TOWARDS THE WOOTZ: IRON AND STEEL TECHNOLOGY IN INDIA

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Iron had a hoary antiquity in India going back to first half of the first millennium BC according to recent 14C dates. The metallurgy of iron slowly evolved over the centuries from a slag rich simple wrought iron to steely iron and later to good quality steel. By 4-5th century AD Delhi iron pillar weighing seven tons was produced, so were sharp edged weapons like daggers and swords. There are textual evidences like Khadgalaksanam (5th century AD) that give meticulous details of technique of high quality production of sword blades. Such technique must have been prevalent in the society for a long time to find mention in a text written by an astrologer cum astronomer like Varahamihira. Indian swords, we know were famous in the ancient world right from 5-4th century BC.

In early medieval India, we come across several important steel producing centres like Sind, Gujarat, Kucca, Assam, Bengal, Bihar, Rajasthan etc apart from the southern India. Most of the above centres were famous for their good quality swords which were exported to different parts of the world through the busy port towns. The Arab and Persian accounts of 10-11th century have acclaimed these ports for their safety arrangements and facilities. Thus trade in Indian iron and steel, especially in the good quality swords was a flourishing one. However, there was a set back in the trade, especially with foreign lands following a political upheaval in most of the northern parts after 1200-1300 AD. The southern part of the subcontinent was relatively less affected by the political turmoil. They continued their production and trade till much later. The Dutch made huge profits till 17-18th century AD by selling Indian swords in Europe that fetched huge profits. This steel became famous in the ancient world as wootz because the originating ports were in southern India. The present paper tries to underline the fact that the foundations for such high quality steel production were laid down centuries back and the Indian iron and steel industry was a flourishing one and was broad based with production centres in several parts of the subcontinent.

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INTRODUCTION

The world famous wootz steel swords with their watering pattern have a long history. Around the beginning of the Christian era, or may be even earlier, India produced a very special kind of crucible steel, generally known as wootz or ukku. It became famous as Damascus steel in the ancient world because it found its way in the world market through the traders who purchased the steel in India and dispersed it to different parts of the world. In the medieval period Persian merchants stayed at several port-towns of southern India for acquiring the wootz steel for days together. The Geniza records of the eleventh and twelfth centuries bear testimony to the export of Deccan iron and steel to the Middle East1. Fakhr-al-Mudabbir (11th century AD) thought that the Indian swords were the best. The Damascus sword or Maujḏārya was considered exclusive by the Arab world. It is said that these swords could fetch the highest price in the world market. It was not known till much later that the steel for these swords was originally produced in India. Its emergence on the scene presumably, is an outcome of a long metallurgical tradition undergoing through a process of trial and error. The present paper seeks to examine the process of development of iron and steel making in India. The issues that are involved are: beginning of iron in India, development of technology, rise of regional centres with their special traits, innovations achieved by the metal workers over the centuries, changing configurations of techno-cultural and social dimensions that get reflected in metallurgical feats at different stages. There appears to be an emphasis on manufacturing of sharp-edged tools, implements and weapons at certain period in the Indian history. With improving skill and good quality products, Indian steel gained attention of the contemporary world civilization leading to trade in such commodities.

Iron made in India was a commodity with certain features that find mention in several documents of pre-Christian era. Just to mention a few
here, Herodotus describes iron arrowheads being used by the Indian soldiers fighting in the battle of Thermopylae in the 5th century BC. Around the same time, Ktesias gratefully acknowledged the gift of ‘exquisite swords’ of Indian iron/steel made to him by the king and his mother at the Persian court. Quintus Curtis records that in north-western India, Alexander was presented 30 talents of Indian steel as a tribute in the form of ingots along with gold dust and other precious items in 326 BC. Arrian mentions about import of Indian steel to Abyssinian ports.

These accounts bear a clear testimony to the special status enjoyed by the Indian iron and steel right from the ancient times. It also suggests that Indian iron and steel was very much in demand in the ancient world that held the sway till pre-modern times as it was being exported to various parts of the old world.

The mastery of iron technology manifests itself in the form of the colossal structures like the seven-ton iron pillar at Delhi (4-5th centuries AD). It has withstood the ravages of time for centuries. The technique adopted by them was such that either it slowed down the rusting significantly or it almost stopped it once the oxide layer was formed. This property has earned the Mehrauli iron pillar (Fig. 1), a title of the ‘Rustless Wonder’ by T.R. Ananthraman2. Equally intriguing are the large beams at the Sun temple at Konark (Fig. 2) that date back to the 9-10th century, as also the iron pillar at Dhar in central India. Besides the quality of iron, these examples testify to the large scale of iron production and forging. This in turn bears testimony to presence of a well-organised system capable of turning out tonnes of iron as early as the beginning of the Christian era. No wonder that the skill and the expertise could easily be exploited by the state machinery during the medieval times for manufacturing cannons that adorn several important buildings today (Figs. 3, 4).

