restricted...
excavation of a vast archaeological deposit, clearly indicates that the copper smelting industry at Ahar, was probably extensive.

**Importance of Ahar as a Chalcolithic Period copper smelting centre.**

During the last decade and a half more than a dozen Chalcolithic sites were trenched in Western India, Central India and Northern Deccan. But so far, excepting Ahar, no other site has yielded remains of Chalcolithic Period copper metallurgy. The metallurgy of copper, during the period was restricted. Certainly it was not as wide spread as the artifacts of the metal. In this connection the following observation may be interesting.

During the Chalcolithic Period, the location of a metallurgical centre must have been determined by two factors, namely (1) proximity of the ore deposits and (2) availability of abundance of fuel. It is obvious that, transportation of these vital materials over vast distances was none too easy during the period. In Western India, the Aravalli region amply satisfied both the conditions necessary for setting up the copper metallurgical industry. The chalcopyrite ore deposits in the region, though poor in quality, are abundant. The fuel needed for metallurgical industry was wood charcoal. As the region is wooded to-day, it is possible to presume that it was wooded during the Chalcolithic Period as well. Therefore, as has been
indicated by Professor Sankalia, it is possible to observe, "the possibility of copper metallurgy in this region attracted the earliest colonisers to Ahar and other sites in the Banas Valley".

Ahar is situated in the midst of chalcopyrite ore deposits. Within a radius of twenty miles around Ahar, the ore deposits are observed at Dev Bari, Delvara and Kotri.

Ahar being a copper smelting centre of the Chalcolithic Period, its excavation of Period I levels must have yielded a large number of copper artifacts. But the number of artifacts actually recovered, is very small. But the complete absence of stone tools at the site clearly points that, there must be many more copper implements buried underneath. Further horizontal excavation of the site in this connection, is an urgent necessity, as it is the key site for early Indian copper metallurgy.

As has been pointed out in Chapter I, a number of 'Ahar Ware' sites are observed in the Banas Valley of the Aravalli region. It is but necessary to excavate at least a few of them. Horizontal excavation of Ahar and vertical excavation of a few of the other 'Ahar Ware' sites, will very probably bring to light more interesting data regarding Chalcolithic Period copper metallurgy.

Evidence of fluxing of copper ore.

The analytical data of the slag above shows a very high percentage of silica in the composition of the slag.
This is not without interest to this study. It indicates the probability of fluxing the copper ore.

While smelting copper, silica is mixed with the crushed ore, as an agent to flux it. Fluxing promotes fluidity in the smelting charge, lowers the fusion temperature of the ore and facilitates the removal of impurities from the extracted metal. The impurities are separated out in the form of slag. To-day, some of the common fluxing agents employed in smelting copper ore are lime, calcium phosphate, calcium sulphate, barium sulphate and silica. The fluxing agent unites chemically with the gangue of the ore to form fusible silicates - the slag.

In this connection, the high percentage of silica in the composition of the metallurgical slag recovered from Ahar, is interesting. It may be due to deliberate addition of silica during the smelting process, as a fluxing agent, or it may be a part of the ore mass. If however, it is a deliberate addition, it is possible to observe that, the copper metallurgical techniques practiced during the Chalcolithic Period was quite advanced.

In order to ascertain this aspect of the Chalcolithic Period copper metallurgy, the sample of copper ore obtained from Khetri was subjected to a quantitative chemical analysis.

Analytical Study of the Sample of Copper Ore.

The copper ore deposit of Khetri constitutes
chalcopyrite. The mineral is observed to be present in the upper part of a zone of slates and schists of Ajabgarh age. The ore deposit is delineated with ancient mining. The quantitative chemical analysis of the sample gave the following percentage composition:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Cu</td>
<td>4.82</td>
</tr>
<tr>
<td>Sn</td>
<td>nd</td>
</tr>
<tr>
<td>Pb</td>
<td>3.81</td>
</tr>
<tr>
<td>Ag</td>
<td>nd</td>
</tr>
<tr>
<td>Ni</td>
<td>1.97</td>
</tr>
<tr>
<td>SiO₂</td>
<td>16.70</td>
</tr>
<tr>
<td>Na</td>
<td>*</td>
</tr>
<tr>
<td>K</td>
<td>*</td>
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<tr>
<td>Fe</td>
<td>26.93</td>
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<tr>
<td>Zn</td>
<td>1.36</td>
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<tr>
<td>Mn</td>
<td>2.18</td>
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<td>As</td>
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<td>Bi</td>
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<tr>
<td>Al</td>
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</tr>
<tr>
<td>Mg</td>
<td>*</td>
</tr>
<tr>
<td>Cr</td>
<td>*</td>
</tr>
<tr>
<td>S</td>
<td>*</td>
</tr>
</tbody>
</table>

