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Fig. 4: BRG 5762

Fig. 8: (a) MHR 6551, (b) KRD 5914

Fig. 5: BRG 5762B

Fig. 12: BRG 5804

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Evidence of Steel Making at Naikund and its Relationship with Mahurjhari, Borgaon and Khairwada, Maharashtra*

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Abstract

The Early Iron Age Megalithic Culture of Vidarbha dated 700 - 555 +/- 100 BCE has brought to light the evidence of earliest iron working especially smelting in India, from a site named Naikund. This is the only site that has reported an iron smelting workshop from the Early Iron Age-Megalithic level. This probably suggests the existence of a centralised production unit. However, to prove the existence of a centralised production unit, a typo-technological analysis of the artefacts recovered coupled with ethnographic survey would be required. The typological analysis of the objects shows a degree of standardisation based on the usage pattern. Wet chemical analysis aids in understanding the chemical composition of the ore utilized. Micro-structural analysis gives us a clear insight to the existing technical knowledge of iron working. Therefore, the comparative analysis of objects from the excavated megalithic sites (Naikund, Mahurjhari, Borgaon and Khairwada), would aid in proving or negating the possibility of a centralised administrative unit, if negated then the possibility of dispersed administrative units and their probable locations.

Introduction

The present research is devoted to iron technology that developed during the Early Iron Age in the Deccan Peninsular region especially in Vidarbha. The Iron artefacts are found generally from the burials and in less quantity from the habitation. One of the major finds from this culture is the iron smelting furnace and the area designated as the smelting workshop from the site of Naikund. The ore lumps and slag remnants were analysed by Gogte (1980, 1982). However, the technological aspects of the finished artefacts were undermined.

The aim of this research was to specifically understand the iron technology practiced by the Vidarbhan Megalithic community which revolves around the smelting and smithy techniques adopted by the Megalithic community. To achieve this, understanding of the composition of the metal (iron) and gaining an insight into the methods of quarrying, the addition of flux and the final stage of smelting is required.

The Vidarbha region of Maharashtra encompasses the easternmost 11 districts of the state namely Nagpur, Chandrapur, Gadchiroli, Bhandara, Gondia, Wardha, Amravati, Akola, Buldhana, Yavatmal and Washim (Fig. 1). The sites selected for this study were Naikund (NKD), Mahurjhari (MHR), Borgaon (BRG) and Khairwada (KRD), all spread over Nagpur and Wardha districts and fall within the same physiographic and environmental setting.

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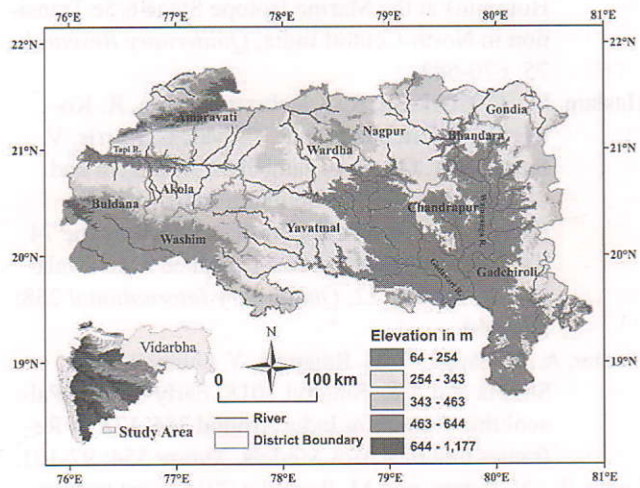

Fig. 1: Map of Vidarbha

The development of the earliest iron production can probably be ascribed to the concentration of the major part of mineral deposits in Vidarbha. One of the major components of iron smelting is coal (fuel) required for iron smelting and the only occurrence in Maharashtra is in Vidarbha. The coal deposits are found in Nagpur, Chandrapur and Yavatmal. The richest deposit is Telwasa (320,000 million tonnes in reserve) in Chandrapur District. Similarly, iron ore deposits in Maharashtra are also found only in Chandrapur, Gadchiroli, and Bhandara districts. The richest and most economic deposit, Lohara (Fe_2O_3: 81.22%), is found in Chandrapur District (DID 2006). Hematite is found in Gondia District from the mines of

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Khursipur and Ambetalao, and the titaniferous magnetite ore with vanadium inclusion is formed within the Amgaon Group which is found in Bhandara District (DID 2006).

The Megalithic iron smelting site of NKD is located on the banks of the River Pench. The site is marked by the clustered stone circles on the left bank of the river and has habitation remains too. MHR, a well-known Megalithic and Early Historic site is located on the Nagpur-Katol road near Junapani. The iron assemblage under study was excavated from the stone circles grouped into four localities (I, II, III and IV) which were excavated for three seasons (1970-1, 1971-2 and 1978-9) by Deo (1973). BRG, located 42 km northeast of Nagpur in Nagpur District, when first identified had 48 stone circles (IAR 1980-81: 40). But now the site does not exist anymore. KRD, a Megalithic habitation-cum-burial site, located on the right bank of the River Dhan in Wardha District, has about 1400 Megalithic burials (IAR 1981-2: 51-2).

