Metallurgy and Archaeology: A case study on iron objects from the megalithic sites in Nagpur, India

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1. Introduction

Bronze and iron objects are among the most important archaeological materials bearing crucial information on the role of an ancient region or community in the creation and transmission of cultural ideas and practices. The production of bronze and iron involves a series of engineering processes including the smelting of raw materials from ores, and the making of alloys and various thermo-mechanical treatments applied in fabrication. Each of these individual processes can be achieved in a number of different ways depending on technological and sociopolitical environments. These processes can be combined to establish a unique technological tradition that reflects temporal and regional characteristics. The individual engineering processes and their combination in space and time can only be traced through the application of strictly scientific methodologies developed in metallurgy. This fact emphasizes the importance of metallurgy in archaeological investigations to the general understanding of ancient communities.

The early iron technology based on bloomery smelting was presumably invented in the West and diffused toward the East while another technology based on cast iron originated from the East and made its way to the West (Maddin 1996; Needham 1980; Rostoker and Bronson 1980; Tylecote 1992; Wagner 1996). The data currently available on bronze technology also demonstrate the existence of spatiotemporal variations in alloy making as well as in fabrication techniques (Barnard 1961; Chernykh and Kuzminykh 1989; Park et al. 2011). In spite of the importance of bronze and iron artifacts as a potential means for exploring the history of ancient India, not much is known of the regional technological status relating to their production, let alone the role of India in the creation and diffusion of the related technologies. With this problem in mind, this article will focus on some Indian iron objects and illustrate the nature of data attainable from metallurgical investigations and their interpretation.

It is interesting to note that some of the most important iron objects from the megalithic sites at the Nagpur district in Maharashtra, India were made in unique shapes reminiscent of those excavated in the southern part of the Korean peninsula. Despite the substantial distance in geography and chronology, the similarity in their typology leads one to suspect the particular iron objects as suggestive of an ancient interaction between the two regions that has yet to be discovered.

The Korean counterpart includes a special family of iron artifacts in the form of narrow plates with a fan-shaped blade on one or both ends. Those with a blade only on one end, basically axes, have generally been recovered from earlier sites than those with blades on both ends. It is generally accepted that the latter evolved from the former with certain modifications in shape, and eventually replaced the former. These plate-type objects have continuously been recovered from sites of the first century BC (Yi et al. 1989) and onwards, primarily in the former Gaya and Silla territories located near the southern coastal area of the Korean peninsula. Given their frequency, abundance and the substantial variation in their shape and size, they must have represented the iron industry of the two kingdoms. They were made of low carbon iron, frequently with slag inclusions spread in ferrite backgrounds. Some of them were given a carburization treatment on both ends. This would allow them to meet a wide range of consumer needs at the time as effective intermediaries yet to be shaped into edged or pointed objects, with minimal forging and thermal treatments. This plate-type object could best be produced directly from bloom iron though it could also be made indirectly from treating cast iron.

A collaborative research project has been launched to find evidence, if any, for the possible exchange of specific technological ideas that may have been responsible for the appearance of typologically similar artifacts in India and Korea. As an initial step to this end, some of the iron objects excavated from the megalithic sites at Nagpur, which are currently stored in the Deccan College, were examined for their microstructures and chemical compositions. During the selection of objects to be examined, it was immediately evident that the sites had also produced numerous copper-based objects. Evidently, the bronze metallurgy must have played a crucial role in the megalithic communities and provides another topic of significance to be probed in the future for the understanding of their cultures.

A number of iron and bronze objects from the Indian megalithic sites are currently under careful examination using metallurgical techniques to characterize the associated technologies in terms of smelting, alloy making and various thermo-mechanical treatments done in fabrication. Some of the preliminary results thus far obtained from the iron objects will be presented in this article, with a special emphasis placed on identifying specific technologies practiced at the sites, which will then be compared and contrasted with those practiced in ancient Korea.

