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FROM WROUGHT IRON TO STEEL: BEGINNING OF STEEL MAKING IN EASTERN INDIA

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In Indian sub-continent the earliest evidence of iron making is noted from Rājā-Nal-Kā-Tilā dated c. 1600 BC. In Eastern India iron is noted from a number of sites including Pāṇḍu Rājār Dhibi, Barudih, Chirand, Mongolkot, Bahiri, Hatikra, Golbai Sasan and Badmal. The aborigines initiated iron technology in Eastern India during 1000 BC. Subsequently it was popularised. The iron making technology in Eastern India completely initiated a new craft and the people developed and flourished using this craft. In case of iron, a solid-to-solid transfer of iron ore into spongy mass was a practical success, not only due to easy availability of iron ores but also mastering direct reduction technology. They also knew the technology of tempering and quenching. Iron technology had been initiated in this region independently right at the Ferrochalcolithic Cultural sequence.

Key words: Carburisation, Direct reduction, Ferrochalcolithic, Quenching, Tempering

INTRODUCTION

Beginning of iron technology is rather interesting topic in case of Indian sub-continent. Once Chakrabarty pointed out that iron technology got widely disseminated in first halves of first millennium BC. Excavations revealed the origin of iron around c.1000 BC in Eastern India[1]. Recently excavated sites of Raja-Nal-Ka-Tila and Malhar of Southern Uttar Pradesh have pushed back the antiquity of iron, which was well before 1500 BC[2].

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The iron manufacturing in this part of country was well revealed from the presence of iron artifacts, slag and remnants of furnaces.

BEGINNING OF IRON TECHNOLOGY

The beginning of iron technology has been identified at Transition or Ferrochalcolithic phase. The discovery of iron and its simple extracting technique along with forging technology had totally replaced the need for use of copper except for manufacturing of ornaments and utensils. It is with highest probability, one may accept that the iron technology was popularized in Eastern India during 1000 BC. The discovery of iron had initiated a new craft and the people developed and flourished using this craft. The high degree of skill associated with specialization was soon accepted by society with esteem.

In case of iron, a solid to solid transfer of iron ore into spongy mass was a practical success, not only due to easy availability of iron ores but also because the direct reduction into iron could be achieved in the furnace itself. There is no doubt that the furnace remnants can help us to trace iron-manufacturing techniques. The modern trend in archaeometallurgical studies is to highlight the techno culture of a society based on the following three basic factors established by de Rijk[3]. This hypothesis is well applicable for Eastern India also. Considering the same, one may categorize the availability of ore and fuel, to convert the same into metal, as the <u>first factor</u> of flourishing of metal trade or use. Eastern India is definitely fortunate with its abundant mineral resources. Moreover, the presence of dense forest with good quality of wood was very suitable for metal craft. Both high-grade as well as low-grade iron ores are available here.

The <u>second factor</u>, for metal manufacturing, is definitely the knowledge and skill of the artisans. During the aforementioned Neolithic - Chalcolithic transition, use of metal and its manufacturing was known to them and definitely the people practiced it. Here also, one can see the effect of traditional techno culture on the primary need of the people.

The <u>third factor</u> is the socio economic condition, there was need for metal, but inadequate supply of copper hindered the growth of Chalcolithic industry. Invention of easier iron manufacturing technique compared to copper totally changed the demand of the people. The village settlements were developed in Chalcolithic Eastern India, but the traders were not capable enough to supply copper- bronze to them. In the beginning iron was available in plenty through out the lateritic / limonitic belt.

THE BACKGROUND OF IRON TECHNOLOGY

The introduction of Iron technology in Eastern India had created havoc in society and the high degree of skill associated with specialization was soon accepted with esteem. This pyrotechnic was different from copper smithy, where technology of handling the liquid metal was a bit complicated. The direct reduction into iron could be achieved in the furnace itself. The first question generally raised is, whether iron technology was indigenously developed in these region or had by diffusion technique. The stages of development of iron technology in Eastern India are as follows: Stage-I, wrought iron without carburization; Stage-II indicated carburization in iron. In Stage-III, an all round development was noted in carburization with quenching and tempering[4,5].