Materials Studied

Five hundred and sixty seven artefacts were systematically recorded and typologically analysed based on usage, and further categorised into variants. Table 1 shows the distribution of artefacts from the four sites. The number of artefacts recovered from different sites is entirely dependent on the number of burials excavated, and the occurrence of artefacts as burial offerings is directly proportional to the richness of the site. Although adze, locally known as *rapi*, dominated the entire assemblage, the axes dominated the assemblage in case of Borgaon. Adze has been described in multiple ways by various scholars. Park and Shinde (2012) described them as fanned blades joined in-between and of no real use. However, the same tool has been described as a double-sided blade tool which was probably used for minor surgical purpose based on ethnographic evidence from a tribal society in Kurnool District, Andhra Pradesh. The second artefact that dominates the assemblage is the nail parer, and has also been described as a surgical tool. The tool has a pointed drilling end with a spiralled body and the other end ending in a triangular blade. Lamp stands come third in dominance; however, there is a marked absence of the same from the assemblage recovered from Naikund and Khairwada. This artefact (n=66) dominates the assemblage recovered from Mahurjhari.

Materials for Metallographic Study

Metallographic examination deals with the study of the internal structure of a material under varied magnification and resolution. The study of microstructure deals with the atomic arrangements in a crystalline material and gives us an idea of the chemical, mechanical and magnetic properties of the material. A total of 16 artefacts have been selected (Table 2). Samples were well selected, as improperly prepared samples can lead to erroneous results.

Table 1: Artefacts available from four Vidarbha Megalithic sites

Artefacts	NKD	KRD	BRG	MHR	Total
Adze	3	7	11	93	114
Arrowhead	2	2	1	1	6
Axe	1	2	13	26	42
Bangle	0	0	0	1	1
Borer	0	0	0	1	1
Chisel and chisel point	2	4	2	34	42
Dagger	5	0	3	18	26
Fish hook	0	0	0	1	1
Hoe	1	2	2	1	6
Horse bit	3	3	0	15	21
Ingot	2	0	0	0	2
Knife	7	1	3	11	22
Ladle	0	0	2	11	13
Lamp	0	0	6	66	72
Nail	0	0	0	3	3
Nail parer	2	9	2	62	75
Pan	2	0	0	0	2
Ring	0	1	0	9	10
Rivette	0	0	0	2	2
Rod	0	4	0	14	18
Sickle	0	0	0	2	2
Slag	3	0	0	0	3
Spear/Spear head	0	0	1	0	1
Spike	0	0	0	20	20
Tang	5	0	1	31	37
Unidentified objects	4	4	2	14	24
Wire	0	0	1	0	1
Total	**42**	**39**	**50**	**436**	**567**

