IRON TECHNOLOGY IN THE FIRST MILLENNIUM B. C.
A Fresh Approach to its Socio-Economic and Environmental Implications

Dissertation submitted to the Jawaharlal Nehru University
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CERTIFICATE

Certified that the dissertation entitled "Iron Technology in the First Millennium BC : A Fresh Approach to its Socio - Economic and Environmental Implications" submitted by Ms. Sreya Guha for the award of the degree of Master of Philosophy of this University, has not been previously submitted to any other University and that this is her own work.

We recommend th~~at~~ the dissertation be placed before the examiners for evaluation.

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For My Mother

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(SREYA GUHA)

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CHAPTER I

INTRODUCTION

The Approach

The Iron Age in India is a well-researched period of history but none the less the sources provide enough evidence to attempt fresh examination from a fresh perspective. This thesis dares to suggest a re-examination of the sources in order to find answers to certain aspects of the subject that have largely been ignored.

Ironically the inspiration to study the sources from a fresh perspective comes from reading studies of the indigenous iron and steel industry in the modern period and accounts of ethnographers, travellers and British officials of the 18th, 19th and 20th centuries. Scholars who have studied the indigenous industry and its decline in the 19th and 20th centuries have pointed out that the causes for decline lay in the very nature of the industry. Such is the view of historians (1), ethnographers (2) and technical experts (3). By reading such accounts it becomes clear that the nature of the technology imposed severe constraints on the scale of production. The fuel consumption, types of furnaces used and the lack of fluxing hinders large scale production. The technology described in such accounts is not very different from that reconstructed by archaeologists at ancient smelting sites. If the technology is similar, it follows that the constraints imposed on production will also be similar. Keeping this in mind, we are compelled to wonder at the scale of production at these ancient smelting sites in early India. From this it logically follows that the production was limited, then we may not necessarily be justified in talking about the 'revolutionary' role of iron in the first millennium B.C. because to a large extent it is the scale of production that would determine the role of iron tools in subsistence and craft production and transport technology. We are of course assuming that the quantity of iron tools in use at any time is a key variable.

There is a rich body of literature on the Iron Age. The works may be categorised as technical studies and those dealing with socio-economic aspects. Unfortunately, the two kinds of studies seem to remain independent of each other. Very few historians have included technical studies to enrich their study of the Iron Age. D.K.Chakrabarti (4) is one of the few exceptions though he has not emphasised this aspect because his focus is not on technology as such.

Interest in Indian iron and steel dates back to an early period. Some of the most significant reports on 'Wootz' steel were by Francis Buchanan (5) in the early nineteenth century. Buchanan's accounts are mainly confined to South India particularly Karnataka, Kerala and Tamil Nadu. He describes in detail the process of obtaining steel directly from the ore by melting the crushed ore in a clay crucible with leaves of certain trees. However, his accounts show the difference in the smelting traditions of North India and South India. (6) Other such descriptions of iron smelting traditions of different parts of the country are also to be found, such as that of Bailey's note 'On Iron Smelting (1879-80)' (7) Warth's 'Iron Making in South India (1894)' (8); Heyne's 'Iron Works at Ramanakapettah (1795)' (9); Franklin's, 'The Mode of Manufacturing Iron in Central India (1829)' (10).

A major ethnographic work is that of Verrier Elwin. In his monograph The Agaria (1942) (11) he discusses in detail their skills in the craft of iron smelting.

Alongwith the interest in indigenous industry, was the effort to analyse the composition of early Indian iron objects. The first attempt in this direction was that of Robert Hadfield (12) who analysed three specimens of Sri Lankan iron objects and also of the iron pillar at Delhi. Gradually reports of chemists began to be included in excavation reports, the first being D. R. Bhandarkar's Excavations at Besnagar (1913-14) (13) which included an early analysis of a specimen from the Heliodorus pillar. Other metallographic studies are of specimens at the site of Dhatwa in K.T.M.Hegde's, 'A Model for Understanding Ancient Indian Metallurgy' (14), M.D.N.Sahi's 'Origin of Iron Metallurgy in India' (15), H.C.Bharadwaj's 'Aspects of Early

Iron Technology in India' (16) as also studies included in excavation reports.

Other than these technical studies, research emphasising literary data was also undertaken. This was first used by M.N.Bannerjee in a paper entitled 'On Metals and Metallurgy in Ancient India' (1927) (17). Using evidence from the Ṛg Veda, the author tried to establish the antiquity of Indian iron. This argument gained much popularity and was followed by scholars such as N.R.Bannerjee (18) until it was refuted by D.K.Chakrabarti (19).

The research on the Iron Age has of course been largely based on archaeological data. The first paper to base itself exclusively on archaeology was D.H.Gordon's (20) who thought iron could have been introduced in India between 600-700 B.C. A similar argument was followed by R.E.M.Wheeler (21). However, following this a great number of new sites were excavated, throwing new light on the subject. It is now believed that iron technology was not imported to India but developed indigenously in different pockets of the subcontinent.

In contemporary times, the effort has been to systematise the available data on the Iron Age and analyse its socio-economic impact. For this, preliminary research on archaeology, literary texts, metallurgy, geology and ethnography has been used.

Historiography

The advent of technological innovations in iron working and their impact on the socio-economic environment of the first millennium B.C. has been analysed by certain scholars. One of the earliest scholars who discussed the date of the introduction of iron in the economy and its importance in the Indian context was D.D.Kosambi in his book, Introduction to the Study of Indian History (1956) (22). The book is a general historical narrative in which the author has attempted to trace in chronological order successive changes in the 'means and relations of production' (23). Kosambi deals with iron in the context of the eastward expansion of the Aryans in the first half of the first millennium B.C. He feels that iron tools were essential to clear the thick forests of the Gangetic valley. He cites literary evidence to show that iron was being used in agriculture since 700 B.C. (24).

Kosambi's argument though sketchy, took on the nature of a sacred truth for scholars who wrote on the subject after him. N.R.Bannerjee in his Iron Age in India (1965) (25) followed the general argument that iron was essential for agricultural expansion in this period.

The discussion on the socio-economic impact of the introduction of iron has strangely been concentrated on the issue of agricultural expansion and the rise of urban centres in the middle Gangetic valley in the first millennium B.C. This is because the assumed connection between iron and urbanism was most obvious in this context.

R.S.Sharma in an article titled 'Material Background of the Origins of Buddhism' (1968) (26) went as far as to suggest that the 'one single factor' that transformed the material life of the people around 700 B.C. in East U.P. and Bihar was the beginning of the use of iron implements. This is also the general theme of his later work, Material Culture and Social Formations in Ancient India (1983) (27).

A.Ghosh in his monograph , The City in Early Historical India (1973) (28) has studied the role of iron in the Ganges basin in the first millenium B.C. in the context of the phenomenon of urbanism in the early historical period. Based on the literary and archaeological sources and certain sociological theories on urban development, he examines the question if the historical city is a survival or revival of the Indus city. Ghosh does not find iron technological innovations to have played a very importnat role in urbanism in the Gangetic valley. He attributes the rise of cities to the initiatives of the mercantile class and the role of trade. As regards agriculture he finds copper-bronze tools suitable for the task of forest clearance and cultivation.

The most recent work on the subject of the role of iron is D.K.Chakrabarti's The Early Use of Iron in India (1992)

(29). The book is one of the few that deals with the subject in all its aspects - studying the available archaeological, literary as also ethnographic material. Geological and metallurgical details have also been included (30). The author attempts to establish the antiquity of Indian iron and steel. He cites archaeological evidence such as that of Ahar where iron objects and slag have been found in 'chalcolithic levels'. (31) However, Chakrabarti's thrust is not on the study of the technology as such and therefore he has not looked at the sources for such evidence regarding technology in particular.

The focus of this thesis is on early iron technology and its potentials and limitations. An attempt has been made to study the available data from a new perspective in order to ask new questions of the sources. The study concentrates particularly on sites showing evidence of iron smelting such as iron slag, crucibles, furnaces. Such evidence is available for many sites in the subcontinent. Thirty sites have been included in this study, the choice being dictated by the published data available. Since the date of introduction of iron varies from region to region, the periodisation is deliberately broad in order to include as many sites as possible for which excavation reports and metallographic studies are available. Four categories of source material have been utilised - arachaeological, technical, literary and enthnographic. The chapters are not categorised according to the sources. Rather, the sources have been examined with a particular set of questions in mind, in order to understand the potential of ancient Indian iron technology and the limitations it imposed, in its nascent stages,on the scale of production. This theme has been stressed in my argument because it must be realised that if we are to understand the impact of iron in the economy we must have some knowledge of the scale at which it was produced.

References

1. S.Bhattacharya, 'Iron Smelters and Indigenous Iron and Steel Industry of India' in Surajit Sinha (ed.), Aspects of Indian Culture and Society (1972), pp.133-51.
2. V.Elwin, The Agaria (1942).
3. F.Bailey, 'On Iron Smelting', Indian Forester Vol 5 1879-80, p.167.
4. D.K.Chakraborti, The Early Use of Iron in India (1992).
5. F.Buchanan, A Journey from Madras through the Countries of Mysore, Canara, Malabar, 3 Vols (1807).
6. C.E.A.W.Oldham (ed), Journal of Francis Buchanan kept during the visit of the District of Bhagalpur in 1810-11 (1930).
7. F.Bailey, op.cit.
8. H.Warth, 'Iron Making in South India', Indian Forester, Vol. 20 (1894), pp.100-103.
9. B.Heyne, 'Iron Works at Ramanakapettah' in Dharampal (ed) Indian Science and Technology in the 18th Century (1971).
10. J.Franklin, 'The Mode of Manufacturing Iron in Central India' in Dharampal (ed) Indian Science and Technology in the 18th Century (1971).
11. V.Elwin, op.cit.
12. D.K.Chakrabarti, in Early use of Iron in India (1992) cites R.Hadfield, 'Sinhalese Iron and Steel of Ancient Origin' Journal of the Iron and Steel Institute , pp. 134-72 (1912) and 'Science Analyses the Iron Pillar of Delhi' Indian Trade Review 26 Nov. 1912.
13. D.R.Bhandarkar, Excavations at Besnagar Annual Report of ASI (1913-14), pp. 186-226.
14. K.T.M.Hegde, 'A model for understanding Ancient Indian Metallurgy', Man, Sept. 1973, Vol. 8 No 3, pp. 416-422.
15. M.D.N.Sahi, 'Origin of Iron Metallurgy in India' Proceedings of the Indian History Congress, 41st Session 1980, pp. 104-111.
16. H.C.Bharadwaj, 'Aspects of Early Iron Technology in India' in D.P.Aggarwal and A.Ghosh (ed.), Radio Carbon and Indian Archaeology (1973), pp. 391-399.
17. M.N.Banerjee, 'On Metals and Metallurgy in Ancient India' Indian Historical Quarterly, No. 3, (1927), pp. 121-33.
------------, 'Iron and Steel in the Rig Vedic Age' Indian Historical Quarterly, No. 5,(1929), pp. 432-40.
------------, 'A Note on Iron in the Rig Vedic Age' Indian Historical Quarterly, No. 8, (1932), pp. 364-6.
18. N.R.Bannerjee, Iron Age in India, (1965).
19. D.K.Chakrabarti, 'Iron in Early Indian Literature' Journal of the Royal Asiatic Society,(1979), pp. 22-30.
20. D.H.Gordon, 'The Early Use of Metals in India and Pakistan' Journal of the Royal Anthropological Institute, (1950), pp. 55-78.
21. R.E.M.Wheeler, Early India and Pakistan, (1959).
22. D.D.Kosambi, An Introduction to the Study of Indian

History, (1956).

23. Ibid. p. 1.
24. Ibid. p. 138.
25. N.R.Bannerji, op. cit.
26. R.S.Sharma, 'Material Background of the Origin of Buddhism' in Mohit Sen and M.B.Rao (ed.), *Das Kapital Centenary Volume - A Symposium*, (1968), pp. 59-66.
27. ----------, *Material Culture and Social Formations in Ancient India*, (1983).
28. A.Ghosh, *The City in Early Historical India*, (1973).
29. D.K.Chakrabarti (1992), op. cit.
30. N.R.Banerjee (1965) preceeded Chakrabarti in using this methodology but did not elaborate on it.
31. D.K.Chakrabarti (1992), op. cit., p.,170.

CHAPTER - II

WEAPONS, AGRICULTURAL IMPLEMENTS AND CRAFT TOOLS USED IN THE EARLY IRON AGE AND THE EARLY HISTORICAL PERIOD (C.800-200 B.C.)

Before embarking on an analysis of the nature of iron technology and the early role of iron in the economy it is necessary to have some knowledge of the nature of the objects found for our period and area of study. As already mentioned the period of study is deliberately broad, that is from c. 800-200 B.C., in order to include as many sites as possible for which detailed excavation reports and metallographic studies are available. Since the aim of this thesis is not a pure quantification of objects excavated, the parameteres of time and space have been kept flexible in order to gain a better understanding of the technology and its socio-environmental implications.

Iron objects have been found all over the Indian sub-continent in the course of excavations. The sites has been divided into various iron bearing zones by scholars such as D.K. Chakrabarti (1) and the Allchins. (2) Chakrabarti has divided the sites into six 'nuclear regions' depending on their location. These are : Baluchistan, the North West, the Indo-Gangetic Divide and upper Gangetic Valley, the middle and lower Gangetic Valey, Malwa and Vidharbha in Central

India, Deccan and the megalithic South. The classification of the Allchins varies to some extent. They have divided the sites into five zones - the Indus system and Baluchistan, North India and the Gangetic Valley, Deccan, Southern nuclear region, Megalithic South.

Since including all these regions is beyond the scope of this study, we have included sites only of the Northern and Central regions with comparisons with the evidence from other sites wherever possible. The emphasis being on technology and use patterns rather than spatial distribution, only those sites have been discussed in details for which evidence for smelting is also available.so that the production process can also be reconstructed.

The criteria according to which sites have been included are the availability of detailed reports, metallographic studies, presence of evidence for localised production of iron, other than the obvious criterion of falling within the spatial and time frame of this study. Therefore, a classification along geographical lines is not required for this study . However, since knowledge of the nature of finds is essential prior to further analysis, this chapter is devoted to the compilation of the finds at the sites included.

The following list includes short resumés of the important sites included for detailed study. Tables 3-5 present the iron objects at some of these sites in tabulated form.

AHAR District Udaipur. Occupation at Ahar has been divided into two periods. Period I is Chalcolithic and Period II is early historical marked by iron and copper. There is evidence of copper smelting in Period I and iron smelting in Period II.

ATRANJIKHERA - District Etah. The site is on the bank of the Kali Nadi. It reveals continuity of occupation beginning from the early second millennium B.C. to medieval times. The earliest period is represented by the Ochre Coloured Pottery (OCP), followed by the Black and Red ware (BRW), Painted Grey ware (PGW) and Northern Black Polished ware (NBPW) in Periods II, III and IV respectively. Iron first occurs in Period III. Presence of slag from the earliest levels indicates that iron was locally smelted.

DHATWA - District Surat. The site is on the Tapi river. Excavations revealed Chalcolithic occupation dated to C. 15th to 10th century B.C. and early historical from C. 5th -4th century B.C. to 3-4 th century A.D. Iron is first found in levels dated approximately to second century B.C.. There is evidence of a flourishing iron smelting industry.

DHULIAPUR - District Midnapur. Excavations reveal that the neolithic culture was succeded by the Iron Age culture. Large quantities of slag have been found indicating local smelting activities.

HASTINAPURA - District Meerut on the bank of on old bed of the Ganga. Excavations show five period of occupation with a break between each. Iron occurs in Period II, represented by PGW, but the only objects found are slag lumps. Iron objects are more numerous in Period III, represented by NBPW. The earliest occupation of the site is represented by OCP and the last by medieval glazed pottery.

HATIGRA - District Birbhum. Chalcolithic levels at the site are succeded by an early Iron Age occupation.

KANKRAJHAR - District Midnapur. Finds are similar to those at Dhuliapur. Iron Age succeeds the Neolithic levels at the site.

KAUSAMBI - District Allahabad, on the Yamuna. Four periods of occupation have been identified at the site. Iron occurs in Period II with PGW and BRW.

MAHURJHARI - District Nagpur. A Megalithic site dated to the 7-6 th century B.C. Iron occurs in the Megalithic burials. These is no evidence of habitation at the site. Similar evidence is found at the neighbouring site of Junapani.

NAGDA - District Ujjain. Excavations reveal three occupational levels. Period I is Chalcolithic, period II is pre-NBPW and Period III is early historical. Iron first occurs in period II.

NAIKUND - District Nagpur. Megalithic site in the Vidharbha region. Assemblage in the burials is similar to Mahurjhari. However, the site has both a burial and habitational mound. There is evidence of iron smelting from the earliest levels. It is the only site where a brick furnace has been found. It is dated to the 7-6th century B.C.

RAJGHAT - District Varanasi. Excavations reveal a continuous sequence of six periods from NBPW to medieval period. Iron occurs from the earliest levels. There is evidence of both copper and iron smelting.

TAKALGHAT - KHAPA - District Nagpur. Twin megalithic sites in the Vidharbha. Khapa is a burial site while Takalghat has a habitational mound. There are three phases of occupation. Iron occurs at both sites but more so at the burial site. Dated to the 7th-6th century B.C.

TAXILA (in Pakistan). The site is an early city of Gandhara. Three successive cities had been identified as Bhir Mound (C.500 B.C. to 200 B.C.), Sirkap (200 B.C.-c.100 A.D.), and Sirsukh (Kusana Period). In 1980 a new habitation was identified at Haithal. The earliest city at Taxila is now dated to c. 1000 B.C. This culture has a marked Gandhara nature but from the Bhir mound period there is a strong Gangetic character.

UJJAIN - District Ujjain. Excavation reveal four successive periods of occupation from 750 B.C. - 1500 A.D. Iron occurs from period I. There is evidence of a flourishing iron smelting industry.

The iron objects found in the excavations may be divided under three heads to facilitate analysis : (i) weaponry (ii) craft tools and implements (iii) household objects. Other than these three catagories of objects, slag lumps have been found at sites where iron was smelted. Since their discussion has been included in a separate chapter, these slag lumps have not been dealt with here. Objects of indeterminate shape or unidentified objects have also not been included. Tables 3 to 5 give a general idea of the range of objects found at different sites, allowing comparisons between sites.

WEAPONRY

Weapons of different categories have been found at sites. The main types found are :

(1) Bows and arrows : The bow and arrow is the supreme weapon in the ancient period. Every hero mentioned in texts is an accomplished archer. No bow is found in archaeological remains but arrowheads are found at all sites and are of numerous shapes. We may compare the shapes found at three major sites for which details are available.(Table-1). Atranjikhera(3) and Kausambi(4) and Taxila (5). At these sites bone arrowheads have also been found in the same levels as the iron arrowheads. It is intersting to note that the

introduction of iron does not affect the popularity of bone of these sites. At Atranjikhera for example, in the PGW phase (6) while forty three of the seventy one bone objects are arrowheads, only twenty one of the one hundred and thirty five iron objects are arrowheads. In the NBPW phase(7), one hundred bone objects are arrowheads while thirty of the three hundred and thirty eight iron objects are arrowheads. However, iron is the more widely used material. Other than arrowheads, bone is used only for pendants, beads and styli. While iron is used for other weapons such as spears and javelins, for tools, impliments and household objects. Simiarly at Taxila,(8) bone and ivory are used for bangles, beads, pendants, amulets, combs, antimony rods, handles, ear cleaners and flesh rubbers, other than arrowheads. However, iron is used for weapons of eight types such as javelins, dagger, sword, spearhead, spud, elephant goad and armour plates, for implements of twenty two types including tong, anvil, hammer, nails, axes, adzes and fifteen types of household objects such as sieve, spoon, lamp, bell, cauldron, tripod, bowl.

At Kausambi(9) arrowheads of bone, ivory and horn appear along side iron arrowheads. At the site 370 iron arrowheads have been found in NBPW levels out of a total of 678 objects which are in a tolerable state of preservation. Weapons are most numerous at this site and very few other artefacts of iron have been found.

Arrowheads are the most commonly found artefacts. They are found at almost all the sites but their relative numbers vary. While at Kausambi 30% of the objects are arrowheads, at Mahurjhari(10) only 10% of about thirty objects found in the graves at the site are arrowheads.

(ii) Spearheads - Next to arrowheads, spearheads are the most commonly found weapons. They too are found at almost all iron- bearing sites. At Atranjikhera(11) out of thirty-nine weapons, eight are spearheads, in the PGW levels and out of sixty in the NBPW levels, twentyfour are spearhead. At Kausambi(12) fifty eight spears and javelins have been found. They have been categorised into five types, all of which occur in both levels.(Table-2). Spearheads are not so numerous at any other site. At Mahurjhari,(13) no spearhead has been found but 'sulas' or spikes have been excavated. These are of two types those with a knobbed tang and with a plain tang. The longest specimen measeres 97 cm. Ten such 'sulas' have been indentified at the site.

(iii) Battle Axe - Axes are found at many archaeological sites but it is difficult to establish whether they were used for battle or as a tool. At Taxila(14) seven axes have been found at Sirkap and one at Bhir Mound. They are of four different types. At Atranjikhera (15) one each has been found in the PGW and NBPW levels and one in the late levels at Hastinapura. (16). At Mahurjhari (17) and other sites in the Vidharbha axes of two types are found - those with elongated body and those with thick broad body. All these axes have cross- fasteners. They vary greatly from the socketed axes found at Taxila. Very few have been found at habitation sites. Most of the specimens are from the burial sites--seven are found at Khapa(18) and twenty eight at Mahurjhari.(19)

(iv) Swords and Daggers - Swords and daggers are not very numerous and belong to late levels. At Taxila(20) three types have been identified and they belong exclusively to the 1st c. A.D. Swords blades are not found at any North Indian site.