nd = not detected
* = not determined
The analytical data above indicate that the percentage of copper in the ore is very poor, less than five percent. An analysis of three samples of Chalcopyrite collected from Barkera, a site near Khetri, showed 0.95%, 2.10% and 11.8% of copper. The copper ore in this region is uniformly poor.

The percentage of silica in the ore sample is less than 17%. In view of the fact that the percentage of silica in the metallurgical slag recovered from Ahar is more than 35%, more than the double of silica present in the ore, it is possible to observe that, the high percentage of silica in the slag was due to deliberate addition of silica as a fluxing agent, while the ore was smelted.

An analysis of slag heaps which are the remains of ancient copper smelting situated in the eastern Alps has also given evidence of fluxing of the copper ore with silica. This copper metallurgy is dated to circa 1700 B.C., a period contemporary with the Period I of Ahar.

An analytical study of copper metallurgical slags recovered from the late Bronze Age levels in Cyprus has shown 28.5% of silica in the composition of the slag.

When chalcopyrite is fluxed with silica in a modern copper smelting process, the percentage of silica is about 33%.

The analytical data of the slag above do not indicate the presence of calcium in appreciable quantities. It is therefore possible to indicate that lime was not used as a fluxing agent, for smelting copper ore, at Ahar.
It has been indicated that the application of fluxing technique was employed in another industry during the Chalcolithic Period. An analytical study of the glazed ornamental beads recovered from the Chalcolithic Period levels at Navdatoli, has brought to light the application of fluxing technique.12

From the foregoing, it is possible to observe that, the copper ore was probably fluxed at Ahar while it was smelted for extracting copper with deliberate addition of silica. From this evidence and the evidence regarding the quality of the metal as observed from the quantitative chemical analysis of the artifacts, and their metallographic study, an attempt is made to reconstruct the important features of the Chalcolithic Period copper ore smelting techniques in the following pages.

Smelting of Copper Ore during the Chalcolithic Period.

The ore obtained from the earth's crust contains a large proportion of unwanted elements. In the chalcopyrite ore of the Aravalli region the percentage of copper has been found to be less than 5%. Over 95% of this ore deposit is unwanted material. It has to be separated from the useful metal. This separation process is smelting of the ore.

Chalcopyrite mineral is a compound of sulphides of copper and iron. The modern smelter of chalcopyrite proceeds in four stages in his smelting process. Approximately, these stages are as indicated below.
Ore dressing. Ore dressing is the first metallurgical treatment of the ore excavated from the mines. The ore is crushed, ground and then concentrated by flotation or gravity separation process. During the Chalcolithic Period however, the crushed ore was probably concentrated by such physical means as hand picking. The bright brass yellow pieces of chalcopyrite can be easily separated by hand picking. The hand picked ore pieces were then powdered and the ore was probably further concentrated by winnowing. The Loharias concentrate their iron ore powder, to-day, by winnowing.

Roasting. The concentrated ore is roasted in air to convert the sulphides into oxides. Elements like sulphur and arsenic volatilize in the process. It is worth while noting here that the process of roasting was ably carried out during Chalcolithic Period. The negligible quantities of sulphur and arsenic present in the representative Chalcolithic Period copper artifacts, as indicated by their quantitative chemical analysis shows that the ore was thoroughly roasted.