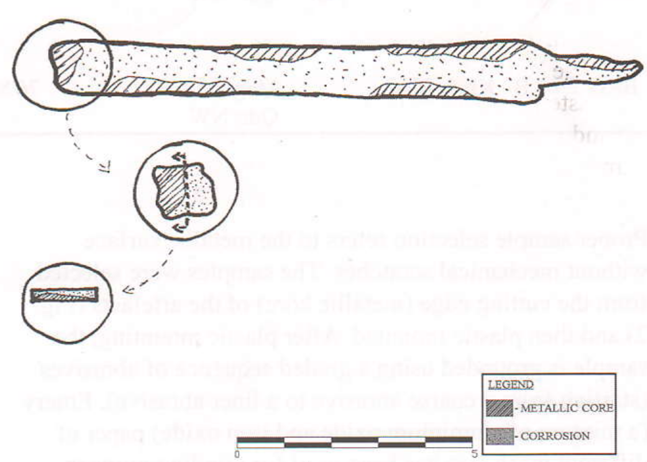

Fig. 2: Sampled Section of KRD 6831

Table 2: Samples selected for metallographic examination

Accession No.	Artefact	Provenance	Length (mm)	Breadth (mm)	Thickness (mm)	Description
NKD 5866	Nail Parer	LOCUS: II Meg: 7	110.81	-	6.11	Elongated cylindrical object, rod-like object
NKD 5861	Nail Parer	Locality: V Md: 1 Tr: C1 Layer: 3	104.35	-	4.24	Elongated cylindrical object, rod-like object
MHR 6419	Spike Blade	Meg: 8 Qdr: SW	153.56	11.4	2.14	
MHR 6551	Spearhead/Dagger	Meg: 7 Qdr: SW	183.33	23.66	3.58	
MHR 6490	Nail Parer	Meg: 11 Qdr: NW	68.49	-	3.95	
MHR 6446	Adze	Meg: 17 Qdr: SW	67.53	28.79	1.95	
MHR 6078	Dagger	Tr: II Qdr: SW	170.12	12.85	3.6	Broken from the tanged end
MHR 6031	Adze	Meg: 7	61.11	37.57	1.37	Only the (broken) broader working edge
KRD 5914	Horse Bit (Type 1a)	?	-	-	-	Broken
KRD 6841	Arrowhead	Locus: II Tr: A Depth: 1.70 m Layer: 4	-	-	-	Broken
KRD 6839	Arrowhead	Locus: II Tr: A Depth: 1.15 m Layer: 3	-	-	-	Broken
KRD 6819	Nail Parer	Locus: I Meg: L9 Qdr: SE	48.41	-	5	Broken from the gripping end
KRD 6831	Chisel	Locus: II Tr: A Depth: 1.30 m Layer: 3	59.56	-	-	Broken from the tanged end
BRG 5804	Lamp Stand	Meg: 35 Qdr: NW	-	-	-	Lamp with part of the circumference broken-handle at 90°. Probably used as lamp because the handle is turned at an angle to aid in hanging.
BRG 5762	Spearhead/ Dagger	Meg: 35 Qdr: NW	103.5	32.69	2.15	Functionally can be identified as short dagger but technologically it could be a spearhead. The length is small for a dagger.
BRG 5762 B	Knife Blade	Meg: 35 Qdr: NW	76.83	25.33	1.46	Knife blade broken from both ends, rusted and corroded.

Proper sample selection refers to the metallic surface without mechanical scratches. The samples were selected from the cutting edge (metallic core) of the artefacts (Fig. 2) and then plastic mounted. After plastic mounting, the sample is grounded using a graded sequence of abrasives (starting from a coarse abrasive to a finer abrasive). Emery (a mixture of aluminium oxide and iron oxide) paper of different mesh size has been used for grinding purpose, followed by polishing using diamond slurry. The slurry is made using one part of abrasive suspended into 10 parts of distilled water (Vander Voort 2010). After the final stage of polishing, the sample is etched with Nital to reveal the microstructure. If the sample is over etched, the etchant is removed by re-polishing. The study showed the evidence of steeling and also evidence of failed attempts at steeling, which proves that there was an indigenous development in iron technology.