It may be interesting to note here that the British rated Indian iron much higher and considered it more appropriate than iron produced by their own units for constructing bridges etc. An example in the case is the famous ‘tubular bridge’ built in the early parts of the 19th century across the Menai Straits in the United Kingdom. It is categorically stated, “...its (iron’s) superiority is so marked, that at the time when the Britannia tubular bridge across the Menai Straits was under construction preference was given to the
use of iron produced in India. It has been recorded that 50 tonnes of Indian steel have been used in construction of the famous London Bridge. This proves beyond doubt that iron and steel produced in India was rated highly and was considered to be superior by the Europeans in pre-modern times. Because of this it was being imported from India by the 19th century Britain for crucially important functions where strength and durability was a key factor. The swords made in India were prized all over the world. The sword of Tipu Sultan is almost a legend. These facts have rarely been mentioned or brought to the notice in the publications on history of metallurgy (of iron). It is, therefore high time that a systematic study of iron technology is undertaken at this stage. We propose to take a close look at the stages of
development of iron in India, its evolution at the level of industry, the centres of production of iron and steel up to pre-modern times. This will provide an insight on history of iron and steel in India including the wootz steel.

**THE ZONAL DISTRIBUTION OF IRON WORKING IN THE INDIAN SUBCONTINENT**

The Indian subcontinent is a large land-mass with diverse ecological and geological features. This has influenced the pattern of growth of cultures in this region. This cultural diversity is fully corroborated in the archaeological remains of different cultural periods that appear to be far more pronounced at earlier stages. We have identified at least five cultural zones, A to F, for the study of Iron Age cultures in the Indian subcontinent (Fig. 5).

![MAP SHOWING IRON AGE SITES](image)

*Fig. 5. Regional distribution of Iron Age sites*
The north-western part of the subcontinent (zone A) has Gandhara Grave Culture, the Baluchistan region that is hilly and rugged has a cairns burial practice that is unique of its kind, not found in any neighbouring region. The burial objects are in good number. The Gangetic plain does not have anything common with the above. Even within this region the upper part (zone B) of the plain is different from the middle and lower parts (zone C). In the heart land of the Indian subcontinent in the Ganga Yamuna doab, we come across the Painted Grey Ware (PGW) culture. It begins with iron. But on more westerly sites of the culture, e.g. Rajasthan, Haryana (Bhagwanpura where it overlaps with late Harappan culture) and Punjab (Ropar) no iron is associated with this culture. Presumably, there was no iron in the earlier phase of PGW as is clear from the evidence of the above sites; it is hard to understand the mechanism of the dispersal of the know-how of iron metallurgy on the more easterly PGW sites in c. 1100/1000 BC. Here attention may be drawn to the very interesting piece of evidence from Noh in Bharatpur, (Rajasthan) where bits of iron were found in the pre-PGW cultural horizon. It is possible to deduce from the evidence that some kind of accidental discovery was made as a result of an appearance of smelted iron, perhaps as a by-product of copper working. What must have followed as a natural corollary was the recognition of iron as a metal in its own rights and its subsequent exploitation.

In lower and middle Gangetic plains, the Chalcolithic culture with black-and-red ware and black slipped ware is succeeded by an iron bearing cultural horizon. At this cultural stage except for introduction of iron all other features remain the same. There is a plethora of Chalcolithic cultures in the Vindhyan and Aravalli ranges (zone D). It has sites like Ahar, Eran, Kayatha, Nagda, Prakash, Bahal etc. This zone has evidence of early occurrence of iron in the Chalcolithic milieu. The dates of Ahar and Eran go back to 1400-1300 BC.

Southern India has a megalithic tradition. In this region of the Indian subcontinent, the evidence of megalithic burials with their early dates is also significant. At the settlement site of megalithic culture at Takalghat (Deo 1982) iron appears in the earliest levels, with a few indeterminate objects but it gradually gains popularity. The typology of these megalithic burials shows a distinct character. Some new ¹⁴C dates of 1400 BC have come to light
(Table 1) from Vidarbha region of Maharashtra (zone E). These dates are 2940±160 BP, 3080±120 BP and 2820±100 BP. The calibrated ¹⁴C dates will fall in the range of 1393 to 834 BC. These dates push back the antiquity of iron bearing levels to 1300 BC in Vidarbha region. The situation of peninsular India (zone F) is also interesting. At sites like Tadkanhalli, Komaranhalli, Hallur etc., ¹⁴C and TL dates take its antiquity to 1400 BC.