(v) Body Armour - The only site where armour plates have been found is Taxila (Sirkap).(21) Eighteen such plates have been excavated besides three links of chain, two armplates and one helmet. The armour plates are well preserved. They are curved to fit the shape of the body and pierced with holes for lacing.

(vi) Horse - equipment - This category of objects may be included in the section on weapons. Such objects are found only at Taxila,(22) Takalghat-Khapa(23) and Mahurjhari(24).At Taxila more than four specimens of horse-bridle have been found. Bits which would have been attached to bridles are of three types-those with inter-locked bars, those with an additional ring and those with an additional bar.

TOOLS AND IMPLEMENTS

The second important category of iron objects to be found are tools and implements. These may be further divided into two categories-craft tools and agricultural implements. The nature of the tools and implements throws light on the nature of the economy at the sites just as the study of the weaponry helps to reconstruct ancient warfare. Unlike the case of weaponry, it is difficult to find references to craftsmens tools in ancient texts. References to agricultural implements are more numerous. Among the craftsmens tools found at archeological sites are :

Tongs : Tongs are not commonly found but they are of great significance because they are an essential item of the smith's tools kit. Without tongs it would be near impossible to handle hot metals in the forge or hold crucibles of molten metal. The tool imparted much efficiency to the smiths' craft. The tongs (kuṭilika) are mentioned as a blacksmiths tool in some texts.

In archaeological remains, a number of tongs are found at Taxila (25) and two at Atranjikhera (26). At both sites the tongs are of iron and no other material. It become obvious that this innovation marked a great improvement in the metalworker's technique, making him more dexterous at his craft.

Anvil – Anvils made of metal are rarely found in excavations. The only site they are reported at is Taxila (27) where anvils of few types have been found. All could have been used for metallurgy. Till today, metal anvils are rarely used by the smith. A large flat stone serves the purpose. The same probably held true for the ancient period. Literature refers to the anvil (adhikarṇi) as one of the smith's tools.

Hammer – Hammers vary in shape according to their use. Hammers too are rarely found in excavations, the exceptioal site being Taxila (28). This is suprising since this is a tool of common use.

Saw – The only site where an iron saw is found is Taxila (Sirkap) (29) ; though copper and broze saws were used by the Harappans. At Brahmagiri certain objects have been identified as saws but this has not been established.

Axe/Adze – The axe and the adze are found at almost all important iron bearing sites. The axe is a chopping tool and may be used as a weapon as well. The adze is a lighter tool used for slicing. It is essentially a carpenters implement. Both axes and adzes are found at Taxila (30) . All the axes are socketed. They are more numerous at Sirkap than at Bhir mound. In the upper Ganga plain axes are rare. Only two are found at Atranjikhera, (31) one each in the PGW and NBPW levels. These agains are socketed. No adzes are found at this site. In the megalitlic sites of Vidharbha axes and adzes are the most common objects. At Mahurjhari (32) 28 axes and 16 adzes are found and at Khapa (33) 15 adzes and 7 axes. Socketed axes are absent at these sites. All axes are with cross-fasteners.

Chisel - Chisels have many uses. They are used by carpenters, masons and smiths. Chisels are reported from Sirkap,(34) Atranjikhera,(35) Hastinapura,(36) Khapa,(37) and many other sites. Iron chisels from the megalithic levels of Brahmagiri and Adichanallur are bevelled on both faces and were perhaps used as tips for wooden ploughs.(38)

Knives - Knives are the most commonly used imlpements. In the archaeological remains, in the North-West,knives are found at Bhir Mound and Sirkap.(39) The types are straight backed, tanged and convex edged. In the megalithic period, iron knives with blades with short tang are found at Takalghat-Khapa.40)

Nails - Iron nails are found at Takalghat - Khapa(41) in the megalithic context and in the early historical levels at Hastinapura(42) and Kausambi(43). They are variously shaped - circular, hooked, oblong, bulbous. At Hastinapura(44) and Gangapur(45) copper nails occur in the same levels. While nails are numerous at sites, literary references to these are few. Hardly any text mentions nails in particular. However nails would have been essential to many artisans - carpenters in particular.

Hoe - The hoe is the simplest of agricultural implements, at times little more than a digging stick equipped only to loosen the soil. The hoe is one of the implements not found at sites in the North-West, not even at Taxila (46) where particularly a wide range of implements have been found. One hoe is found in the NBPW levels of Atranjikhera(47). At Naikund (48) and Mahurjhari(49) complete hoes have been found. S.B Deo refers to them as short ploughshares.

Sickle - The sickle is a reaping instrument with a short handle and semi-circular blade. It is found in the early historical context at Ujjain(50), Kausambi(51), Hastinapura(52).

Ploughshare - The ploughshare is a pick like objects with a large pointed blade fixed to a plough, used for cutting in the soil. The iron ploughshare is found in the earlest context at Jakhera (53) in the PGW levels. At Atranjikhera(54) it is found in the NBPW levels. The other sites where they are found are Saradkel(55) and Kausambi(56) plough shares are conspicuous by there absence at all other sites.

HOUSEHOLD OBJECTS

Objects of domestic use such as dishes, spoons,bangles, needles are found at many sites but they are not numerous. It appears that for such purposes copper-bronze was the prefered metal because the types that occur in these metals are restricted to articles of ornamentation or domestic use. Iron, because of certain physical properties such as hardness and toughness was used largely for weapons and tools/implements.

Iron in Warfare - what clearly emerges from the archaeological data is that weapons are available in larger numbers at all sites with the exception of sites in Gujarat (57) where tools and implements are more numerous. The Iron Age in Gujarat however, belongs to a later period. In the Ganges basin in particular both archaeological and literary data point to the abundance of weapons. The Ṛg vedic references are to metal implements of war and hunting in particular. In Later Vedic texts there are references to agricultural implements as well but these are outnumbered by the references to weapons. The weapons mainly referred to in Vedic literature are the sword, spears, arrows, bows. The best sources to study weapons are the Epics which specifically mention iron weapons such as spear, arrows bows, ,swords, and fortifications. The Arthaśāstra too devotes a chapter to the discussion of weaponry though not iron weapons in particular. If we consider the period between c 1000 B.C. - 300 B.C., that is the period which saw the introduction and acceptance of iron in the Ganges basin, we find that it coincides with the transition from tribal polities to monarchical states. The period saw the gradual transformation of small janapadas to large monarchies. Initially we hear of 16 mahajanapadas in the region. In 600 B.C. they are reorganised into 4 large states Magadha, Kashi, Anga, Vat and by 321 B.C. the great Mauryan empire evolves with its base at Magadha. Iron weapons would have given a superior edge to the janapada warfare. Inevitably it must have played an important role in state formation in the region. Archaeological evidence shows that with the introduction of iron weapons, weapons of other metals such as copper-bronze dwindle in numbers.

<u>Iron in agriculture</u> : The role of iron in agriculture is the subject of a long standing debate, in context of the Gangetic valley. It is the opinion of scholars such as Kosambi(58) and R. S. Sharma(59) that iron was one of the essential factors that changed the material life of people in the region around 600 B.C. It is felt that without the iron axe and plough it would be impossible to clear the land and till the soil of the Ganga basin. It is certain that iron had considerable impact on the economy or else it would not have spread so easily. Archaeology suggests C.1000 B.C. as the date for introduction of iron in the region. The earliest objects are weapons. Literature attests the use of iron in agriculture by c. 700-600 B.C. In the Śatapatha Brāhmaṇa (13-2.2.16-19; 13-3. 4.5) iron is associated with the pesantry and people in general (60) (700 B.C.). The Suttanipata makes a references to iron plongshare (c.500

B.C). The concern for plough agriculture can be inferred from details given about agriculture. The farmer is asked to prepare the ground and sow seeds carefully and supply water and fire(61). Paṇini (62) refers to the plough by many names–sīra (iv.2.184), hala (iii 2.183, iv 4.81, vi.3.83). In the Arthaśāstra the main agricultural implements was the plough. By this period the transition to plough agriculture was complete in the Ganges basin.

Archaeological evidence to corroborate the date from texts is insufficient. Hardly any ploughshares or other agricultural implements are found at sites. The earliest dated ploughshare is found in the PGW levels of Jakhera and in the NBPW levels of Atranjikhera. At Atranjikhera other agricultural implements are also rare. In the NBPW levels, 4 sickles, 1 spud, and 1 hoe have been found besides the ploughshare. Sickles are also found at Jakhera and Kausambi. Such implements are rare in other regions as well. In the Vidarbha, hoes are found at Mahurjhari and Naikund. In Malwa, sickles and hoes are found at Nagda, Maheshwar – Navdatoli and early historic Ujjain. They are the main tool types in Gujarat but in a later period (C. 500 B.C. and later).

The archaeological evidence presented in this chapter gives a fair idea of the nature and typology of iron objects found in the period and area of study. However this knowledge is not sufficient to gain an understanding of the nature or the scale of production. In order to do so we must undertake a study of the archaeological evidence for smelting activities and take the help of metallographic studies conducted by scientists. The following chapter is devoted to such a study.

Table 1: ARROW HEADS FOUND AT ATRANJIKHERA, KAUSAMBI, TAXILA

	ATRANJIKHERA		KAUSAMBI		TAXILA	
ARROWHEADS	PGW	NBPW	PGW	NBPW	BHIR MD	SIRKAP
IRON						
1. Rhombic cross section.				*	*	*
2. Square cross section.				*	*	*
3. Rectangular cross-section.				*		
4. Conical blade lozenge cross- section.				*		*
5. Socketed.			*	*		*
6. Knife blade, lozenge cross- section.				*	*	*
7. Triangular cross section.	*	*		*	*	
8. Double tanged.				*		
9. Three bladed.				*		*
10. Barbed blade.				*	*	*
11. Leaf shaped blade cross-section.	*	*		*		
12. Circular cross-section.			*			
13. Irregular cross-section.			*			
14. Bud shaped.			*			
15. Double grooved			*			
16. Four bladed.						*
17. Elongated Leaf shaped.	*	*				
18. Elongated straight blade.	*	*				
19. Cylindrical	*	*				
20. Bioconvex	*	*				
21. Club shaped	*	*				
22. Triangular pointed tip.		*				

'*'=PRESENT

TABLE 2: SPEARS AND JAVELINS FOUND AT ATRANJIKHERA, KAUSAMBI, TAXILA

	ATRANJIKHERA		KAUSAMBI		TAXILA	
SPEARS/JAVELINS	PGW	NBPW	PGW	NBPW	BHIR MD	SIRKAP
1. Leaf shaped lozenge cross-section.		*	*	*		*
2. Solid point, plain long lozenge cross-section.			*	*		
3. Large, flattened leaf shaped, with lozenge cross-section.		*	*	*		*
4. Socketed head and circular cross-section.			*	*		
5. Socketed head and rectangular cross-section.			*	*		
6. Heavy with fore-shaft.	*					*
7. Triangular, elongated.		*				
8. Elongated thick.		*				
9. Cylindrical pointed.		*				
10. Dagger shaped.		*				
11. Four sided pike-head.						*
12. Three flanged head.					*	
13. Socketed conical.						*

'*'=PRESENT

TABLE 3: IRON OBJECTS AT TAXILA

OBJECTS	BHIR MOUND (6-2 BC)	SIRKAP (3 BC - 2 AD)
WEAPONRY		
1. Spearhead	1 Spike shaped with tang.	2 1. Leaf shaped, socketed. 2. Dagger shaped, socketed.
2. Javelin	1 (Three flanged head)	2 (Four flanged with long shaft)
3. Spud	-	1
4. Arrow head	10 (double tonged, only in one case barbed and ribbed)	3 (Knife blade head Conical head and 3 bladed head)
5. Sword	-	3 (Straight, double edged with cross-guard)
6. Dagger	1	4 (Doubel edged, straight blade, cross guard, one shod with bronze, with tang)
7. Elephant Goad	1 (Sharp Point at one end andcurved hook at other)	1 (Similar to that in Bhir Mound)
8. Armour	-	(18 Armour plates, 3 links of a chain, 2 arm plates 1 Helmet.
TOOLS & IMPLEMENTS		
9. Tong	1	a number of specimens
10. Anvil	1 (Square with pointed legs)	3 (Square with splayed top, 2. Stool, type 3. Sound, bar type)
11. Hammer	-	a number of specimens
12. Saw	-	1
13. Clamp & Staple	-	a number of specimens
14. Chain	-	a number of specimens
15. Spades/Hoe	-	a number of specimens
16. Weeding fork	-	a number of specimens

TABLE 3: IRON OBJECTS AT TAXILA (Contd.)

OBJECTS	BHIR MOUND (6-2 BC)	SIRKAP (3 BC - 2 AD)
TOOLS & IMPLEMENTS		
17. Sickles	-	more than one specimen
18. Ingot	-	more than a hundred specimen
19. Flesh-hook	-	-
20. Shovel	-	2
21. Horse Bridle	-	4
22. Folding Chair	-	-
23. Pin/Nail	10 1. Perforated Law 2. Disc Head 3. Splayed Head	a number of specimens
24. Chisel	-	2 1. straight edge (stone workers) 2. curved edge (carpenters)
25. Knife	2 (straight edged, straight, backed tanged)	2 (straight backed, tanged, convex edge)
26. Scissors	-	1
27. Socket	-	-
28. Bar	-	-
29. Adze	2 (their rounded top tapering blade)	3 (broad blade)
30. Axe	1 (socketed, drooping blade)	7 1. Socketed, splayed 2. Socketed, long black 3. Socket projected over handle.

TABLE 3: IRON OBJECTS AT TAXILA (Contd.)

OBJECTS	BHIR MOUND (6-2 BC)	SIRKAP (3 BC - 2 AD)
HOUSE HOLD OBJECTS		
1. Scale pan	1 (rounded, with two loop handles)	1
2. Sieve	1	-
3. Cauldren	-	4
4. Tripod	-	2
5. Bowl	-	3
6. Dish/Saucer	-	3
7. Frying pan	-	2
8. Spoon	-	4
9. Lamp	-	1
10. Candelabrum	-	3
11. Incense burner	-	1
12. Bell	-	5
13. Lock, key	-	1
14. Finger-ring	-	-
15. Wheeled brazier	-	1

TABLE 4: IRON OBJECTS FOUND AT SOME SITES IN PGW/NBPN CONTEXT

	ATRANJIKHERA		HASTINAPURA		KAUSAMBI
OBJECTS	PGW	NBPW	PGW 1100-880	NBPW CB-3BC	NBPW
WEAPONS					
1. Arrowhead	21	30	1	-	370
2. Spearhead	8	24	-	-	58
3. Shafts	10	5	-	-	-
4. Dagger	-	-	-	-	-
TOOLS+IMPLEMENTS					
5. Sickle	-	4	-	-	-
6. Spud	-	1	-	-	-
7. Ploughshare	-	1	-	-	-
8. Hoe	-	1	-	-	-
9. Khurpi	-	2	-	-	-
10. Clamp	21	39	-	-	-
11. Ring-Faster	-	4	-	-	-
12. Socketed Clamp	-	4	-	-	-
13. Staple	-	3	-	-	-
14. Bolt	-	1	-	-	-
15. Plumb-Bob	-	4	-	-	-
16. Nail	20	73	-	-	-
17. Bar	7	12	-	-	-
18. Hook	7	18	-	-	-
19. Borer	6	18	-	-	-
20. Chopping Knife	-	1	-	-	-
21. Tongs	1	1	-	-	-
22. Chopper	-	10	-	-	-
23. Pipe	-	3	-	-	-
24. Scraper	-	3	-	-	-
25. Chisel	6	14	1	-	-

contd....

OBJECTS	ATRANJIKHERA PGW	ATRANJIKHERA NBPW	HASTINAPURA PGW 1100-880	HASTINAPURA NBPW CB-3BC	KAUSAMBI NBPW
26. Axe	1	1	1	-	-
27. Adze	-	-	-	1	-
28. Knife	3	13	-	-	-
HOUSE HOLD OBJECTS					
29. Lid	-	1	-	-	-
30. Disc	-	1	-	-	-
31. Bangle	2	3	-	-	-
32. Needle	1	-	-	-	-

TABLE 5: IRON OBJECTS IN THE MEGALITHIC CONTEXT IN VIDHARBHA

OBJECTS	Takalghat	Khapa/Gangapur		Mahurjhari	Naikund
WEAPONS					
1. Spearheads	-	-	1	10(Sulas)	-
2. Sword	-	1	-	-	-
3. Arrowheads	3	4	1	3	-
4. Dagger	1	3	-	17	-
TOOLS/IMPLEMENTS					
1. Nails	4	2	2	1	-
2. Knife	1	1	-	-	1
3. Chisel	-	4	6	11	3
4. Spikes	-	1	1	-	-
5. Axe with	1	7	-	28	4
6. Double edged	2	15	9	16	2
7. Blade with tang	1	-	1	-	-
8. Bar/rod	1	1	-	-	-
9. Fish-hook	1	1	-	-	-
10. Nailparer cum ear-pick	-	7	8	22	-
11. Hoes(short plough-share)	-	-	-	2	1
12. Tang pieces	3	7	8	4	2
13. Sickle	-	-	-	-	-
14. Champ	-	-	-	-	-
15. Horse equipment (bits, sheets)	-	1	-	6	-
HOUSE HOLD OBJECTS					
1. Ladle	2	8	7	-	-
2. Candlebra	-	1	-	-	-
3. Lamps	-	-	-	15	-
4. Bangle	-	3	-	-	-
5. Rings	-	-	-	-	-

REFERENCES

(1) D.K. Chakrabarti,. 'The beginning of Iron in India.' Antiquity, Vol.50 (1976), pp. 14-125.
(2) B. and R. Allchin, The Rise of Civilisation in India and Pakistan.(1983), pp.308-346.
(3) R.C.Gaur, Excavations at Atranjikhera, (1983).
(4) G.R.Sharma, Excavations at Kausambi, (1960).
(5) J.Marshall, Taxila (1951), Vols.1-3.
(6) Gaur, op. cit, p. 219-30 & p. 214.
(7) Ibid., p.412-21 & p. 422 ff.
(8) Marshall, op.cit., (Vol-II) pp. 651-666.
(9) Sharma, op.cit., p.47.
(10) S. B. Deo, Mahurjhari Excavations 1970-2, (1973), p.47.
(11) Gaur, op.cit., p.222-3, and p.424-5.
(12) Sharma, op. cit., p. 48 .
(13) Deo, (1973), op. cit.
(14) Marshall,op.cit.(Vol-II) pp.551-2 .
(15) Gaur,op.cit.,p.230 & p.440.
(16) B.B.Lal, 'Excavations at Hastinapura and other Explorations,' Ancient India Nos.10 & 11 (1954-55),p.97.
(17) Deo,(1973), op.cit.,pp.43-44.
(18) Deo,(1970), Excavations at Takalghat and Khapa,p.48.
(19) Deo,(1973), op.cit.,pp.43-44.
(20) Marshall, op.cit.,Vol-II pp.554-5.
(21) Ibid., pp.549-50.
(22) Ibid., pp.550-51.
(23) Deo,(1973) op.cit.,pp.51-52
(24) Deo,(1970) op.cit.,p.49.
(25) Marshall., op.cit.,pp.554-5.
(26) Gaur,op.cit.,p.228.
(27) Marshall, op.cit.,pp.555-6.
(28) Ibid.,p.555.
(29) Ibid.,p.554.
(30) Ibid.,pp.552-3.
(31) Gaur,op.cit.,pp.230 and p.240.
(32) Deo,(1973),.op.cit.,pp.43-44.
(33) Deo,(1970),op.cit.,p.48.
(34) Marshall,op.cit.,p.553.
(35) Gaur,op.cit.,p.226 & 438.
(36) Lal, op.cit.,p.97.
(37) Deo,(1970) op.cit.,p.47.
(38) Allchin & Allchin, op.cit.,p.344.

(39) Marshall,op.cit.,p.554.
(40) Deo,(1970) op.cit.,p.47.
(41) Ibid.,p.48.
(42) Lal,op.cit.,pp.97-98.
(43) Sharma ,op.cit.,p.45.
(44) Lal,op.cit.,pp.96-97.
(45) Deo,(1970) op.cit.,p.51.
(46) Marshall op.cit.,pp.559-61.
(47) Gaur, op.cit.,p.426.
(48) Deo and Jamkhedkar,Naikund Excavations (1982).
(49) Deo,(1973) op.cit.,p.47.
(50) N. R. Bannerji, Iron Age in India (1965),p.179.
(51) Sharma ,op.cit.,p.45.
(52) Lal,op.cit.,p.97.
(53) M.D.N. Sahi, 'Excavations at Jakhera', Man and Environment,No.2,(1978),pp.101-3.
(54) Gaur, op.cit.,p426.
(55) A. Ghosh, An Encyclopaedia of Indian Archaeology (1989),p.393.
(56) Sharma, op.cit.,p.45.
(57) R.N. Mehta and S.N. Chowdhary, Excavations at Dhatwa (1975).
(58) D.D. Kosambi, 'An Introduction to the Study of Indian History' (1956).
(59) R. S. Sharma, Material culture and Social Formation in Ancient India (1983).
(60) Kosambi, op.cit.,p.116.
(61) R. S. Sharma, op.cit.,pp.120-121.
(62) V.S. Agarwala,Indian as known to Panini (1953),p.198 & 234.
(63) R. P. Kangle,The Kautilya Arthashastra, Part-III(1969).

