Chapter - III

MATERIALS AND METHODS

Introduction

In the recent past, typological analysis of iron artefacts recovered from Megalithic sites has received much attention. With the discovery of the iron smelting furnace at Naikund using the Three Probe Resistivity, Gogte (1980, 1982) attempted to reconstruct the iron smelting procedure practiced by the Megalithic society and the various mechanisms involved in the smelting process. The chemical composition of the cinders, iron ore lumps and slags were further confirmed through X Ray Diffraction and Mossbauer Spectroscopic analyses, and the efficiency of the iron smelting procedure was also ascertained. Although the evidence of smithery activity in the form of finished artefacts was evident, yet no efforts were made to understand the smithery techniques adopted by the Megalithic iron smiths of Vidarbha. Attempts were made at categorizing the artefacts typologically. Scientific understanding was introduced with the 3-Age System by C. J. Thomsen while categorizing the artefacts according to their technological advancement, and Relative Dating of artefacts was also introduced. However, processualist approach helped to bring out the dynamism in the static material culture and to reconstruct the processes involved in manufacturing the artefacts and the prevalent know-how. This called for application of scientific techniques and theories from the field of Anthropology. The attempts being made to reconstruct the cultural systems and societal orders required material culture to play an important role as they were variables creating transformations in the socio-cultural system (Clarke, 1978).

By the beginning of the Twentieth Century, material culture started to receive increased attention. A few iron implements from some sites were subjected to microscopic analysis to understand the rate of carbon distribution (Park, 2012); microstructure analysis of artefacts made of high-tin bronze (Srinivasan, 1998a,1998b and 2006); metallographic and chemical analyses of copper artefacts (axe from Somnath and knife from Langhnaj) (Hegde, 1991). Similar analyses were carried out in respect of iron objects from Dhatwa (Hegde, 1991) and the iron objects from the

Megalithic levels of Southern India (Mudhol, 1997). However, constructing general societal theories using science would not have much significance unless the influence of social and economical system is also taken into consideration (Hodder and Hudson, 2003). Therefore, the proposed methodology involves scientific analysis, in tandem with an attempt to construct the social traits, through documentation of living megalithic traditions within the same cultural zone, and an ethnographic documentation of the present day non-industrial iron-smiths living in close proximity to the Megalithic sites being studied. These are done with a hope that, to some extent, they may help in understanding the socio-economic dimensions of the society, although one is aware that a great amount of subjectivity creeps in while interpreting the ethnographic data.

This chapter deals with materials used in this analysis (iron implements and utilitarian objects) recovered from various Megalithic Early Iron Age sites of Vidarbha (Maharashtra) that were excavated, and the methods adopted to analyse them. It also generates the necessary data (typology, microstructure and compositional). In order to draw analogies, new methods of research; ethnographic studies have been suitably adapted and applied by taking proper care to cut down subjectivity.

The chapter has been divided into various segments. The first part deals with the general description of the array of iron objects obtained from various excavated Megalithic Early Iron Age sites, the sampling strategy adopted and the reasons for adoption of the specific strategy. The second part of the chapter deals with the variety of methods adopted, such as morphometric analysis, chemical analysis and metallography, followed by ethnographic survey and experimental smithery activity. The last two methods are expected to help in drawing analogies and in attempting to explain the processes adopted by the Megalithic iron smiths and their probable trade nexus.

3.1 Iron Artefact Assemblage

Most Megalithic sites of Vidarbha have brought to light a wide array of iron objects.

Early Iron Age society is marked by a transition from copper to iron. Firstly, the use of copper was limited to objects of decorative purpose like bud finial lid, bird finial lid and horse ornaments. On the other hand, iron was used for making heavy duty tools and other household artefacts like nails. Along with the metal assemblage, ceramics like Black and Red Ware and Black Ware continued from the Chalcolithic period, along with the introduction of Micaceous Red Ware which was chiefly used for mortuary purpose such as sarcophagus and urns. The dominance of iron artefacts proved that the iron technology had gained a prominent position and formed a major component of the Megalithic tool industry. Considering the significant proportion of iron artefacts found, the megalithic society of Vidarbha has been rightly termed as the Early Iron Age Society (Deo, 1985).

The Megalithic sites which have yielded iron objects are Takalghat-Khapa (TKG) (Deo, 1970), Mahurjhari (MHR) (Deo, 1973, IAR: 2001-02 and 2002-03, Mohanty, 2003a, 2003b), Naikund (NKD) (Deo and Jamkhedkar, 1982), Borgaon (BRG) (IAR 1980-81), Khairwada (KRD) (Carey, 1871 and IAR: 1981-82), Bhagimohari (BMR) (IAR: 1982-83 and 1983-84), Raipur Hingna (Deglurkar and Lad, 1992), Dhamna Linga (DMN) (IAR: 2001-02 and 2002-03, Gupta and Kellellu, 2005 and Kellellu, 2015), Dhaulameti (DMT) (Kellellu, 2015), Vyahad (VHD) (Meshram and Kellellu, 2009 and Kellellu, 2015) and Junapani (Rivett Carnac, 1879 and Leshnik, 1970). Along with finished objects, remnants of iron smelting activity were also unearthed from Naikund.

The materials from the Megalithic sites of Vidarbha have been classified under two broad categories by the excavators of the sites:

1. Utilitarian
2. Ritualistic

These utilitarian artefacts were used for regular activities on a daily basis such as for cooking, digging, cutting etc., and have been found in considerable quantity from the habitation levels as well as from the burials as mortuary goods. However, ritualistic artefacts are those which were specifically made for mortuary purpose, and were used only for ritualistic burial. They are miniature forms of the original artefacts, and no wear marks due to use are found on them as they were interred for use after death. They are found only at burial sites. The complete array of artefacts are given in a detailed format in Section 3.1.1 and 3.1.2.

3.1.1: Utilitarian Artefacts

This category of artefacts was further segregated based on typological and functional attributes as explained below: The categories are classified according to their usage:

3.1.1.1: Household Objects

These artefacts were used for regular household activities, such as for cooking and serving food (ladles, iron cauldrons and pans), hanging lamps for worshipping or for performing rituals, and knives for other activities. Nails and rod fragments are also included in this category (Fig: 3.1).