<table>
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<tr>
<th>Site</th>
<th>Lab-ref.</th>
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<td>PRL-2049</td>
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<td>1423 (1307) 1144</td>
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<td>3450 ± 90</td>
<td>1993*</td>
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<td>BS - 1593</td>
<td>3540 ± 90</td>
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<td>1879 (1522) 1442</td>
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<td>BS - 1759</td>
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<td>BS-1939</td>
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<td>1993*</td>
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<td>920 140</td>
<td>1200 140</td>
<td>Deo 1991: 193</td>
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<td>PRL - 730</td>
<td>920 140</td>
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<tr>
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<td>PRL - 1361</td>
<td>2940+160</td>
<td>1393 (1205, 1205, 1188, 1181, 1149,</td>
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It may be added here that in quite a few of the above zones, we have come across ethnological evidence and survival of iron working till recent decades. This reinforces the assumption that there is long and widespread tradition of iron making in several of the above zones. Special mention may be made here of the Vindhya – Kaimur belt in the middle Ganga plain. There are early $^{14}$C dates of iron from the Vindhyan sites like Malhar, Nal-Ka-Tila and Koldihwa going back to first half of the second millennium BC. They push the antiquity of iron by centuries. Noteworthy is the fact that there is a frequent occurrence of pre-industrial iron working in the remote hilly parts rich in iron ore and forests (for fuel). Interestingly, this region is still inhabited by the iron smelting groups like the Agarias and the Asurs who smelted and produced high carbon iron till recently. Thus there is an uninterrupted history of iron working here. There must have been stages through which this iron working must have gone through.

**STAGES OF DEVELOPMENT OF IRON METALLURGY**

The history of iron metallurgy manifests a long process of evolution. Both archaeological and literary traditions of India point to the fact that it took centuries of concerted effort to improve upon the metallurgical processes. It is the spirit of human endeavour which allowed man to innovate, improvise and master technology through experimentation. The technology of iron developed from simple wrought iron to steel, from tiny bits and small objects to colossal structures like victory pillars.

At least three stages of development of metallurgy are discernible in ancient world civilizations including India. At stage I, or early iron level, iron does appear on the scene but basically more as a status symbol. It is primarily ornamental than functional. In several parts of the world one comes across bimetallic objects like gold or bronze daggers with iron blades or some objects that are parts of the ‘dress uniform’. The Bronze Age chieftains donned such iron ‘weapons’ as status symbols. In India, so far we have rarely come across iron objects of this type. Only bits of iron have been found at some sites in pre-iron stage, such as at Noh in Rajasthan (in BRW phase). A few pieces of bimetallic objects of iron and bronze have come to light from the Andhra and Vidarbha megalithic burials (personal observation). Iron at this stage had hardly an edge over the earlier metal tools in use.
Occasional carburisation has been detected on analysis of artefacts of this period.

In India, the development of iron technology was indeed very gradual. It does not fully replace bronze even for hunting or war objects. Sites like Hastinapur in district Meerut (Painted Grey Ware phase, PGW henceforth, c. 1100-1000 BC) have yielded copper arrowheads. Iron implements at this stage were sometimes replicas of early bone or stone objects of Neolithic-Chalcolithic period indicating a gradual transformation of medium that is modelled after bone prototypes. Even as late as 700-600 BC a socketed arrowhead with holes for fastening came to light from Khairadih, a site in district Ballia, Uttar Pradesh. Deliberate carburisation has been noted in certain cases from this period onwards.

At stage II or Middle Iron Age in India (7-6th century BC to 2nd - 1st century BC), deliberate smelting is common. The techniques of carburization and quenching have been discerned. The ironsmiths selectively applied the specific techniques wherever required. Quenching was definitely known by 600-500 BC as indicated by the textual evidence. A rich variety of iron objects are mentioned in Pali and Sanskrit texts of 5-4th centuries BC. The reference that the monks should carry either earthen or iron ware with them clearly testifies that iron objects were no longer considered valuable and were meant to be used by common man.

It is at this stage that good quality of iron and steel is known to have been produced. It is evident from several examples noted above like the gift of 30 talents of steel ingots to Alexander or presentation of swords to Ktesias (5th - 4th BC) in the Persian court. Suśruta (6th century BC) had evolved surgical methods of treatment and had used steel instruments for conducting surgery. A good number of surgical instruments have been mentioned in Suśruta Šamhitā. These well documented instances prove beyond doubt that high quality iron was being produced in India at least by the 5-4th century BC or even earlier.

Arthaśāstra lists a large variety of weapons including armours of iron. A net like (lauha jālikā) armour of iron to be worn in the battle field has also been mentioned. A heavy use of iron is thus indicated by 4-3rd century BC. The ironsmiths must have developed the capability to meet such growing demands of iron by this time. The Mauryan imperial power must have played a key role in organizing such crucially significant industry.
There were officials designated for it. There was an in-charge of mines (Ākārāḥāra) to take care of such affairs.