In Eastern India all these stages were attained prior to 3rd century BC. Sites of Eastern India are shown in 5 zones. These are 1. Sanjoy - Subarnarekha - Tarafeni valley, 2. Ajoy - Damodar - Kunur valley, 3. Senuwar - Chirand - Taradih region, 4. Sites from the Mahanadi Valley of Orissa. 5. Sites from Assam, Manipur and Nagaland. The fifth category indicated the early beginning of iron, however, this lacks of archeological records.

In Zone-1, Iron Age occupations have been found on the Neolithic level. This zone includes Dhuliapur, Kankrajhor, Barudih, Laljal, and Belamu. The first three excavated sites have furnished evidence of iron manufacturing associated with Iron Age occupations. The last two sites have indicated the presence of iron objects. In these sites, Chalcolithic culture is totally absent. In fact, the areas covered fewer than three districts of Eastern India, viz. Singhbhum, Mayurbhanj and Midnapur may be considered as the region where iron technology was independently developed. In Zone-2, the evidence of iron was authenticated from the late Chalcolithic phase, around 1000 BC. The known evidences in this zone were from excavations at Pandu Rajar Dhibi, Mangalkot, Mahisdal, Bahiri, Banesvardanga, and Hatikra where large-scale iron manufacturing was detected. This iron was associated with the Chalcolithic or black-and-red ware strata in these sites.

In Zone-3, human habitation initiated at the Neolithic phase. Example may be cited for Raja Nal-Kā-Tilā, Malhar, Senuwar, Chirand and Taradih. In a greater context Sonpur may also be included in this zone, although the Neolithic stage was not detected. However, at Sonpur, evidence of iron was noted in the late Chalcolithic phase. In Chirand and Taradih, evidence of iron manufacturing has been noted in Post-Chalcolithic (period III). At Senuwar, the use of iron objects has been attested from the NBP occupational level resting over the Chalcolithic deposits.

In Zone-4, in the Mahanadi Valley, in state of Orissa, a few new sites are under excavation. Examples may be cited for Sisupalgarh and Golbai Sasan. The Period IIB of the later site bears the same cultural traits continuing from the previous Chalcolithic level IIA. This level indicates the presence of an iron Celt with its crude manufacturing technique borne by its forged layers[6]. The recently excavated sites, Manamunda and Deuli, in Boudh District of Orissa, are included here, where iron objects, iron slag and ores discovered, identifying an early iron-manufacturing centre. The former site has recovered implements and nail made of iron, used in boat making. Recent archaeological excavation has also been conducted at Badmal and a preliminary report has been made[7]. The most interesting feature is the ^{14}C dating of the site which is appended in Table-1.

In Zone-5, very little study has been made. The study revealed the discovery of megalithic burials at Nagaland and Manipur regions. In Assam areas, iron technology flourished in early historic period. Still now our knowledge is incomplete in this part of the country.

Analysis of iron objects slag and ores recovered from excavations at different sites, has provided some indications that iron was manufactured on

Table 1. Calibrated Radiocarbon Dates

Sl. No.	Lab. No.	Period	Trench No. & Depth from the Surface	Radiocarbon Dates (Calibrated)
1	KIA 20153 Sample-1	IB	BDM-I/ Trench-II, 125cm	One Sigma Range: BC 799 – 766 Two Sigma Range: BC 810 – 760
2	KIA 20154 Sample-2	IB	BDM-I/ Trench-II, 115cm	One Sigma Range: BC 799 – 776 Two Sigma Range: BC 810 – 750
3	KIA 20155 Sample-3	IB	BDM-I/ Trench-II, 50cm	One Sigma Range: BC 775 – 759 Two Sigma Range: BC 789 – 539

a small scale contemporary to late Chalcolithic age. Further, evidence of furnaces and iron smelting activities, are also known through excavation and exploration work in the above zones. A meaningful picture is drawn indicating the details of iron technology in Eastern India.