2. Experiments

Small metallographic specimens taken from the selected iron objects were mounted and polished following standard metallographic procedures. The specimens were then etched with a solution of 2 volume % nitric acid in methanol for the examination of their microstructures using an optical microscope and a scanning electron microscope (SEM). The alloy composition was measured using the energy dispersive x-ray spectrometer (EDS) included with the SEM instrument and reported in weight fraction.

3. Results

Figure 1a and 1b present the general appearance of two axes recovered from the megalithic burial sites at Khairwada and Mahurjhari, respectively, in the Maharashtra province of India. Arrows a, b and c shown in both axes locate the respective spots at the blade, flak and rear from which specimens were taken for metallographic examination. Figure 1c-1h are optical micrographs illustrating various structures at different parts. The micrographs are placed in the column below the axe they represent and Figure 1c, 1e and 1g and Figure 1d, 1f and 1h present the structures at the blade, flank and rear of the associated artifact, respectively. The dark rhombuses in the micrographs are the result of the Vickers Hardness measurements made using a 500 g load. The hardness of each specimen is specified by the numbers given near the rhombuses. The substantial difference observed in hardness is associated with the varying microstructures determined by the carbon levels of the specimens and the thermal treatments applied in fabrication. In both axes, the specimens from the flank, represented by Figure 1e and 1f, consist of relatively soft ferrite grains whose carbon content is negligible. The blade and rear, however, contain microstructures that are much harder than ferrite and attainable only in high carbon steels. It is to be noted that Figure 2c-2h all contain non-metallic inclusions spread over the metal background.

Figure 2a-2d present SEM micrographs providing a highly magnified view of the high carbon structures shown in Figure 1c, 1d, 1g and 1e, respectively. Figure 2a and 2b are similar in that they consist primarily of pearlite structures containing 0.77% carbon. The structure in Figure 2a from the blade, however, contains tiny particles of cementite spread over the pearlite background whose inter-lamellar spacing is much finer than that in Figure 2b from the rear. By contrast, the high carbon structures shown in Figure 2c and 2d from the other axe contain evidence of special thermal treatments that were applied during fabrication. The structure in Figure 2c from the blade is morphologically similar to the martensite phase that forms upon quenching. However, the Vickers hardness value Hv=438, as determined by the size of the rhombuses in Figure 1d, is substantially lower than those normally obtained in fresh martensite of a comparable carbon level. This lower hardness implies that the specimen was tempered following a quenching treatment in an effort to reduce brittleness at the expense of hardness. Figure 2d from the rear consists of the cementite phase precipitated in the form of networks against the ferrite background. This peculiar structure, which does not develop in the normal eutectoid phase transformation, demonstrates that the specimen was given an excessive tempering treatment subsequent to quenching. As a result, the hardness measured in Figure 1h (Hv=258-296) is much lower than that in Figure 1d.

Figure 3a and 3b present iron objects recovered from the megalithic site at Khairwada. They are in the form of a thin plate that is much longer than it is wide. They are of uneven width, which increases to either end giving the impression of a blade. The point of minimum width is positioned near one end that is much smaller than the other. This shape does not suggest any specific functional purposes. They were recovered from the majority of the megalithic sites excavated in Nagpur, frequently in larger quantities than any other items, and may have played an important role in the local iron industry. Figure 3c-3h, optical micrographs, are arranged in a similar manner to those in Figure 2. Figure 3c, 3e and 3g and Figure 3d, 3f and 3h illustrate the microstructures at the front blade, flank and rear blade of the object in Figure 3a and 3b, respectively. The micrographs from the object in Figure 3a all consist of ferrite grains with some non-metallic inclusions elongated along the forging planes, indicating that the artifact was forged out of almost pure iron. However, the specimens from the other artifact are shown in Figure 3d, 3f and 3h to have been made of high carbon steel whose carbon level is near eutectoid, i.e., 0.77%. The specimen from the blade of this object is severely corroded and intact structures are found only at the narrow band running diagonally from the upper left corner of Figure 3b. The structure in this band consists mostly of pearlite with a little ferrite precipitated at the grain boundaries, suggesting that the original structure was more or less similar to that in Figure 3f. The absence of ferrite in Figure 3h implies that the carbon concentration in this specimen is a little higher than the others. Non-metallic inclusions are also found present in this object, particularly in Figure 3f.