CHAPTER III

PRELIMINARY INVESTIGATION OF THE TECHNOLOGY : ARCHAEOLOGICAL EVIDENCE

Metallographic Studies

The Iron Age brought in a new stage in metallurgy because a new set of techniques such as tempering, quenching, carburising were introduced. The hardness of iron and steel depend on the total control over the production process rather than the inherent properties of the ore. Therefore the iron smith requires control over the temperatures, furnaces & fuels. The extraction of iron from the ore is a two-step process. Iron does not melt at temperatures less than 1585 degree centigrade. This could not be obtained in ancient furnaces. The ore was reduced to a viscous, spongy, mass called 'bloom'. To extract the iron the 'bloom' was taken hot from the furnaces and forged on an anvil to squeeze out the entrapped slag. The 'bloom' was repeatedly heated and forged in order to remove all the slag. The end product was iron ore of great purity. Iron smelting requires the use of correct flux to remove impurities from the ore. Flux is any chemical substance that reacts with the impurities in the ore by lowering their melting points so that they flow out easily as slag, quickening the process of separation of ore and metal. However, high iron content in the slag found at various smelting sites in the subcontinent shows that no flux was used. Iron requires a carbonized fuel for smelting and the best known fuel at the time was charcoal, which not only burns hotter than wood but also creates a reducing temperature in the furnace, that is eliminates oxygen and infuses the metal with carbon.

The sites showing evidence of smelting in the protohistorical and early historical period are spread all over the subcontinent. An attempt to reconstruct the technology used at these sites makes it clear that while a basic technique was used, there are regional variations that cannot be overlooked. The reconstruction is mainly done by analysis of the iron objects, slag remains and furnaces found at the smelting sites. Unfortunately, metallographic studies are available for very few sites but where ever they are, they are of immense significance. An attempt to reconstruct the metallurgical technique was made at Dhatwa,(1). No furnaces have been found at the Dhatwa but the author has attempted to reconstruct the type of the furnace probably used.(Fig.4). The iron industry at the site is dated between c. 400 B.C. - c.A.D. 300 century . More objects and large quantities of slag were recovered from the upper-most layers, indicating that the industry grew in strength in course of time. Slag samples show that the technique was wasteful. No flux was used to remove impurities and therefore the iron content in the slag was high. The metal samples shows a high degree of purity. Iron was extracted by a simple method by directly firing the ore along with charcoal in small crucible shaped furnaces. The 'bloom' was forged into strips while red hot on an anvil and welded together to form tools(2). Tables 1 and 2 show the comparison between the composition of slag and metal at the site.

The data show that both samples were of wrought iron which is too soft a material to manufacture agricultural tools out of. Analysis of a hoe shows that the object was made from strips of metal welded together to give strength. It is significant that at Dhatwa the craftsman did not manufacture steel, which could have been produced by infusing the metal with more carbon.

At Rajghat(3), too this process was used to extract metal from the ore. However at this site the metal shows the presence of carbon, showing that the metal was carbonized while forging. The carbon content, however is too low to qualify as steel which contains at least 0.25 - 0.3% carbon(4). At the site there is evidence of early experiments of the smiths. Heaps of slag containing high quantity of iron oxide is found. These represent the partially successful reduction caused by inappropriate smelting conditions. No flux was used. The composition of metal shows the presence of slag indicating that the process was not entirely successful. The metal shows great purity (Table 4) but in most cases the slag remained. Slag analysis shows that much of the metal was lost in the slag. The question that arises is why no flux was used for smelting iron while there is evidence that it was used for copper smelting(5). The silica content in copper slag found at the site is 39.17%. Only 1% of metal is lost in the slag, indicating that the extraction was successful. Table 3 shows the comparison of the chemical composition of copper and iron slag found at Rajghat.

Flux was used to lower fusion temperatures and to remove impurities at other copper-smelting sites as well. At Ahar(6) the slag shows high percentage of silica (35-38%). The impurities in the metal show that the ore came from Khetri. The silica content in the ore is only 16.70% while that of the metal is almost twice that. This indicates that the silica was been artificially added.

At Atranjikhera(7) the slag has been found in both PGW and NBPW levels, along with black smiths tools such as tongs, clamps, knives and also smelting furnaces. The ore was smelted in open pit-like furnaces where temperatures were raised high enough to allow the bloom to collect at the bottom. As in the cases mentioned above, no flux was used and the percentage of iron remaining in the slag was high.

At Ujjain(8), slag and unsmelted ore has been found in Period II (500-300 B.C.) and III (200 B.C. onwards). Lumps of calcite and quantities of lime have been found close by. According to the excavator, at Ujjain there is evidence for the use of flux. A simple method of smelting was employed. Several alternate layers of charcoal and ore were laid, covered thickly with clay to prevent the heat from escaping, allowing for passages for intake of air and escape of gases and outlets for slag. Charcoal was used as a fuel according to the excavator. The smelted metal was cooled by immersing it in water and beating it with hammers to remove the slag.

At Tadakanahalli(9), a megalithic site in Karnataka, the earliest date for iron is 1000 B.C.. Yet again the same method was used. The objects were forged from the 'bloom'. The 'bloom' was beaten into sheets, according to excavators, in order to beat out the slag and repeatedly heated to carbonize the iron. Unlike any of the sites mentioned so far, at Tadakamahalli, the objects were made of low carbon steel. The carbon content varied from 0.5 - 0.7 %. The technique as reconstructed by the excavators was as follows: layers of iron were forged together. Sheets of wrought iron and steelwere used alternately to from bars. These bars were folded in a manner that made the steel layers come to the outer surface. A similar process was later used at Hatigra.

At Hatigra(10) in Birbhum district the 'Iron Age' (dated 900 B.C.) followed the 'Chalcolithic' period but the cultural changes between the levels are not very distinct. The sample analysed from a dagger found at this site appears to be steel because the carbon content is high. According to the analysts the high carbon content is due to exposure of the metal to heat, in either the smelting furnace or in the forge at around 1200 degree centigrade. There is no evidence for the use of flux. The specimen contains a trace of silica, probably the slag that was not squeezed out. Since the metal was exposed to prolonged heating, probably most of the slag was beaten out. The specimen at Hatigra indicates a more advanced stage of iron technology, than at any other site discussed so far.

At Kankrajhar and Dhuliapur(11) in Midnapur district, large quantities of slag and ore are found, besides objects such as nails, arrowheads, spearheads. At Dhuliapur(12) lumps of burnt clay have also been found in the same levels from furnaces used for smelting iron. Four tuyers were recovered. They were vitrified and slagged, indicating prolonged use in smelting operations. The tuyers are in the shape of truncated cones. Analysis of the slag specimens show that the ore was not heated beyond 1100 degree centigrade indicating that the furnaces at this site were inferior to those at Hatigra. The extraction was not very successful because the percentage of iron in the slag is high. However, analysis of the objects shows that the purity of the metal was high. It must be noted that the percentage of silica in the slag is relatively high, so possibly flux was added. This can also be concluded from the fact that the impurities in the metal are few and nor was the metal exposed to temperatures high enough to allow the slag to flow out naturally.

At Naikund (13) in the Vidarbha, the iron smelting industry was also at a stage of infancy. The industry is dated to a later period (7th c. B.C.) but is the first megalithic site to give evidence of an iron smelting furnace. The most remarkable aspect of this site is a unique furnace that has been excavated. Such a furnace is not found at any other site and nor is its use recorded in context of the indigenous industry.(see Fig-5). The furnace is brick built. The bricks are wedge-shaped and fitted together to prevent any loss of air. Apart from this 40 kg. of iron slag was found. Based on the tests carried out it has been estimated that the smelting operations were not very successful. 1Kg of iron ore yielded only 350 gm. of pure iron. The remaining was lost as slag. This is supported by the evidence from a piece of tapped slag fused with bricks which weights 6.3 Kg. . This was the total slag from a single operation for which about 10-12 Kg. of ore was used.

Having studied the metallographic analyses of iron objects and slag in order to understand the smelting technique, it would be interesting to compare it with similar studies conducted on objects crafted by indigenous iron smelters of more recent times. Such evidence is available for the Agarias(14). The technique of such smelters is almost identical to that reconstructed from evidence at archaeological sites. The tables below shows that the percentage composition of the metal and slag is very similar to that at most site. The process was equally wasteful of iron since almost 60% of the slag consists of iron oxides. The metal again is very pure and was obviously refined for a long time since the percentage of impurities is very low and nor is there any evidence of the addition of flux.(see Table-9 & 10).

It is unfortunate that the metallographic studies of other sites are not available, hampering a detailed analysis and comparison of production technology in different regions. None the less, a preliminary comparison indicates the following :-

(i) Tadakanahalli probably shows the earliest evidence for iron smelting and manufacture of low carbon steel. (about 1000 B.C — 900 B.C). But we have not gone into the excavator's arguments for establishing the antiquity of this phase.

(ii) Manufacture of low carbon steel is not recorded at any site other than Hatigra and Tadakanahalli.

(iii) Other than Ujjain and Dhuliapur no site shows the use of flux. While lime is added at Ujjain, silica in Dhuliapur. There was knowledge of fluxing at Rajghat in the pre-Iron Age period. While the knowledge was used for copper smelting, it was not used for iron. It is probable that the ancient iron smith depended on the natural silica content in the ore and the wood ash from burning charcoal as flux. However, it remains a mystery why flux was not added at other sites.

(iv) The method used at all the sites to extract the metal is refered to as the 'direct' method. In this method the ore was not melted but reduced to a spongy mass. Temperatures high enough to melt iron could not be reached in the furnaces found at the sites.

(v) At Tadakanahalli the objects were manufacture from bars of iron formed by welding together sheets of wrought iron and steel. At Dhatwa the wrought iron was beaten into strips and welded together.

(vi) The efficiency of the furnace differs from region to region. While at sites such as Hatigra and Rajghat the furnaces could withstand higher temperature, at the others temperatures only upto 1000 degree centigrade were attained. The nature of the furnaces found in archaeological excavation has been discussed in the next section of the chapter.

Early Furnaces

The study of furnaces found in archaeological excavations is useful in reconstructing ancient iron technology. It is unfortunate that apart from two sites Naikund and Kumbhariya, no ancient furnace was been been excavated which could incontrovertiably be an iron furnace. These furnaces are dated to the 7th century B.C. and 10-11th century A.D. respectively. For an earlier period, other than some fire-pits there is hardly any evidence available. However putting together this scanty material with the knowledge of the furnaces used by indigenous iron-smelting tribes, could perhaps help in drawing certain conclusions.

So far, in no excavation has any furnace been found which can be dated to the Chalcolithic period. Copper 'bun'(15) ingots have been found at Lothal and a number of copper and bronze objects have been recovered from excavations at Harappa and the Chalcolithic sites. Many of these objects have been analyzed, throwing light on ancient copper smelting technology(16).

The evidence from Kumbhariya(17), a village near Ambaji, in North Gujrat would suggest that the same type of furnace was used for both copper and iron smelting. Furnaces found here are dated to the 10-11th c. A.D. The furnaces are broken at the bottom and have slag adhering to them. Analysis of this slag shows that some were used to smelt iron, and some copper. The furnaces are small in size, shaped like crucibles and are made of clay. They have an opening for the draft and another to let the slag flow out. Thus they are very similar to those used by many present day metal working people like the Agaria and Lohar.

The furnace is the most important structure in a smithy. The furnace is an apparatus for applying heat to metals. Metal has to be extracted from the ore by burning the ore along which fuel in the furnace. In order to be forged the metal has then to be repeatedly returned to the furnace.

The essential technique employed by early iron smelters was thus : The ore was collected and prepared for the furnace by crushing and roasting on an open flame. Charcoal was prepared by burning wood in a reducing atmosphere. Charcoal is the ideal fuel for iron smelting because it is free from impurities which react with iron and its high carbon content creates a reducing atmosphere in the furnace, essential for the smelt. [A reducing atmosphere means burning in the minimum of oxygen, and high percentage of carbon monoxide while an oxidizing atmosphere is one where maximum oxygen is used, to eliminate carbon monoxide]. Ore and fuel are poured into the furnace, either alternately or together. The furnace is lit and more and more fuel and ore are added. Air is forced in through an opening in the furnace with the help of the bellows. When the iron is ready, the bellows are stopped, and the mouth opened. The metal collects in the form of a spongy mass at the bottom. This is pulled out with tongs though an opening at the back of the furnace which allows the slag impurities in the ore to flow out in the form the slag.

The 'bloom' as the metal is now called is viscose and encrusted with impurities or gangue. This is beaten out by repeatedly hammering on the anvil and returning it to the furnace. By the same process the metal is carbonized or case-hardened and ready to be forged into objects.

The furnace is at the very center of activity in the smithy. However, the furnaces used in the simple technique described here, are not very efficient. To begin with furnaces are small and can smelt only small amounts of ore at a time. Secondly they are made of unbaked clay, in which it is impossible to achieve very high temperatures. Therefore the iron does not melt but is reduced to a spongy bloom. The temperatures are adequate to melt copper (1200 degree centigrade) but not iron which melts at 1535 degree centigrade. Much of the heat is also lost because the furnaces are not properly sealed, and there are holes for the air to enter and slag to be eliminated. To achieve temperature high enough, large quantities of charcoal are consumed. Charcoal is expensive and difficult to get. Most indigenous smelters use charcoal 5 to 6 times the ore to get at the metal(18). The method is wasteful in another respect. The temperature is not high enough to fully separate the ore and the metal. Therefore much of the metal remains in the slag. Analysis of slag at various sites as also the slag left behind by iron-smelting tribes shows that 30-40% of the slag consists of iron(19). None the less, there is little change in the furnaces used by the ancient and present day smiths. It would seem that inspite of the technical defects, this type of furnace was best suited to their purposes.

Evidence for furnaces have not been found at many sites. The most important evidence has been found at Naikund(20), where an iron- smelting workshop has been excavated. The other sites where furnaces or fire pits used for metal working have been found are Daimabad(21), Atranjikhera(22), Ujjain(23). At Nevasa(24), Pd. VI (dt. 1400-1700 c. A.D.) reveals the plan of a structure with four rooms where large deposits of ash and burnt wood have been found. One of the rooms was probably a kitchen while another was a workshop for making glass bangles.

One of the best examples of an ancient furnace comes from Naikund(25), a well-known megalithic site dated to around 7th C. B.C. Circular clay bricks were found scattered in the trench excavated. With these the furnace was reconstructed. The bricks were placed one above the other. The bricks interlocked easily because some of the bricks were concave and others convex. The bottom of the furnace was also paved with bricks. These bricks were fused with slag. At the bottom was a hole. Two tywers, made of clay were also recovered from the trench. These perhaps connected the bellows to the furnace. 40 Kg of iron slag was recovered from the trench, along with cinder. Chemical analysis of the cinder and slag shows that they contain 50-60% iron oxide(26). The analyst estimates that starting with 1Kg iron ore, the smelter got about 350gm of pure iron. The remaining came out as slag in which about 300gm of iron oxide was lost. A unique piece of tapped slag found, fused with bricks lining the tapping hole(27). This weighed 6.3Kg which was obviously from a single smelting operation. The technique seems to have been rather wasteful since 60% of the iron was lost in the slag. No evidence of the use of flux was found.

The analyst has also tried to locate the source of the ore used at Naikund. Large deposits of ore have not been located so far. 1Km. South east of the workshop is a 'nala' where ore was found in the form of rubble. It appears that the smelters used local sources for ore. The ore is mainly hematite quartzite in pieces of the thickness of 3-5 cm(28). The smelting technology prevelent at Naikund does not vary much from the usual technique used by the pre-industrial smelting industry described above. A major difference however lies in the construction of the furnace which is unique because it is made of baked bricks.

Furnaces of a very different nature have been found at Atranjikhera(29), in the Etah district of U.P.. The furnaces is belong to the SP 6 of the PGW phase at the site. They were pear shaped (Fig.3) furnaces – simple pits, sometimes with openings for the introduction of the nozzles of the bellows. Earthern vessels lay near by, probably water pats for the use of blacksmiths. Inside these pits were found rounded tapering clay lumps and burnished tools. Some were found outside these pits along with pieces of iron slag. It is likely that these pits were iron furnaces. Similar pits have been found in SP7. SP1 and 2 have circular fire pits containing ash, charcoal and brick bats(30). Some also have charred grains and animal bones. These could have been sacrifical pits.

In the NBPW(31) period too the excavations have yielded furnaces. Phases A has a fire-pit similar to those described above. Near it lie iron objects, two arrowheads and one spear, along with iron slag. Phase D is the most important because it has a room within which is a furnace and a row of fire pits each separated from the other by a mud-brick placed on either side. This appears to have been a workshop.

The presence of iron objects, discovery of furnaces, slag and blacksmiths tools, suggest that the site was a manufacturing and smelting center. The excavator has tried to reconstruct the possible process of smelting used at the site(32). He rightly concludes that the ore and fuel were together put into the pit. The temperatures were raised with the help of leather bellows. However, he incorrectly states that molten metal flowed out in fluid form and settled at the bottom. An open crucible furnace of this type, the most primitive of its sort would not be able to generate temperatures as high as 1535 degree centigrade which is the melting point of iron. At best the metal would have settled at the bottom as 'bloom'. The method used at the site was no less wasteful, Analysis of the slag shows that 50-60% of the slag was iron oxide(33). The source of the ore has been identified as the hematite- quartzite bands of the Agra-Gwalior range.

Similar to the furnaces found at Atjranjikhera is the one reconstructed by Hegde(34) in context of the ancient iron smelting industry of Dhatwa(Fig.4), one of the earliest iron smelting sites of south Gujarat. It is dated to the 3-5 th C. A.D. The amount of slag recovered from the site indicates a small-scale but flourishing industry. The implements found are related to agriculture and crafts. These is a total absence of weapons. Obviously the industry catered to the needs of the local agricultural community.

No furnace was discovered in the excavations. However, with the help of ethnographic evidence and the scanty evidence at the site, the excavators have reconstructed the type of furnace which the smelter probably used. The furnace was probably a cylindrical, clay-lined crucible-shaped shaft furnaces, dug into the ground. Holes are provided to insert the nozzles of bellows. The temperature was raised upto 1100-1200 degree centigrade to allow the slag to flow out, allowing the metal to collect as a spongy 'bloom'. There is evidence that the ore was roasted before smelting.

Yet again the analytical studies show that the metallurgy practiced at the site was wasteful. The slag contains 61-62% iron oxide but as in the above cases the resultant iron is very pure. The source of the ore has been identified as the basal laterite bed within 2 Km of the site. Both hematite and limonite were used. The limonite was roasted to convert it to hematite.

A similar open-type furnace has been excavated at Ujjain(35). The furnace belongs to Period II at the site which belongs to the NBPW phase (500-200 B.C). Accordingly to the excavator the technique employed was thus alternate deposits of charcoal mixed with iron ore and lime were laid. This was covered with clay to prevent the heat from escaping. Through the remains do not reveal this but they must have been appartures to allow the air in and the slag to flow out. This excavator too thinks that molten iron was collected in such a furnace but as mentioned above that would be impossible in such a simple furnace.

The most significant fact about the technique used at Ujjain is the use of flux. This is one of the very few sites with such evidence. In this case lime was used as a flux,in order to remove the impurities from the ore. The case of flux is not common in the indigenous smelting process. The Agaria ignore the large deposits of lime near their home, though the lack of fluxing leads to a lot of waste of both metal and fuel. However, the quantity of the iron produced is very pure and malleable.

The open type furnace described here is very similar to that used by the Gadulia Lohar(36), an iron-working community. Their furnace is a T-shaped pit made in the ground. Fuel and iron are heaped into this. An earthen pipe connects the furnace to bellows. Present day Lohars confine themselves entirely to black - smithy. They use scrap iron collected in the city. However, they do have a tradition of smelting ore.

A furnace of a very different type has been found at Nalanda(37). It belongs to the historical period. It is brick built and consists of few chambers, made by dividing a square. Each chamber is provided with two flues - one for the draft and another for the slag. Little else is known about the smelting industry at the site.

Another unique furnace has been found at Kumbhariya(38), Gujarat, dated to the 10-11th A.D. The furnace shows evidence of being used for both copper and iron smelting. The temperature at which copper melts (1200 degree centigrade) is adequate for smelting iron (1100-1200 degree centigrade) therefore the furnace can be used for both metals. These furnaces are also of the open type - small in size, crucible shaped and made of clay. They are all forced-draft, slag-tapping furnaces.

At Kodumanal(39), Tamil Nadu an iron smelting industry dated between 3rd century B.C. and 3rd century A.D. has been identified. At this site the furnaces are placed at the periphery of the habitation. A circular base of a furnace has been excavated and also several tywere pieces with vitrified mouths. There are granite slabs near the furnace which were probably used as anvils. Another crucible furnace was found at the site. The unique feature of this furnace is that it occurs as a cluster of furnaces. The main furnace is surrounded by 12 small furnaces placed at regular intervals. Alongside this, a vitrified crucible has been found. This cluster of furnaces was probably used for steel making by the 'crucible method'. Buchanan's**(40)** account of the steel making industry in the neighbouring area also mentions a cluster of furnaces such as this, where a number of sealed clay crucibles with ore and some woody matter were heated and directly reduced to steel. Such furnaces are not found in North India.

Furnaces used only for copper smelting have been found at Daimabad**(41)**. The two furnaces were located in a 'copper smiths workshop'. Both of them are 'U' shaped and their walls have been burnt red. Both contain ash. They belong to Phase IV (Malwa Culture), Structural Phase A at the site. The next phase at Daimabad (Jorwe Culture)**(42)** has two huge pottery kilns. They are pits excavated in the ground and backed by mud platforms. They consist of three parts - the outer wall, central ash packing and inner burnt wall. There are two stoke holes. Charcoal was used as fuel.