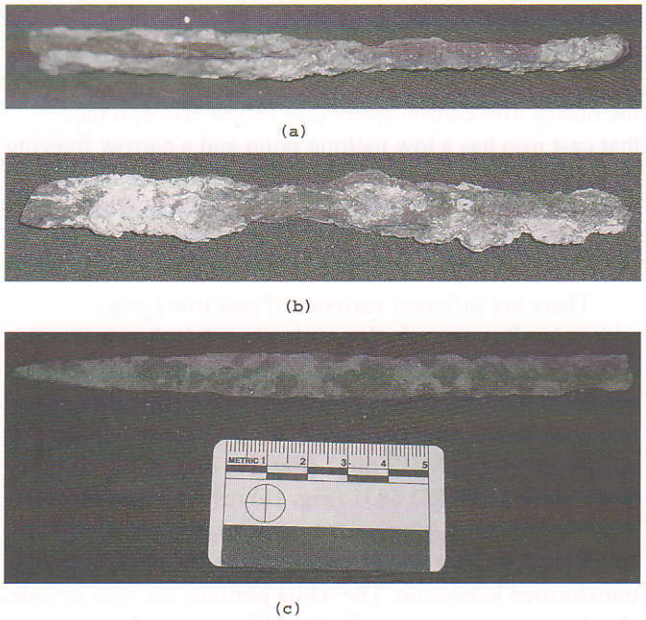

Fig. 3: (a) NKD 5866, (b) NKD 5861, (c) MHR 6419

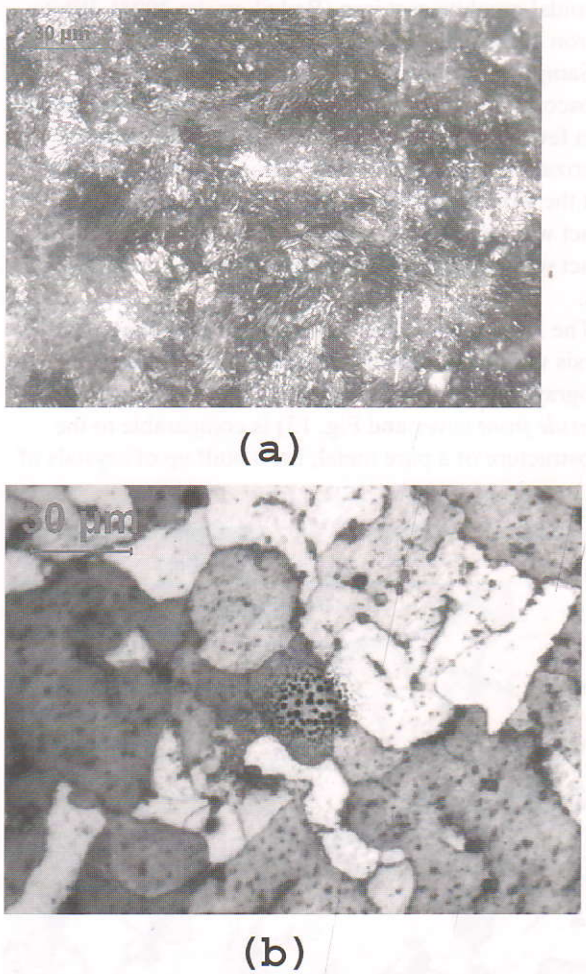

Fig. 6: (a) Optical micrograph showing lamellar formation in MHR-6419, (b) Optical micrograph of BRG 5762B showing ferrite-pearlite structure

Metallographic Examination

There were samples [NKD 5866 (Fig. 3: a), NKD 5861 (Fig. 3: b), MHR 6419 (Fig. 3: c), KRD 6839, BRG 5762 (Fig. 4, *please see inside front cover*) and BRG 5762B (Fig. 5, *please see inside front cover*)] which show microstructures representing hypo-eutectoid steel composition. The optical micrographs of MHR 6419 (Fig. 6: a) and BRG 5762 B (Fig. 6: b) show pearlite embedded in primary ferrite. According to metallurgy text books, steels with less than 0.77% C are known as hypo-eutectoid steel. To form this composition, low carbon α ferrite gets formed along the austenite grain boundaries which results in formation of two phases α and γ phase. The austenite phase gets converted into a combined phase of ferrite and cementite. The SEM micrographs [NKD 5866 (Fig. 7: a), NKD 5861 (Fig. 7: b), KRD 6839 (Fig. 7: c) and BRG 5762 (Fig. 7: d)] show a pearlitic structure. Here hypereutectoid steel is cooled from 100% austenite-carbon solid solution and cementite is formed along austenite grain boundaries in the $\gamma + Fe_3C$ region (Reardon 2015).

Three samples [MHR 6551 (Fig. 8: a, *please see inside front cover*), MHR 6490 and KRD 5914 (Fig. 8: b, *please see inside front cover*)] have given evidences of failed attempts at steeling. The microstructures reveal ferrite grains with formation of iron carbide at grain boundaries. The high proportion of ferrite grains in comparison to the iron carbide formation suggests that the hardness of the structure was not elevated and carbon absorption was not achieved properly. The optical micrograph of KRD 5914 (Fig. 9) shows a matrix which is predominantly built up of ferrite grains with a few colonies of pearlite and has evidences of a high cooling rate which denotes the artefact was probably quenched.

Five samples, [MHR 6446, MHR 6078, MHR 6031, KRD 6819 and KRD 6831], point towards the production

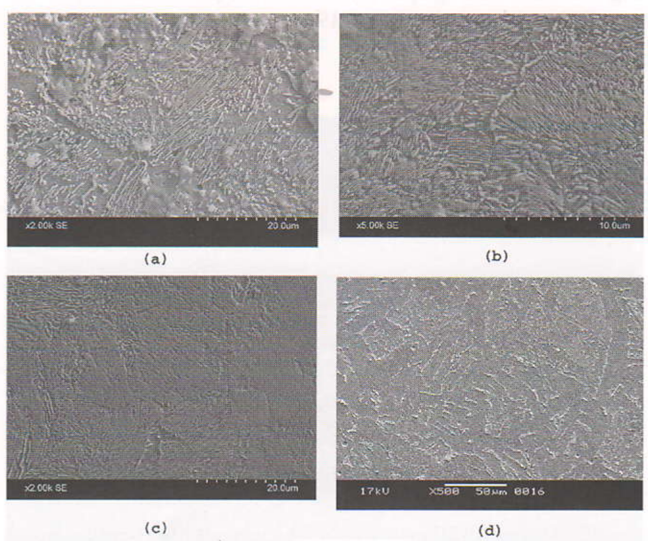

Fig. 7: SEM showing lamellar formation (a) NKD 586, (b) NKD 5861, (c) KRD-6839, (d) BRG 5762