At stage III, or Late Iron Age, the metallurgy of iron improved tremendously in the Indian context. A rich variety of tools, implements, weapons, household objects become common. The 7375 mm long, 416 mm in diameter (at bottom) and 304 mm at top Mehrauli iron pillar weighing 6096 kg belongs to the Gupta period (4-5th century AD) an age of culmination of technological skill. Sophisticated weapons like tridents, swords, and caltrops reportedly of good quality steel were used.

The organizational capabilities intensified in course of time. It is fully evidenced in colossal structures that came into existence in the early centuries of the Christian era. The homogeneity of iron structure perceptible in iron pillar is an example. The raw material for a seven tonne iron must have been provided by an organized network of iron industry. The study of the Konark beams clearly indicates that it was manufactured by forge-welding square rods of small sections using lead between the joints. This must have been a technique evolved by the ironworkers of eastern India by 9-10th centuries AD. Such steel was occasionally commissioned by the rulers who wished to immortalize their victories and achievements.

During the Early Medieval Age there must have been pressure on the artisan class to produce iron objects in large number, especially to assist in the agricultural and war sectors. Though the archaeology of early medieval times is not very well documented, the rich literary evidence of the period does provide valuable data on the socio-economic life. There were two types of activities in the field of iron working. One was production of homogenous type of wrought iron being employed in colossal structures commemorating events of great significance to people. The second was production of good quality iron and steel for weapons, tools and implements. The literary evidence being discussed below corroborates that steely iron was being manufactured from much earlier times.

**LITERARY EVIDENCE**

There is also an interesting reference to a very shining iron that had the colour of a fish (silvery white that shines like a star). It has been referred to with a specific term, 'sikkāyas' perhaps referring to the shining steely
iron.* It could possibly be referring to the famous crucible iron that came to be known as wootz steel. In the Hindi translation of Buddhācaryā (Rahul Sankritiyayan) there is reference to a weapon called ‘maitaj’ which is said to have been made by mixing the iron dust and flesh of dead birds. Could it be referring to some kind of steel prepared in crucibles? Organic matter like this (including rice stock and salt, flesh, or plant extracts etc.) is variously mentioned in forging and manufacturing of iron objects or steel.

Quenching has been referred to in the early Buddhist text Saṃyuktanikāya (500-400 BC)*. The iron plough share that has been heated for the whole day makes a strong hissing sound when dipped in water. A relatively later text ‘Milinda Panho’* also refers to quenching of an iron pierce (ayasulāni) into a stream.

Besides such technical information, the Pali texts even suggest ways of safe keeping of iron objects against rusting and corrosion. Objects like needles, it is suggested, may be kept in cases or in some kind of powder or alternatively, should be smeared with wax. Similarly, larger iron implements may be smeared with oil for protection against corrosion (Jātaka No. 542, p.224). Pāṇini’s Aṣṭādhyāyī (4-5th century BC) describes metalsmith’s, specially ironworker’s implements like ‘Ayaghana’ or hammer (3.3.82), ‘kuṭilika’ or hook (4.4.18). Iron ploughs were fashioned with the help of these implements (4.1.42). Axe has also been mentioned as an implement (3.2.82). Amarkoṣa, a Sanskrit dictionary, refers to tejas, tīkṣṇa etc. i.e. shining, sharp and so on. It implies the general properties attributed to iron and steel in 5-4th century BC.

Pāṇini the grammarian makes a categorical list of different types of artisanal activities prevalent in North-western India during his times (4th century BC). It includes among other crafts also smithy (4.1.159). Two classes of craftsmen are identified - those who served the ordinary village folk and those who worked for the royalty. Patañjali calls the latter Rājaśilpī (2.2.1). The village craftsmen were also classified under two distinct categories - the one who stayed put in his own workshop and the other who went out to work at different places and visited the site of work. It has been especially

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* It may be interesting to mention here that in the Vindhyan region (at Wadruffnagar, district Surguja, Chhattisgarh) we have noted the ethnic workers producing silver white iron locally called caraka loha (sāraka loha) generally used for fashioning sharp-edged objects.
true of the carpenters (grāmakautabhyam takṣaṇa, Patañjali 5.4.95). Such descriptions suggest an evolving system of craft practices that developed into organised groups into the successive centuries. Some of these must have developed into specialized classes later identified as castes due to their professions.