The chronology of the beginning of iron has been shown for different sites. From these studies of iron objects and slag, incorporated with the available ^{14}C dates, it may be concluded that there were differences in smelting practice in these four zones. There is no doubt that iron was initiated earlier than 16th century BC. The issue of the metallurgical excellence may be highlighted on the basis of the iron objects obtained from Bahiri, Barudih, Golbai Sasan, Hatikra, Khairadih, Mangalkot, Pandu Rajar Dhibi, etc. These observations clearly indicate that iron manufacturing was not an isolated practice in this region. Iron technology had been initiated in this region independently right at the Ferrochalcolithic cultural sequence.

To identify the origin of the steel manufactured, metallography and its study only can help. Example may be noted for a Sassanian sword, dated c. 6th century AD, as mentioned by Craddock[8]. Through etching with nital, the specimen revealed a structure of cementite globules in an irresolvable matrix of pearlite. The original cast structure with the cementite precipitated around the pearlite grains has been preserved even in the corroded areas. Hardness of the analyzed blade was 400 VPH. The studies of Rai *et al* is also important in these contexts that have shown the nature of megalithic iron. Their methodology with SEM studies indicated that carburisation was not recorded in megalithic iron objects[9].

Whatever may be the case for Megalithic iron objects, the well dated evidence of carburization is well noted from the excavated materials of c. 1000 BC level from Hatikra, where existence of Widmanstätten pattern is found in a knife[10]. The metallographic analysis clearly exhibits that after finished forging, the knife was left over the furnace for subsequent carburization. The Fig.1 indicates the electron photomicrograph resolved pearlitic structure at a magnification of 3000X.

In Pandu Rajar Dhibi iron appeared at period IIB with C14 date of nearly 1050-950 BC [970 BC (KN-3640) and 930 BC (PRL-1183)]. The saucer shaped iron object, analyzed through Computer Automated Electron Probe Micro Analyzer (EPMA), revealed a matrix of iron, cobalt, oxygen

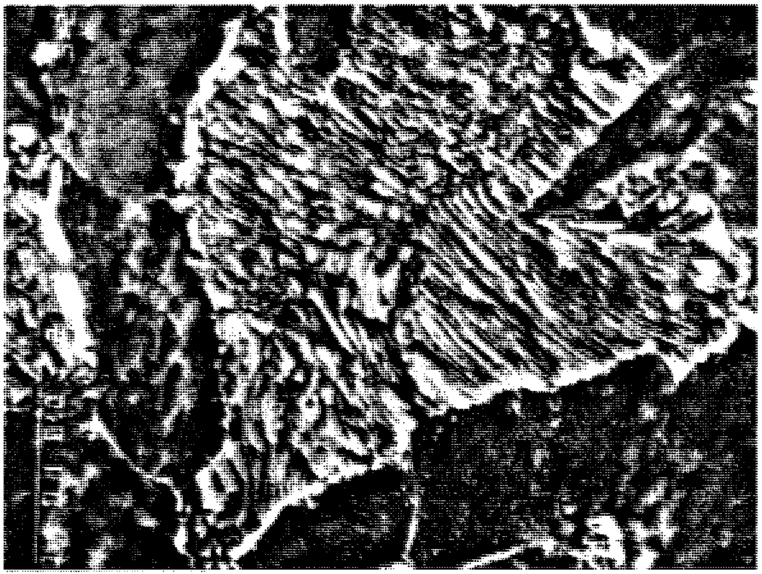

Fig. 1. Electron photomicrograph of iron implement of Hatigra, 3000X

and potassium along with a high amount of iron silicate (fayalite) inclusions which indicate clearly that carburization did not take place. During third century BC, the smiths learnt the addition of carbon to iron. The sickle recovered at this level indicated that they hardened the carburized iron by heating to red-hot and then quickly cooling (quenching) in water. To make the hardened iron less brittle, they reheated it to an intermediate temperature (tempering)[11].