4. Discussion

In both functional and technological aspects, axes such as those shown in Figure 1a and 1b constitute a typical member of the group including various edged and pointed objects and may best represent the general iron tradition established in an ancient community. The microstructure data of the axes examined show that the specimens from their flank consist mostly of ferrite while those from their blade and rear end are filled with the phases observed in high carbon steel. The dominance of the ferrite phase in their flank suggests that the axes were made primarily of low carbon iron. The increased carbon level in the other specimens suggests a special treatment that was intended for functional purposes. Though it is not clear at the moment how the carbon level was adjusted, it was likely achieved either by the carburization treatment directed at the specific parts or by joining a steel strip where required. In any case, the technology involved in their manufacture can be divided into two stages including the production of the raw material, which is low carbon iron, and the control of carbon concentrations, termed steelmaking in modern terminology. Specifically in India where there was no large-scale production of cast iron until quite recently, low carbon iron readily available in the megalithic communities must have been the product of bloomery smelting. Then the best technique for steelmaking, i.e., raising the carbon level is carburization in which pieces of iron are heated for a prolonged period inside a burning charcoal environment to induce carbon penetration from the surface. The iron tradition in the megalithic sites under consideration may therefore be characterized by the use of a bloomery process in smelting and carburization in steelmaking. The level of technological sophistication achieved by the local ironworkers is clearly evident in one of the axes where quenching followed by tempering was applied. This cannot be done without the complete understanding of the material properties as determined by the complicated phase transformations that are induced through the fine adjustment of treating time and temperature.

In bloomery smelting, forging has to be applied near the end of the process for the removal of slag inclusions, and the final product naturally takes on the form of a plate. Therefore, if no restriction is imposed on the carbon contents, plate-type objects similar to those in Figure 3a and 3b can readily be manufactured directly out of the smelting process itself. The presence of elongated non-metallic inclusions in most specimens from the two objects is a clear indication of the forging given for the dual purpose, i.e., the removal of slag and the shaping of the objects. In view of the carbon levels that are generally very low in bloomery iron, the high carbon structures observed consistently in all the specimens from one of the plates indicate that it was subsequently treated in a steelmaking process based on carburization. The unique shape and size of the present objects were probably determined by taking into account the conditions imposed in manufacture and use such as the furnace configurations in carburization, treating time and temperatures, and the ease with which they were handled in fabrication, transportation and actual service. For instance, if an iron plate is to be carburized in a furnace set at 1,000°C within a working day to the same extent as found in the object examined, its thickness should be on the order of 1 mm.

Although no specific usage is suggested in their appearance, the plate objects examined hold in their unique shape and microstructure crucial information on the infrastructure of the local iron industry. It is certain that both were initially forged out of low carbon bloomery iron. Their peculiar shape suggests that they were not a final product but served as intermediaries for an engineering process yet to be performed. One of them consisting of high carbon phases indicates that they were used as a feedstock in a carburization treatment. No iron tradition can be established without an effective means for steelmaking. In this respect, the plate-type objects examined must have played a crucial role in the successful establishment of the Indian megalithic iron tradition by serving as a component of the particular steelmaking process through carburization. In theory carburization can be applied to objects of any shape and size. In practice, however, it could be a complicated and costly procedure without the proper facilities and technical skills. In general, steel is needed only at a critical part such as edges and points, as is exemplified in the two axes in Figure 1a and 1b. There are two choices that can be made when an increased carbon level is required only on a limited part of an object. In one case, carburization treatment is directed at the specific part after the object has been finished shaping. In another case, small pieces of steel are first prepared and then attached to the main body at the critical location. The iron plates shown in Figure 3a and 3b correspond evidently to the latter case. One such plate can be used in making a number of edged or pointed objects such as axes, chisels, adzes, awls, nails and arrowheads if properly cut horizontally, vertically or both. As such, the production and circulation of these plates in the Indian megalithic communities must have given much freedom to the ironworkers. It is expected that they allowed the suppliers to specialize in fewer items while the consumers enjoyed the freedom to meet their varying needs with a minimum work and technological requirements.