*Arthaśāstra*, a treatise on statecraft composed in 4-3rd century BC, offers valuable information on the socio-economic life from 6-5th century to its period of composition. Interestingly, even *Arthaśāstra* refers to iron as *kalāyasa* as apposite to *lohitāyas* (*Arth. II, 6.55)*. *Arthaśāstra* recognizes mines to be an important source of income for state. “Miners are the source of treasury: from treasury come the power of government; and the earth whose ornament is treasury is acquired by means of treasury and army.” (XII.2.85). The duties of superintendent of mines are well defined in *Arthaśāstra* (*Arth. XVIII.102*). A number of types of bows and arrows are mentioned here such as *venu, sāra, sataka, danḍāsana, naraca*- their ends are made of iron, bone or wood as to cut, rend and pierce. The most effective weapon of the age was the sword. Different varieties of swords *viz. nistriṃśa, maṇḍalāgra, asiyasti* etc were mentioned. The handles were fashioned of rhino horn, buffalo horn or ivory or wood or even bamboo.

*Parasu, kuthāra, paṭṭasa, khanitra, kuddāla, carka, kanacchedana* are all razor-edged weapons. Most of these weapons (though it is rarely mentioned) must have been presumably of iron and steel. Such detailed description of each type of weapon meant to serve a specific purpose suggests a well-developed state of art (of arms and weapons and thereby of metal craft). Chapter XVII.2.102 of *Arthaśāstra* substantiates this contention wherein mention is made of *loha jālikā* (a coat made of iron mesh) for covering the body including the head and arm to be worn in the battlefields. Shamashastry in his edition on *Arthaśāstra* has highlighted the use of three types of iron armours- ‘Paṭṭu’, ‘Kavaca’ and ‘Ṣūtrakā’ all of iron. Such armours if made of iron require a refined and highly developed skill of smithy. Indeed, if these literary references are a guide, the craft of smithy appears to be extremely well developed by 400-300 BC in India.

The 4-5th centuries AD witnessed an era of prosperity, and an overall growth in different fields. The age earned the title of the Golden Age of Indian history. However, following the heydays of the Imperial Gupta rule,
a decline set in social economic and political arena. One may wonder about the status of metal technology at this juncture of political turbulence. With the disintegration of the central power, the country was divided into small states. The provincial rulers declared themselves independent. Internecine wars and feuds became common. In such turmoil, weapons must have assumed a great importance. Victory pillars and monuments were erected for the display of wealth and power. Under these circumstances the industries capable of providing the tools, equipment, and weapons must have been much sought after. During this period, the demand for better, efficient and effective weapons for winning wars, tools and implements of masonry, building material, agricultural implements must have multiplied manifold. In a nutshell, one could say that despite the adverse socio-political situation, the productive mechanism was not adversely affected. Alberuni’s oft quoted observation that in India the farmers continued to till their fields while an army marched by, is applicable to the present situation.

**Technique of Making of Sharp-aged Tools, Implements and Weapons**

Sword making seems to be an area of expertise in ancient India. The famous scientist of 5th century AD, Varāhamihira, considered it important enough to incorporate a separate section on it called *Khādgā laṅṣaṇam*. The tradition seems to have continued through the medieval times right up to the pre-modern ages when we hear of the legendary sword of Tipu Sultan. The Arab and Persian traders took the swords to European markets. The Damascus steel with its exquisite watering pattern is too well known to call for any further discussion on the subject here. Suffice it to say that once the metallurgy was perfected, the demand for iron grew. Indian iron became a prized commodity, an object of export to various ancient civilizations, till recent centuries.

Varāhamihira in his *Khādgālaṅṣaṇam* (XVIII, 23-26), dated to c. 550 AD, elaborates the carburization and hardening processes of iron swords. ‘Make a paste of gelatin from the sheep’s horn and pigeon and mouse meat with the juice of the plant *Arka* (*Caetropis gigantica*) and apply this to the steel after rubbing it with sesame oil. Heat the sword in the fire and when it is red hot sprinkle water on it or milk of mare (camel or goat) or ‘ghee’
(clarified butter) or blood or fat or bile. Then sharpen the edge on the lathe.’ Also ‘plunge the red hot steel into a solution of plantain ashes in whey kept standing for twenty hours, then sharpen on the lathe.’

There are also references to thrusting the blade directly into the trunk of plantain tree and allowing it to cool overnight. This would first convert the austenite into martensite and transform it into tempered martensite ‘due to reheating of the sharp edge of the blade by the flow of the heat from the thick back edge’\textsuperscript{12}. Such descriptions suggest that the artisan communities of 5\textsuperscript{th} – 6\textsuperscript{th} century AD developed very complex processes of carburization and tempering.

The saliency of Indian iron is well testified by Rasaratnasamuccaya (RRS), a 10-12\textsuperscript{th} century text on alchemy. It is not difficult to presume that a well-developed scientific basis must have evolved and they were documented in detail. A very fine classification of different types of iron has been attempted in the text showing a deep understanding of behaviour of iron in the smelting-refining process. Three basic types of iron with different sub-types (according to their properties and nature) have been categorised in Rasaratnasamuccaya. One of the sub-types, kālāyasā was described as ‘bluish black in colour, dense, smooth, heavy and bright in appearance, whose sharpened edges do not get spoiled even by hammering.’ This description is close to that of the Damascened steel swords ‘of a dull blue colour marked with ten millions of meandering lines’ which are compressed and elongated cementite grains or streaks in pearlite-graphite-martensite matrix”, maintains Biswas\textsuperscript{13}.