Iron objects of Chirand and Taradih revealed the lamination or layering technique for fabrication of implements[12]. The Period IIB of Golbai Sasan bears the same cultural traits continuing from the previous Chalcolithic level IIA[13]. This level indicates the presence of an iron Celt with its crude manufacturing technique borne by its forged layers. Sisupalgarh of Orissa was excavated and detail reports had been published[14]. From this site around two hundred iron objects including nails, spikes, staples, sickles, arrowheads, spears, caltrops etc were obtained. An over all growth of iron metallurgy was exposed in this site. Unfortunately no metallographic analysis has been made so far.

From the metallography and chemical analyses that made so far revealed no evidence of iron making through crucible steel route. Craddock has correctly identified that the Eastern India's iron objects prior to 4th century AD were not made through crucible steel route. His assumptions are matching with the analyses from the excavated sites of Eastern India, mentioned earlier[15].

THE FORMS OF IRON AND STEEL

In recent past, lots of interests have been generated by the scholars to study the olden iron and steel making in India. There are three basic forms of iron namely wrought iron, steel and cast iron. The classification is based on the amount of carbon in iron. Wrought iron contains all most pure iron with negligible amount of carbon. It may contain slag inclusions as left over silica mixed with iron. In steel it contains up to 2% carbon, mostly as solution. Whereas, in cast iron carbon contains 2% and above, the later exists as free or as a compound of iron carbide (Fe_3C). The basic principle of manufacturing steel is made of two different processes. The former is a solid to solid transfer, as practiced at bloomery iron. In the second one, solid iron ore is converted on to liquid (?) crucible steel. In case of Eastern India solid iron ore is converted into sponge iron similar to the bloomery iron mentioned above and is further modified into steel, where sponge iron forged thoroughly and reheated in charcoal furnace. Subsequently a solid carburization is conducted and steel was made. In case of South India, especially in late medieval period, steel-making practice was conducted through the crucible steel root[16]. As per Craddock's opinion, as well as with our experience it is found that it might be very difficult to differentiate between bloomery iron and fined cast iron. Perhaps the less absence of siliceous inclusions and presence of carburization may be accepted as steel.

The name crucible steel is given to these types of steel, since the process is conducted at liquid state in a crucible made of high refractory materials. Initially wrought iron, made from iron ore in solid-to-solid transformation, was strongly heated in closed crucible with carbonaceous materials other than charcoal. In medieval period some places in China and also in India, combined melting of cast iron and wrought iron in measured quantity in crucible were known. However, in India, the production of cast iron in the furnace was considered to be a bad omen and smelters controlled the production avoiding its formation during production of bloomery iron[17]. The iron used for the Delhi iron pillar was from bloomery iron. From the published compositions, it is known that for making the pillar iron was extracted from the bloomery furnace route[18].

The details of metallurgical aspects of Eastern India including Bihar, Jharkhand and West Bengal are now available. The studies of metallic remains of Iron-age of Eastern India have shown that there was a tremendous growth in metal technology. Though iron has its early origin in the late Chalcolithic period, it took a few centuries to attain perfection. In the beginning, iron was simply extracted but later, the carburizing process or steeling - farther increased the strength of the tool types and implements. The use of the process of carburisation was noted at Hatikra. In this site one iron object has revealed a low carbon hypoeutectoid steel. The manufacturing process indicates a long time exposure in either the smelting furnace or at the smithy forge at a temperature of around 1200° centigrade. This was evidenced by an Widmanstätten structure. An electron photo micrograph was obtained at 3000X showing a broken lameller pearlite (Fig.1.) The same was also noted at Barudih which is also one of the earliest steel making centre of Jharkhand[19]. A photomicrograph at 1000X revealed a lameller structure of pearlite colonies concentrated along ferrite grain boundaries (Fig. 2). In Bahiri, the evidence of iron slag pointed to its being one of the early iron producing centers[20]. The