3.1.1.2: Agricultural Implements

Agriculture involves tilling the land, cultivating and harvesting cash crops and food grains, where certain tools are used to achieve specific goals. Tools like axe were probably used for forest clearance; sickle was used for cutting food grains, digging tool and hoe was probably used for tilling the soil (Fig: 3.2).

3.1.1.3: Carpentry Tools

This activity requires wood working and carving. Chisels have been commonly found. However chisel point, borer, drill point, engraver and iron rivet have been found from selected sites, as has been discussed in the fifth chapter (Fig: 3.3).

3.1.1.4: Surgical instruments

Instruments for surgical or operating purposes are specifically designed for special purpose, such as mechanical cutters for making fine cuts on the human skin. Double sided blade tool (Adze/ *Rapi*) and a single blade tool with a pointed end (Nail Parer) have been designated as surgical tools (Fig: 3.4).

3.1.1.5: Fishing Tools and Tackles

The only tool that can be assigned to this activity is the fish hook. However there are variants within the same type, and have been found only from Bhagimohari and Mahurjhari (Fig: 3.5).

3.1.1.6: Horse Ornaments

Certain specific types of artefacts used for riding purpose such as bridle, stirrups and bits have been grouped under this category (Fig: 3.6).

3.1.1.7: Defensive and Offensive Weapons

Certain equipment and resources are specifically fashioned for protection and for attack against unforeseen dangers arising either from animals or humans, and the same objects were probably used for hunting purposes too. Under this category, artefacts like arrowheads, daggers, spears, spearheads, spikes and battle axes can be categorized (Fig: 3.7a & 3.7b).

3.1.1.8: Multi-purpose Tools

These are artefacts used in multiple ways for a number of activities. Within this category, artefacts like rings, wire, knives and pans have been categorized as they could be used in multiple ways.

3.1.1.8: Multi-purpose Tools

The Megalithic society in the Vidarbha region is equated with the birth of iron technology. The early iron smelting and smithery industry is marked by the remains of industrial raw materials and wastes in the form of slag fragments, ore lumps and ingots.