It may be worth underlining an interesting fact that King Bhoja (1010-1053 AD) of Dhar composed a treatise on iron manufacturing in the 10-11\textsuperscript{th} century AD. He even mentioned a couple of other texts like Lohārṇava and Lohādāsp on this subject which had been composed earlier. This testifies that iron and steel making had evolved into a full fledged science in India by this time. This tradition continued even during the subsequent centuries.

A fourteenth century AD work, Sāraṅgdhara Paddhāti\textsuperscript{14} by the alchemist Sāraṅgdhara describes the technique of manufacturing swords. He has also given a detailed account of the quality of iron that was to be used for the manufacture of different types of swords. The colour of swords, according to him depended on the type of iron (ore?) that was used in their manufacture. Sāraṅgdhara Paddhāti also provides evidence on several
important centres of sword making of his time. Special mention may be made of Kahatikhattara, Ṛṣikā, Banga, Śurparaka, Videhī, Āṅga (already mentioned in the Agni Purāṇa), Madhyamgrāma, Bedideśa, Sahagrama, Kālinjar. It is unfortunate that the treatise is no longer available to us. But the fact that there were a large number of iron making or sword making centres, to be more precise flourished in several parts of the country at this juncture.

**Distribution and Marketing Mechanism of Iron and Steel in India up to Pre-modern Times**

There appears to be a well entrenched iron industry in India dealing with sharp-edged weapons. These were also in great demand in the contemporary world. Thus there evolved an organized trade mechanism over a period. The contemporary accounts – both foreign and indigenous provide support such a contention. Many of these documents belonging to different cultural stages suggest that Indian iron was in demand in the ancient world. The accounts of an Egyptian-Greek merchant in his book, Periplus of the Erythrian Sea, testifies to the export of Indian iron to Abyssinia in the 1st half of the early centuries of the Christian era. Periplus gives a detailed account of the voyages undertaken by its author and the ports he had visited. The most important harbour was Barygaza, a corrupted Greek form of Bhrgukaccha (modern Broach or Bharoch) on the mouth of the river Narmada. It was a busy port town where goods were brought in from distant parts of the subcontinent, like Kashmir and Hindukush mountains, so that they could be exported to foreign countries. Other port-towns mentioned in the text are Pratisthāna (Paithan), Tagars (Ter), Sopārā and Kalyāna (on Bombay coast). Several places on the Malabar Coast also find mention there. The ports of Muchiripattanam and Nilakanth mentioned there in have yielded old inscriptions saying that these places abound in “ships sent there with cargoes from Arabia and by the Greeks”. Indian ships almost regularly sailed to Arabian and African harbours. There is mention of a colony of Indian traders in the island of Socorta. Among the articles of export from India were spices, perfumes, medicinal herbs, pigments, pearls, precious stones, iron and steel, copper, sandalwood, animal-skin, cotton cloth, silk yarn, muslin, indigo, ivory etc.
The historian of medieval times, Idrisi, makes a specific reference to purchase of Indian steel swords. Even the Chinese scholar Chau Ju Kua (8th century AD) talks of import of steel rods (ingots?) from India through the sea route during early medieval period. Indian ships brought back horses and exported copper, tin, lead and solid steel (ingots?), spices, drugs, cotton cloth, precious stones, timber, leather goods and other luxury items. In the early medieval ages, India carried out trade with Iran, Iraq (ancient Mesopotamia), Indonesia, and as mentioned above, with China. There are references of rich Indian traders living in Mesopotamia. India received gold in return.

During the Early Medieval times, there grew friendly and commercial interactions with the Arabs. At this juncture, the Indian science and technology were at their peak. The early Arab writers of 9-10th centuries have written profusely about the agricultural practices, fertility of the soil, and techniques adopted by Indian cultivators. They also refer to the metal and metal–working as a successful vocation of specialist craftsmen of this period. Abhidhānaratnamālā, a text of this period, makes a list of metals that includes copper, bell metal, iron and steel, lead, tin, silver and gold. Different parts of the country were famous for different metals.

Although an organised activity in trading sector had already started from the Buddhist times itself as evident from innumerable Jātaka stories, trade activity intensified over the period. The trade organizations or šrenies had evolved as strong bodies with an identity of their own during the early medieval age (Medhatithi16 VIII, 41).