It may be a useful exercise to compare these ancient furnaces with the furnaces used by the present day iron-smelting tribes. Accounts of the 'native' method have been written by many travellers and administrators of the 19th - 20th centuries. The furnace used by the Gadulia Lohar has already been described. Apart from this 'open type' furnace the main types of furnaces documented are -**(43)**

a) the cylindrical shaft furnace used by the Agaria, made of unbaked clay. The furnace was fed with fuel from an apperture at the top and was lit from below. At the base were the openings for the draft and outflow of slag. The ore was reduced to a spongy 'bloom' and removed by breaking the front wall;

b) a similar furnace as the above but smaller in size. The bloom in their case was removed from the top and not by breaking walls;

c) a circular furnace tapering towards the top. The apertures for slag and draft were at the bottom. The slag in this case did not flow out but was tapped off from time to time;

d) a cylindrical shaft furnace built of sun-dried bricks with a front wall built of clay which is broken to remove the bloom;

e) the Gonds use a furnace built of clay and small stones in a conical shape. The only opening is for the bellows. From time to time a hole is made and the slag tapped off. This is thereafter sealed, till the bloom is ready.

f) In Manipur the furnace is a truncated cone. The layers are inserted from the back. Fuel and ore are fed through a chimney. This furnace is more efficient because the heat is not allowed to escape.

g) In Kangra the furnace is of cylindrical clay with tywers attached at the base at opposites ends. At the base of furnace is a perforated plate to let the slag run enter a slag pit dug into the ground.

h) In Kathiawar the ore and fuel were separated inside the furnace. The ore was kept in a separate furnace and furnace and the flame allowed to play over it.

The last three furnaces described seem to be improvements upon the more primitive furnaces described previously. It is the simpler versions that would be relevant to us, because these were similar to those found in the archaeological excavations. The most popular furnace both in the archaeological excavations and amongst present day smelters, appears to be the simple pit furnace. This was the most inefficient of all the furnaces but perhaps its simplicity was its greatest advantage. The Naikund type brick built furnace is unique for the period. It is the only furnace of this type to be dated as early as 7c.B.C. However, it does not appear to be popular in the ancient period or amongst present day smelters. Perhaps the purpose is equally served by a shaft made of clay rather than mud bricks.

All the furnaces use the 'direct method' of smelting. The ore was smelted in the presence of large quantities of ore to convert it directly into wrought iron. As against this, 'indirect' process is one in which the ore is smelted into pig iron and then converted by puddling in a reverberatory furnace into wrought iron. However, there is remarkable variation in the types of furnaces used in the indigenous iron smelting industry.

Unfortunately all the furnaces suffer from serious defects which greatly impairs the efficiency of the smelting technology. The efficiency of smelting depends of the efficiency of the removal of unwanted minerals in the ore. The furnaces were incapable of generating sufficiently high temperatures to make the iron melt. The metal was obtained in the form of 'bloom' which had do be refined to eliminate the slag. Slag analysis has shown that about 60% of the slag consist of iron oxide. Therefore 3/4 of the metal in the ore was being lost. However, the redeeming fact is that the iron which was obtained was very pure and of very high quality.

TABLE 1 : PERCENTAGE COMPOSITION OF SLAG AT DHATWA

SAMPLE	Fe_2O_3	S_1O_2	CaO	MuO	AL_2O_3	MgO	P_2O_5
Layer 1 200-300 AD.	61.26	0.78	1.96	10.47	0.46	tr	-
Layer 2 400-200 BC.	62.57	0.82	1.76	12.42	0.58	tr	-

TABLE 2 : PERCENTAGE COMPOSITION OF METAL (SPECIMEN FROM A HOE) AT DHATWA

SAMPLE	Fe	Mu	Si	P	Ca	Mg
1	99.76	tr	-	tr	-	-
2.	99.84	tr.	-	tr	-	-

TABLE 3 : PERCENTAGE COMPOSITION OF SLAG AT RAJGHAT

SAMPLE	Fe	S_1O_2	Al_2O_3	CaO	MgO	MnO_2	CuO	SO_3	P_2O_5	T_1O_2
Copper slag from chalcholithic levels	38.72	39.17	12.02	5.39	0.62	-	1.25	0.20	-	-
From slag From PGW Levels	74.43	16.32	4.25	1.20	0.45	-	-	-	Tr	Tr
From slag From PGW Levels	72.12	17.48	5.20	1.65	0.80	-	-	-	Tr	Tr

TABLE 4 : PERCENTAGE COMPOSITION OF OBJECTS AT RAJGHAT

SAMPLE	Fe	S_1O_2	Al_2O_3	T_1O_2	CaO	Mgo	Cu	Ni	Cr	P_2O_5	S	C	MU	CO	Z
BLADE pdIB 600-400 B.C.	91.21	0.88	0.5	Tr	0.32	0.15	-	Tr	-	0.24	0.19	0.15	-	-	
ARROW-HEAD pd.IB 600-400 B.C.	85.7	3.8	2.01	Tr	1.20	0.24	-	Tr	-	0.15	0.12	0.20	-	-	
NAIL pdIB 600-400 B.C.	92.3	2.8	1.7	Tr	0.82	0.80	0.1	Tr	-	0.22	0.08	0.42	-	-	

TABLE 5 : COMPARISION OF SLAG AND METAL COMPOSITION AT ATRANJIKHERA

SAMPLE	Fe_2O_3	S_1O_2	CaO	MgO	MnO_2	Al_2O_3	P_2O_5	T_1O_2	CU
Slag form PGW Levels	66.6	25.6	1.3	0.2	-	5.0	-	-	-
Object from PGW Levels	89.36	0.53	0.60	0.12	-	1.33	0.33	Tr	-

TABLE 6 : PERCENTAGE COMPOSITION OF SLAG AND METAL AT KANKRAJHAR/DHULIAPUR

SAMPLE	Fe_2O_3	MnO_2	Al_2O_3	S_1O_2	CaO	MgO	P_2O_5	T_1O_2	CuO	SO_3	Na_2O	K_2O	Ni	Pb	Zn
Slag at Dhuliapur	71.88	0.60	4.4	10.28	1.8	1.45	0.47	0.50	0.02	1.7	0.07	0.17	-		-
Slag at Kankrajhar	68.03	0.89	4.3	19.89	1.4	1.00	0.30	0.60	-	-	-	-	-	-	-
Object from Dhuliapur	base	0.006	-	- -	-	-	-	0.06	-	-	-	0.05		-	0.00
Object from Kankrajhar	base	0.013	-	- -	-	-	-	0.09	-	-	-	0.09		0.025	0.00

TABLE 7 : PERCENTAGE COMPOSITION METAL (SPECIMEN OF A DAGGER) AT HATIGRA

C	Mn	P	S	S_1	N_1	Cu	Al	Co	Pb	Sn	Sb	Tc	Zn	Fe
0.35	-	0.51	0.15	0.102	0.036	0.108	0.027	0.037	-	0.001	0.016	0.008	-	base

TABLE 8 : PERCENTAGE COMPOSITION OF SLAG FROM NAIKUND

SAMPLE	Fe_2O_3	FeO	SiO_2	Al_2O_3	MuO	MgO	P_2O_5	Total
Sample 1 (Tapped Slag)	20.41	41.97	17.31	6.23	0.16	8.93	0.38	95.39
Sample 2 (Glassy Slag)	7.33	8.81	48.74	9.59	0.53	5.68	0.16	80.84

TABLE 9 : PERCENTAGE COMPOSITION OF SLAG IN AN AGARIYA FURNACE

SAMPLE	FeO	Fe_2O_3	Metallic Iron	SiO_2	Al_2O_5	T_1O_2	MnO	P_2O_5	CaO	MgO	Carbon
Slag	53.40	10.01	1.60	18.00	9.02	0.30	4.75	0.450	0.40	2.16	0.28

TABLE 10 : IMPURITIES IN THE SMELTED METAL (%)

C	Mn	S	P	S_1
0.78	0.10	trace	0.140	0.075

TABLE SHOWING DIFFERENT TYPES OF FURNACES FOUND AT ARCHAEOLOGICAL SITES.

NAME OF SITE	APPROX. DATE	DESCRIPTION OF THE FURNACE
NAIKUND	7 C.B.C.	Cylindrical furnace made of clay bricks. Bottom of the furnace also paved with bricks. Hole at the base to accomodate tywers. No hole for slag to flow out. A slag tapping furnace.
ATRANJIKHERA	C.800-200 B.C	Pear-shaped pit furnaces. Sometimes with openings for the nozzles of the bellows. The fuel and the ore mixed together and placed inside the crucible and lit. Appears that the furnaces were of the open-type and not sealed with clay on top.
UJJAIN	500 B.C.	A crucible furnace similar to those found in Atranjikhera. Probably had openings to allow the drought in. Flux was used in this furnace. The excavator is of the opinion that the crucible was filled with ore and fuel and then sealed with clay to keep the heat from escaping.
NALANDA	HISTORICAL PERIOD	Brick built. Divided into 4 chambers, made by dividing the square. Each chamber has two flues for the bellows and the slag.
KUMBHRAIYA	10-11th C.A.D	Furnaces used for both-copper and iron smelting. Small, crucible shaped and made of clay. They have an opening for flow of air but none for slag. A slag-tapping furnace.
DAIMABAD	1100-1000 B.C	Used for copper smelting. U shaped with walls burnt a deep red. They are simple pit furnaces.

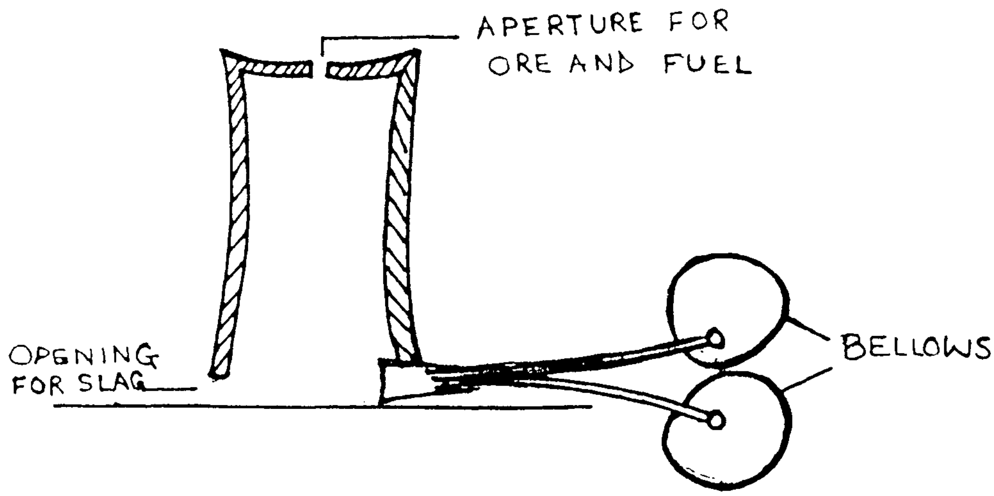

Fig. 1 AGARIA FURNACE

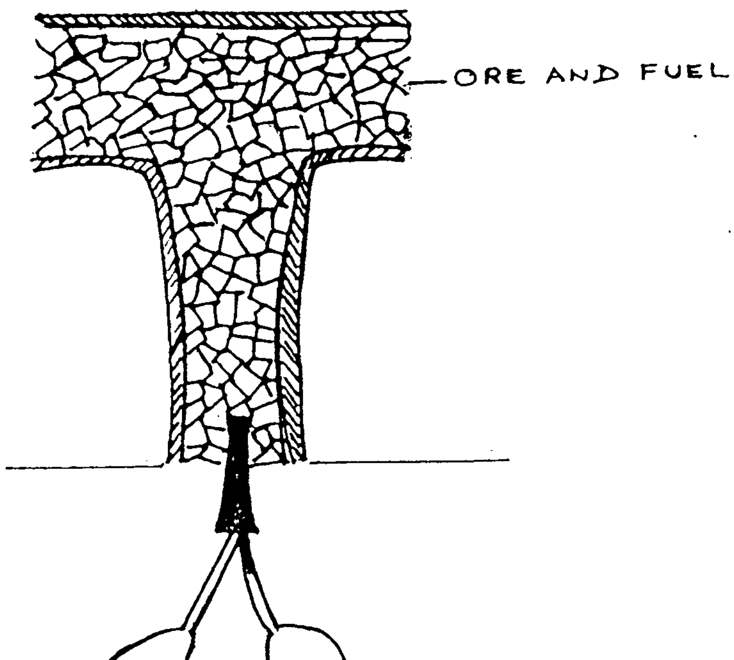

FIG. 2. LOHAR FORGE

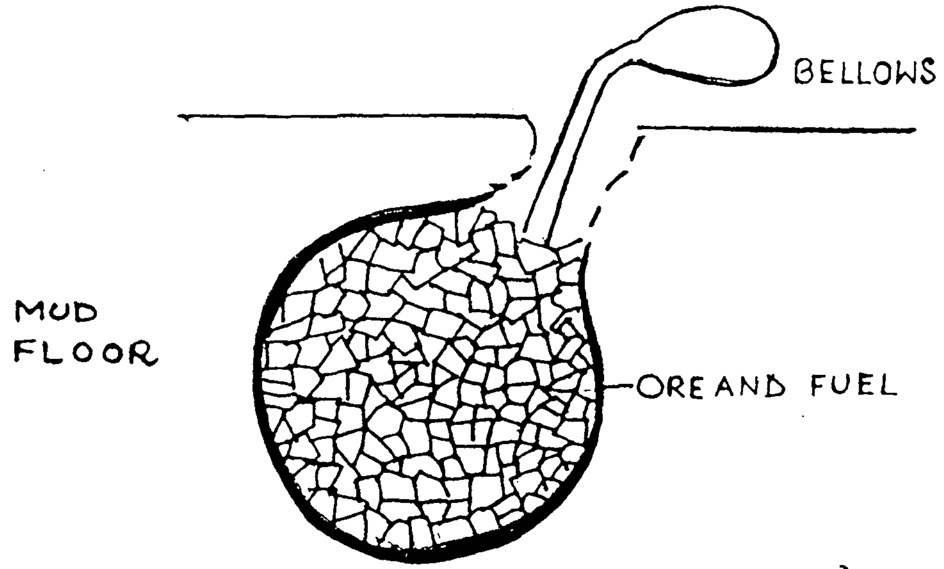

FIG. 3 PEAR SHAPED FURNACED AT ATRANJIKHERĀ

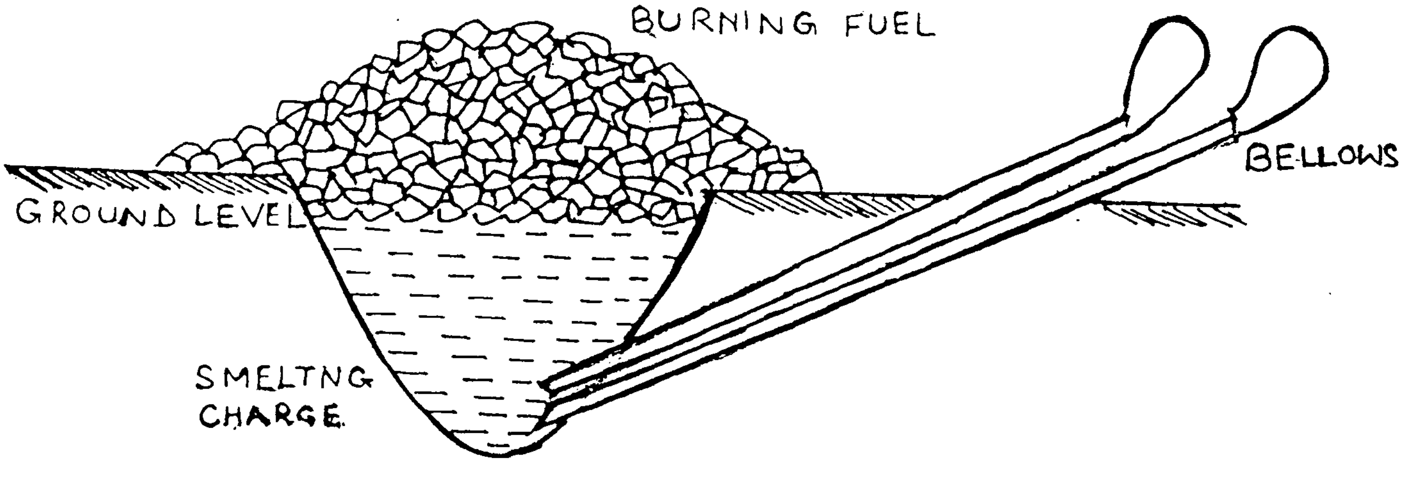

FIG. 4 RECONSTRUCTED FURNACE AT DHATWA

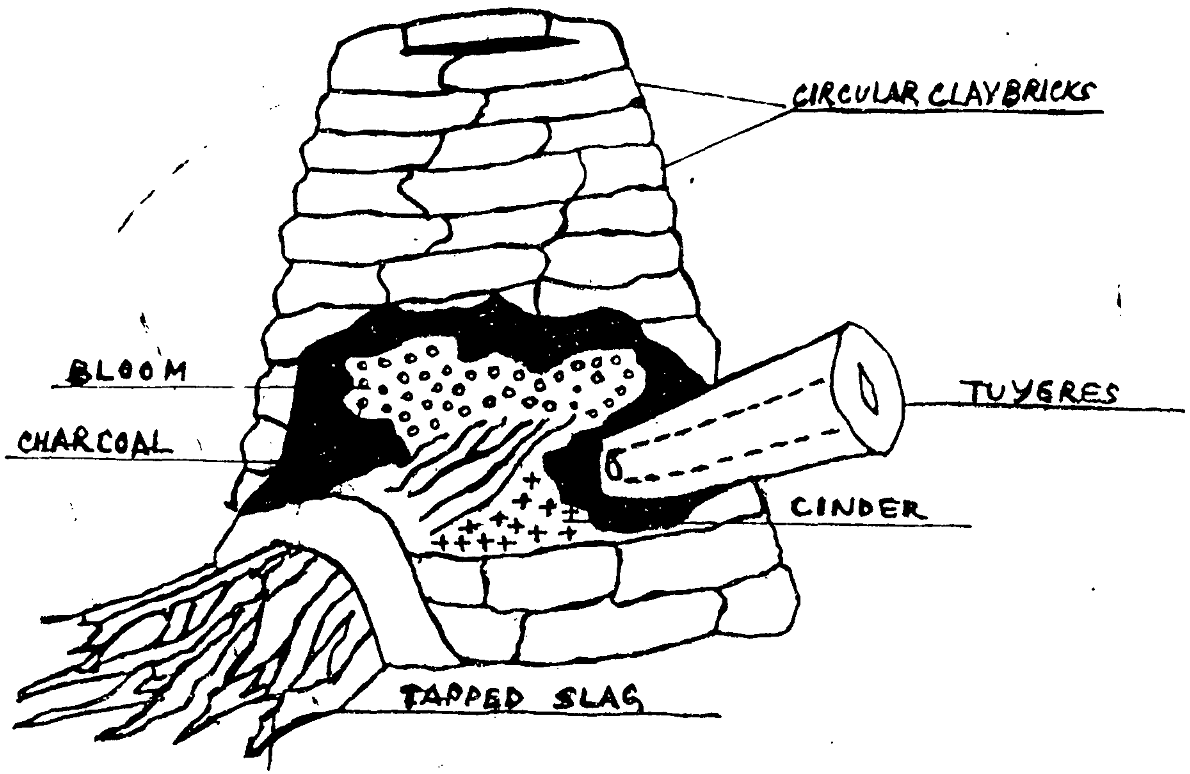

FIG. 5 FURNACE RECONSTRUCTED FROM THE EVIDENCE AT NAIKUND

References

1) K.T.M Hegde, 'A model for understanding Ancient Indian Metallurgy', Man, Sept. 1973,pp.416-22.
2) Ibid., p.419.
D.P. Agrawal and A.Ghosh (ed).Radiocarbon and Indian Archaeology, (1973) Delhi.pp. 391-399.
4) Ibid., p.393.
5) Ibid., p. 395-6.
6) K.T.M. Hedge, 'Technical Studies in Copper Artifacts Excavated from Ahar' in H.D. Sankalia, S.B. Deo and Z.D. Ansari, Excavatious at Ahar (1969), Poona, pp.225-8 M.D.N. Sahi, 'Origin of Iron Metallurgy in India',PIHC (1980), 41st Session, pp. 104-111.
7) O.P. Agarwal, 'Scientfic and Technological Examination of some objects from Atranjikhera' in R.C. Gaur, Exacavations at Atranjikhera , (1983), Delhi,. pp. 487-498.
8) N.R. Bannarjee, Iron Age in India (1965) Delhi.
9) O.P. Agarwal, Harinaraian and S.K. Bhatia, 'Technical Studies of Iron Implements from the Megalithic site Tadakanahalli, Purattava , No.12, 1980-81, pp. 97-100.
10) N.C. Ghosh, Arun K. Nag, P.K. Chattopadhya, 'The Archaeological Background and Iron Sample from Hatigra, Purattatva No.18, 1987-88. pp. 21-27.
11) S. De and P.K. Chattopadhya, 'Archaeometallurgical Studies at Kankrajhar and Dhuliapur', Purattatva No.20, 1989-90 pp.115-7.
12) Ibid., p.116.
13) V.D. Gogte, 'Megalithic Iron Smelting at Naikund' in S.B. Deo and A.P. Jamkhedkar, Naikund Excavation (1982),pp.52-59.
14) V. Elwin, The Agaria (1942), p.275.
15) A. Ghosh, 1989, An Encyclopedia of Indian Archaeology, Vol 1,p.321-2.
16) K.T.M. Hedge in Sankalia et. al. 1969. Excavations at Ahar pp.225-8 and in Mehta and Choudhary, Dhatwa, pp. 48-56.
17) Ghosh, op.cit., Vol 1, pp.48-56.
18) Reports of the Geological Survey of India, Vol XXV.
19. V. Elwin, The Agaria, pp.194.
20. S. B.Deo and A.J. Jamakhedkar, Naikund Excavations.
21. S.A. Sali, Daimabad.
22. R.C. Gaur, Excavations at Atranjikhera.
23. N.R. Banarjee, Iron Age in India, pp.178-181
24. H.D. Sankalia et. al, From History to Prehistory at Nevasa, p.64 ff.
25. Deo and Jamkhedkar, op. cit., p.11, p.52-59.
26. Ibid., p.59.
27. Ibid., p.55.
28. Ibid., p.56.
29 Gaur, op. cit., p.12.
30. Ibid., p.126.