Lamp

Lamp

Pan

Nail

Fig. 3.1: Household Objects

Sickle **Axe**

Digging Tool **Hoe**

Fig. 3.2: Agricultural Objects

Borer **Chisel**

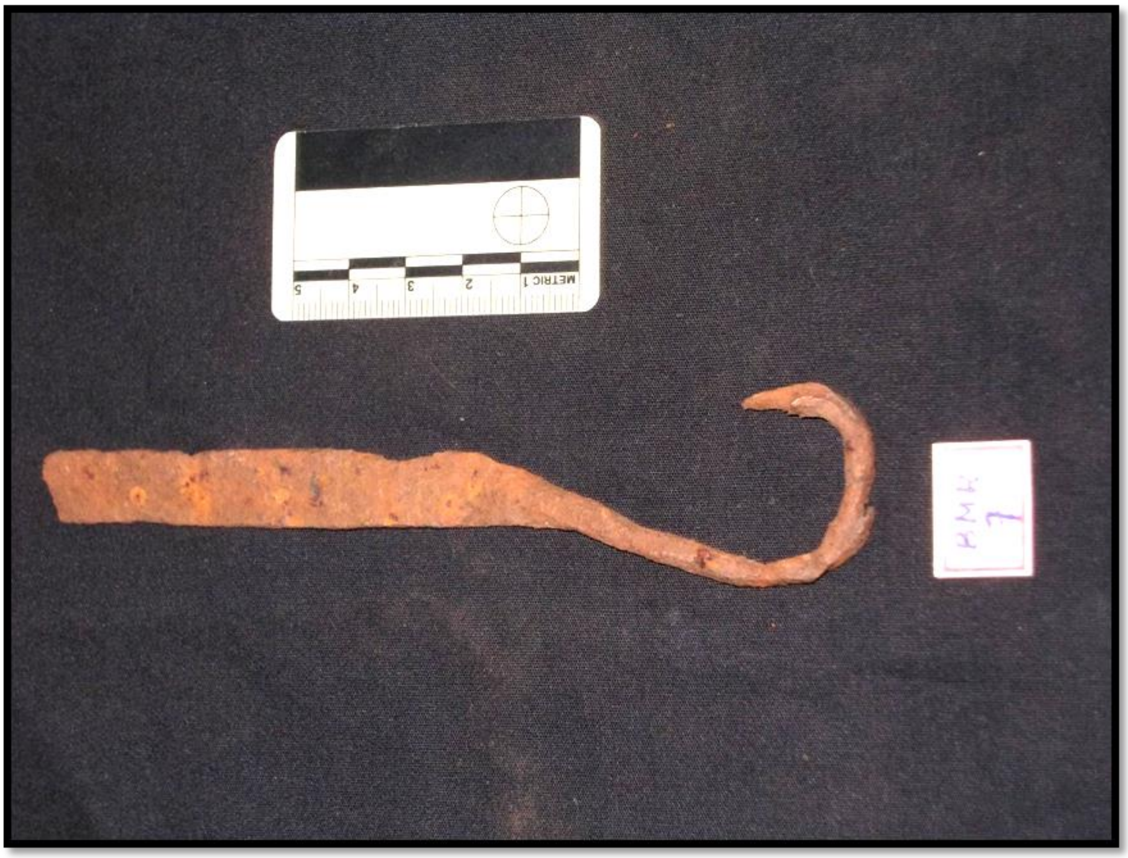
Rivet

Fig. 3.3: Carpentry Tools

Nail Parer

Adze

Fig. 3.4: Surgical Tools



Fish Hook

Fig. 3.5: Fishing Tool

Horse Bit Type 1b

Horse Bit Type 1a

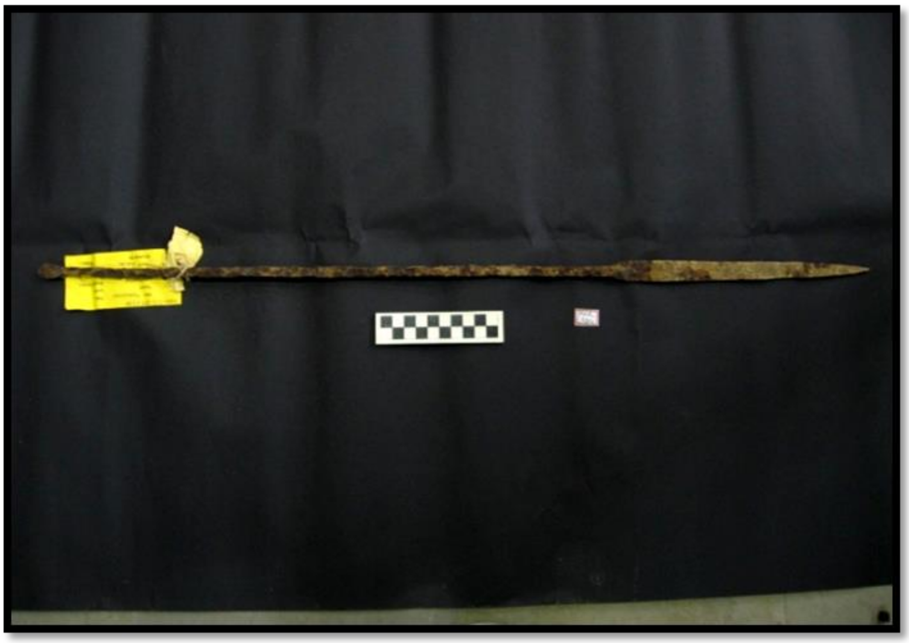
Fig. 3.6: Horse Ornaments

Arrowhead

Spearhead

Fig. 3.7a: Defensive and Offensive Weapons

Dagger



Spike

Fig. 3.7b: Defensive and Offensive Weapons

3.1.2: Ritualistic Artefacts

Objects associated with rituals related to funerary activity have been grouped under this category.

The first chapter has already thrown some light on the megalithic activities of Vidarbha region, along with description of skeletal remains and objects used in daily activities which were interred as funerary objects. The ritualistic objects are symbolized by their shape and size. They were miniature forms of the original objects. Objects classified under this category are:

- Miniature Axe: The artefact (KRD: 6845) has been grouped under this category as its dimensions (L: 38.7 mm x B: 23.3 mm x Tk: 4.12 mm) do not conform to the other axes found
- Miniature Chisel: The chisel found from Bhagimohari (BMR: 68) having the dimensions L: 58.74 mm x B: 4.34 mm x Tk: 1.38 mm has been grouped in this category.

Naikund displays the least variation in the array of finished objects. On the other hand, Vyahad, Mahurjhari and Bhagimohari provide a wide variety in tool typology indicating a variety of workmanship, and reflect all the categories of activities that were undertaken within a megalithic society. The objects from Naikund are heavily corroded and thickly encrusted, making them unsuitable for chemical analysis. However, implements from Vyahad were least affected by nature and show a significant degree of preservation.

3.2 Methods of Study

At the outset, iron artefacts from eight sites were first collected. The well preserved ones were easier to work with, and they were categorized typologically and functionally.

3.2.1: Typological and Functional Analysis

Iron implements found from each site were categorized separately. In the process of categorization, various sub-groups and sub-types were formed. Within the category of 'Utilitarian Objects', a sub-group was formed named as 'Defensive and Offensive Weapons'. Under this sub-group, Daggers form one type, Spikes form another type. This categorization is based not only on the functionality, but the shape and size of the artefacts are also considered. For example, while Spike is a projectile tool, Dagger is a hand held tool. However, tools with multiple functions were grouped under a separate category as a specific use could not be assigned to them. The typological categorization facilitated an estimation of the distribution of tool types.

3.2.2: Quantification and Statistical Analysis

After classifying the objects, each and every artefact, inclusive of the raw materials (ore lumps) and wastes (slag), was manually measured using a digital sliding calipers. A data sheet was made for recording specific parameters:

- Length (so as to estimate the average size of the object which has already undergone changes due to natural and anthropogenic effects)
- Maximum and minimum breadth (estimation of mould size and parameters for standardization)
- Diameter (only for nail parer, ladle, lamp stand, ring and nail)
- Thickness (if cast, it would help to estimate the thickness of the mould used)
- Weight (marker for metallic core preservation)

The statistical analysis of the above data enables quantitative comparison amongst artefacts of the same type but procured from different sites. The outliers found would be the specific marker of an indigenous type from a specific site. For example, the engraver found at the site of Dhaulameti (DMT) would be considered as an indigenous tool type, made specifically for this site by local iron smiths or acquired through trade. As no smithy activity has been reported from DMT, therefore it is probable this tool type was acquired through trade.

3.2.3: Sampling

Samples are units which are selected from a population in such a way that they represent the characteristics of the total population. While sampling, proper care was taken to ensure that they are representative in terms of its relative homogenity, and also that the frequency of sampling covers the entire population. However, while sampling archaeological samples, a degree of randomness comes into play. Certain basic questions like what the population consists of, from which section the sample should be clipped off, how many samples from similar types of artefacts, need to be answered before beginning the sampling procedure. Not all objects can be sampled, as conservation and preservation of artefacts are the main concerns of an archaeologist. Representative artefacts from all the eight sites are not part of the sample body. Dhamna Linga and Dhaulameti iron artefacts were only a part of the morphometric analysis, as samples were not available for chemical and metallographic analysis, since these metallic artefacts fall as antiquities under the Antiquity Act. So, sampling of the artefacts was not allowed as it involves destructive analysis. The iron artefact population from Naikund has not been represented correctly in the sample body. This is because most of the artefacts were eliminated due to their rusted and corroded nature, and had no metallic core which is required for metallographic analysis.

Therefore the samples were chosen on the basis of their state of preservation and whether they were representative. Accordingly, multiple samples from similar types of artefacts, from the total population of 958 iron artefacts from 8 excavated megalithic sites, were selected.

Samples chosen for analysis are:

- 3 samples (KRD-1 and VHD-2) were selected for Wet Chemical Analysis.
- 3 samples (KRD-1 and VHD-2) were selected for XRF Analysis.
- 32 (archaeological samples) were selected for Optical Microscopy, Scanning Electron Microscopy and EDX.
- 6 (ethnographic samples) were selected for Optical Microscopy.