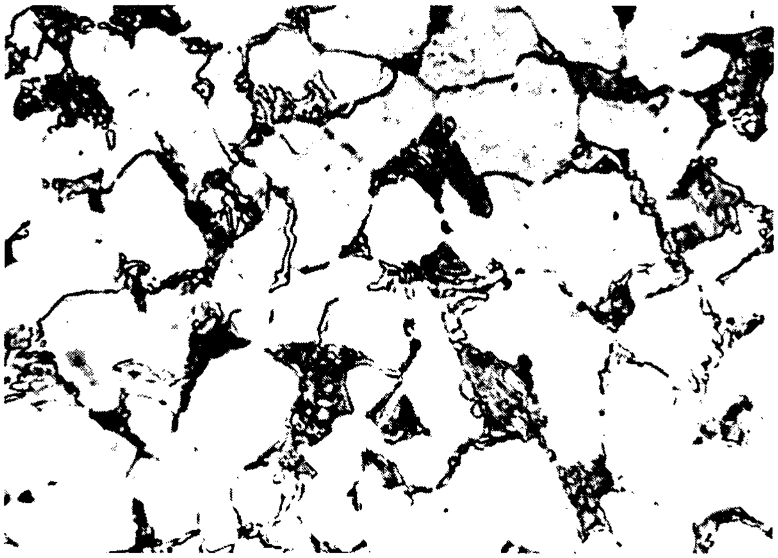

Fig. 2. Photomicrograph of an iron implement from Barudih showing lameller pearlite in ferrite grain boundaries at 1000X

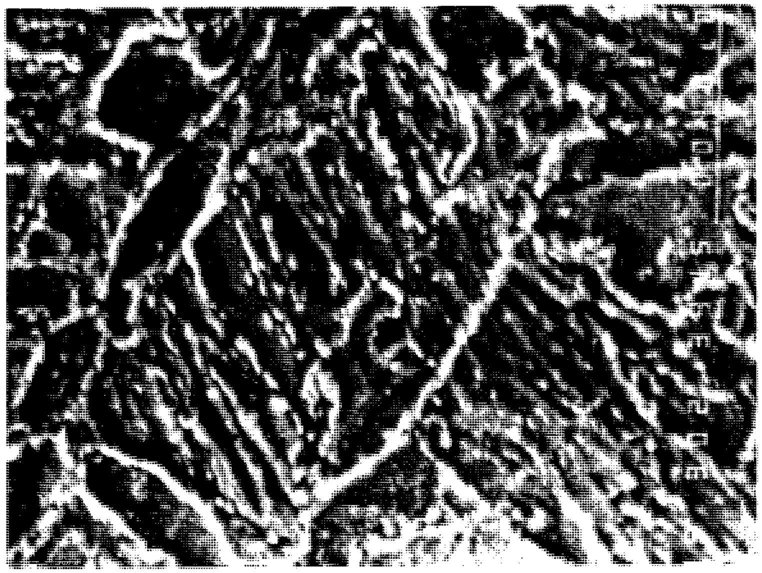

Fig. 3. Electron photomicrograph at 3000X clearly represents its tempered martensitic structure from a sickle at Pandu Rajar Dhibi

use of quenching and tempering, however, were noted in the 3rd century BC in Pandu Rajar Dhibi. From a sickle, an electron photomicrograph at 3000X clearly represents its tempered martensitic structure (Fig. 3). Undoubtedly this is the landmark on steel making only that marking overcome with the addition of alloy to steel.

To overcome our less knowledge on the early iron objects of Orissa especially at Mahanadi Valley we have initiated an in-depth search. To begin with the side Badmal has been identified.

EXPERIMENTS AT BADMAL

As mentioned earlier, only four iron objects have been selected for metallographic examination. The detail metallurgical reports have been made, including microstructures, micro-hardness, PIXE etc. The preliminary archaeological reports have also been published elsewhere. The earliest object is a spearhead (BDM-18) recovered from period IB i.e. Iron Age level, belonging to the early part of the first millennium BC. Other three objects are drill bit (BDM-7), another drill bit (BDM-8) and a toothless saw (BDM-16). The details of the objects are shown in Table 2. The corresponding