31. Ibid., p.246-257.
32. Ibid., p.219-220.
33. Ibid., p.498.
34. Mehta and Chowdhary, op. cit., pp.48-56.
35. Banarjee, op. cit., pp.178-181.
36. Elwin, op.cit., p.194.
37. P.K. Misra, The Nomadic Gadulia Lohar of Eastern Rajasthan.
38. Ghosh, op.cit.,pp.304-6.
39. K. Raju, Iron and Gemstone Industries as revealed from Koadumanal Excavations', Puattatva No.20,1989-90, pp.111-112.
40. F. Buchanan, A Journey from Madras though the Countries of Mysore, Canara & Malabar, 3 VOLS, 1807.
41. Sali, op.cit.,p.93.
42. Ibid., p.125-128.
43. Elwin, op. cit, p.181-82, p.21 ff.
H. Warth, 1880-81, 'Iron works in Kumaon' and 1894, 'Iron making in South India', Indian Forester,Vols 6 & 20.
D.K. Chakrabati, Early use of Iron in India, pp.134-138.
S. Bhattacharya, 'Iron Smelters and Indegenous Iron and Steel Industry of India' p.144.

CHAPTER- IV

EVIDENCE FROM ETHNOGRAPHY AND LATER HISTORICAL ACCOUNTS. AND FORESTRY RECORDS

"She presses down the bellows with the strength of her heels.
He wields the heavy hammer with all his weight.
From the ground he gets stone,
From wood he makes charcoal,
The fire burns fiercely as the bellows blow,
The bellows sound 'sair ser',
The little hammer clatters 'tining tanag'
A shower of sparks flies into her breast,
He puts it in black,
He pulls it out red,
Standing he beats it,
Squatting he fashions it,
The Chonkh girl blows the bellows at the forge,
Like a dream it sounds 'datter thunda',
How happy I feel !
The Chonkh boy beats with the hammer,
The hammer whistles as he swings it round.
And I feel very happy" (1)!

This song sung by the Agaria, an iron - smelting tribe of Central India, describing the age old scenes at their smithies, could describe the workings in many present day smithies in rural India. Their technique of their craft may be the most 'primitive'but is has survived the longest.

That they are the upholders of an ancient tradition has been acknowledged by many. In 1988 Valentine Ball wrote. " The rude smelting furnaces of the natives ... are probably to a great extent, the lineal descendents of a system of iron manufacture, which in the earliest times of which we have any record, must have been on a scale of considerable magnitude." (2)

The indigenous industry has been much abused by early European authorities writing on the subject. It was condemned as 'primitive'. The cause is held to be the 'native' artisan's indifference to technical improvement. The 'native character' is thought to be unresponsive to innovations. The indigenous process is considered to be 'wasteful' for a number of reasons. The furnaces are very simple and crude and incapable of withstanding very high temperatures. Therefore, iron cannot be melted, it is extracted as a spongy 'bloom' containing almost 30-40 % gangue. No flux is used to facilitate smelting and about 30% of the iron is lost in the process. Given the low temperature, the absorption of carbon is low, so only wrought iron is produced. This is further carbonised to form low-carbon steel. Thus enormous quantities of fuel are consumed.

What was not recognised by these early European authorities was that the technology was ideally suited to the conditions. Charcoal, though expensive makes the best iron. Charcoal iron is more malleable and purer than pig iron from coke furnaces(3). The local craftsman had mainly to cater to the agricultural community. To craft agricultural implements by hand, malleable iron which could be easily managed in a simple smithy was required. The smelter and black smith could not afford to have an elobarate smithy because they had to always be on the move, in search of ore. Even in the 19th century inspite of the competition from cheaper factory made pig iron the Indian blacksmith preferred charcoal iron(4).

The indigenous smelting industry is not confined to any particular region. In the Indian Subcontinent, iron ore is found in almost every region. It must be kept in mind that the indigenous smelters had no difficulty in obtaining enough ore from deposits which would otherwise be considered uneconomical(5). They could use small granules or friable bits of quartzite, washing or winnowing the ore out of them. Thus the survey of the distribution of iron ores on the basis of the Geological Survey of India reports are not wholly representative of the sources open to a pre-industrial iron smelter.

This fact is borne out even by the evidence for our period of study. There is hardly a district where iron artefacts have not been found in the course of archaeological excavations and in most, ancient slag heaps have also been found. The indigenous industry must have flourished where ever there was ore and plenty of forests to supply charcoal. At most of the iron producing sites, the ores used are those which could be locally procured.

No elaborate mining was required to unearth the ore. Most of it was available on the surface in the form of quartzite shist, iron stone and bands in sandstone formations. In 1942 Elwin wrote that very often the Agaria find ore on the surface(6) They consider it as "the iron sending its children for a walk in the open air". If more ore is required they dig near these surface finds . The pits are shallow, not deeper than 5-6 feet. They fill baskets with earth from these pits. The women sort out the stones and carry home as much as they can. It must be noted that instead of using the superior haematite ore found abundantly in their belt, the Agaria seem to prefer the inferior limonitic ores(7).

The methods of smelting and iron working practiced till now by the tribes in India have not changed much from their ancient traditions, steeped in myth and folklore. This could perhaps be similar to the methods of smelting and forging adapted by smiths in ancient times for which there are no written records. A study of these methods could help in reconstructing ancient iron technology.

The most well known of such tribes is that of Agaria, whose customs and traditions have been documenmted by Verrier Elwin in his monograph, The Agaria(1942). The name Agaria is applied loosely to many people who use iron smelting methods in Central India and Bihar. These include the Asur of Ranchi and Palamau, Binjhia of Bihar and Lohar of Bengal. There are many septs in the tribe - the Patharia, Chokli, Asur , Birasur, God-dhuka, Agaria, Mahali Lohar and Khuntia.

The craft of the Agaria is fully immersed in myth. From mining to forging, everything is fully established in myths. Elwin describes them as "a people absorbed in their craft and their material, they seem to have little life apart from the roar of their bellows and the clang of the hammer upon iron"(8).

It is the task of the women to get the smithy ready for the day's work. They prepare the furnace, fix the bellows, light the charge and set the work in motion. They even put in the ore and fuel and begin the smelting. Eventually the men arrive at the smithy and take over. While the women work the bellows, the men attend to the furnace. The task of taking out the bloom and actually forging it is the mens'.

The technique of the Agaria is very simple. During the day the men and women go out into the jungle to collect ore and prepare charcoal. The ore is cleaned of earth, broken into bits and roasted in an open fire. The ore is slipped down into the furnace by a feed hole and mixed with the charcoal already put inside the furnace. The kiln is lit. After a while the slag is allowed to flow out of the furnace. As the work progresses , more and more fuel and ore is poured in. The blast is provided with a pair of bellows worked by the feet. The smelt takes two to five hours, depending on the kind of ore used and the amount of iron required. When the iron is ready, the mouth of the furnace is broken and the bloom lifted out. The bloom is hammered gently with a heavy hammer to remove the slag. The iron is returned to the furnace in which some chaff is put to help it burn. This is done to refine the iron. After a couple of hours the iron is ready to be crafted into implements. The iron is again placed on the anvil and hammered by two men to remove the remaining slag. If required it is put back in the furnace or else it is beaten into the required shape while red hot, repeatedly returning it to the fire. In between it is immersed in a pile of cow-dung ash. Clay is sprinkled on the iron whenever it is returned to furnace. Gradually the iron is beaten into shape. In the end the piece is tempered by being put very slowly into water. If the piece of smelted iron is bigger than required, it is cut in pieces and worked seperately.

The Agaria do not have to look far for ore. They recognise a good digging site by the colour of the soil. Very often ore is found on the surface. They dig shallow pits, sorting out the lumps of ore from the earth. The furnaces are incapable of reducing ores such as haematite or magnetite which occur in association with lateritic rocks. They prefer the limonitic ores which though inferior are easier to smelt.

The Agaria are also expert charcoal burners(9). Good charcoal is essential to make good iron. It is usually made of 'sarai', (Boswellia serrata) wood, though dhamin (Grewia latifolia) and 'saj' (Terminalia tomentosa) are sometimes used. The technique used is very simple. The wood is cut and laid out as in a funeral pyre. The wood burns for one hour or two. Then the charge is extinguished and the charcoal allowed to cool. The Agaria are not very particular about the different kinds of charcoal as the Gonds, another iron smelting tribe are. The Gonds use charcoal of the 'Saj' tree for roasting the ore, for smelting they make charcoal from karra (Holarrhena antidysentica) wood or tamarind (Tamarindus Indica) and for refining they use mahua (Bessia latifolia) wood(10). Where wood is scarce the Chokli Agaria sometimes make 'garkoda'. A pit is dug, dry & green twigs are thrown into it and lit and then covered with earth.

Almost all branches of the tribe use a similar furnace. The furnace is a cylindrical clay kiln. Sometimes it is slightly tilted. At the top there is an opening to receive the charcoal and at the base, there is another mouth to take the blast and allow the iron to be removed. Above the kiln is a bamboo platform down which ore and charcoal are poured into the furnace. The Mahali Asur do not use this platform. At the base, towards the back is an opening which allows the slag to flow out. The Asur have a custom of dropping balls of mud down the shaft to check the uprightness of the working shaft.

The bellows used by all branches of the tribe are the same. They are very different from the hand bellows of the

Lohar. They are made of wood and covered with animal hides. They are worked by the feet. An earthen twyer connects the bamboo poles of the bellows to the furnace, concentrating the blast of air upon the fire. The bellows are very important even with regard to social organization. The septs of the tribe are demarcated according to the manner in which they keep their bellows in place. The Patharia place heavy stones, the Khuntia fix them with pegs. So important is the distinction that there can be no inter-marriage between those who use a peg and those who use a stone. There is no inter-dining and they do not even share their pipes(11).

The Agaria furance suffers from certain defects most obvious being the lack of flux in the smelt. This means a longer smelt and a waste of ore(12). Slag analysis shows that it is highly ferruginous. The refining process becomes longer since slag remaining in the iron has to be removed. During refining as much as 20-30% of slag seperates out.

Another defect lies in the release of draft in the furnace. The bamboo pieces connecting to the bellows end an inch from the mouth of the twyer, resulting in a loss of blast and the fire does not achieve higher temperatures. As a result the expenditure on charcoal is enormous. By one estimate 14 tons of charcoal are said to yield 1 ton of iron(13). Another disadvantage of the smithy is that it is so constructed that it cannot be used during rains. In many cases the smithy is in the open.

However, their technique has one advantage that makes up for all the defects. The iron produced is very pure and of a very high quality. Since it is smelted longer and refined repeatedly it is pure as also malleable(14).

Techniques essentially similar to that employed by the Agaria have been reported from elsewhere. They are frequently referred to as the 'direct process' in such accounts.

An early account of iron-making in Kotkai district (1879-80) reads thus (15) : Ore (probably magnetite) is taken from the mines and mixed with fine sand in a ratio of 10:100. Unlike the Agaria this process seems to use sand as a flux. Therefore it is incorrect to say that the use of flux was totally unknown in India. It may have been uncommon, but not unknown. The furnace used here is also a cylindrical clay one but it is mounted on a platform over an ash pit. The bottom of the furnace is stopped by a perforated plate of clay. Burnt-clay nozzles are inserted through which two pairs of goat-skin bellows are worked. Charcoal is put inside the furnace till it is full and the ore is scattered on top. Ore and fuel are repeatedly added. Once in a while the slag is allowed to run out. The iron collects as bloom at the bottom of the furnace. 32 seers of ore give 16 seers of iron. 50 seers of charcoal is required for the smelt. This ratio is similar to that of the Agaria who obtain 40 units of end product for every 100 units of ore.

Another account describes the furnace as a shaft of clay, filled with charcoal and a charge of 40 pounds of ore. Air is driven by bellows consisting of two cylindrical leather bags, pressed alternately through funnels of clay. After two hours, the bloom is removed . It is reduced to 18-20 pounds. No flux is used. Accordingly to the anonymous writer of this report, the direct process is best suited for Indian ores since they need to be reduced and infused with carbon, because they lack carbon.

Buchanan describes the smelting techniques of the Kols of Bhagalpur thus : "Their furnaces are very rude and placed in the open air. It is made of unbaked clay but is shaped like a bottle, narrow on top and swollen at the bottom. At the base is a semi-circular opening . A clay pipe receives the nozzle of the bellow. Charcoal and ore are placed alternately inside the furnace. More fuel and ore is added as the smelting proceeds. Some dross is also sprinkled. When the operation is finished the spongy mass is taken out, cut in two and wrapped in clay. Like the Agaria, the Kol discover the ore by observing it on the surface and then follow the veins. They differentiate bettween two kinds of ores - asul (pure) & dusura (second rate)(16).

Ramanakapettah,(17) village in Tamilnadu, is situated in the vicinity of iron mines. An account of 1795 describes the industry to be in a 'wretched situation'. In this description the techniques vary in only some details from the ones above. The ore is not roasted or crushed but thrown directly into the furnace. The charcoal is largely obtained from the Mimosa sundra but other hard woods are also used. The furnace is supplied air with bellows. There is an aperture to allow the gangue to run out. This aperture is opened thrice in the course of the smelt. At the end of the smelt the 'bloom' is collected and the remaining slag beaten out.

In another account dated 1829**(18)** the smelting traditions of Central India, in particular, Jabalpur, Panna and Sagar are described. In all cases the woods preferred for charcoal are teak, mahua and bamboo, the last being given the preference. Unlike any of the other such accounts, this author mentions the use of hand worked bellows. Detailed description is given of the measurements. However, this reference is unique and not found elsewhere. The mode of smelting and refining is identical to that described by Elwin.

These descriptions of the 'direct process' do not vary greatly from a contemporary account of a similar technique practised in Vienna**(19)**. The ore was reduced by a cylindrical shaft furnace which received constant supply of ore and charcoal. At intervals the bloom was removed. This bloom was transfered to the hearth where it was turned into wrought iron. 200 kg of charcoal was required to obtain 100 kg of iron.

The 'direct process' was the technique for making wrought iron. Wrought iron is refined ore of iron infused with carbon. However the carbon content is low, therefore the iron is soft and malleable. What gives iron its superior edge is that it can be turned into steel, one of the hardest alloys known.

There are many references to the manufacture of 'wootz' or steel in South India. One of the classic accounts is that of Buchanan(20). Describing the steel making process in Mysore he writes, "the locally smelted ore was cut into pieces. These were placed in crucibles made in a conical form of unbaked clay, along with water, a stem of tayengada (Cassia articulata) and 2 green leaves of hungary (Convolvulus latifolia). The mouth of the crucible was covered with clay. The crucibles were dried near the fire. About 15 were fitted in each furnace. The furnaces were worked for 4 hours, at the end of which the crucibles were opened and steel had parted from the impurities". An identical process has been described in other contemporary accounts(21). In one case steel was directly obtained from the ore. Steel making was however, confined only to certain districts in South India. It was not as common as iron-smelting.

Other than the Agaria, another well known community that specialies in iron-making, is that of the Lohar(22).

Often the Agaria and Lohar are considered to be part of a heterogeneous 'caste'. However, they can be differentiated. Though the Agaria are surrounded by the Lohars - the name which some of the Agaria have even adopted. The main craft of the Agaria is to burn charcoal and extract iron from ore. The Lohar do not practice iron-smelting. Their speciality lies in crafting iron objects. The Agaria use feet bellows. Bellows are very important to the tribe. The septs of the tribes are demarcated according to the manner in which then use their bellows. The Lohars use hand bellows. The Agarias cover their bellows with cowhide which the Lohar do not touch. The Agaria worship tribal gods and demons while the Lohar worship Hindu gods. They derive their profession from Vishwakarma.

The name Lohar is derived from the Sanskrit Lauha-kara. The term Lohar is commonly used in many Indian languages. The Lohars are of two types, those who are settled in villages and cater to the needs of particular villages and those who are nomadic and visit villages to undertake jobs that the village smiths cannot undertake. Such blacksmiths are known as Gadulia Lohar. They are known to be better skilled than the village Lohar.

The village Lohar is considered to be a village menial who makes and mends iron implements mainly those for agriculture. For this the is usually paid in kind. For making new implements the Lohar is paid separately. He is always supplied with the iron and charcoal by the villagers. The smiths are assisted by the women who blow the bellows and drag hot iron from the furnace, while they wield the hammer.

The technique of the Lohar consists of two stages. First is the task of refining and improving the quality of the iron and second is moulding the metal to the desired shape. Both stages require repeated heating and hammering. The Lohars use scrap and discarded pieces of iron for reshaping them into tools and implements. The pieces are refined by heating them repeatedly and hammering them. With prolonged heating in a charcoal fire and subsequent hammering the surface of the iron hardens and at least the surface is converted into steel with the infusion of carbon. Thereafter the pieces are shaped by heating and hammering with different tools.

The forge is a T-shaped pit in the ground. Fire wood is placed at the bar end and the bellows placed at the vertical end. One person holds the object over the fire and then instructs others on how to hammer it. The Gadulia Lohar are said to be relatively skilled and take on work which the village blacksmith is incapable of doing, such as, making an anvil or fixing the loop of a cart wheel.

A few Lohar households possess a stock of iron to work with. This they obtain from iron smelters such as the Agaria. The Agaria too practise blacksmithy but on a limited scale23). They mainly craft rings,amulets, charms and some weapons and tools for other tribals. They do not cater to settled village communities such as the Lohar.

The forge of the Agaria is simpler than the Lohars'. It is a mere hole filled with charcoal with the nozzle of the bellows fixed to it. There is a flue to allow the slag to escape. A short wall is erected to direct the fire.

The forge is open air or in a thatched hut while the Lohars is in a proper house and in the case of the the Gadulia, next to his cart. As mentioned above, the Lohar uses hand bellows therefore sits nearer to the fire. He too erects a short wall but only in order to protect himself from sparks. Other than these differences, the essential technique of working the metal remains the same though the Lohar is the better craftsmen.

In conclusion,we may reconstruct the essential technique of the indigeneous smelting traditions. First the iron ore was smelted into bloom, that is a spongy mass of semi-processed iron by burning the ore and fuel in the furnace . Next the bloom was refined in the forge to eliminate whatever impurities remained. It was then tempered by allowing it to cool gradually and then hardened by quenching it while red hot in cold water. The end product was wrought iron. Steel was produced by further carburisation of wrought iron.

While this is the basic technique there are regional variations with regard to furnaces. Ethnographic accounts mention three types of furnaces. The most common was the large furnace used throughout Central India-cylindrical in shape, made of unbaked clay. There were openings at the base to allow the slag to flow out and to remove the bloom. The second type was a large one, often as high as 10 feet. Alternate layer of ore and fuel were placed. Blast was provided at the bottom with bellows. The bloom was removed by breaking open the front portion of the furnace. The third type was used in South India. It was circular at the base and tapering towards the top. The openings for slag and bellows were at the base.

Two process of steel making have been reported. The first was more common and is known as case-handling. The object of wrought iron was heated in a charcoal fire in order to infuse it with carbon. As a result the surface at least became of low carbon steel.

The more complicated process has been reported from South India which was based on the principle of carburisation of wrought iron. This involved the use of crucibles. Wrought iron was placed in these crucibles, which were sealed and placed in a furnace.

The only fuel used in all these cases was charcoal. Coal was never used by the indigen ous smelter or smith. According to Geological Survey estimates the proportion of charcoal to that of iron was 5:1. However, in many accounts the propertion is 2:1. More charcoal was consumed in the refining process and eventually when the tool was crafted. As a result the smithy was never f ar from a source of fuel. Coal was not used becauseit has other impurities that react with the iron. Further more, charcoal iron is more malleable and pure.

In most cases flux was not used, though it was not unknown. In a few instances limestone(25) or sand was used. Often wood ash was considered a natural flux. However analysis of the slag shows that it contained very high percentage of iron. This was the price paid to extract very pure iron.

References

1. V.Elwin, The Agaria, (1942),.p.169-70.
2. V. Ball quoted in N.R.Bannerji,Iron Age in India,(1965), p. 186.
3. Anon.,'Iron making in India', Indian Forester, Vol. 6,. p.202-10.
4. S.Bhattacharya,'Iron smelters and the Indigen ous Iron and steel industry of India' in Aspects of Indian culture and Society,Surajit Sinha(ed.),p.146.
6. Elwin,op.cit., p.173.
7. Ibid., p. 176.
8. Ibid., p.xxvii.
9. Ibid., p.121.
10. Ibid., p.122fn.1.
11. Ibid., p. 195.
12. Ibid., p.194.
13. Bhattacharya,op.cit, p.148.
14. Elwin,op.cit, p. xxv.
15. F.Bailey,'On Iron smelting', Indian Forester, Vol.5,. p.167.
16. C.E.A W. Oldham, Journal of Francis Buchanan, p.15.
17. Dharampal(ed.),Indian Science and Technology in the 18th Century, (1971), pp.263-67.
18. Ibid., pp.269-90.
19. Anon., op.cit.,pp.202-10.
20. F.Buchanan, A Journey from Madras,.Vol.1.
21. H. Warth, 'Iron making in South India', Indian Forester,Vol. 20.1894, pp. 100-103.
    Russell and Hiralal, Tribes and castes of Central Provinces, p. 123.
22. P.K.Mishra, The Nomadic Gadulia Lohar of Eastern Rajastan, p. 72 ff.
23. Elwin, op. cit.,p. 195.
24. Bhattacharya, op.cit., p. 148.
25. Warth, op. cit., p.202-10.