3.2.4: Chemical Analysis

3.2.4.1: Wet Chemical Analysis

The study of past human remains deals with the anthropogenic remains as well as artefactual remains related to societies. Renfrew and Bahn (1996) have defined archaeology as the study of humans who formed themselves into groups and exploited their surroundings for their own needs. The study of the humans includes what they ate, artefacts they made, the socio-political system and their belief system. Inferences about the intangible elements such as the socio-political system and the belief system are based on the tangible material evidences such as structures, pottery, metallic artefacts, faunal and human remains etc. A proper comprehensive understanding of the material remains is better attained by the application of organic as well as inorganic chemistry (Pollard, et.al, 2007). Over the years compositional analysis has gained a strong foothold as an aid in interpretation of archaeological records.

Analytical chemistry deals with quantitative as well as qualitative identification of elements in inorganic as well as organic samples. Earliest use of instrumental chemistry was for answering the question of provenance, which was based on the systematic relationship between the chemical composition of the artefact (most often using trace elements, present less than 0.1% by weight) and the chemical composition of one or more of the raw materials involved in the process of manufacturing (Pollard, et.al, 2007). However, provenance studies on metallic artefacts have become redundant. Metallic objects survive over a considerable period of time and can be transported easily or can be melted and reused for casting. Before the development of instrumental chemistry, gravimetric and volumetric method was used for analyzing archaeological objects.

Gravimetry is the method of determining an element through the measurement of the weight of the insoluble product of a chemical reaction involving that element. This was the chief tool of quantitative analysis until the development of instrumental chemistry till the early twentieth century (Pollard, et.al, 2007). This method is the most accurate method of calculating components, although the process is time consuming and requires a sizeable amount of the sample. For example, Martin Heinrich Klaproth (1743-1817) gravemetricaly analysed and provided an approximate composition of six Greek and nine Roman copper alloy coins, a number of other metal objects and a few pieces of Roman glass (Martin Heinrich Klaproth's Beiträge zur chemischen Kenntniss der Mineralkörper as cited in Pollard, et.al, 2007).

The principle on which the analysis is based is the transformation of the element or radical to be determined is converted into an insoluble precipitate which is suitable for weighing (Jefferey, et. al, 1989), and then by applying the method of mole value calculation, the weight of the element or radical is calculated by using the formulae of the compound and the atomic weights of the constituent elements. This method was specifically used for analyzing the iron content of the selected samples.

Determination of Iron:

First a fragment weighing about 60 gms was finely ground to 200 mesh size i.e. the particle size is 75µm / 0.075 mm. Then the finely powdered sample was dissolved in concentrated hydrochloric acid, adding a few drops of concentrated Nitric Acid. To enhance the reaction it was heated for a few minutes. After completely dissolving the powdered sample, excess dilute Hydrochloric Acid was added to the solution and evaporated to dryness, leaving behind a solid residue. This residue was again dissolved in dilute Hydrochloric acid and heated for 15 minutes. Then the solution was filtered through Whatmann 41 filter paper, transferred to a volumetric flask and the volume increased to 250 ml. by adding distilled water.

25 ml, of the above solution was filtered out in a 500 ml, conical flask and 25 c.c. of concentrated Hydrochloric acid was added. The Fe^{3+} was reduced to Fe^{2+} by using aluminium foil. The solution was diluted with water to 100 ml, to adjust the pH at 2(N) acidity. Now 5 ml, H3Po4 and 4.5 drops of Barium Dyphenyl Sulphonate (B.D.S) indicator was added to it. The solution was then titrated with standard (N/20) $K_2Cr_2O_7$ (Potassium Dichromate) until the colour changed from green to violet. This titre value corresponds to total iron (Fe^{2+} + Fe^{3+}) and the difference (V_2-V_1) gives the amount of Fe^{3+} (Indian Standard Methods of Chemical Analysis of Iron Ores, 1996).

3.2.4.2: Energy Dispersive X-Ray Spectrometry

Energy Dispersive X-Ray Spectrometry (EDS) is a powerful analytical tool for identifying elements. By performing EDS we can calculate the concentration of that element based on the amount of X-Ray. It involves an electron probe which bombards a solid metallographic sample with a beam of high energy electrons, which in turn produces an X- Ray spectrum. Scanning Electron Microscope (SEM) also uses electron probe for producing electron images and it is also used for EDS analysis by coupling it with a X-Ray spectrometer. The advantage of this (SEM and EDS) is that one has the freedom to choose a particular area to be analysed (Reed, 2005).

3.2.4.2.1 Sample Preparation for EDS

First the specimen is prepared for SEM. However it has to be ensured that the sample is vacuum compatible. Then the samples are made electrically conducting by giving a surface coat of vacuum evaporated carbon, as the coated carbon is not detected by the X-Ray spectrum. When a sample is prepared only for SEM, gold coating is usually used. The EDS instrument is coupled with a detector and an amplifier. Liquid nitrogen is let into the chamber for cooling of the detector and the amplifier, and also to minimize the electronic noise (Reed, 2005).

3.2.4.3: X–Ray Fluorescence (XRF)

This method is used for the analysis of elemental composition of the artefact. XRF can detect a wide range of elements from trace composition to pure elements. The powdered sample is irradiated with a beam of X-Rays, which excite the electrons in the lower energy bands of atoms which cause them to be ejected. The electrons from a higher energy band enter the lower energy band to take the position of the ejected electron. In this process a certain amount of energy is released. The wavelength of this energy is a characteristic property of each element. The percentage of the element present in the sample is done by measuring the intensity of the particular elements wavelength. So the intensity of the peaks gives us the percentage of the concentration of that element (Haschke, 2014).

3.2.4.3.1: Sample Preparation for XRF

Usually the powdered specimens are used when the original object is heterogeneous in nature and the top layer of the surface is corroded and cannot be converted to a flat inclusion free surface.

A fragment of the sample is crushed to a particle size less than 60 μm. This is achieved by manual grinding using mortar and pestle. The grounded powder is placed in the powder holder that is inserted directly into the specimen chamber of the machine (Injuk, et.al, 2006).