Table 2. Analysed iron objects

Sl. No.	Trench No.	Sample No.	Depth	Object	Length mm	Breadth mm	Thick mm
1.	BDM-I	BDM-18	75 cm	Spearhead	82.0	23.0	7.0
2.	BDM-II	BDM-7	15 cm	Drill bit	38.0	6.4	7.0
3.	BDM-II	BDM-8	15 cm	Drill bit	62.5	7.3	8.0
4.	BDM-II	BDM-16	35 cm	Toothless saw	50.5	19.0	4.2

Table 3. Detected Elements in Wt% through External PIXE

Sample No.	P	S	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu
BDM-18	0.15	0.13	-	-	0.13		0.70	95.15	0.15	-
BDM-7	0.49	0.41	0.41	0.29	0.076		0.58	95.76	0.29	0.12
BDM-8	0.58	0.40	0.23	-			0.44	95.71	0.27	
BDM-16	0.53	0.43	0.12	-		0.06	0.56	95.08	0.43	

Table 4. HV values

Sample No.	Hv at ferrite areas	Hv at other areas
BDM-18	0.15	0.13
BDM-7	0.49	0.41
BDM-8	0.58	0.40
BDM-16	0.53	0.43

analyses by External PIXE have been shown in Table 3. In Table 4 the Vickers Hardness values are shown, the values have been taken on ferrite regions also other than ferrite but not on the slag inclusions.

Through in-depth studies we have obtained the following metallographical structures from this site. The photomicrograph of the specimen BDM-18, at 100X showing rows of slag inclusions entrapped between the layers of iron strip in ferrite matrix (Fig. 4). The photomicrograph of the specimen BDM-18 has identified massive ferrite grains surrounded by pearlite in traces, in grain boundary at 1000X (Fig.5). The photomicrograph of the specimen BDM-8, at 500X, showing mixed structure, with elongated slag inclusions, massive ferrite and Neumann bands (Fig. 6). The photomicrograph, BDM-8, at 500X, showing mixed structure, with elongated slag inclusion. No evidence of annealing was revealed in this specimen (Fig. 7). The photomicrograph, BDM-7, at 500X indicated a mixed structure of course grain pearlite (Fig. 8). The photomicrograph, BDM-7, at 500X indicated

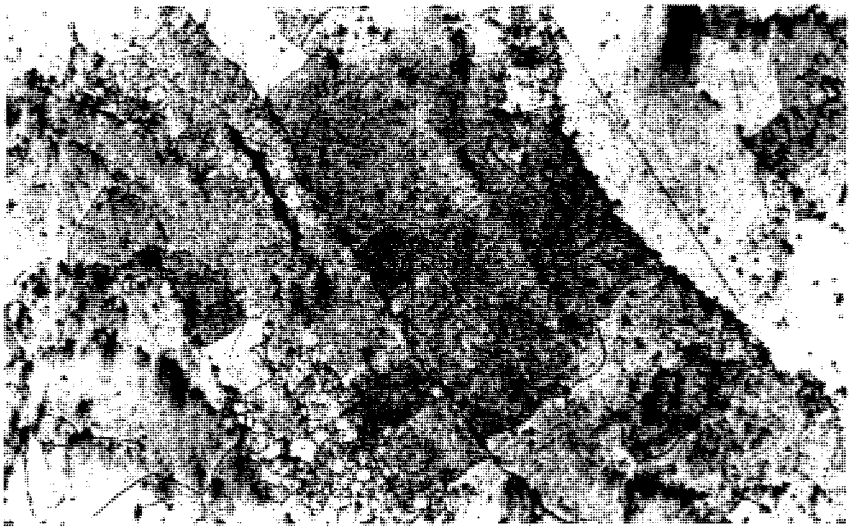

Fig. 4. The photomicrograph of the specimen BDM-18, at 100X showing rows of slag inclusions entrapped between the layers of iron strip in ferrite matrix.