Fig. 9: Optical micrograph of KRD-5914 showing the predominance of ferrite

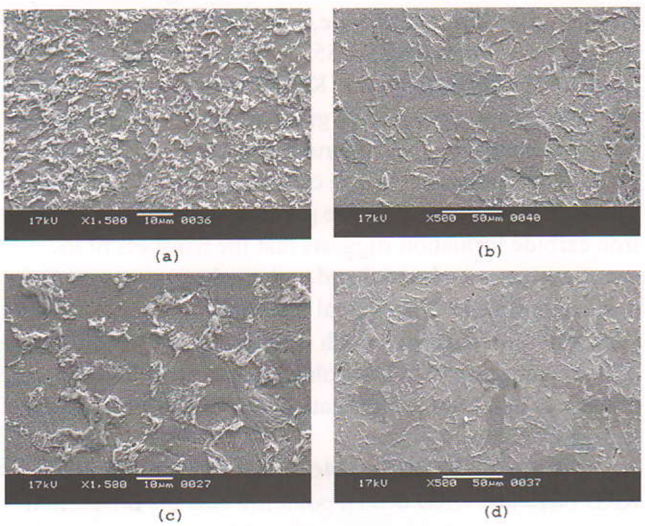

Fig. 10: SEM Micrographs (a) MHR 6446, (b) MHR 6078, (c) MHR 6031 and (d) KRD 6819

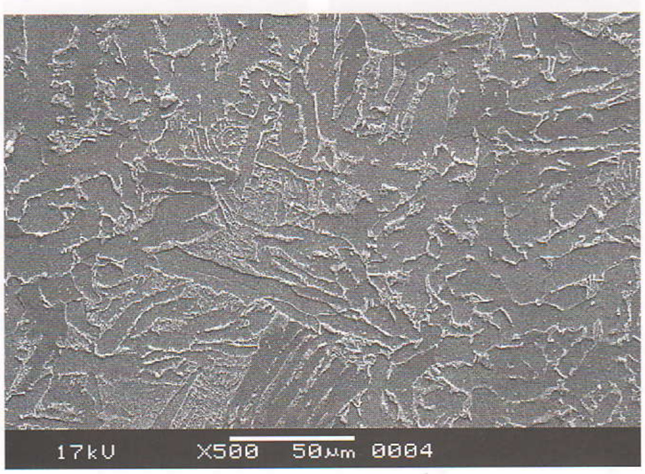

Fig. 11: SEM micrograph showing white cast iron

of cast iron. Cast iron can be described as an iron-carbide alloy which is similar to steel, but possesses higher carbon levels. It retains the advantages of eutectic solidification in the binary iron-carbon system. In simple terms, it means that cast iron has a low melting point and a narrow freezing range in comparison to steel and actually aids in fluidity to fill the moulds used for casting the artefacts. Cast irons have a melting range of about 400° C (720° F) which is lower than steel (Reardon 2015).

There are different varieties of cast iron (grey, white, ductile, etc.) which vary in physical, chemical and mechanical properties. The microstructure of cast iron is identified by the formation of austenite dendrites. The SEM micrographs of samples MHR 6446 (Fig. 10: a), MHR 6078 (Fig. 10: b), MHR 6031 (Fig. 10: c), KRD 6819 (Fig. 10: d) and KRD 6831 (Fig. 11) reveal the structure of white cast iron. At room temperature, the structure consists of primary dendrites of pearlite with interdendritic transformed ledeburite. The white portions are iron carbide, also known as cementite (Fe_3C). This is formed when it is annealed at a temperature ranging between 800 °C and 950 °C. This process was responsible for the formation of spheroidal graphite cast iron (Radzikowska 2004). White cast iron is hard, brittle and difficult to work on.

Sample KRD 6841 was processed for optical microscopy, and the micrograph shows some ferrite grains with a few colonies of pearlite, with probable traces of carburization. The microstructure does not reveal much about the working of the artefact. No other area in the artefact was suitable for metallographic analysis as the artefact was extremely rusted with almost nil metallic cores.

The last evidence derived from the metallographic analysis was the utilization of pure iron. The optical micrograph of sample number BRG 5804 (Fig. 12, *please see inside front cover* and Fig. 13) is comparable to the microstructure of a pure metal, i.e. a built up of crystals of

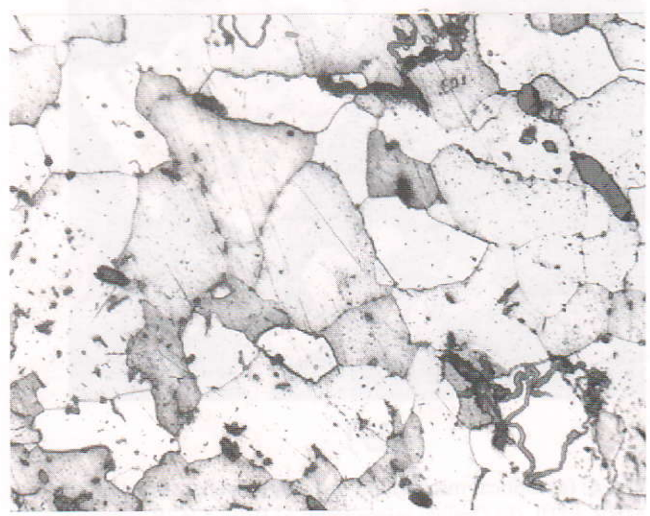

Fig. 13: Optical micrograph showing pure ferrite structure

the same composition which is termed as ferrite (Rollason 1973). The micrograph shows the dominance of alpha ferrite grains with the presence of a few slag stringers.