3.2.5: Metallographic Analysis

Metallography is the primary method of examination of metallic objects. It is the study of the structural characteristics of a single phased metal or multi-phased alloy. It aids in the determination of grain size and non-metallic inclusions. Microstructural analysis also reveals the mechanical and thermal treatments given to the artefact (Avner, 1974). However to get a clear microstructure, great care has to be taken in the preparation of the specimens. The main aim of a metallographic sample preparation is to obtain a flat scratch–free, mirror-like surface. To prepare such a sample we have manuals by Indian Standard Institutions and books on physical metallurgy by Avner (1974). There are manuals for metallographic analysis of ancient metal artefacts by Scott (1991) which provide the necessary guidelines.

3.2.5.1 Sample Preparation

First the specimen for metallographic examination needs to be selected. For instance, in case of ancient materials, a corrosion-free surface is chosen. As far as ancient samples are concerned, microscopic examination will generally determine the treatments given to the metal while shaping the tool / object. Its chemical composition would lead to understanding of the provenance of the metal.

3.2.5.1.1: Sampling for Metallographic Studies

The objective of the investigation decides the sampling strategy. If the sample in question is a casting specimen, then a sample perpendicular to the surface will have to be chosen as its microstructure will show variations in structure from the outer core to the inner core.

However hot-worked or cold-worked specimens need to be studied using both transverse and longitudinal specimens (Fig: 3.8). The transverse sections reveal information about structural variation, non-metallic inclusion, degree of corrosion etc, while longitudinal sections show variations due to heat treatment and deformation in grain boundaries (ASTM, 2009).

3.2.5.1.2: Size of Sample

According to the norms, specimens to be polished for metallographic examination should not be more than 12-25 mm. (0.5-1.0 in) in size if it's a square specimen. If it is cylindrical, then it should be 12-25 mm. in diameter (Fig: 4.9). The dimensions of the specimens have to be within specified limits as the specimen holders have a specific size in both the optical and scanning electron microscopes (ASTM, 2009).

3.2.5.1.3: Mounting of Sample

Specimens which are fragile, or too small to handle and oddly shaped, are difficult to handle during the process of polishing. Therefore they should be mounted to ensure a surface agreeable for micro-structural study. Mounting can be done by two processes either mechanical mounting or plastic mounting. Sheet or strip specimens are generally mechanically mounted by inserting clamps. However plastic mounting is a more commonly used method. Within this method, we have two variants, i.e. compression mounting and castable plastic mounting (ASTM, 2009).

Compression mounting requires the use of a mounting press which operates at around 140°c - 180°c. The samples are thermo set. However samples for archaeo-metallurgical studies are usually mounted using castable plastic, and are prepared at room temperature. The moulds used are cut portions of PVC pipes of 2 cm. diameter and 2 cm. in height.

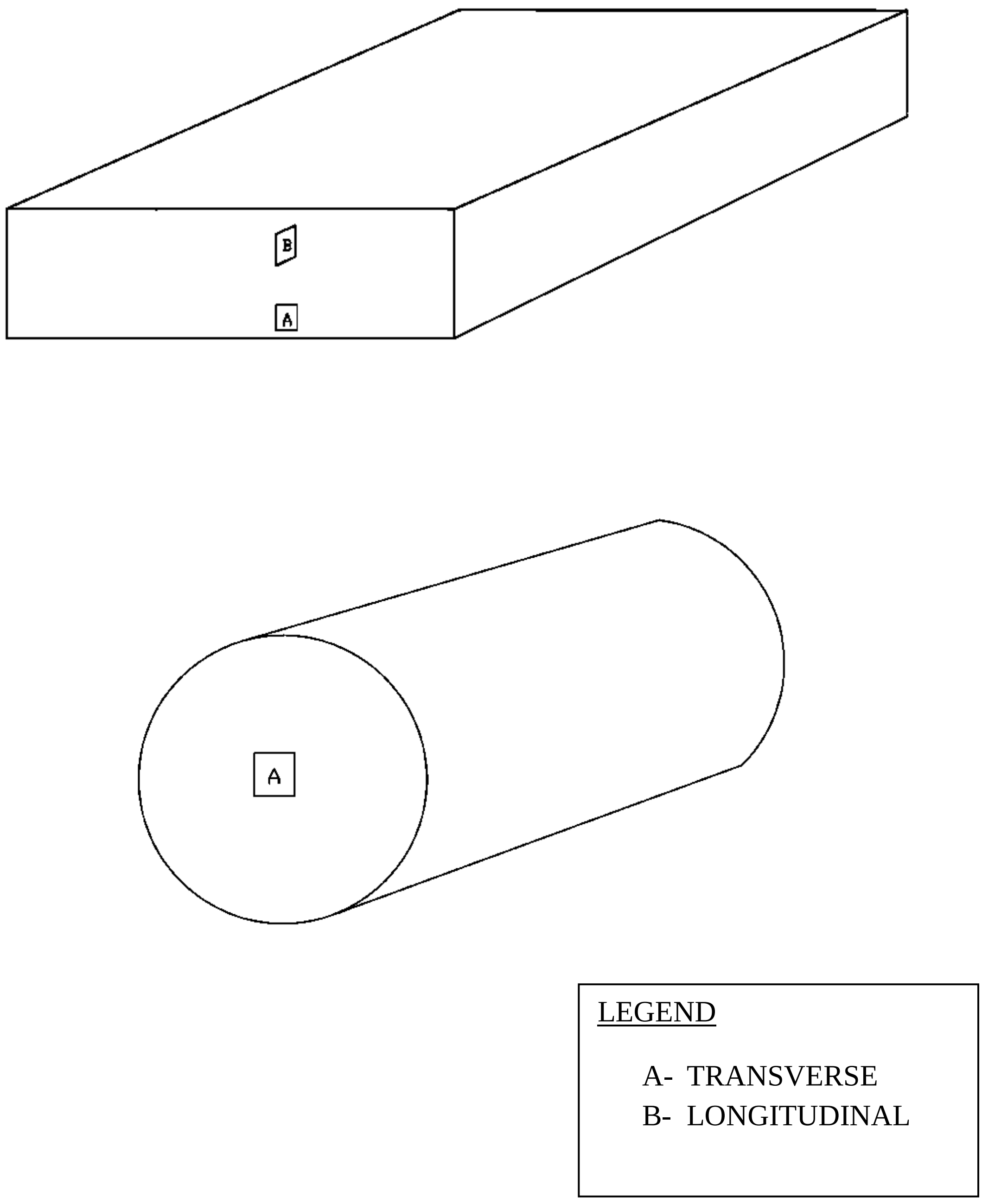


Fig 3.8: Diagram Showing Transverse and Longitudinal Sampling Areas.