Fig. 5. The photomicrograph of the specimen BDM-18, at 1000X showing massive ferrite grains surrounded by pearlite in traces, in grain boundary.

a mixed structure of course grain pearlite steel with partially spherodised carbides and angular Widmanstätten patterning (Fig. 9.). The photomicrograph, BDM-16, at 100X, indicate a fine grain corrosion layers, in ferrite matrix

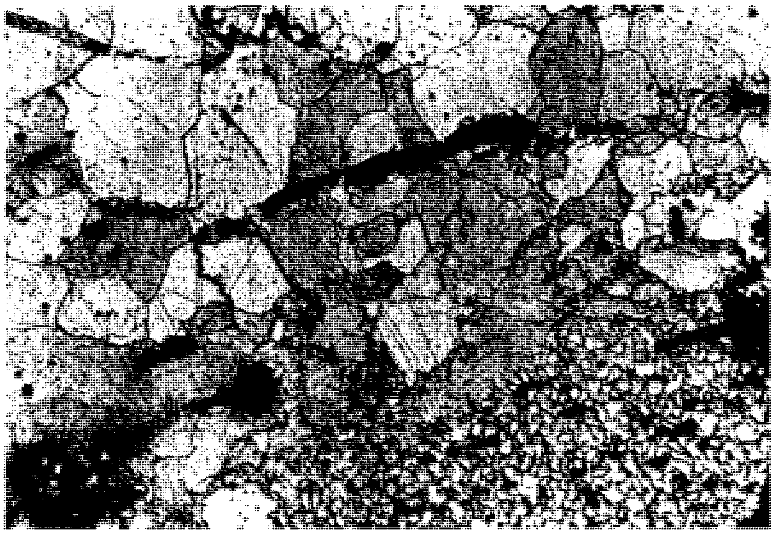

Fig. 6. The photomicrograph of the specimen BDM-8, at 500X, showing mixed structure, with elongated slag inclusions, massive ferrite and Neumann bands

Fig. 7. The photomicrograph, BDM-8, at 500X, showing mixed structure, with elongated slag inclusion

(Fig.10). The photomicrograph, BDM-16, has identified fine ferrite grains along with slag inclusions at 500X (Fig. 11). Low level of nickel and vanadium clearly suggests the use of vanadiferrous iron ores very much available in this part of the country.

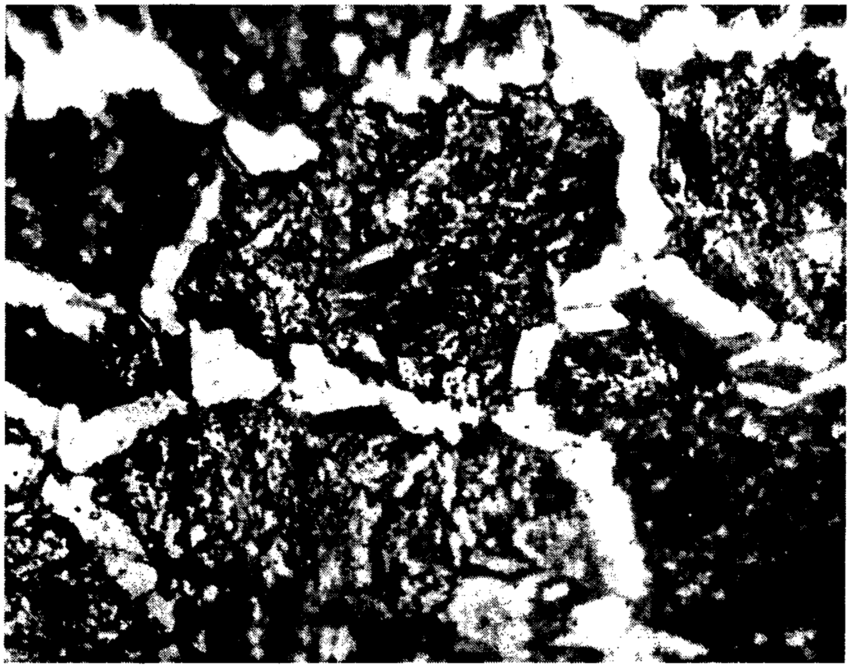

Fig. 8. The photomicrograph, BDM-7, at 500X indicating a mixed structure of course grain pearlite.