In the 12th century AD, Hemachandra who lived in the court of king Kumārapāla in Gujarat clearly wrote about five distinct categories of organizations of big business enterprises. Prastārika, an organization dealing in metals, like, gold, silver, copper, iron etc. was one of them. They wielded great power and sometimes even politically influenced the policies of the state; they carried out inland as well as international trade. Huge ocean going freights have been mentioned right from the times of Pāṇini. Colonies of Indian traders were established outside the country also. Thus commodities manufactured in different parts of the country were brought to the port towns and exported to different parts of the world, including the Arab world mentioned above, where the Indian swords were highly prized.
India seemed to have carried out overland and sea trade with West Asia, China, South-East Asia and also Africa. Trade with the Gulf region has been frequently mentioned in various texts including the Purāṇas. A large number of port towns from Sind (Bambhore) in present day Pakistan through those in central–western parts of India (Gulf of Cambay, Broach) right up to the peninsular India (Coromandel, Cochin, Kaveripattanam etc.) were busy ports. Agni Purāṇa (CCXLV, 21) describes five centres that were famous for sword making. They are Khaṭṭikhattara and Rṣika (not identified so far), Surpāraka (Sopara), Vanīga (Bengal) and Anāga (Bhagalpur, Munger districts of Bihar). Ibn Haukal17 mentions the city of Debal in Sind as a famous sword-making centre. Good quality swords were being produced at Kuri in Kutch.

Such well-established trade must have provided incentive to iron and steel industry of India. There were well-established port towns in ancient India that find mention in literature from time to time. Banbhore or Bambhore was a busy ancient port on the river Indus in Sind. It was located 40 km east of Karachi - Periplus refers to it as Barbaricum and Ptolemy as Barbari. This was an active and busy port at least from the 1st to 13th century AD. Ancient ceramics from Syria, Susa and Iran have been found there. Likewise, Al Idrisi rated the Gulf of Cambay as a beautiful and the safest seaport. The writings of Istakhari and Ibn Haukal in 951 AD describe it as an important port. The latter has praised the swords made at Debal in Sind18. Āl Masūdi, also of the 10th century AD, and al Birūnī have mentioned Broach as an important port. It is the place where river Narmada meets the sea. Up to the 11-12th century AD, the Chinese and Arabs frequently visited the Indian ports. Although it has not been possible to get a detailed inventory of the commodities that were being traded, but it is a fact that Sind, Gujarat, Kacch, Bengal, Bihar and Peninsular India were famous for their steel, especially for the highly acclaimed sword that they produced. There is every likelihood that steel, especially swords must have been important export item. Later on, as late as the British period, the indigenous industry was flourishing in different parts of India.

There was an export of 10,109 pounds of steel in 1657AD and over 5 lakh pounds of ironware in 1667 AD19 in medieval period. The Dutch imported nearly 20,000 ingots of wootz steel in the 17th century from south
India. "...the effect of Dutch and English purchase was to extend the production of indigo, cotton, and probably silk". Besides these agricultural produces, salt petre and iron were also in demand. The Dutch purchased large amounts of iron and steel from Golconda region exporting shiploads from Masulipatnam. "About the year 1660 the Dutch were active in developing the iron industry in the Godavari delta,". The Dutch had formed companies and managed to earn huge profits through organized voyages from 1600 AD. The Batavia Journal gives a detail of these voyages, especially from Coromandel Coast between 1610 AD and 1624 AD. In the later years, in 1657 it is recorded by Manucci that 'India exported over 10,000 pounds of steel and over 5 million pounds worth of iron ware. In the 17th century, the Dutch establishment shipped from India 20,000 ingots of wootz steel'. They were in such an urgent need of pig iron, iron bands, iron bars and cannon balls, that they organized a manufactory system of production of these items in their factories. Varied iron products like nails, cannon balls, iron bars and iron bands were exported from Coromandal to Batavia. Spikes, bolts and anchors were produced in India for shipyards at Narasipur, Masulipatnam, Pulicat etc. In the Qutbshahi Kingdom, Indalvi (near modern Nizamabad) was the centre for manufacture of swords, daggers and lances, made from iron that was mined in the Kalaghat hills.

Some of the centres that produced high quality iron and steel in earlier period survived till pre-modern times. These production centres remained active till the British period in Assam, Bengal, Orissa, Madhya Pradesh, besides the better known centres in parts of Deccan and southern India. This was documented by European geologists and engineers who visited these parts of the country from time to time (Table 2).