CHAPTER V

THE QUESTION OF FUEL

It is now being appreciated that the availability of fuel, that is charcoal is of central importance to the iron-smelting industry. The greatest advantage of charcoal is that it is a 'reducing ' fuel. Unlike wood, charcoal is composed largely of pure carbon. When wood is burnt in a closed chamber, with a minimum of oxygen, it becomes infused with carbon while the other elements are burned off in the charring process. This is known as charcoal. When charcoal is burnt it produces quantities of carbon monoxide gas and creates an oxygen starved atmosphere. Coal is also a carbon rich fuel but it has to be moved and more significantly, it contains a number of impurities which are harmful to metals. It is only in the 17th century when a process called 'coking' was found for removing these impurities that coal replaced charcoal as the major fuel used in the iron industry(1).The main impurity in charcoal is ash, which actually acts as a fluxing agent, while smelting.

As mentioned above charcoal is a reducing fuel that is, as it burns it creates a oxygen starved atmosphere. To smelt iron a strongly reducing atmosphere is absolutely essential and only a carbonized fuel will do. While smelting, oxygen has to be removed from the ores. If the supply of air into the furnace is stopped, it will hamper the burning process by lowering the temperature below the point at which the metal separates from the other elements in the ore. The alternative is to use a carbon-infused fuel such as charcoal. When burnt the carbon will react with the oxides in the ore and the draft to form carbon monoxide creating an oxygen starved atmosphere.

Having established that charcoal is essential for iron making, we shall now make an estimate of the fuel requirement for the industry. By calculating the fuel requirements we can draw an estimate of the wood required for charcoal making.

According to the estimates of the Geographical Survey of India(2) it was found that in the indigenous smelting furnace the proportion of charcoal to iron was 5:1 approximately. Similar experiments carried out by the Forest Research Institute(3) have estimated the proportion to be 6:1. When the smelted metal (bloom) is forged, that is refined by hammering and reheating the proportion of charcoal to 'bloom' is 2:1. The refining process is repeated till almost all the slag is eliminated . Thus in all,the ratio of fuel to the end product stands at 14:1 or 14 kgs. of charcoal have to be burnt to obtain 1 kg. of refined wrought iron prior to its crafting.(see Table no.1) Similar estimates are given in all accounts of the indigenous smelting industry. George Watt in his <u>Dictionary of the Economic Products of India</u> (4) mentions that in Nimar Province (in 1883) to produce 15 lakh of wrought iron per day, 12556754 kgs (12359 tons) of charcoal was burnt annually. It was also estimated that 74214 tons of wood was required to produce this much charcoal. Therefore the ratio of wood to charcoal stands at 6:1. The F.R.I. experiments estimate the ratio to be between 6 :1 to 4:1 depending on the wood used. It was shown that some woods are better suited to charcoal production. Hardwoods with a close grain make the best charcoals.

Given estimates of this proportion we may wonder about the way in which the smelter would have ensured his fuel supply. Is is definite that the choice of fuel would have put pressure on the surrounding forest reserves. The impact of pyrotechnologic industries on forestry has been studied by archaeologists in the Mediterranean, Eastern Anatolia and Southern Iran.

In the Mediterranean(5) in a study of pyrotechnologic industries in antiquity , it was found that the industrial hearth furnace and kiln have caused widespread environmental degradation. To supply one traditional kiln for "one burn" in the highlands of Greece required 1,000 donkey loads of juniper wood. The archaeologist estimates that 70-90 million tons of slag have been recovered from the Mediterranean littoral, representing 50-70 million acres of trees. To this may be added the degredation caused by other pyrotechnologic industries such as brick making and lime kilns. The archaeologist has thus found sufficient evidence for progressive energy shortage.

Similar studies in the Near East(6) based on data such as slag deposits, number of furnaces and the quantity of ore mines, by Lee Horne have tried to asses the environmental impact of metallurgical activities. Experiments conducted showed that seven times the quantity of wood was burnt to obtain a quantity of charcoal.

Ethnographic studies among communities in India specializing in charcoal making and iron smelting give some idea of fuel demands of the traditional industry and the woods preferred for charcoal making. In all cases hardwoods(7) with a close grain makes the best charcoal. The trees preferred are Sal, Khair, Sissoo, Teak, Kikar, Neem, Oak, Box. Buchanan in a description of the iron industry at Seringapatnam mentions that only bamboo was used to make charcoal. The Agaria make the best charcoal out of the sarai tree. "Where there are sarai trees, there you will find Agaria", it is said. While sarai is preferred, dhaman and saj are also used. The Agaria do not use different kinds of charcoal for different purpose as do the Gond. The Gond use saja charcoal for roasting the ore, Karra charcoal for smelting or else tamarind. For forging, charcoal from mahua wood is used. In the Kumaon, charcoal of rhododendron and oak are preferred while in the lower hills, chir pine is used. In Bihar, sal and bija are used. Wood is selected very carefully for the charcoal. Only live wood is used not dead or rotting trees(8) . Only when wood is scarce roots and twigs are used.

There are two ways in which charcoal is produced in the indigenous process-in a pit or by building a pyre. The former method is used only when there ia a scarcity of wood. The process is very simple. Wood is cut up into billets and heaped in a pit whose dimension vary with the quantity of wood to be burnt. Both dry and green wood are used(9). The pit is covered with earth or sand to shut out the air. The fire is lit and when burning well the rest of the wood is thrown in and left open for 4-5 hours. When done, the pit is cooled and opened, In this process nearly 1/6 - 1/4 of the wood remains unbrunt. The Agaria(10) and Gond consider charcoal made this way to be inferior and only to be used in the forge. However, accounts from South India mention this as the only method used for charcoal making(11)

In Central and North India charcoal makers prefer to use the pyre-method. The Agaria build a pyre with fresh green wood and half burnt wood from earlier burns. It is lit and allowed to burn for an hour or so. Thereafter the wood is scattered. Earth is thrown to extinguish the fire. Water is never used for it spoils the charcoal.

Another account(12) of this method is described thus. About 25000 billets of wood are stacked together, leaving a shaft to drop in a ladleful of ignited charcoal. There is an opening to allow air. When charring is complete, the stack is allowed to cool for 2-3 days. Earth is thrown to extinguish the embers.

As already mentioned the fuel demands in the indigenous process is very high. The ratio of the finished product to fuel stands at 1: 14 while the ratio of charcoal to wood burnt is 1:4 to 1: 6. Therefore the ratio of the end product to wood is between 1:56 to 1:84. This enormous requirement was the bane of the traditional industry . S. Bhattacharya(13), in his study of the the industry in the 19th and 20th century has identified the shortage of fuel as one of the main causes of the decline of the industry. A similar view is held by Elwin(14) in his account of the Agaria. Elwin also discusses the decline of the industry in other parts of the country and finds the scarcity of charcoal as one of the major causes. The reports of forestrs(15) repeatedly deplore the 'wastefulness' of the 'native' process and stress the need for stringent forest laws to stop villagers from cutting woods from forests. Thus, in the colonial period the traditional industry declined not so much from the influx of 'English' iron but from the shortage of fuel. Having studied the material available from ethnographies we shall now compare it with the evidence for charcoal making from archaeological sites. Unfortunately, such evidence has not been documented in many cases and not been analyzed in most cases. Detailed analyses of charcoal remains are available for only some sites such as Atranjikhera(16)Daimabad(17), Sisupalgarh(18), Prakash and

Jagatrama.

One of the best documented sites is Daimabad(19) It is a Chalcolithic site in Maharashtra. From Daimabad there are seven samples of charcoal ranging in age from the Salvda to Jorwe cultures. In most cases the specimens were found on house floors. Only in Phase V were they found and in Phase III in a pit. This information throws light on the exploitation of wild plant life at the site, in this period but it is not possible to know the exact use of these trees. Since agriculture was practiced at the site, the implements must have been crafted out of these timbers. Many of the woods could have also been utilized as fuelwood and for charcoal making, since some of there are ideally suited to the purpose. What is more important is that the inhabitants were familiar with a fairly wide range of charcoal which could have been put to various uses. It must be noted that it appears from the present day distribution,over the centuries the inhabitants went further from the site in search of timbers. The earliest fuel to be used were those found in the immediate surrounding of the site, in the thorn forest such as _Acacia sp._, _Zizyphus mauritiana_ and _Cassia fistula_. These trees are found at the site today but according to experts they were more distantly located in prehistoric times. Exploited timbers found even farther away such as _Dalbergia latifolia_ which today occurs 300 Kms.west of the site. This tree grows in a moist deciduous forest along with other species such as Pterocarpus marsupium and Trema orientalis which were exploited in the Jorwe phase The forests in the vicinity of the site are of dry deciduous type.

At another site Atranjikhera in Etah district (U.P.) too there is evidence for wood being transported for considerable distances**(20)**. Chir (Pinus roxburghii) has been found in the earliest levels of Atranjikhera. Chir grows on the lower hills of the North-Western mountains and is now used for railway sleepers, house building cheap packing cases and constructional purposes. One of its early uses was for house posts. Sissoo, (Dalbergia latifolia) Sal (Shorea robusta) and babul (Acacia nilotica) have been found in association with chir. These are abundant in the environs of the site. All tree timbers are today commercially important. The babul is a most famous fuel wood and charcoal making tree of India. Though it is not possible to locate the precise use of these timbers in the pre-historic period, it is probable that many of the uses would be the same as todays. It is indeed significant that from an early period, well valued timbers were known to the people of Atranjikhera in preference to many others that were indigenous to the site. A considerable knowledge of forestry is a pre-requisite for such a selection. It must also be noted that the inhabitants were willing to transport choice timbers from considerable distances given the existing economic conditions. For example chir, today is found in sub-tropical pine forests in almost pure association with no underwood and few shrubs, throughout the North West Himalayas between 1000-1800 m. It is absent in Kashmir. Therefore it was not a local timber of the Doab. It was brought from the hills, over 800 km away. Since chir is not a superior timber, being only moderately strong, it is a puzzle that is was such a prized wood. One of the explanations offered for this phenomenon by the scientists who have examined the wood remains at the site was that wood was used in rituals as incense(21). Chir wood when burnt gives off a mild fragrance.

It is important to discuss one of the other uses of chir. Chir makes excellent charcoal. Coniferous trees like chir give three times less ash than deciduous trees . Therefore the charcoal is almost free from any impurity. While 10,000 parts of Oak give 250 parts ash, the same quantity of chir gives 83 parts of ash. Fewer the impurities in the charcoal, purer is the quality of the smelted metal when it is burnt in a furnace. Other than chir, the other coniferous timbers found at Atranjikhera are deodar (Cedrus deodara) and devidiar (Cupressus torulosa). While deodar is the strongest of Indian conifers, devidiar is one of the most durable coniferous woods. These timbers grow at even higher altitudes than chir. Both timbers belong to moist temperate forests extending along the entire length of the Himalayas between the pine and sub-alpine forests in Kashmir, Himachal Pradesh, Punjab, U.P., Darjeeling and Sikkim, between 1500 and 3300 m. Found in Pd IV (NBPW)of the sites the distances these woods travelled was tremendous.

The distribution of other timbers found at Atranjikhera is as follows. In the OCP levels, Sissoo, Sal and babul have been found. Sissoo is indigenous to the Himalayan foothills from Indus to Assam, extending along the backs of rivers into the plains. It is a strong, tough and very hard timber, making excellent fuel wood and very suitable for charcoal making. It is also used for superior furniture and carvings. Sal has two clear zones of distribution–along the foot of the Himalayas upto 900–1200 m and south of the Ganges, throughout central India. The timber is very strong and hard. It is extensively used by iron-smelting communities for charcoal making. Babul is indigenous to Deccan and Sind. It is abundant in the dries parts of North India and avoids the rocky hills of Central India and the moist tracts of the Himalayan foot hills. Babul even now is a locally found timber and is predominately used as fuel wood and for charcoal making. Sal and Sissoo are now found 2–300 Kms.away from the site but perhaps they were found nearer to the site in protohistoric times. More significant is the discovery of teak in Pd. II (BRW). Teak (Tectona grandis) is one of the most valuable timbers of India. It is indigenous to South India. Therefore, this too was a timber transported from considerable distances. The inhabitants seemed to have realized at a very early stage the value of this timber which till today is the most prized wood in the country. Evidence for the use of any other wood is not found in this period. In the next period (PGW-Pd. III) chir is the only wood found and it is reintroduced after a gap of approximately 300 years. As mentioned above Deodar and Devidiar are found in the NBPW levels. Other timbers of this period are saj (Terminalia tomentosa) and farash (Tamarix articulata)(22). The latter is native to the Ganges basin and the former occurs throughout the country, upto heights of 1200 m. It is most common in Bihar & Andhra. It is found in the environs of the sites. Both timbers are traditionally used as firewood.

Atranjikhera and Daimabad are two of the best documented sites with regard to the evidence for charcoal. At the site of Sisupal- garh, an early historical site in Orissa(23) , remains of five different timbers and bamboo have been found in the early historical context at the site. Three timbers have been identified. They are Holarrhena antidysenterica ,Boswellia serrata and Soymida febrifuga or Karra, Salai and Rohan respectively. One specimen each of Acacia, Casearia and Bamboo has also been found but the species have not identified. All the trees are found in Orissa, in the vicinity of Sisupalgarh, till today. The excavators have not identified the uses of these timbers, We may assume that the uses were no different from the traditionally known uses of today.

Textual references to plants are numerous(24) Texts dated to our period, mention plants in number of contexts, usually of their use. The texts refer particularly to their use in the natural contexts. Comprehensive studies of literary reference to plants are available which are helpful to our study such as S.C. Banerjee's, Flora and Fauna in Sanskrit Literature.(25)

Texts mention not only the names of a number of plants but give associated information such as the process for the luxuriant growth of diseased trees, trees that are considered beneficial and those detrimental. Certain trees became objects of veneration, particularly those used in sacrifices such as the uḍumbara (Ficus glomerata) which was used for making razors in holy rites as also for making the king's throne, kadira (Acacia cathechu) was used for making sacrificial posts. Bilva (Aegle marmelos) and Palāsa (Butea frondosa) were used for making staffs. From the Vibhiṭaka (Terminalia belerica) dice were made. The most renowned plant in ancient times was probably the Soma (not identified) from which an exhilaraling drink was made. The familiarity with plant diseases existed. The Sitādhyaksa (Superitendent of Agriculture) of the Arthaśāstra was required to have knowledge of this. Trees became so important that their felling without reason or permission was looked upon as a penal offence.(26) Degrees of punishment, commensurate with the seriousness of the offences have been prescribed. Though the uses of plants have been mentioned in great detail, the references to charcoal making trees are not numerous. Other than the Rājavṛkśa (Euphorbia tirucalli), no other tree has been praised specifically for this property.

Based on archaeological studies, ethnographic accounts, textual evidence and contemporaryforestry records a list of timbers which could have been utilised for charicoal making, is given below. The identification of the botanical names with sanskrit names is based on Monier-Wlliams'. The distribution and description of plants is based on that of Hookes, Duthie,Roxburg and publications of the Forest Research Institute,Dehra Dun.(27)The Wealth of India, published by the CSIR(28) gives details regarding the uses of these trees. It is possible that the distribution has changed over time, so the reconstruction of proto-historic patterns can be tentative, at best. As regards their usefullness, we may conjecture that the present day uses may have been known earlier too. In this context, textual references are useful. To avoid repetition of the references to the literature on modern use of the identified timbers, they are not mentioned in the text. The complite list has been presented in tabulated form(Table 3) but some of the entires require more detailed description,especially those which appear to be the ideal woods for charcoal making. These are :

Acacia arabica(babul):- This is one of the best fuelwoods of India. It makes good charcoal. The wood is very strong(29) and hard (30)and very tough. It is used for making wheels, agricultural implements. The decoction of the bark is used as medicine. The tree is commonly found in the dry plains and low hills of the country, only avoiding moist areas. The timber has been found at four archaeological sites-Lothal,Maski,Prakash and Sisupalgarh but no where has its use been specifically identified. Babul is also preferred for charcoal making because when burnt its ash content is less than other hardwoods.

Acacia cathechu(Khair):- A thorny deciduous tree found abundantly throughout India except in moist regions. The wood is hard and used for wheels and agricultural implements. It is the source of the cathechu dye. It is also a good firewood and gives excellent charcoal. The tree is mentioned in ancient texts and its charcoal is supposed to be particularly useful to blacksmiths. The timber has been found at four archaeological sites- Lothal,Maski,Prakash, Sisupalgarh.

Anogeissus latefolia(bakli):- Indigenous to tropical thorn deciduous, this is a very tough and extremely hard wood and considered one of the best for tool handles,carts and poles. It yields a gum which is used as medicine. It is mentioned in ancient texts and found at two archaeological sites- Daimabad and Prakash. In some regions it is used for charcoal making.

Bessia latifolia(mahua):- A large deciduous tree. It is fast growing and gregarious, dominating the forests it is found in. The trees is revered by some tribes and not felled. Elsewhere it is heavily lopped for fodder, particularly in Rajasthan. The wood is hard and tough and used for carts and agricultural impliments. However, its flowers and seeds are more important. They are eaten and liquor is prepaired from them. It is found throughout India in tropical moist decidious forests. The Agaria, Gond and Koli use the wood for making charcoal for iron smelting.

Bosswellia serrata(salai/sarai):- A gregarious deciduous tree commom on the dry hills, throughout Indian plains. The wood is moderately hard and used for making boxes and chests. Today its main commercial use is as pulp for making newsprint, The tree yields a resin called Indian Frankincense. The bark has medicinal properties and the flowers and seeds are eaten. It is mentioned by Verrier Elwin as the Agaria's first choice for charcoal making. It is said that they move where ever the tree grows. Elwin, strangely refers to the tree as 'sarai' which is not recorded any where else, this being the name of another tree (Polygonum polystachyum) found in the temperate Himalayas.

Cedrus deodara(deodar), Cupressus torulosa (devidiar) and Pinus roxburghii (chir) are the three conifers included in the list. All three are large evergreen conifers with moderately strong wood, the deodar being the strongest. Their wood is resinous, particularly that of chir which is India's principal resin- producing tree. All three trees have been identified by charcoal remains at archaeological sites. Their use, however, has not been satisfactorily identified. According to forestry records conifers form the second category of trees preferred for charcoal making (the other being that of deciduous hardwoods) Their greatest advantage is that on burning they yield little ash. The ash contents of devidiar is 0.099% as compaired to 5.00% for peepal. Since these trees have great commercial importance today, they are not used locally for charcoal making.

Dalbergia sissoo(sissoo):- A strong tough and very hard deciduous tree. It occurs throughout the sub-Himalayan tract upto 900m.It extends along river banks onto the plains. It is considered among the best fuelwoods and is very suitable for charcoal making. It is today, one of the most important timber trees of the north. It is mentioned in ancient texts. It has been identified by charcoal remains at Atranjikhera and Hastinapura.

Holarrhena antidysenterica (karra):- A moderately strong tree spread all over the plains of India. Its bark is used as medicine and timber for toys, sticks, pencils. It is used extensively as fuelwood and for charcoal making locally for iron smelting.

Prosopis spicigera(khejra):- A tree spreed throughout the dry deciduous and thorn forests of the Indian plains. The wood is hard and used for carts and agricultural implements. The pods are eaten. The wood is used for fuel and charcoal making for iron-smelting.

Pterocarpus marsupium(bijasal):- A large deciduous tree occuring throughout the greater part of peninsula and also the sub- Himalaya traits of U.P. The wood is very hard and durable. It is used for counstruction and carts and agricultural impliments. The leaves are excellent fodder. The tree is used locally for making charcoal for the blacksmith.

Rhododendron arboreum(burran):- A tree introduced and naturalised in sub-tropical pine forests. It is found in the upper regions of Punjab, Kashmir and the hills of South India above 1500m. Its wood is used for tool-handles,boxes and for making plywood and the flowers are eaten. In the Kumaon it is important as a fuel and used to make charcoal for iron smithies.

Shorea robusta(sal):- An important large tree of the decidious forest of North India. It has a gregarious nature, growing extensively and dominating all other types in a forest. It is spread along the base of the Himalayas upto 900-1200m. as also on the hills of central India. The tree yields a fragrant resin. it is found at the archaeological sites of Atranjikhera, Pataliputra and Jagatrama. It is used locally for charcoal making for iron smelting.

Terminalia tomentosa(saj):- A large decidious tree. It is one of the commonest and most widely distributed in the broad leaved Indian forests. The wood is hard and used for construction and agricultural implements. Its bark contains tanin. It has been identified in the charcoal remains at Atranjikhera and Prakash. It is used locally to make charcoal for iron smelting.

Trema orientalis(gio):- The gio, or the charcoal tree, as the name suggests is essentially a fuel wood. It is also used for making chests. It occures along the foot of the Himalayas, in Bengal, Bihar and South ward up to Kerala. It has been found in the remains at the site of Daimabad.

Having studied the evidence available, we find that the evidence from archoeology, ethnography and forestry records appear to converge on certain points. It must be stressed that the conclusions from the archaeological evidence is only tentative and must be studied in context with the hard facts that timber experts provide us. Since it is practically impossible to determine the use of these timbers in ancient times, we may assume that some of the traditional uses known today may have been known in protohistoric times.