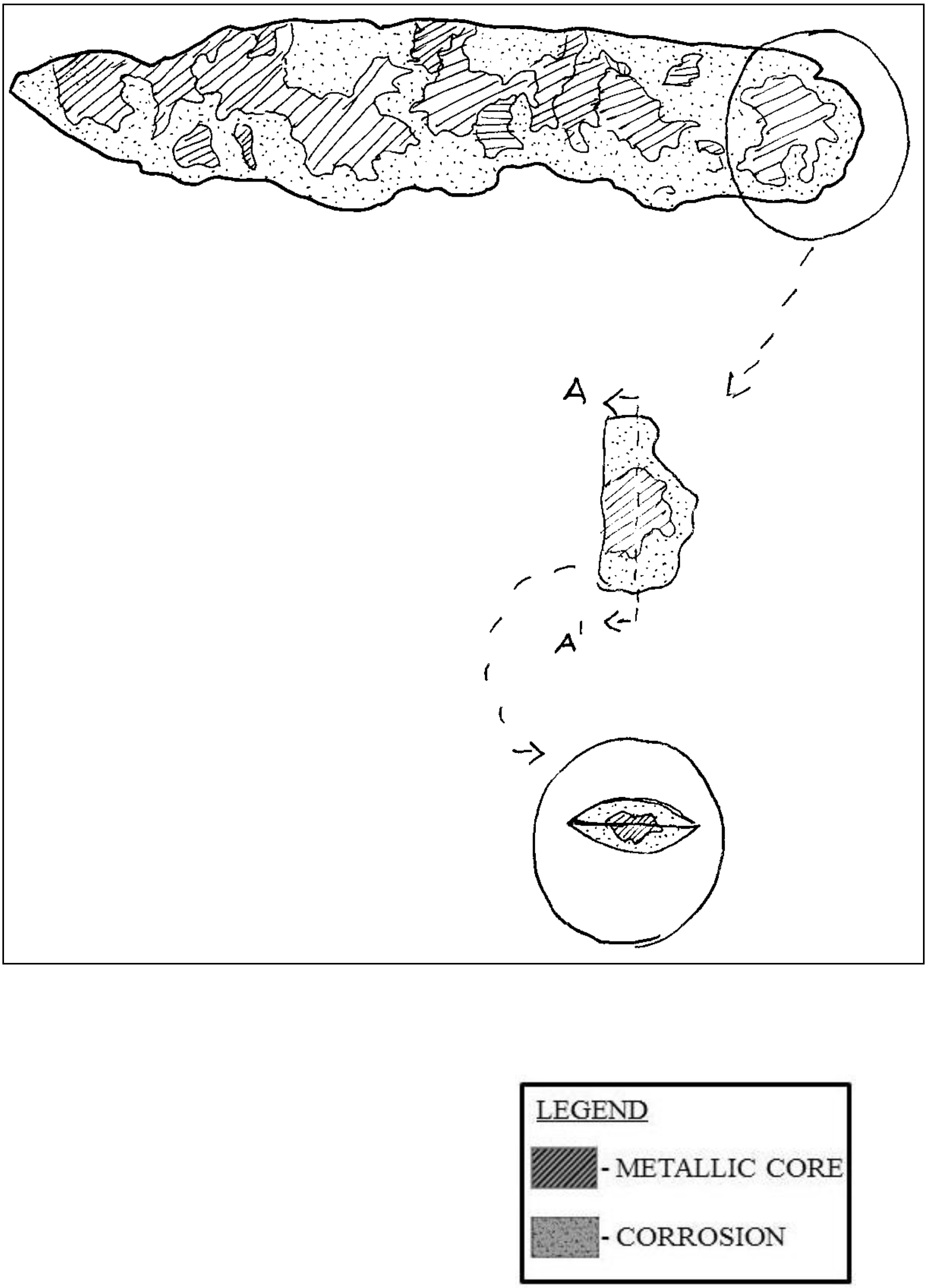


Fig. 3.9: Diagram Showing Sampled Specimen to be Later Plastic Mounted

3.2.5.1.3.1: Stages of Mounting

1. First a 2 cm. diameter PVC pipe is cut into 2 cm. sections.

2. The cut specimen is placed in the middle of the pipe holder.

3. Then the compound DPI–RR cold cure, which is in powder form, is added to the cast, acrylic repair material, which is resin, is added drop by drop to the cast.

4. The mounted specimen is then allowed to set for a period of 12-24 hrs (Fig: 3.10).

3.2.5.1.4: Rough Grinding

The aim of this procedure is to ensure that the end product has a flat semi-polished surface. To attain this result, the mounted sample is polished on a motor-driven belt polisher (Fig: 3.11).The process is repeated till a flat surface is achieved. The specimen has to be dipped in water at regular intervals so as to cool the surface and prevent any thermal effect (Indian Standards Institution, 1985).

3.2.5.1.5: Fine Grinding

After a flat surface is attained, fine grinding is done so as to remove the damage to the surface during rough grinding. During this process the sample is ground on a series of abrasive emery paper of different grit size (3, 2, 1, 0.1/0, 2/0, 3/0, 4/0). While grinding, the sample should be moved back and forth at a regular pace to ensure even grinding. While changing the emery paper, the sample should be rotated by 45°-90° so as to remove the preceding grinding marks (ASTM, 2009).