Chemical Analysis

The application and interpretation of chemical compositional data is necessary to understand the technical know-how prevailing in the society which is under study here. The chemical compositional data of the artefacts helps us to identify the probable ore sources that were utilized by the Early Iron Age iron smelters. The carbon content also helps throw some light on the smithy activity. Firstly, we will discuss about the other elements present in steel samples KRD 6839 (Table 3; Fig. 14: a) and BRG 5762B (Fig. 14: b). Carbon is the most important alloying element as it enables hardening and aids in the formation of cementite (Fe_3C), pearlite and other iron-carbide phases. The next major element is Silicon (Si) which acts as the principle deoxidizer in the process of steel making. Aluminium (Al) also possesses the quality of a deoxidizer and aids in grain growth prior to the quenching stage. Presence of oxygen is detrimental to the quality of steel produced. Vanadium (V), when added as an alloying element, aids in grain growth during heat treatment. However, the addition is limited to about 0.5% otherwise it would adversely affect the hardening of steel. Cobalt (Co) has a high solubility rate in α and γ but has weak carbide formation (Rollason 1973). The content of sulfur (S) needs to be controlled as welding ability is adversely affected with the increase in sulfur content. The presence of arsenic (As) should be limited to below 0.3% as it increases the susceptibility of steel to temper embrittlement (Reardon 2015). The chemical composition of the samples indicating failed steel attempts (Table 4; Fig. 15: a and b) have evidence of manganese (Mn) and niobium (Nb) which helped in improving fatigue, creep and several other mechanical properties of steel (Collins *et al.* 1961; Linebarger and McCluhan 1981). Similarly chromium (Cr), nickel (Ni) and zirconium (Zr) are also strong carbide formers. Therefore, the samples indicating failed steel attempts failed only due to the inability in controlling the carbon absorption. It is interesting to note that tungsten (W) was used as an alloying element in producing cast iron (Table 5; Figs. 16-17). Tungsten reacts with carbon to form either WC or W_2C or with iron to form Fe_3W_3C or Fe_4W_2C.