It is therefore possible to observe that the roasting process was prolonged and that it was carried out at a comparatively high temperature, probably above 500°C. This aspect of the Chalcolithic Period copper metallurgy brings to light that the metal workers were experienced in the industry.
It is but necessary to eradicate sulphur and arsenic from the extracted metal. Even small amounts of sulphur if present in the metal, it will not give a good cast. If arsenic is allowed to be present in the metal in quantities of more than 0.6 percent, it will render the metal brittle. Since most of the copper metal extracted during the Chalcolithic Period was used for the production of cutting implements, brittleness in the metal would have vitiated the purpose for which the metal was intended.

(3) Production of mattæ and slag. The roasted ore is intimately mixed with the fluxing agent, silica, for example, and then heated in a furnace at a high temperature, above 1200° C.

(4) Extraction of the metal from the mattæ. Matte is further smelted, again mixed with the fluxing agent, to extract the metal.

To-day this metallurgical process is termed as pyrometallurgy. The term is derived from the Greek word 'Pyros' which means fire. Mutatis mutandis, all these four stages were employed for smelting copper during the Chalcolithic Period. The last three stages are further summarised below with the accompanying reactions, in each stage, along with the probable conditions that prevailed during the Chalcolithic Period.

(1) The ore was slowly roasted for a prolonged period of time, in air, to drive off excess of sulphur and the other volatile elements like arsenic present.
in the ore. The temperature of roasting was probably high, above 500°C. The reactions taking place in the roasting process may be given as

\[ 2\text{CuFeS}_2 + \text{O}_2 \rightarrow \text{Cu}_2\text{S} + 2\text{FeS} + \text{SO}_2 \]

(2) The roasted ore was mixed with sand or powdered quartz and smelted in a furnace. The silica added in the form of sand or quartz powder acted as a flux in the smelting process. Fluxing considerably lowers the temperature of fusion of the ore and also increases the fluidity of the molten matte and hence enables it to be easily separated from the slag.

During this primary smelting process, silica combines with the earths and the metallic oxides present in the ore to form fusible silicates - the slag. The slag has a much lower specific gravity than the matte. Therefore, the slag floats over the molten matte. From above the matte the slag skimmed off. The matte consists of sulphides of iron and copper.

The reactions taking place in this process are complicated. The three main reactions are between (1) cuprous sulphide and oxygen to form cuprous oxide; (2) cuprous oxide and ferrous sulphide to form cuprous sulphide and ferrous oxide and (3) ferrous oxide and silica to form ferrous silicate - the slag.
Copper has great affinity for sulphur. It is on account of this chemical property of the metal, that when the other metals in the ore are oxidised, copper is retained in the form of cuprous sulphide in the matte. All the sulphur available in the melt goes into the formation of cuprous sulphide. When the proportion of sulphur in the melt exceeds that required to form cuprous sulphide, the excess of sulphur combines with the available other metal, whose affinity for sulphur is immediately below that of copper. The main reactions involved in this smelting process may be represented as:

(1) \[ 2\text{Cu}_2\text{S} + 3\text{O}_2 \rightarrow 2\text{Cu}_2\text{O} + 2\text{SO}_2 \]
(2) \[ 2\text{Cu}_2\text{O} + \text{FeS} \rightarrow \text{Cu}_2\text{S} + \text{FeO} \]
(3) \[ \text{FeO} + \text{SiO}_2 \rightarrow \text{FeSiO}_3 \]

(3) In the subsequent smelting operation, metallic copper is extracted from the matte, by fusing the matte with silica in the furnace. This is a process of partial oxidation. Air is blown into the molten mass by force. During the Chalcolithic Period air was probably blown in with the help of bellows. (This aspect of the metallurgy is discussed below.) In this process, iron and other impurities present in the matte are separated out from the molten metal in the form of slag. As the specific gravity of the slag is about 4 and the specific gravity of
molten copper is 8.7, the slag would float on the surface of the molten metal and hence can be easily skimmed off the metal surface.