3.2.5.1.6: Polishing

Polishing is the final stage of sample preparation. It is done by manually holding the sample against a rotating wheel covered with velvet cloth and abrasive material which is 1μm diamond powder (Fig: 3.12). The mounted sample is moved in a circular path around the wheel but opposite to the direction of the wheel movement (ASTM, 2009 and Indian Standards Institution, 1985) (Fig: 3.13). After fine polishing the sample attains mirror-like polish which is essential for good microscopic studies.

3.2.5.1.7: Etching

Polished surfaces do not reveal the entire microstructure, such as grain boundaries and different phases. To reveal such features, the polished metal surface is treated with a chemical reagent which in this case, is Nital (100 ml. Ethanol (C_2H_5OH) + 2 ml Nitric Acid (HNO_3)). This process is known as etching (Scott, 1991).

Nital is applied on the polished surface of the sample using cotton. Then the sample is washed in running water so as to remove any extra reagent and avoid over-etching, and then dried using a hair dryer.

It is important that the sample is immediately examined under a reflected light system of the polarizing microscope, as etched samples get rapidly tarnished when comes in contact with air. This makes it difficult to view the microstructure.

Fig. 3.10: Plastic Mounted Specimen Ready for Microscopic Viewing

Fig. 3.11: Belt Polisher used for Rough Grinding

Fig. 3.12: Wheel Polisher Used for Fine Polishing

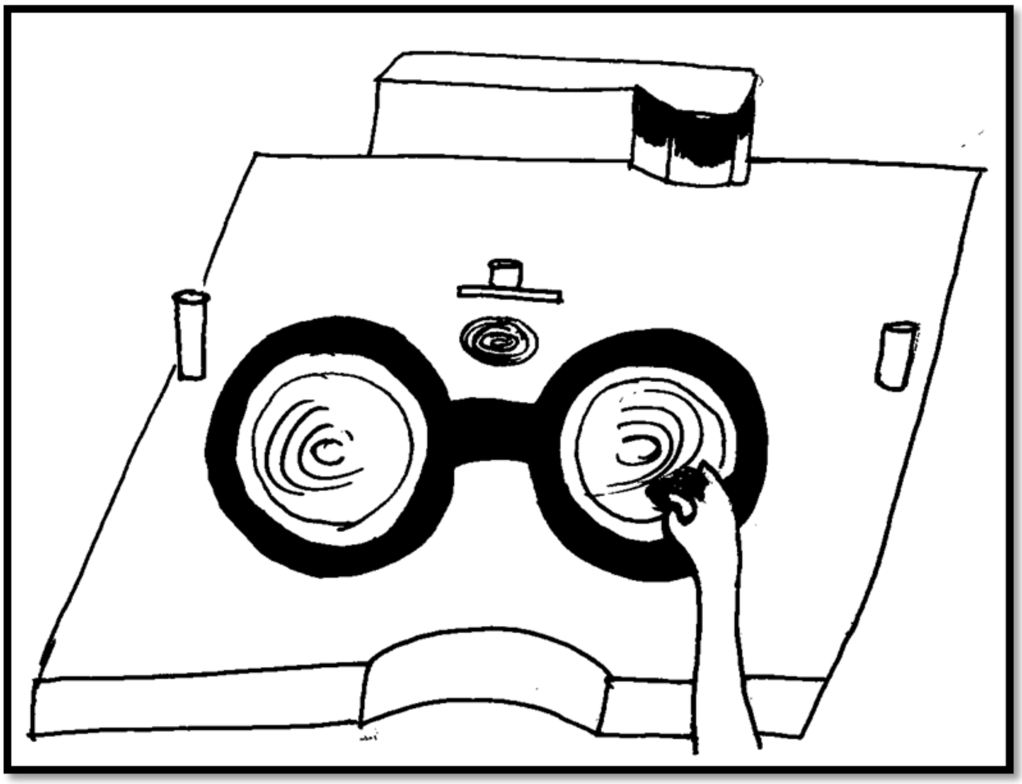


Fig. 3.13: Diagram Showing the Process of Fine Polishing used Diamond Paste

3.2.5.2: Mechanism of Reflected Light Optical Microscopy

An optical light microscope aids in determination of the structural phase present in a material and also in determining the carbon content in a ferrous sample. The viewing of the microstructures is generally done in two stages, firstly before etching the sample and later after etching. The mechanism of reflected light microscopy is based on the combination of various lenses which involves the laws of reflection and the details of the microstructure are revealed.

A metallurgical microscope brightens up the prepared sample with reflected light rays. The light sources used vary in microscopes. Reflected light microscopes, which are used only for viewing and not photo-micrography, use a medium intensity, low-voltage tungsten filament lamp. Earlier carbon arc was used which a high intensity arc was set up between vertical and horizontal carbon electrodes. The high light intensity provides enough brightness for microscopic examination such as phase-contrast. However the use of this light has become obsolete. The commonly used lighting are Quartz-iodine lamp and Zirconium arc lamps, both of which have high intensity and the light spectrum is acceptable for colour photo micrography (Vander Voort, 2007).

The illumination source is connected to a condenser system which comprises an adjustable lens, field diaphragm and an iris diaphragm. The field diaphragm aids in adjusting the image contrast, the contrast is further adjusted and the sharpness of the image is adjusted by reducing or increasing the aperture of the iris diaphragm. The image of the specimen is formed at the objective lens. Subsequently, the eye piece magnifies the image formed by the objective lens. Finally we have the mounting stage, where the mounted samples are placed for focusing and the stage has a X, Y calibrated scale for measuring the features (Vander Voort, 2007) (Fig: 3.14).

However there are limitations in using the optical microscope. The resolution of the photo micrograph and the depth of the field are limited.

3.2.5.3: Mechanism of Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) is used for inspecting the structural features of specimens at very high magnifications (Fig: 3.15). SEM magnifications can go as high as 300,000 times.