Table 3: Chemical Composition of Sample (KRD 6839) indicating steel technique

C%	3.37
Fe%	93.35
Al%	0.26
Si%	0.13
S%	0.01
V%	0.25
Co%	2.07
As%	0.15

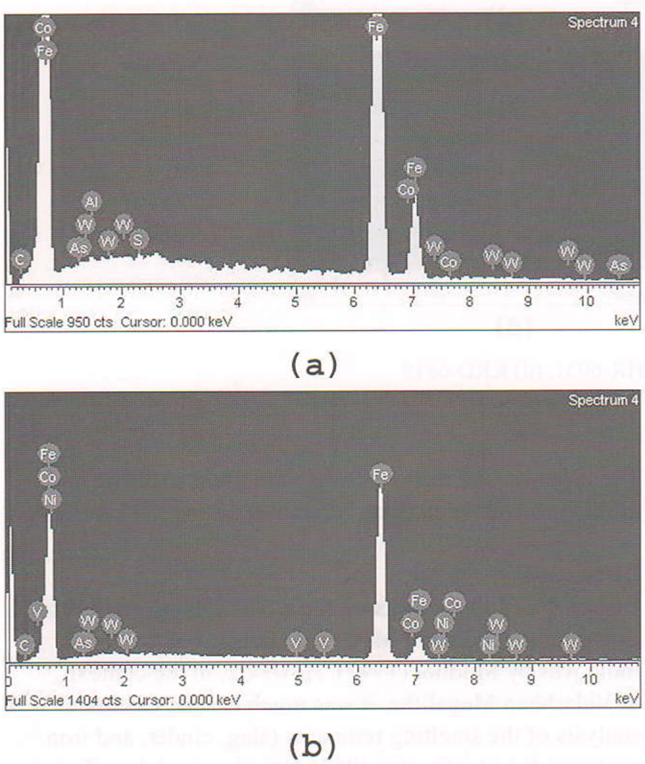

Fig. 14: EDAX composition graph (a) KRD-6839, (b) BRG 5762B

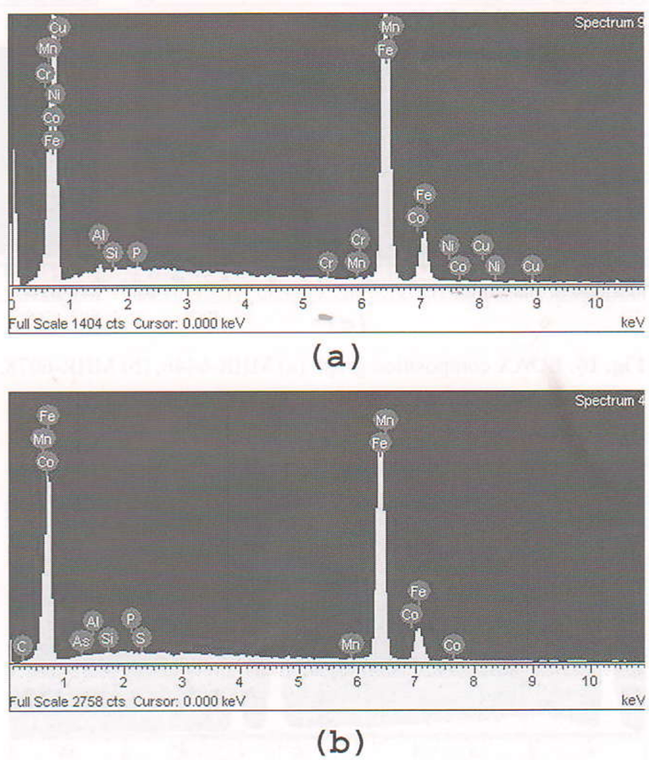

Fig. 15: EDAX composition graph (a) MHR-6551, (b) MHR-6490

Table 4: Chemical composition of samples indicating failed attempts of steel technology

Sample No.	C %	Fe %	Al %	Si %	S %	V %	Co %	As %	Mn %	P %	Cr %	Nb %	Ni %	Zr %	Cu %
MHR 6551	1.9	95.65	0.99	0.54	0.41	0.15	2.68	-	0.06	0.32	0.22	0.45	0.44	0.93	0.45
MHR 6490	3.64	95.37	0.27	1.23	0.12	-	2.52	0.61	0.12	0.28	-	-	-	-	-

Table 5: Chemical composition of samples indicating usage of cast iron

Sample No.	C %	Fe %	Al %	Si %	S %	V %	Co %	As %	Mn %	P %	W %
MHR 6446	3.35	96.87	0.18	0.21	0.12		1.48	0.02	0.07	0.22	
MHR 6078	2.33	95.84	0.33	0.11	0.06		1.9	0.09	0.25	0.21	0.51
MHR 6031	3.13	95.43	0.43	0.05	0.07		2.57	1.19	0.51	0.14	1.2
KRD 6819	3.56	93.29	0.87	0.64	0.25	0.08	3.06	0.65	0.33	0.29	1.83
KRD 6831	5.14	94.2	0.32	-	0.29	-	1.84	0.18	0.32	0.15	0.63

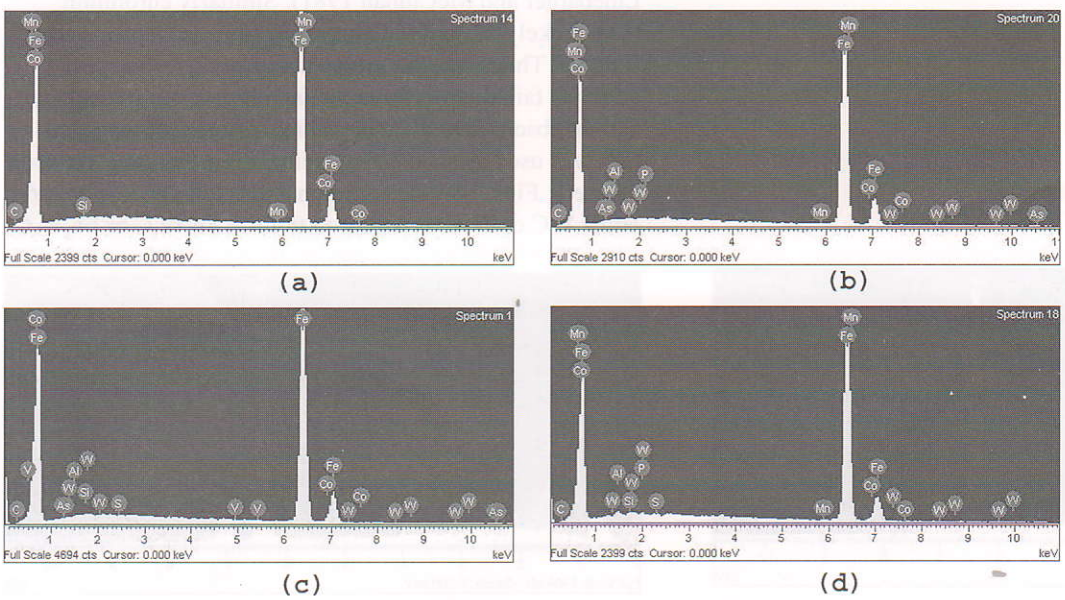

Fig. 16: EDAX composition graph (a) MHR-6446, (b) MHR-6078, (c) MHR-6031, (d) KRD-6819