These centres, however, were in a state of decline during the British period. They had lost their original vigour. The production of iron was generally confined to smaller units in these parts in 18-19th centuries. It has been noted earlier that there were texts composed exclusively on iron metallurgy corroborating that iron had acquired the status of a full-fledged science by the 10-11th century AD or may be even earlier. But it is clearly borne out by the Arab and Persian accounts that Indian science received a serious jolt at the hands of the early Muslim invaders. Sheikh Bu Ali Sina who was an eminent scholar refused to accompany Mahmud on his so-called
Table 2. Showing status of pre-industrial production of iron in India

<table>
<thead>
<tr>
<th>States</th>
<th>Centres</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assam</td>
<td></td>
<td>Cannon manufacturing till the 15th century. About 3000 iron workers</td>
<td>S.F. Hannay 1857, quoted in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>reported in 19th century.</td>
<td>Krishnan 1954.</td>
</tr>
<tr>
<td>Gujarat</td>
<td>Rewakanta</td>
<td>Excellent production centre near Jambughoda (22° 22' N; 73° 42' E) and</td>
<td>Fulijames 1852; W.T. Blanford</td>
</tr>
<tr>
<td>Kathiawar</td>
<td>(Saurashtra)</td>
<td>There were sword - making busy centres right from the early medieval</td>
<td>Jacob 1843.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>days till 19th century or may be even later.</td>
<td></td>
</tr>
<tr>
<td>Orissa</td>
<td>Talcher, Angul,</td>
<td>Iron was so abundant in Balasore that anchor was cast there in moulds.</td>
<td>Captain Hamilton¹ (1708).</td>
</tr>
<tr>
<td></td>
<td>Balasore,</td>
<td>Factories established at various times under the Dutch, French and the</td>
<td>Oldham² (1852). Gleanings in</td>
</tr>
<tr>
<td></td>
<td>Sambalpur, etc.</td>
<td>English.¹ Ore and furnaces were described by Oldham in Talcher.² In</td>
<td>Science¹, 1830; (Rec. Geol. Sur.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sambalpur ³ the annual turn over of iron amounted to 1,000 mounds.</td>
<td>Ind. Vol. X: 182).Vol. VI: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many furnaces were at work in the Rampur coalfield.</td>
<td></td>
</tr>
<tr>
<td>Bengal</td>
<td>Birbhum (Ballia,</td>
<td>In 1852 there were about around 200 furnaces, 25 mounds each, total</td>
<td>Oldham (1852).</td>
</tr>
<tr>
<td></td>
<td>Narainpur,</td>
<td>of about 2,400 tons per annum).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deocha, Dumra</td>
<td>Imports of British and Swedish iron through the port of Calcutta in</td>
<td></td>
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<tr>
<td></td>
<td>and Goanpur)</td>
<td>1849 it amounted to 12,111 tons. The import rose to 19,099 tons in 1850</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and 16,537 in 1851.</td>
<td></td>
</tr>
<tr>
<td>Madhya</td>
<td>Narsinghpur</td>
<td>Tendukhera and Omarpuni were famous for its excellent quality of iron.</td>
<td>Franklin (1829).</td>
</tr>
<tr>
<td>Pradesh</td>
<td>Indore area</td>
<td>Some 70 to 80 furnaces in 1855 producing 40 tons per year were in</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>operation. Its iron was used in 1830 for a suspension bridge over the</td>
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<td></td>
<td></td>
<td>Bias River.</td>
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<td></td>
<td></td>
<td>Large number of furnaces were at work in the Narmada Valley in the</td>
<td>J.P. Kennedy (1855).</td>
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<tr>
<td></td>
<td></td>
<td>former Indore State.</td>
<td></td>
</tr>
</tbody>
</table>
jehad to India because the invaders also destroyed, among other things, Indian Science. The Arab and Persian scholars were shocked by the barbarity of the early Muslim invasions. The libraries of Nalanda and Vikramśīla were targets and victims of this plunders. Its impact on Indian science, craft and technology was indeed devastating. Even al-Birūnī has written about how ‘Māhmud utterly ruined the prosperity of the country’ and how ‘Hindu sciences have retired far away’.

All this had a long lasting impact on Indian iron industry. In the later centuries, iron working became confined to local production units as clearly evident by the above table (Table 2). This also suggests that there were several parts in the Indian subcontinent where iron industry flourished. Many of these centres evolved as sword making centre of repute. The artisans based their work on a scientific foundations laid down by scholars from 5th century onwards. The finished product was transported to different parts of the country and outside through a well-organised trade mechanism. There started a political turmoil in the subcontinent from 10th century onwards, especially in the northern part of India. Assam, Gujarat, Madhya Pradesh, Bengal, Bihar, Orissa etc which were all famous sword making centres according to literary accounts were in a state of turmoil during the medieval times. The state of uncertainty adversely affected their socio-economic condition leading to an all-round decline in trade, commerce and industrial production. Wheresoever a better situation prevailed, industrial activity continued even though at a cottage industry level. The southern parts of India remained a safer haven for the artisanal activities with its steel -ukku or wooz shining all over the world and weaving an enigma around it.

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