During SEM analysis, a deflection coil system scans the sample using the electron probe in synchronism to the electron beam of a separate Cathode-Ray Tube (CRT). The intensity of the CRT formed by the dislodged secondary electrons (electron scattering process) of the specimen itself is recorded to form an image (Reimer, 1998)

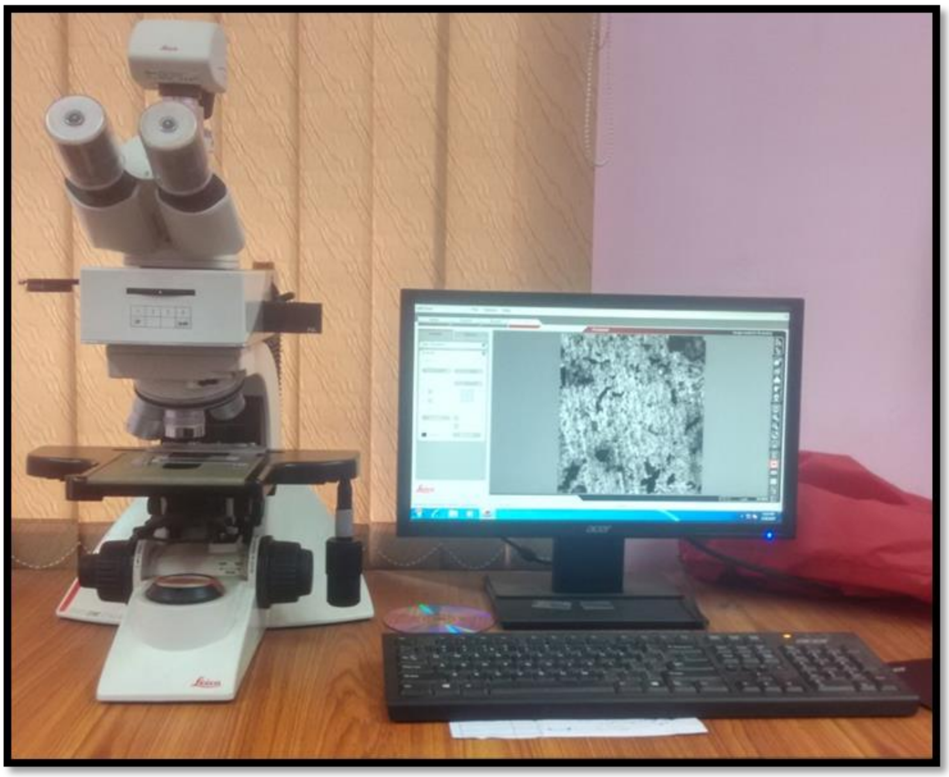


Fig. 3.14 : Optical Microscope Used for Microscopic Studies

Fig. 3.15: Scanning Electron Microscope Coupled with Energy Dispersive X-Ray Spectrometry

3.2.6: Ethnographic Survey

This method of study was developed with the introduction of Middle Range Theory in the field of anthropological research, and was first used to interpret past lifeways by Lewis Binford (1978). This mode of analysis is used to determine the patterns of distribution of archaeological records and the relationship between the maker of the artefact and the artefact themselves. Ethno-archaeology is the study of living societies to aid in the understanding and interpreting of similar archaeological remains. Lee (1979) brought to light the importance of observing ethnic groups such as San of South Africa's Kalahari dessert and Australian aborigines and then drawing analogies to understand past lifeways of pre-historic societies. An ethnographic approach to archaeological data is necessary and allows the observations of a contemporary society to be used as analogies for interpreting earlier societies (Yellen, 1977). However analogies drawn need not be direct relates, as there is no method of proving the present ethnic society is a direct descendant of the pre-historic society that is being studied. Therefore care should be taken while adopting the ethnographic approach.

Ethnographic surveys in the Indian sub-continent were extensively undertaken by government officials during the colonial rule. Verrier Elwin (1942) documented the iron smelting tradition of the *Agaria* tribe. Russell and Hiralal (1916) have recorded the *Lohar* community residing in the Vidarbha region. Agaria's were distinguished by their smelting activity; however Lohars never practiced iron-smelting.

The present study required an ethnographic survey to record the non-industrial iron smithy techniques; keeping this in mind an ethnographic survey of the Lohar community residing in the Nagpur and Gadchiroli was undertaken. Present day traditions, beliefs and rituals were recorded to draw analogies for the early iron producing community of Vidarbha.

Similar survey was also carried out to understand the living megalithic tradition and its symbolism in societal stratification. The Gond settlements in Repanpalli, Bejurpalli and Bhamragadh districts of Gadchiroli were selected for study. The tribe lives in the forested tracts and their main occupation is brewing toddy (country liquor). However each settlement has a Gondi Lohar who is engaged in smithy activity, mainly comprising tools made from metal using the process of remelting. The funerary rites of this tribe were of significance for this study as they still erect menhirs and dolmens for their dead kin. The process of erection of the menhirs and dolmens, and the different rites conducted before the erection of the funerary monument were of major interest. This survey proved to be a major tool in understanding the architectural variations amongst the megaliths and its probable social connotations.

3.2.7: Experimental Approach

For carrying out the ethnographic survey, the lohars, who were located on the vicinity of the megalithic sites, were interviewed regarding the raw materials used by them. However the methods adopted by them for making artefacts similar to those found from the megalithic context were recorded from two workshops (UBL-1 and UBL-2) from the village Ubali. This approach is expected to help understand the smithery activity by the non-industrial blacksmiths of Vidarbha region.

Similar experimental approach has been adopted by Srinivasan (1998a,1998b,2006) in understanding the activities of high tin bronze workers in the Megalithic context of Tamil Nadu based on high tin bronze makers of Kerala. Merkel (1983) had also adopted a similar approach in understanding the copper smelting techniques at the Late Bronze Age site of Timna (Israel) where the furnace was recreated and the smelting process was recorded.

In undertaking the present study, the Lohars were instructed to make adze, axe and nail parer. To facilitate the understanding of the structure and shape of the artefacts, sketches of the artefacts were drawn and the desired features were explained, such as, the end that needed to be sharpened and the gripping end that had to be blunt. Then the process adopted by the Lohars for making each artefact was recorded. This approach firstly aids in understanding the technological processes secondly microscopic analysis of these products aids in co-relating with the archaeological artefacts. The data generated through these experimental objects can be used as cross reference data for archaeological iron samples.

Based on these methods adopted the above mentioned materials were subjected to analysis. The results have been discussed in chapter 4