The most obvious fact that surfaces from this study is that two categories of woods are preferred for charcoal making :- (a) hard deciduous woods which burn well and give sustained heat and leave pleanty of residue ,(b) moderately hard conifers which burn with almost the same heat but for shorter duration, with hardly any residue ,

The preference seems to be for trees that are abundantly found such as mahua, sal, saj, babul, khair, chir, sissoo, salai, gio and khejra in a particular forest. These are gregarious trees that grow well and fast. Our non-random sample does not emphasise fruit trees such as mango, ber or those with medicinal properties such as neem or those that are considered sacred such as peepal and mahua, In all these instances, it appears to me that it is always the abundance of the species that stands out. It would seem that the charcoal makers were conscious of the fact that they should fell trees that are likely to grow back fast or will not be missed, since most of these species grow in pure associations. The less abundant species and those in complex associations are largly ignored such as Hopea, mesua, Kadam, lendi, jamun. These species occur mainly in moist or wet deciduous/tropical forests which have the most complex composition. Even precious timbers such as teak, shisham and cinnamom are not spared since these species are also abundant in their habitants. Since these species have become commercially important only in recent times, it is possible that they too were used for charcoal making. It is only those trees that grow sparsely or are scattered which do not appear in the list, indicating that there was some conscious reasoning that dictated the choice, other than the mere usefulness of the timber.

However, if we consider the estimates calculated at the begning of the chapter, it would seem that even such a consciousness would be of little use. The enormous demands of the iron smelting indústry could only be a fraction of a community's total firewood requirements. It is inevitable that there would have been tremendous pressure on the surrounding forests. Over time, the inhabitants would have to forage further for wood. Such an observation is borne out by the evidence at Daimabad where with every successive occupational level timbers from greater distances were transpated to the sites. 18th and 19th century accounts of the iron smelting industry repeatedly mention the scarcity of fuel being one of the major causes for the decline of the industry. With the above evidence it is not difficult to agree with this view.

TABLE 1

RATIO OF WOOD, CHARCOAL & IRON (IN UNITS)

PROCESS	WOOD	CHARCOAL	WROUGHT IRON
Smelting furnace		5	1
Forging		2	1
Entire process		14	1
Charcoal making	4	1	
Entire process	56	14	1

TABLE 2: LIST OF TIMBERS FOUND AT ARCHAEOLOGICAL SITES.

S.NO.	BOTANICAL NAME	INDIAN NAME	FOUND AT
1.	ACACIA SP.	BABUL	MASKI, PRAKASH(CHALCOLITHIC) SISUPALGARH(EARLY HISTORICAL)
2.	ACACIA NILOTICA	BABUL	ATRANJIKHERA (OCP)
3.	ANOGEISSUS SP.	BAKLI	PRAKASH (CHALCOLITHIC)
4.	BESSIA LATIFOLIA	MAHUA	KIRARI (EARLY HISTORICAL)
5.	BOSWELLIA SERRATA	SALA/SARAI	SISUPALGARH(EARLY HISTORICAL)
6.	CASEARIA SP.	CHILLA	SISUPALGARH(EARLY HISTORICAL)
7.	CEDRUS DEODARA	DEODARA	HARAPPA (HARAPPA), ATRANJIKHERA, (NBPW)
8.	CINNAMOMUM TAMALA	DALCHINI	JAGATRAMA (EARLY HISTORICAL)
9.	CUPRESSUS TORULOSA	DEVIDIAR	ATRANJIKHERA (NBPW)
10.	DALBARGIA SP.	SHISHAM	PRAKASH, (EARLY HISTORICAL)
11.	DALBARGIA LATIFOLIA	SHEESHAM	PRAKASH, (CHALCOLITHIC)
12.	DIASPYROS SISSOO	SISSOO	ATRANJIKHERA (OCP), HASTINAPUR (LATE HISTORICAL)
13.	DANDROCALAMUS SP.	MALE BAMBOO	PRAKASH (CHALCHOLITHIC)
14.	DIASPYROS SP.	TENDU	ARIKAMEDU (EARLY HISTORICAL)
15.	HERITIERA SP.	SUNDRI	ARIKAMEDU (EARLY HISTORICAL)
16.	HOLARRHENA ANTIDYSENTERICA	KARRA	PRAKASH (CHALCHOLITHIC); SISUPALGARH(EARLY HISTORICAL) HASTINAPUR (EARLY HISTORICAL)
17.	MANGIFERA INDICA	MANGO	JAGATRAMA (EARLY HISTORICAL)
18.	MIMUSOPS SP.	MULSARI	ARIKAMEDU (EARLY HISTORICAL)
19.	PINUS ROXBURGHII	CHIR	ATRANJIKHERA (PGW)
20.	SHOREA ROBUSTA	SAL	ATRANJIKHERA (OCP), JAGATRAMA PATLIPUTRA (EARLY HISTORICAL)
21.	SOYMIDA FEBRIFUGA	ROHAN	SISUPALGARH(EARLY HISTORICAL)
22.	TAMARIX SP.	JHAU	ATRANJIKHERA (NBPW)
23.	TECTONA GRANDIS	SHAGUN	PRAKASH (CHALCHOLITHIC); ATRANJIKHERA (BRW)
24.	TERMINALIA TOMENTOSA	SAJ	PRAKASH (CHALCHOLITHIC); ATRANJIKHERA (NBPW); JAGATRAMA (EARLY HISTORICAL)

TABLE 3: REFERENCES TO CHARCOAL-MAKING TIMBERS

BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/BARK	RESIN	FLOWER/FRUIT
1	2	3	4	5	6	7	8	9	10	11
ABIES SMITHIANA	-	-	-	*	ROI	-	*	-	-	-
ACACIA MODESTA	-	-	-	*	PHULAI	-	*	-	-	-
ACACIA ARABICA	-	*	*	*	BABUL	-	*	*	*	*
ACACIA CATHECHU	*	*	*	*	KHAIR	KHADIRA	*	-	*	-
ACACIA SUNDRA	-	*	-	-	LALKHAIR	-	*	-	*	-
ADHATODA VASICA	-	-	-	*	ARUSHA	VASAKA	*	-	-	*
ADINA CORDIFOLIA	-	-	*	-	HALDU	-	*	*	-	-
ALBIZZIA LEBBEK	-	*	-	-	SIRIS	SIRISA	*	*	-	*
ALBIZZIA PROCERA	-	*	*	*	SAFED SIRIS	-	*	-	-	-
ALBIZZIA STIPULATA	-	-	-	*	SIRAN	-	*	*	*	-
ANACARDIUM OCCI-DENTALE	-	-	-	*	KAJU	KAJUTAKA	*	*	*	*
ANOGEISSUS LATI-FOLIA	*	*	*	*	DHAWA	DHAVA	*	*	*	*
AZADIRACHTA INDICA	-	*	-	-	NEEM	NIMBA	*	*	*	*
BAHUNI VAHLII	-	*	-	-	MALJAN	-	-	*	-	*
BESSIA LATIFOLIA	-	*	*	-	MAHUA	-	*	*	*	*
BOMBAX CEIBA	*	*	-	-	SEMUL	SALMALI	*	*	*	*
BOSWELLIA SERRATA	-	*	*	*	SALAI/SARAI	KUNDURU	*	*	*	*

TABLE 3: REFERENCES TO CHARCOAL-MAKING TIMBERS (contd.)

BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/BARK	RESIN	FLOWER/FRUIT
1	2	3	4	5	6	7	8	9	10	11
BOSWELLIA THUR-IFERA	-	-	-	*	SALAI	SALACI	*	-	-	-
BETULA CYLINDRO-STACHYS	-	-	-	*	SAUR DHAK	-	*	-	-	-
BUTEA FRONDOSA	*	-	-	*	DHAK	PALĀŚA	*	*	*	*
BUXUS WALLICHIANA	-	*	-	-	CHIKRI	-	*	*	-	-
CAJANUS INDICUS	-	-	-	*	ARHAR	ADHĀKI	*	*	-	*
CALLOTROPIS GIGAN-TIA	*	-	-	*	AKANDA	ARKA	*	*	-	*
CASERIA GLOMERATA	-	-	-	*	MORI (MARATHI)	-	*	*	-	-
CASTANOPSIS TRI-BULOIDES	-	-	-	*	HINGORI	-	*	*	-	-
CALLICARPA ARBOREA	-	-	-	*	KHOJA	-	*	*	-	-
CARALLIA INT-EGERIMA	-	*	-	-	KIERPA	-	*	*	-	*
CAREYA ARBOREA	*	*	-	-	KUMBI	KUMBHI	*	*	-	-
CARTHAMUS TINCT-TORIUS	-	*	-	-	KUSUM	KUŚUMBHA	*	*	*	*
CASEARIA SP.	-	-	*	-	-	-	*	*	-	*
CASSIA FISTULA	-	*	*	*	AMALTAS	SUVARNAKA	*	-	-	*
CEDARUS DEODARA	-	-	*	-	DEODAR	DEVADARU	*	*	*	-
CEDRELA TOONA	-	*	-	-	TUN	NANDI-VṚKŚA	*	*	-	*
CINNAMOMUM TAMALA	-	-	*	-	TEJPATTA	TEJPA-PATRA	-	*	-	-

contd. .....

BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/ BARK	RESIN	FLOWER/ FRUIT
1	2	3	4	5	6	7	8	9	10	11
COLEBROOKIA ZEY-LANICUM	-	-	-	-	DALCHINI	TAMAL-PATRA	-	*	-	-
CORCHORUS OPPOSTI-FOLIA	-	-	-	*	BINDA	-	*	*	-	-
CORCHORUS CAPU-LARIS	-	-	-	*	NARCHA	KALAŚAKA	*	*	-	-
CORNUS MACROPHYLLA	-	-	-	*	KANDAR	-	*	-	-	-
CUPRESSUS TORULOSA	-	*	*	-	DEVIDIAR	-	*	*	-	-
CYNOMETRA POLY-ANDRA	-	-	-	-	PING	-	*	-	-	-
DALBERGIA LATI-FOLIA	*	-	*	*	SHISHAM	ŚIŚAPA	*	*	-	-
DALBERGIA SISOO	*	*	*	-	SISOO	ŚIŚAPA	*	*	-	-
DADHNE MUCRONATA	-	-	-	*	SATPURA	-	*	*	-	-
DENDROCALANUS SP.	-	-	*	-	BANUS	VANṢA	*	*	-	-
DIASPYROS SP.	-	*	*	-	TENDU	NĪLAVṚKŚA	*	-	-	*
DILLENIA INDICA	-	-	-	*	CHLATA	BHARIJA	*	*	-	*
DILLENIA PENTAGYNA	-	-	-	*	AGGAI	-	*	*	-	*
ECHINOCARPUS DASYCARPUS	-	-	-	*	TAKSAL	-	*	-	-	-
EHRETIA WALLI-CHIANA	-	-	-	*	KALET	-	*	-	-	-
ELAEOCARPUS LANCE-AEFOLIUS	-	-	-	*	SKEDKYEW	-	*	-	-	*
EUCALYPTUS GLO-	-	-	-	*	-	-	*	*	*	-

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BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/BARK	RESIN	FLOWER/FRUIT
1	2	3	4	5	6	7	8	9	10	11
BULUS										
EUGENIA TETRAGONA	-	-	-	*	-	-	-	-	-	-
EUPHORBIA TIRU-CALLI	*	-	-	-	SEHNAD	RĀJAVṚKŚA	*	*	-	-
EUPHORBIA ANTI-GUORUM	-	-	-	*	TREDHARA SEHNAD	VAJRA-KANTAKA	*	*	-	-
EXCOECARIA AGALLO-CHA	-	-	-	*	GHENGWA	-	*	*	-	-
FICUS CORDIFOLIA	-	-	-	*	GYASHWAT	-	*	-	-	-
FICUS INFECTORIA	-	-	-	*	KAHIMAL	PLĀKŚA VṚKŚA	*	*	-	-
FICUS RELIGIOASA	*	*	-	*	PEEPUL	AŚWATHA	*	*	-	*
FICUS RUMPHII	*	-	-	*	GAGJAIRA	-	*	*	-	*
GNETUM SCANDENS	-	*	-	-	MAMEILET	-	-	*	-	*
GREWIA LATIFOLIA	-	*	-	-	DHAMAN	DHANURA VRAKŚA	*	*	-	*
HERITIERA MINOR	-	-	*	-	SUNDRI	-	*	*	*	*
HIPPOPHAE RHAM-NOIDES	-	-	-	*	KALIBISA	-	*	-	-	*
HOLARRHENA ANTI-DYSENTRICA	*	*	*	-	KARRA	GIRI-MALLIKA	*	*	-	-
JUNDERUS EXCELSA	-	-	-	*	ABHAL	VAPUŚA	*	*	-	*
LAGESTROMIA MICRO-CARPA	-	*	-	-	NANA	-	*	-	-	-
LAGESTROMIA PARVI-FLORA	-	-	-	*	DHAURA	-	*	*	-	-

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BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/ BARK	RESIN	FLOWER/ FRUIT
1	2	3	4	5	6	7	8	9	10	11
MIMOSA RUBICAULIS	-	-	-	*	SHIAH-KANTA	-	*	-	-	-
MIMUSOPS SP.	-	-	*	-	MULSARI	BAKULA	*	*	-	*
MANGIFERA INDICA	*	-	-	*	AM	ĀMRA	*	*	-	*
OLEA DIOICA	-	*	-	*	ATTA-JAM	-	*	*	-	*
PHYLLANTHUS EMBLICA	-	-	-	*	AMLA	ĀMLAKI	*	-	-	*
PIERIS OVALIFOLIA	-	-	-	*	BALU	-	*	*	-	-
PINUS DEODARA	*	-	-	*	DEVDAR	PUTUDRŪ	*	-	-	-
PINUS EXCELSA	-	-	-	*	KAIL	-	*	-	-	-
PINUS LONGFOLIA	-	-	*	*	CHIR	SARALA	*	-	*	-
	-	- (3)	-	*	AMLDANDI/ SARAI	-	-	*	-	*
PROSOPIS LATIFOLIA	-	-	-	*	-	-	*	*	-	-
PROSOPIS SPICIGERA	*	-	-	*	KHAR	ARĀTAKI	*	-	*	*
PTEROCARDUS MARSUPIUM	-	*	*	-	BIJASAL	PITASĀRA	*	*	*	-
QUERCHUS ILEX	-	-	-	*	BRE-CHUR	-	*	*	-	-
QUERCHUS INCANA	-	-	-	*	SILA-SUPARI	-	*	*	-	-
QUERCHUS SPICATA	-	-	-	*	BARA CHAKMA	-	*	-	-	-
QUERCHUS SEMECARFOLIA	-	*	-	*	BANCHAR	-	*	*	-	-

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BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/ BARK	RESIN	FLOWER/ FRUIT
1	2	3	4	5	6	7	8	9	10	11
RHODODENDRON ARBOREUM	-	*	-	*	BURANS	-	*	-	-	*
SALIX TETRASPERMA	-	-	-	*	BENTH	VARUNA	*	*	-	-
SESBANIA AEGYPTICA	-	-	-	*	JAINTI	JAYANTIKA	*	*	-	*
SEMECARPUS ANACAR-DIUM	-	*	-	*	BHELA	BILVA	*	-	-	-
SHOREA ROBUSTA	*	*	*	-	SAL	ÁSVAKARNA	*	*	*	*
SOYMIDA FEBRIFUGA	-	-	*	-	ROHAN KANTA	-	*	*	*	-
SPONIA ORIENTALIS	-	-	-	*	-	-	*	-	-	-
STEPHEGYNE PARVI-FOLIA	-	*	-	-	KAIM	-	*	-	-	-
STERCULIA GUTTATA	-	*	-	-	KUNAR	-	*	*	-	*
STEREOSPERMUM SUAVEOLENA	-	-	-	*	PARAL	PATALA	*	*	-	*
TAMARINDUS INDICA	*	*	-	-	IMLI	ĀMLIKA	*	*	-	*
TAMARIX ARTICULATA	-	-	-	*	LAL-JHAVA	-	*	*	-	-
TAMARIX SP.	-	-	*	-	JHAU	PISTULA	-	*	-	-
TECTONA GRANDIS	*	*	*	-	SAGUN	ŚAKA	*	-	-	-
TERMINALIA BELLI-RICA	*	*	-	-	BAHERA	VIBHIṬAKA	*	-	-	*
TERMINALIA CHEBULA	*	*	-	-	HARCHHOTI	HARITAKA	-	*	-	*
TERMINALIA MYCRO-CARPA	-	-	-	*	PANISAJ	-	*	*	-	-

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BOTANICAL NAME	MENTIONED IN/FOUND AT				INDIAN NAME	SANSK. NAME	OTHER USES			
	TEXTS	ETHNO-GRAPHY	ARCHAE-OLOGY	FOR. REC.			TIMBER	LEAF/BARK	RESIN	FLOWER/FRUIT
1	2	3	4	5	6	7	8	9	10	11
TREMA ORIENTALIS	-	-	*	-	GIO	JIVANTI	*	*	-	*
TERMINALIA TOMENTOSA	*	*	*	*	SAJ	ÁSANA	*	*	-	-
TERMINALIA PANICULATA	-	*	-	-	KINJAL	-	*	*	-	-
XYLOSMA LONGIFOLIUM	-	-	-	*	DANDAL	-	*	*	-	-
ZIZYPHUS MAURITIANA	*	-	*	-	BER	AJAPRIYA	*	-	-	*

* = PRESENT

References

1. Lee Horne, 'Fuel for the Metalworker,' Expedition, Vol.25,No.1,1982.p.8.
2. Records of the Geological Survey of India,Vol.xxv
3. Journals of the Forest Reserch Institute.
4. G.Watt, Dictionary of the Economic Products of India , vol.II,p.264.
5. T.A. Wertime,'The Furnace verses the Goat,' Journal of Field Archaeology Vol 10. 1983. pp. 445-452.
6. Lee Horne, op.cit.
7. Indian Forester Vol I p.54 (1875-76); vol,8 p.299(1882-3) vol 10 p.59-61(1884-85);vol 10 p.63; vol 12 p.73(1886-87);vol 19(1893); vol20 p.98-100(1894); vol 20 p.100-103; vol 21 p.263-4 (1895);vol 34 p.210(1908);vol40 p.463(1914); vol 27,p.134 (1901); vol 40 p.96-8(1914).
8. F. Buchanan, A Journey from Madras through the Countries of Mysore,Canara and Malabar, Vol II, p.16.ff.
9. V. Elwin, The Agaria, p.121 ff.
10. Ibid.,p. 123.
11. Buchanan, op.cit.
12. Indian Forester Vol 20, p. 100-103.
13. S. Bhattacharya, 'The Indigenous iron smelting Industry' in Surajit Sinha (ed)., Aspects of Indian Society and Culture.
14. Elwin, op.cit., p.243.
15. Indian Forester, op.,cit.
16. R.C.Gaur, Excavations at Atranjikhera.
17. S.A.Sali, Daimabad.
18. B.B.Lal,'Excavations at Sisupalgarh,' Ancient India, No.7,pp.62-151.
19. Sali, op.cit., p. 611-627.
20. K.A. Choudhary et.al, Ancient Agriculture and Forestry in North India.
21. Ibid., p.77-8.
22. Indian Forester, vol 1, 8 and 10.
23. K.A. Choudhary and S.S. Ghose,' Plant remains from Sisupalgarh,' Ancient India No.7. 1951, pp.3-19.
24. Kumkum Roy,' In which part of South Asia did early Brahmanical tradition take its form,' Studies in History.,Vol IX, no.1,pp.1-32.
25. S.C. Banerji, ' Flora and Fauna in Sanskrit Literature
26. Ibid., p.10.
27. Indian Woods, vols I,II,III,FRI;J.F.Duthie, Flora of the Upper Gangetic Plain, 3vols;. J.D. Hooker , The Flora of British India, Parts I-XVII;W.Roxburgh, Flora Indica, vol. 1-3; H. Drury, Hand-book of Indian Flora, vols 1-3; V.S. Agarwal, Wood Yielding Plants of India; R.N. Parker, Common Indian Trees; K.P.Sagreiya, Forests and Forestry.
28. The Useful Plants of India (extracts from the wealth of India series) CSIR.

29. The strength of wood is defined as its ability to resist external forces landing to alter its shape.

30. Hardness is the property to resist penetration or indentation.

CHAPTER VI

THE CONCLUSION

A NEW HYPOTHESIS FOR FURTHER STUDY

In the forgoing chapters, the subject of our study has been examined from different angles. Having studied the technology of iron production in the protohistoric period in relation to that of modern users of the indigenous technique and having estimated the fuel demands of the industry, we are forced to examine the issue from a fresh perspective. So far, scholars have concentrated on the study of the Iron Age in respect of the changes it brought about. Iron technology did introduce wide ranging changes in the socio-economic environment but was its introduction alone, a critical factor in social change ?

In order to study the extent of these changes, it is necessary to have some understanding of the technology of iron making. In this discussion the aspects highlighted compell us to ask new questions of the data. It is no longer sufficient to merely talk of the role of iron in the economy and not keep in mind that the technology imposed severe constraints on the quantum of output in any one locality because it is this that would determine the impact. There is a large body of literature on the subject but nowhere has this issue been raised.

The impact of the introduction of iron in the economy particularly in agriculture has been discussed largely in the context of agricultural expansion and urbanism in the Gangetic Valley in the first millenium B.C. There is a large body of literature on the subject and considerable difference of opinion has resulted from the debate.