Fig. 9. The photomicrograph, BDM-7, at 500X indicating a mixed structure of course grain pearlite steel with partially spherodised carbides and angular Widmanstätten patterning.

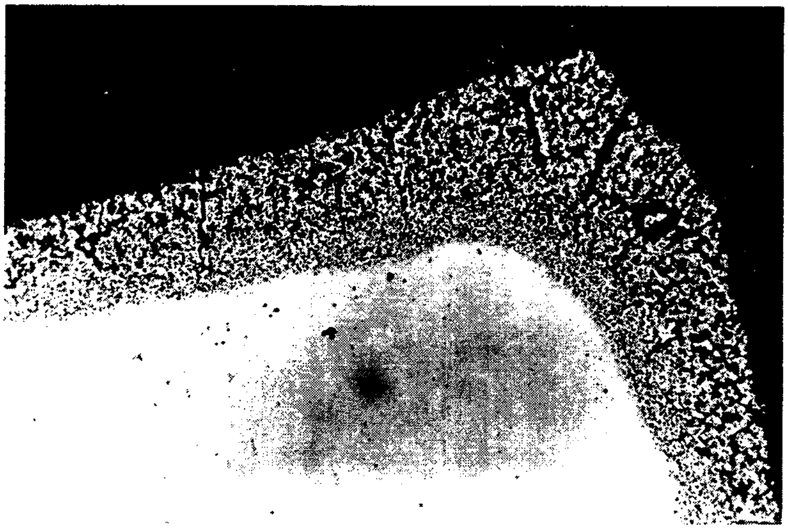

Fig. 10. The photomicrograph, BDM-16, at 100X, indicate a fine grain corrosion layers, in ferrite matrix.

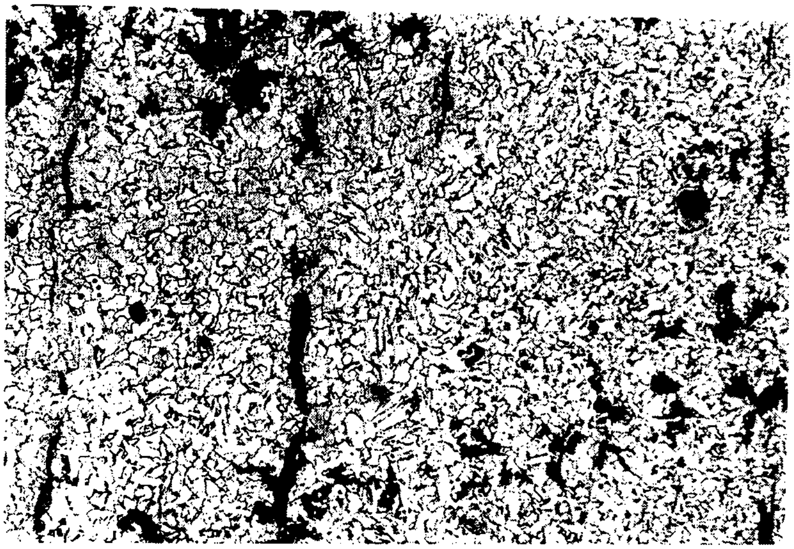

Fig. 11. The photomicrograph, BDM-16, at 500X, showing fine ferrite grains along with slag inclusions.

CONCLUSION

The present observation has highlighted the newly identified centre for origin of iron at the Mahanadi valley. Our study revealed a well developed iron and steel technology at Badmal. We are aware of the presence of layering technology of steel making by welding carburized and non-carburized iron. Our experiments with the specimen BDM-18 (Fig. 4) highlighted layers. But the microstructure clearly identified the layers with slag inclusions and carburized layers. The study revealed the layers but we can not accept that alternative thin sheets had been welded together. These layers formed during alternate forging and heating at charcoal furnace. Smiths fold the product a number of times as per their need. This was the cause of layering techniques and not the so called welding of thin sheets. Hope future scholars would reinvestigate this phenomenon and may have an idea of the initial steel making in Eastern India.

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