Reactions involved in this process are (1) oxidation of iron, lead, zinc and other metals that are present in the matte; (2) partial oxidation of cuprous sulphide to cuprous oxide and (3) interaction between cuprous oxide and cuprous sulphide, to yield copper and (4) reaction between the oxidised impurity metals with silica to form slag. These reactions may be represented as:

(1) \[ \text{FeS} + 3\text{O}_2 \rightarrow 2\text{FeO} + 2\text{SO}_2 \]
(2) \[ 2\text{Cu}_2\text{S} + 3\text{O}_2 \rightarrow 2\text{Cu}_2\text{O} + 2\text{SO}_2 \]
(3) \[ 2\text{Cu}_2\text{O} + \text{Cu}_2\text{S} \rightarrow 6\text{Cu} + \text{SO}_2 \]
(4) \[ 2\text{FeO} + 2\text{SiO}_2 \rightarrow 2\text{FeSiO}_3 \]

Smelting Furnace of the Chalcolithic Period.

While smelting copper ore, particularly a sulphide ore like chalcopyrite, it is but necessary to exclude air from the molten mass of ore and flux for proper reduction of the ore. Therefore, the melt will have to be well surrounded and covered by the burning fuel, so that the melt is retained well within the reducing zone of the fire.
If a part of the melt gets into contact with atmospheric oxygen that part will get oxidised. In order to avoid such oxidation, it is necessary to carry out the smelting process in an enclosed space—that is, in a furnace.

For the purpose of smelting chalcopyrite a high temperature of over 1200°C is needed. An ordinary wood charcoal fire would give a temperature between 750°C to 800°C. This temperature is insufficient to smelt the copper ore. Therefore, a fire activated by some form of forced or induced draught is necessary to reach this high temperature.

It is possible to assume that a furnace with a facility for induced draught, capable of reaching a high temperature of over 1080°C was in use even before the dawn of metallurgy. It has been already pointed out that in the Neolithic Period native copper was cast into small useful objects. For the purpose of casting the metal, it will have to be melted. Copper melts at 1083°C. Since the temperature provided by the wood charcoal fire is limited to 800°C, it is possible to assume that a kind of device to activate the fire to reach the necessary temperature of 1100°C to melt copper was in use much before the Chalcolithic Period. The most simple form of fire which would be capable of generating the required temperature is a simple crucible hearth blown by bellows. Such crucible hearths are being used, to-day, by Loharias—the nomadic metal-working tribe in Western India.
The term Lohar is derived from the Sanskrit words, Loha and Kara. These words when literally translated mean, metallurgist. The Loharias are to-day mainly engaged in small scale iron metallurgy. It is probable, that an unit of Chalcolithic Period copper metallurgical industry was also small, producing a small quantity of the metal at time.

The smelting furnace employed by the Loharias is illustrated in fig. 11. It consists of a clay lined, crucible shaped hollow in the ground with a provision for receiving the air, forced into it, through bellows. The bellows used by the Loharias is made of a skin bag into one end of which is secured a single blast nozzle. The other end of the bag is opened or closed by the manipulation of the hand, in accordance with, whether the bellows are discharging or drawing in air. The artificial draught created by the application of bellows is sufficient enough to raise the temperature of the charcoal fire in the crucible hearth, over 1200°C.

The history of artificial draught created by means of bellows is not well documented. According to Partington the origin of the bellows may be traced to the simple mouth blow pipes. In the metallurgical process of copper and bronze such mouth blow pipes were employed, in ancient Egypt, during the Old Kingdom Period.
FURNACE OF LOHARIAS

Bellows

Ground level

Burning fuel

Smelting charge
The Beni Hasan Picture, dated to the twelfth Dynasty, circa 2000 B.C. to 1780 B.C., shows men blowing the fire in the furnace through tubes held in their mouths.\textsuperscript{14}

However, the Plate L11, published in \textit{The Tomb of Rekh-mi-ri}, Vol. II by Garis\textsuperscript{15}, clearly indicates that by the time of 18th Dynasty in Egypt, circa 1580 B.C., the bowl bellows were used for smelting copper.

The application of similar bowl bellows in copper metallurgy, is also indicated in plate XI, published in \textit{The Tomb of Two Sculptors at Thebes}, by Garis\textsuperscript{16}.

From the foregoing references, it is possible to observe that the use of bellows was quite an ancient practice in Egypt. According to Wainwright\textsuperscript{17}, the use of bellows goes back to the third millennium B.C. in Mesopotamia at Tello.\textsuperscript{17}

Though the remains of Chalcolithic Period copper metallurgy was recovered at Ahar, in the form of metallurgical slags, so far there has been no evidence of Chalcolithic Period metallurgical furnace, in India. A complete structure of furnace with the device for forced draught, would have brought to light, an important aspect of the Chalcolithic Period copper metallurgy.