One of the earliest scholars to link the economy to agricultural expansion was D.D.Kosambi (1). He dealt with iron in the context of the eastward expansion of the Aryans in the first half of the first millenium B.C. The expansion according to him took place along the Himalayan foothills where the softwood was easy to burn. Burning was an established means of land clearance in Vedic texts. The expansion opened up the rich iron mines of Bihar which were exploited for crafting tools and implements. He feels that the Ganges basin with its fertile alluvial soils, heavy rainfall and thick forests could not have been cleared without iron implements. Fire alone would not be enough to burn the deciduous trees of this region because the stumps would send out new roots, though he points out in other context that stone tools could also have cleared the forests (2). Kosambi cites literary evidence to show that iron was being used in agriculture since 700 B.C.

However, it is doubtful if iron could have been useful till the production of steel was known because only carburisation would give a tougher metal than copper or bronze (3). Wrought iron blunts as easily as these metals. Kosambi's argument is based on the assumption that without iron, agricultural expansion in the Ganges basin was impossible without stating why such an assumption was being made. He follows Gordon Childe's view that iron implements made it easier to break the ground, clear it of trees and dig channels, without asking if this holds true in all contexts or if Childe necessarily implies that without iron, expansion would not have been possible.

Following a similar argument, R. S. Sharma (4) went as far as to suggest that the 'one single factor' that transformed the material life of the people around c.700 B.C. in the middle Gangetic valley was the beginning of the use of iron impelements. He dates the introduction of iron in Atranjikhera to 1000 BC (5). According to him, plough agriculture began in the upper Gangetic valley at this time and was brought to the east with the expansion of the Aryans by 700 BC. Plough agriculture and new agricultural techniques led to the foundation of large scale agricultural settlements. New techniques led to the production of surplus on a scale not attained before. This, he feels, prepared the ground for the use of urban settlements in the region around c. 600 B.C. Like Kosambi, he thinks that the thick jungles of the Ganges basin posed a challenge to human ingenuity but the neighbouring areas provided iron with which the forest could be turned into arable lands and settlements. South Bihar posessed copper and iron ores of good quality in abundance and therefore provided some kind of haven for iron users. These jungles could not be burnt because the deep rooted and hard fibre sal, seasum, mahua, peepul trees of the region would have to be cut by an iron axe. According to Sharma, what really gave an impetus to urbanism was the beginning of paddy transplantation. This gave a new orientation to agriculture beacuse it needed constant supply of water and the iron plough share for continual reploughing of the heavy clayey soils that are best suited for wet rice cultivation. However, the references to this date only after 500 BC and Sharma himself dates the introduction of iron in the production system to 700 BC. Therefore agricultural expansion could not have depended on this factor alone.

In a later work (6), Sharma modifies his view somewhat and attributes the rise of urbanism in Bihar and east U.P. in the age of the Buddha to the complex of rice, iron and coins. This was an age of rapid specialisation in arts and crafts. Archaeological and literary data indicate this. Sharma links the rise of crafts to the rise of towns which provided markets and also to the introduction of metallic currency which provides an easy mechanism of exchange. These towns, he feels could only have been supported by an extensive agricultural base.

Sharma's agrument is based on Kosambi's assumption that agricultural expansion was impossible without iron because first, trees could not be felled by any other implement, though as mentioned above, Kosambi himself says that stone could have performed the task and Sharma himself points out that even in the NBPW levels in the sites in the Ganges basin implements are mainly made of wrought iron (7). Wrought iron is not any tougher than copper or bronze (8). It is only steel that gives a better edge to such implements.

Second, Sharma speaks of large scale clearance of forests. Was this really necessary, considering the needs of the population at the time ? Furthermore, forests are not impediments to agriculture. Every agricultural community acknowledges the value of forests. They are maintained as assets (9).

Third, it has been noted that often the heavy plough is harmful to certain soils (10). Such ploughs are suited best to regions with sufficient supplies of water. Their use does not automatically lead to improved yields.

Scholars have argued against the thesis of R.S.Sharma on other counts as well. According to A Ghosh (11) the mere availability of agricultural surplus was not sufficient for the rise of urbanism. He feels that the pre-requisite is not a hypothetical surplus but an administrative and mercantile organisation. Technological change alone is not enough because the mere knowledge of superior technology does not automatically lead to its use in the production system. He points out that the PGW culture which first used iron was too slow moving to fruitfully use the metal. Copper-bronze tools and fire were sufficient to clear forests and this clearance was gradual and according to immediate needs.

N.R. Ray (12) points out that there is not enough archaeological evidence to prove that there was large scale land clearance with the iron axe or cultivation with the iron plough in this period. According to him it was not till the Mauryan period that the quantitative and qualitative use of iron technology and implements took place that could induce 'revolutionary change'. Rather than plough cultivation, it was hoe cultivation that appears to be prevalent. Since the iron objects of this period are mainly weapons, he feels iron played an important role in state formation, giving an edge to the states that used them in warfare.

The issue has been looked at from an entirely new perspective by Makhan Lal (13). According to him the extensive use of iron tools and large scale forest clearance is a myth. In a sample survey of 99 NBPW sites in Kanpur district conducted by him, it was found that 81 of these were below two hectares in size and could not have accomodated more than 500 persons. The average spacing between two settlements in the NBPW period was 9 km. Based on the estimate of Dhavlikar and Possehl (14) that 1 kg. of grain can support 2.5 persons a day and in Kanpur district the average yield per acre is 600 kg, the total land requirement was calculated. It was estimated that land not more than 1 km in radius would be required to sustain a population of 500 people. This much land is available along rivers and lakes and open areas. It may be concluded that land requirement was not so acute as to warrant large scale land clearance.

As far as the role of iron in agriculture is concerned, it is the iron plough which is said to have 'revolutionised' agriculture in this period. However reports on Indian agriculture by experts in the colonial period have noted that in Indian conditions the best type of plough is that which stirs but does not invert the soil. The iron plough is often harmful to certain soils. Soils with clayey sub-soils cannot be ploughed too deeply because this brings up the inferior soil and exposes it to loss of moisture. In the case of such soils, the sun bakes the slice turned over into practically a brick, which is difficult to pulverise again. Furthermore, an iron plough is not only too heavy for the bullocks to move but also too heavy to be easily transported. What is recommended for Indian conditions is repeated tilling with a light plough**(15)**. It has been noted by many experts that the Indian farmer was aware of these facts. Therefore, the mere knowledge of the heavy plough was not an incentive to make use of it.

The lack of fluxing would have affected yields to a large extent. Slag analysis shows the large percentage of iron which was being lost. Analysis of the metal however, shows the purity of the metal. The metal hardly includes any impurities since it is exposed to heat for a long period and refined in the forge till all the slag is squeezed out. However, some samples are examples of unsuccessful smelts because slag inclusions in them is high.

Besides the fact that the technology was at an experimental stage, the furnaces used for smelting too were very simple structures. Most of them were open crucible-type pits where temperatures higher than 900 degrees centigrade could not be attained, causing yields to suffer. It is not clear if these pits were merely heaped with ore and fuel or sealed with clay. The furnace at Naikund(16) however, must be mentioned as an exception, since it is the only brick-built furnace to have been found in any excavation. In fact such a furnace is not described in any ethnographic account discussed in chapter III and nor is it presently used. It is a mystery why such an improved model did not become popular.

While discussing the Iron Age, it must be kept in mind that most of the objects recovered from sites are of wrought iron. Wrought iron is a soft metal (17). Its maximum resistance to traction is 280 N/sq. mm. only by beating and reheating, that is by carburising its resistance increased to 700 N/sq. mm. However, bronze when beaten cold has resistance of 880 N/sq. mm. Therefore it cannot be automatically assumed that iron was the tougher metal. It is not until steel was introduced that the real advantage of iron was realised and it became widespread. Low carbon steel (0.2 - 0.3 % carbon) has resistance equal to that of bronze and that with 1.2 %

carbon has resistance of 910 N/sq. mm. When the same steel is hammered cold its resistance increases to 1175 N/sq. mm., giving it literally the 'cutting edge'.

Other than the technological aspect, we have also highlighted the question of fuel in chapter IV. It is well established that prior to the use of coke, charcoal was the only fuel used for iron smelting because of its reducing action. Experiments have shown that enormous quantities of fuel are consumed for iron smelting. The ratio of fuel to the end product stands at 14 : 1. Since the indigenous process of charcoal making is inefficient, 4-6 kgs of wood are burnt for each kilogram of charcoal. Therefore, 56 kgs of wood are required to produce 1 kg. of wrought iron. Given such estimates, we may wonder about the scale of production. It is difficult to assume that there were centres producing iron objects on a mass scale because the immediate forest cover would simply have been insufficient to support it. It has been pointed out that not all timbers are used for charcoal making. It is those trees which are most commonly found in the neighbouring forest which are felled for the purpose. To ensure regeneration of the forest steps are taken to prevent indiscriminate felling. Therefore the need for sufficient fuel becomes more acute.

In the case of the Agaria, whose technique is almost identical to that of the ancient smith, it has been pointed out that the only factor that helped the Agaria to persist with their outmoded technology till the early 20th century was their efficient utilisation of resources. The craft was practised by small dispersed groups which produced just enough to cater to local needs. Archaeological evidence too supports this view because at most of the smelting sites as far as we know the industry was small scale at the local level and usually geared to supply to local demands. It is possible that there were many such small centres of production which exploited the locally found ore and fuel reserves.

It would perhaps be more plausible to suggest that in the ancient period, the blacksmith's craft was a specialised one and it was the occupation of groups which produced on a scale that allowed the exploitation of ore and fuel in a sustainable manner.

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Reference

1. D.D. Kosambi, An Introduction to the Study of Indian History, (1956).
2. Ibid., p.138.
3. R. Maddin, James D. Muhly, T. S. Wheeler, 'Beginning of the Age of Iron' in Yves Coppens (ed.), Scientific American (1983), pp.192-200.
4. R. S. Sharma, 'Material Background of the Origins of Buddhism', Das Kapital Centenary Volume - A Symposium, Mohit Sen and M B Rao (ed.), (1968), pp. 59-66.
5. In another article 'Iron and Urbanisation in the Ganga Basin' IHR, Vol I, 1974, Sharma rejects this early dating based on fresh evidence stating that in Atranjikhera iron can be dated to 800 BC because only one sample may be dated to 1025 BC.
6. R. S. Sharma, Material Culture and Social Formations in Ancient India, (1983).
7. Ibid., p.94.
8. R. Maddin et. al., op. cit.
9. Madhav Gadgil, 'Deforestation : Problems and Perspectives' Foundation Day Lecture, May 12, 1989 Society for Promotion of Wasteland Development, New Delhi.
10. J. A. Voelker, Report on the Improvement of Indian Agriculture, (1983). London.
11. S. Sangwan, 'Trial of Strength' NISTAADS (unpublished).
12. N. R. Ray, 'Technology and Social Change in Early Indian History', Puratattva, No. 8, 1975-6, pp. 132-138.
13. Makhan Lal, 'Iron Tools, Forest Clearance and Urbanisation in the Gangetic Plains', Man and Environment No. 10, 1986, pp.83-90.
14. Makhan Lal, op.cit., p. 87. cites M. K. Dhavalikar and G. L. Possehl, 'Settlement and Subsistence Pattern of an Early Farming Community in Western India' Purattatva No.7, pp. 39-49.
15. Alexander Walker, 'Indian Agriculture' (1820) in Dharampal (ed.), Indian Science and Technology in the 18th century (1971) pp. 229-256 and J. A. Voelker, op.cit.
16. S. B. Deo and A. P. Jamkhedkar, 'Naikund Excavations 1978-80 (1982), p.11.
17. R. Maddin et. al., op. cit.

BIBLIOGRAPHY

Agarwala, V.S., 1953, India as known to Panini, Lucknow.

Agarwal, O.P., Hari Narain and S.K.Bhatia, 1980-81, 'Technical Studies of Iron Implements from the Megalithic Site - Tadakanahalli', Purattatva' No.12, pp.97-100.

Agarwal, O.P.,1983 'Scientific and Technological Examination of Some objects from Atranjikhera' in R.C.Gaur, Excavations at Atranjikhera, Delhi, pp.487-498.

Aggarwal, V.S., 1970, Wood Yielding Plants of India, Calcutta.

Allchin, Bridget and Raymond, 1983, The Rise of Civilisation in India and Pakistan, Delhi, pp.308-346.

Anon., 1880-81, 'Iron Making in India', Indian Forester, Vol.6, pp. 202-10.

Bailey, F., 1879-80, 'On Iron Smelting', Indian Forester, Vol.V, p.167.

Banerjee, M.N., 1927, 'On Metals and Metallurgy in Ancient India', Indian Historical Quarterly, No.3, pp.121-33.

_______________, 1929, 'Iron and Steel in the Rig Vedic Age', Indian Historical Quarterly, No.5, pp. 432-40.

_______________, 1932, 'A Note on Iron in the Rig Vedic Age', Indian Historical Quarterly, No. 8, pp.364-6.

Banerjee, N.R., 1965, Iron Age in India, Delhi.

_______________,1986, Nagda, New Delhi.

Banerjee, S.C., 1980, Flora and Fauna in Sanskrit Literature, Calcutta.

Bhandarkar, D.R., 1913-14, Excavations at Besnagar - Annual Report of ASI, pp. 186-226.

Bhardwaj, H.C., 1973, 'Aspects of Early Iron Technology in India' in D.P.Aggarwal and A.Ghosh (ed.), Radio Carbon and Indian Archaeology, Bombay, pp.391-399.

Bhattacharya, S., 1972, 'Iron Smelters and Indigenous Iron and Steel Industry of India' in Surajit Sinha (ed.), Aspects of Indian Culture and Society, pp. 133-51.

Buchanan,F., 1807, A Journey from Madras through the Countries of Mysore, Canara, Malabar 3 Vols., London.

______________, 1934 (reprint), An account of the District of Shahabad in 1812-13, Patna.

Chakrabarti, D.K., 1976, 'The beginning of Iron in India' Antiquity, Vol.50, pp.114-25

__________________, 1979, 'Iron in Early Indian Literature', Journal of the Royal Asiatic Society, pp.22-80.

__________________, 1992, The Early use of Iron in India, Delhi.

Chowdhary K.A. and S.S.Ghosh, 1951, 'Plant Remains from Harappa',Ancient India, No.7, pp. 3-19.

______________________________, 1952, 'Wood Remains from Sisupalgarh;Ancient India, No.8, pp.28-32.

Chowdhary, K.A., K.S.Saraswat and G.M., Buth, 1977, Ancient Agriculture and Forestry in North India, New Delhi.

Dasgupta, P.C., 1964, Excavation at Pandu Rajar Dhibi, Calcutta.

De, S. and P.K.Chattopadhya,1989-90.'Archaeometallurgical Studies at Kankrajhar and Dhupliapur', Purattatva, No. 20., pp.115-7.

Deo,S.B. and M.K. Dhavlikar, 1968, Paunar Excavations, Nagpur.

Deo, S.B., 1970, Excavations at Takalghat and Khapa, Nagpur.

__________,1973, Mahurjhari Excavations,-1970-2, Nagpur.

Deo, S.B. and A.P. Jamkhedkar, 1982, Naikund Excavations, Nagpur.

Dharampal, (ed.), 1971, Indian Science and Technology in the 18th Century, Hyderabad.

Drury, H., 1864, Handbook of Indian Flora, Vols.1-3, Travancore.

Duthie, J.F., 1903, Flora of the Upper Gangetic Plains, Vols.I - III, Calcutta.

Elwin, Verrier, 1942, The Agaria, Calcutta.

Franklin, J., 1971(reprint), 'The Mode of Manufacturing Iron in Central India' in Dharampal (ed), Indian Science and Technology in the 18th Century, Delhi.

Gadgil, Madhav, 1989, 'Deforestation : Problems and Perspectives', Foundation Day Lecture, Society for Promotion of Wasteland Development, New Delhi.

Gaur, R.C., 1983, Excavations at Atranjikhera,Aligarh.

Ghosh., A., 1973, The City in Early Historical India, Delhi.

Ghosh, A., (ed), 1989, An Encyclopaedia of Indian Archaeology, New Delhi.

Ghosh, N.C., Arun K. Nag, P.K.Chattopadhya, 1987-88, 'The Archaeological Background and Iron Sample from Hatigra', Purattatva, No. 18, pp. 21-27.

Gogte, V.D.,1982, 'Megalithic Iron Smelting at Naikund' in S.B.Deo and A.P.Jamkhedkar, Naikund Excavation, pp. 52-59.

Gordon, D.H., 1950, 'The Early Use of Metals in India and Pakistan, Journal of the Royal Anthropological Institute, pp.55-78.

Griffith, R.T.H., 1896-7, The Hymns of the Rig Veda Vols.I,II, Benaras.

Hedge, K.T.M, 1969, 'Technical Studies of Copper Artefacts Excavated from Ahar, in H.D.Sankalia, S.B.Deo and Z.D.Ansari, Excavations at Ahar, Poona, PP.225-8.

_____________, 1973, 'A Model for Understanding, Ancient Indian Metallurgy', Man, Vol.8, No.3, pp.416-422

Heyne, B., 1971 (reprint), 'Iron Works at Ramanakapettah' in Dharampal (ed.), Indian Science and Technology in the 18th Century, Delhi.

Hooker, J.D., 1880-90, The Flora of British India, Parts I-XVI, London.

Horne, Lee, 1982, Fuel for the Metalworker, Expedition, Vol.25, No.1, pp.6-13.

Indian Forester, Vols.1,8,10,12,19,21,27,34,40. F.R.I., Dehradun.

Indian Woods, Vols. I,II,III, F.R.I., DehraDun.

Jarrige, Jean-Francois and M Santoni, 1979, Fouilles de Pirak, 2 Vols. Paris.

Kangle, R.P., 1965-69, The Kautilya Arthaśāstra Parts I-III, Bombay.

Kosambi, D.D., 1956, An Introduction to the Study of Indian History, Bombay.

Lad, Gauri, 1983, The Mahābhārata and Archaeological Evidence, Poona.

Lal, B.B., 1949, 'Excavations at Sisupalgarh', Ancient India, No.7, pp. 62-105.

________, 1954-55, 'Excavations at Hastinapura and other Explorations, Ancient India, Nos. 10 & 11, pp.5-151.

Maddin R., J.D.Muhly and T.S.Wheeler, 1983,'Beginning of the Age of Iron' in Yves Coppens, (ed.),Scientific American, pp.192-200.

Makhan Lal, 1986, 'Iron Tools, Forest Clearance and Urbanisation in the Gangetic Plains' Man and Environment, No.10, pp.83-90.

Marshall, John, 1951, Taxila, Vols. I-III, Cambridge.

Mehta, R.N. and S.N.Chowdhary, 1975, Excavations at Dhatwa, Baroda.

Misra,P.K., 1977, The Nomadic Gadulia Lohar of Eastern Rajasthan, Calcutta

Monier - Williams, 1936, Sanskrit - English Dictionary.

Oldham, C.E.A.W., (ed.), 1930 Journal of Francis Buchanan kept during the visit of the District of Bhagalpur in 1810-11

Parker, R.N., 1933, Common Indian Trees, DehraDun.

Raju, K., 1989-90, 'Iron and Gemstone Industries as revealed from Kodumannal Excavations', Purattatva, No.20, pp. 111-112.

Rawat, A.S., 1991, History of Forestry in India, New Delhi.

Reports of the Geological Survey of India, Vol.XXV.

Ray, N.R., 1975-76, 'Technology and Social Change in Early Indian History', Purattatva, No.8, pp.132-8.

Roy, Kumkum, 1993, 'In Which Part of South Asia did Early Brahmanical Tradition (in the First Millennium B.C.) take its form, Studies in History, Vol.9, No.1, pp.1-32.

Roy, T.N., 1983, The Ganges Civilisation, Delhi.

Roxburgh, W., 1832, Florica Indica, Serampore.

Russel R.V. and Hiralal, 1916, The Tribes and Castes of the Central Provinces Vols 1-4, London.

Sagreiya, K.P., 1967, Forests and Forestry, New Delhi.

Sahi, M.D.N., 1978, 'Excavations at Jakhera', Man and Environment, No.2, pp.101-3.

__________, 1980, 'Origin of Iron Metallurgy in India', Proceedings of the Indian History Congress, 41st session, pp. 104-111.

Sali, S.A., 1982, Daimabad, New Delhi.

Sangwan, S., 1989, 'Trial of Strength', (unpublished article) NISTADS.

Sankalia, H.D., S.B.Deo, Z.Ansari and Sophie Ehradhart, 1960, From Prehistory to History at Nevasa (1954-56), Poona.

Sharma, G.R., 1960. Excavations at Kausambi, Allahabad.

Sharma, R.S., 1968, 'Material Background of the Origin of Buddhism' in Mohit Sen and M.B.Rao (ed.), Das Kapital Centenary Volume - A Symposium., pp.59-66.

Sharma, R.S., 1974, 'Iron and Urbanisation in the Ganga Basin', Indian Historical Review, Vol.1

______________, 1983, Material Culture and Social Formations in Ancient India, Delhi.

Voelker, J.A., 1983 (reprint), Report on the Improvement of Indian Agriculture, Delhi.

Walker, Alexander, 1971 (reprint) 'Indian Agriculture (1820)', in Dharampal, (ed.), Indian Science and Technology in the 18th Century, pp. 229-256.

Warth, H., 1894, 'Iron Making in South India', Indian Forester, Vol.XX, pp.100-103.

Watt, G., 1889, Dictionary of the Economic Products of India, Vol.II.

Wealth of India Series, 1986, Useful Plants of India, CSIR, New Delhi.

Wertime, T.A., 1983, 'The Furnace versus the Goat', Journal of Field Archaeology, Vol.10, pp. 445-452.

Wheeler, R.E.M., 1959, Early India and Pakistan, London.

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