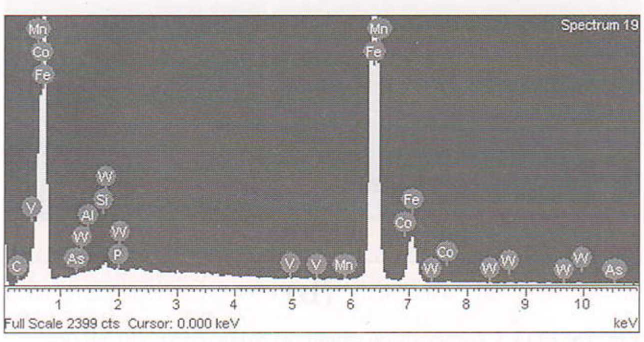

Fig. 17: EDAX composition graph of KRD-683

The properties of tungsten refine the grain structure and provide resistance to decarburization during cold working.

Discussion

One of the earliest works on the technological aspects of iron artefacts from the Megalithic context of Southern India was by Mudhol (1997). However, in the context of Vidarbhan Megaliths, it was much earlier. Chemical analysis of the smelting remnants (slag, cinder, and iron ore) was done by Gogte (1982) to understand the efficiency of the smelting process undertaken by the Megalithic iron-smelters at Naikund. The ore analysis (X-Ray

Diffraction and Mossbauer Spectroscopy) also helped in understanding the deposits (magnetite and hematite), which were probably exploited by the megalithic iron smelters. Iron artefacts from Vidarbhan Megalithic sites have not received similar treatment. However, the attempt at scientific analysis in the region of Vidarbha was spearheaded by Munshi and Sarin (1970) especially when one spear from Takalghat-Khapa was analysed for chemical composition and based only on the chemical composition, it was assumed that it was steel. The method adopted was incorrect and faulty. Similarly, an axe from Mhaurjhari (Joshi 1973) was also chemically analysed, and based on the iron content (99.1%) and carbon content (0.9%) it was assumed that it was steel. Recently two metallurgical studies by Deshpande *et al.* (2010) and Park and Shinde (2012) had been undertaken on samples from the Megalithic context of Vidarbha. Both studies involved selected samples from only a few sites and the samples studied were not representative of the tool assemblage. They have not contributed much to our understanding of the Megalithic iron producing society, although metallographic studies of the iron artefacts from this context were attempted for the first time.

The present study revealed that the iron assemblage comprised of a variety of tools conforming to various functional groups. Multi-functional tools dominated the assemblage. Tools like adze and nail parer, which are identified as tools for surgical purpose based on ethnographic evidence (Personal Communication: Ismail Kellellu 2012) dominate the tool assemblages from all the sites except Naikund, Borgaon and Mahurjhari, where nail parer occupies the third position. Naikund has yielded considerable evidence of smelting activity in the form of slag. From the archaeological remnants such as cinders, ore lumps, and tuyeres, it is possible to suggest that this was the primary centre for extraction of iron and production of tools.

The finished artefacts were possibly transported to other settlements, where they were probably utilized by different groups of artisans and craftsmen. It is important to note that 80% of the entire assemblage has been recovered from the burial context as they were ritualistically buried.

The microstructural analysis of the selected artefacts showed that the samples from Naikund were heavily corroded, with minimal metallic core left. However, based on the SEM micrographs, it is revealed that smithery techniques such as making steel was in practice and the samples with evidence of steeling have revealed that knowledge of smelting, as well as the quality of metal used was always sustained. The knowledge of smelting is evidenced by the purity of the metal (Fe: 97-93%) as well as other beneficial elements included. While manganese has a property of inducing hardness, it also has the tendency to cause cracking of metal when the artefact is quenched. Therefore, it is necessary that the Mn level is below 0.5% which clearly shows that basic knowledge of the properties of elements was known to the Early Iron Age Megalithic iron-smelters.

Along with the steel technique, there is evidence of different grades of cast iron which is distinctively different from steel due to its high carbon content (2-4%) demonstrating that smelting activity was not fully achieved to eliminate all the unwanted gangue material. Sample BRG 5804B shows the usage of pure iron where no heat-treatment was involved and the artefact was made using a basic forging process. All these stages prove that the metallurgical techniques were still at an experimental stage and that it improved through multiple failed attempts at steel making. This suggests that probably iron smelting and smithy developed indigenously in Vidarbha and was improved upon by the smithers, which led to the artefacts being produced through different techniques. It is also important to note that both hematite and magnetite were used, although hematite was the most commonly used given its deposits were more abundant. Usage of magnetite, which is identified through the presence of titanium in the compositional analysis, is limited and not found from the above studied three sites.

The metallographic analysis of the artefacts presented in this paper shows that majority of the artefacts withstood the forces of nature as most of the tools have retained the metallic core.

Acknowledgements

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