Nevertheless, the fact that the metal was extracted from chalcopyrite ore and useful objects were produced from the solid metal by melting it and then casting it to the required shapes, \textit{ipso facto}, indicates, that during the
Ghalcolithic Period in India, there were metallurgical furnaces. It is quite probable, as pointed above, that the quantity of metal extracted at a time was small and the furnaces employed were also small.

**Purification of extracted copper during the Chalcolithic Period.**

The smelted copper is termed to-day as raw copper or blister copper. It is about 98% pure. Quantitative chemical analysis of the representative artifacts has indicated that certain specimens of the metal produced during the Chalcolithic Period are also equally pure. But such high purity in the metal could not have been had right after the smelting stage. It is natural to expect the metal to be contaminated with cuprous oxide in that stage as molten copper possesses great avidity towards oxygen.

However, the metallographic examination of the specimens has revealed that only a few of the artifacts were contaminated with cuprous oxide inclusions. And such inclusions were particularly observed around the porosity holes. As has been pointed in Chapter V, these cuprous oxide inclusions could be attributed to poor casting technique rather than to the process of extraction of the metal. The metal produced in the Chalcolithic Period was relatively pure.

Such high purity in the metal indicates purification of the metal after it was extracted. It is quite probable
that the extracted metal was melted in a crucible, within the reducing zone of the fire and was subjected to further reduction by poling. Poling was used to purify the extracted metal from very early times. According to Pliny\textsuperscript{18} Poling was employed by the Roman metallurgists.

Application of poling technique for purifying copper from cuprous oxide is very simple. Conveniently long green wooden poles are forced under the surface of the molten metal and the melt agitated. The parts of the poles which are within the liquid metal while agitating the liquid, get burnt. The volatile carbon compounds produced by the burning of the poles, within the metal, reduce the cuprous oxide present.

Metal melting crucibles in the Chalcolithic Period.

For the purpose of melting copper, a crucible is necessary to hold the molten metal. It is of course of clear that such crucibles were in use even before the Chalcolithic Period. Native copper was melted and cast into small useful objects, during the Neolithic Period.

Prehistoric metal melting crucibles are made of coarse pottery. One such crucible was recovered from one of the Indian Chalcolithic sites, Mohenjodaro.\textsuperscript{19} Gowland\textsuperscript{20} in his "Early Metallurgy of Copper and Tin and Iron in Europe", gives an excellent description of prehistoric metal melting crucibles recovered from the European sites. But Ahar is yet to yield such a crucible.
Nevertheless, with the available evidence, it has been possible to bring to light, in this study, the following aspects of the Chalcolithic Period copper metallurgy:

(1) The slag like material recovered from the Period I levels at Ahar is a copper metallurgical slag. Therefore, Ahar was a Chalcolithic Period copper smelting centre.

(2) The high percentage of silica in the slag, which is more than double of the silica content of the Khetri copper ore sample indicates that, the ore was fluxed with deliberate addition of silica, while it was smelted.

(3) Negligible quantities of sulphur and arsenic in the copper artifacts of the period indicates that the copper ore was thoroughly roasted and smelt. An analytical study of the Mohenjodaro copper artifacts has indicated that some of these specimens recovered from that site constituted as high a percentage of arsenic as 4.42. This high percentage of arsenic in these metal specimens, as an impurity, indicates that the techniques of roasting and smelting of the ore adopted for the extraction of copper employed in these objects was not as advanced as the ones adopted for the extraction of the metal employed in the production of artifacts recovered from Ahar, Navdatoli, Chandoli, Somnath and Langhpaj.

(4) The copper metal produced in the Period was relatively pure. The high purity of the metal indicates the possibility of further purification of the metal after it was extracted.
These aspects of Chalcolithic Period copper metallurgy lead one to observe that the industry was progressing during the Period and the metal workers of the Period were experienced, they were much beyond the experimental stage and in fact possessed advanced technical knowledge in copper metallurgy.
References