In his recent paper, Park showed that the ancient iron industry of Korea, particularly in the southern part of the peninsula, was established based on the production and circulation of special plate-type iron objects. In earlier times, they were made in the form of axes just like those shown in Figure 1a and 1b. With the passage of time, their shape changed to that of a thin rectangular plate with a fan-shaped blade attached on either end. These objects are remarkably similar to those presented in Figure 3a and 3b in their role as versatile intermediaries that can be used to make a variety of edged and pointed functional objects and thereby meet a wide range of consumer needs. In addition, they were both forged out of low carbon iron and their fanned-ends were often carburized. Despite the differences found in their exact shape and the extent of carburization, it is difficult to deny the possibility that they were somehow related. The recent evidence presented for the practice of bloomery smelting in the southern part of the Korean peninsula (Park and Rehren 2011) suggests that the Korean objects, like their Indian counterparts, were also produced directly from low carbon bloomery iron rather than from the indirect and complicated process involving cast iron. By contrast, plate-type iron artifacts so far reported in China (pers. comm. Dr. Chen at the School of Archaeology and Museology of Peking University) are distinctly different in appearance and, more importantly, were all made indirectly from cast iron. The existence of the unique plate-type iron objects in ancient Korea, therefore, challenges the premise that the Iron Age in Korea began and developed with the dominance of the Chinese style of technology, based on cast iron, and raises a serious question on its origin. A future study is necessary to determine if the iron tradition of the Indian megalithic communities had any influence on the beginning of the iron production in ancient Korea.

5. Closing Remarks

The analytical data presented above show that the use of a bloomery process in smelting and carburization in steelmaking constitute two major factors characterizing the iron tradition of the Indian megalithic communities. It is likely that the plate-type objects examined played a key role in the successful establishment of this tradition in the megalithic iron industry. They could be used as intermediaries to be forged into critical parts of various tools and weapons and also as a means for trade. In the latter case, their value would depend on size and carbon levels. The invention of such intermediaries reflects the high level of technological status that was achieved by the megalithic ironworkers in an effort to maximize the potential of the specific iron tradition under the given social and cultural environment.

The existence of such an advanced technology naturally raises a question on its origin, development and diffusion in space and time. Typological examination of the iron objects from a group of the megalithic sites within the district of Nagpur suggests that they shared a common iron tradition. It is yet to be discovered, however, if this is the case with other megalithic sites scattered over the vast territory of the Indian subcontinent. It would be of great interest to see if the technological sophistication as apparent in the objects examined came to exist as a result of the innovations made during the megalithic period or if it was inherited from the previous native civilizations or was driven by foreign influences. The evolution of this particular iron tradition in the subsequent generations provides another topic of significance to study.

It is interesting to note that some plate-type iron objects showing remarkable similarities in typology and technology appeared first in the Indian megalithic communities and then in the southern coastal area of the Korean peninsula. Despite the substantial difference in space and time between the two regions, the technology applied in their production as well as their role in iron industry seems almost identical. It is even more interesting to realize that similar objects have not been reported in China, which has long been considered as the sole origin of Korean iron. This is not surprising, however, since the specific objects can best be produced directly from bloomery iron rather than indirectly from the Chinese style of technology, based on cast iron. The evidence recently identified for the practice of bloomery smelting in South Korea supports that these iron plates were likely produced directly from bloomery iron. This theory is supported by their Indian counterparts that were indeed an outcome of the bloomery tradition.

Our collaborative research is just beginning and many more iron and bronze objects from collections with varying chronological and regional contexts must be subjected to a rigorous scientific examination to reach a more general conclusion. Nevertheless, the results presented above reveal important information that can hardly be obtained without the integration of metallurgy and archaeology. More importantly, this information stimulates numerous well-defined questions of substantial significance to be generated, which may readily be solved in the future research to the better understanding of the history of India and Korea and their probable interaction in the past.

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