IRON TECHNOLOGY IN SRI LANKA : A PRELIMINARY STUDY OF RESOURCE USE AND PRODUCTION TECHNIQUES DURING THE EARLY IRON AGE[1]

The purposeful exploitation of mineral resources in Sri Lanka commenced from the pre-3rd century B.C. period. These resources included mineral stones, iron, copper, gold and mica. This study attempts to outline some problems related to resource use and production techniques, with special reference to the iron technology during the Proto-Historic period and the Early Historic period. The chronological scope extends approximately from B.C. 7th century to 2nd / 3rd century A.D. and in Table I we have indicated an internal periodization on the basis of the dominant techno-cultural elements present within the above chronological context, which also covers the period that had formative and transitory socio-economic structures.

In this connection it is necessary to emphasise three factors. That is, the Mesolithic 'Balangoda' culture in

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1. Certain aspects noted here were presented in a paper titled 'Some Mineral Resources Utilized during the Early Iron Age of Sri Lanka' at the *International Symposium on the Geology of Sri Lanka*, University of Peradeniya, September 1983. A draft of the present study was presented at *The World Archaeological Congress*, (Southampton, September 1986), titled 'The Utilization of Metallic Resources during the Early Iron Age of Sri Lanka: a multi-faceted study of the metal technology and production techniques'. I am grateful to Mr. D.E. de S. Jayawardena (Director, Geological Survey Department), Mr. Siran Deraniyagala (Consultant, Archaeological Survey Department), Professors Kapila Dahanayake, Chandra Dissanayake and Dr. H.B. Maliyasena, (University of Peradeniya), and also to Ms. Culani Rambukwella (IFS) for their co-operation and assistance in the course of this study.

TABLE 1

Chronology	Technology	Dominant Culture	Primary Institutional Structure
Pre 6th Century B.C. (Pre Historic)	Stone Age	'Balangoda Culture'	Hunting, gathering, Fishing; tribal society.
7th to 4th/3rd Century B.C. (Proto Historic)	Iron Age	Megalithic-BRW	Swidden and plough agriculture, small tanks, pastoral activity, limited crafts, clan-based villages, household economy, chiefdoms.
3rd Century B.C. to 2nd/3rd Century A.D. (Early Historic)	Iron Age	Indo-Aryan	Urbanization, hydraulic civilization, the script and coinage in use, the emergence of craft and commercial guilds, long-distance trade, stratified society, state formation.

certain areas was directly succeeded by the Proto-Historic iron-using Megalithic - Black and Red Ware (BRW) culture.[2] Second, the latter drew much of its techno-cultural elements from the broader cultural matrix in Peninsular India.[3] Thus in an effort to illustrate this cross-regional and cross-cultural interaction, we have introduced archaeological and ethnographic data related to Pre-Industrial metallurgical traditions in Peninsular India. Third, the above epochs, located within chronological phases, does not necessarily represent a blanket development covering the whole island. One has essentially to bear in mind the uneven development of such processes in time and space.

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2. The Megalithic burials essentially represent a cult practice associated with clan-based societies. In Sri Lanka these sites are mainly distributed in the West, North West, the Jaffna Peninsula and in the North Central areas. Recently (1985) an urn-burial site was found at Kataragama in the South East. The 1969 Citadel excavation at Anuradhapura revealed that the earliest habitation layer associated with the Iron Age at that site coincided with the Megalithic-BRW horizon. The stratified context of the techno-cultural phases at Anuradhapura are: 3A (Megalithic-BRW), 3B (Megalithic-BRW and transitory), 4A and 4B (Early Historic) (*vide* Deraniyagala 1972b; Begley 1967; 1981; Parker 1884).

3. The Megalithic burials in Peninsula India have a wide typological range, viz. urns, cists, menhirs, cairn and stone circles, to name a few. Around 1000 B.C. this culture introduced the use of iron, paddy, the potters-wheel, the horse, minor irrigation and a sedentarized village life to Southern Deccan and South India (*vide* Gururaja Rao 1972; Leshnik 1974; Sundara 1975).

Pre-Conditions

The utilization of iron may be considered the technological demarcation distinguishing the Proto-Historic period from the Pre-Historic period in Sri Lanka.[4] In the absence of a pre-existing metallurgical tradition, i.e. the Chalcolithic, the transition from a stone-using to an iron-using culture had to gather its own momentum of technological evolution depending upon certain conditions.

It is therefore necessary to indicate certain determining factors or pre-conditions leading to a viable utilization of mineral resources in Pre-Industrial societies. First, we may take up the demand for either utilitarian or luxury items and the functional value of the product based on a particular raw material. 'Luxury' items, more often can be equated with status-giving prestige goods. The functional value of such objects may be ritualistic, ceremonial or even purely ornamental. By contrast, certain items have a greater functional or utilitarian value stemming from the demand largely geared to domestic/household requirements and those utilized in a range of other economic activity. The demand itself may differ in its quantity and quality, depending upon the degree of variation present in the ecology of the habitation zones and, consequently, governing the level of material development in each society. The functional value of iron implements within a particular socio-economic and developmental epoch, therefore, is an important determining factor precisely because it reflects the qualitative development of the production technique and the quantitative utilization of iron implements.

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4. The iron technology was introduced to both Peninsular India and Sri Lanka by the intrusive Megalithic culture. The techno-typological forms of the iron artefacts found within Str. 3A and 3B of Anuradhapura are nearest to the Megalithic assemblage in Peninsular India (Deraniyagala 1972b : 152).

The second factor in this process is access to resources. Access may be direct or indirect. In certain cases communities may dwell within easy reach or, at times, in association with strategic resources. There are also instances where these resources may be located at distant places. In addition, a particular community controlling an area possessing certain strategic resources may obstruct other groups gaining access to such locations. In our context there is an apparent overlap between internal resource areas and settlement zones, specific areas and regions mentioned in the literary texts, craftsmen or specialists mentioned in the Early and Later Brahmi inscriptions and routes of communication linking particular ecological zones. There are also known instances where raw material resources, found in the vicinity of the habitation zones, have been deliberately avoided due to beliefs and traditions associated with particular societies.

The third is the possession of a suitable craft technology, which is an important overlapping condition to the above factors. This means the availability of a technology capable of exploiting mineral resources and manufacturing finished products. A suitable technology cannot be a determining factor *per se*. For instance, if there are no other supplementary factors such as a demographic expansion, social stratification or an expansion in economic activity, consequently leading to a greater demand for luxury or utilitarian items, then the functional value of the technology will not appreciate. It is equally important to bear in mind that, in the actual utilization of mineral resources (or for that matter any other raw material), ancient communities successfully operated quantities that may be considered, under modern technology, as totally inadequate. Finally, in this total mechanism, communication played an extremely crucial role. This implies the forms of transportation and the routes used as well. These are vital to maintain an assured supply of raw material from source areas to centres of production, where a regular circulation of finished products helped maintain an equilibrium in the production-distribution network.

The Ecological Backdrop

It goes without saying that the ecological implications had considerable influence upon resource utilization and the functional value of a particular technology during the formative period.

In Sri Lanka the settlement and the subsistence ecology of the Early Iron Age was associated with the arid/semi-arid bio-climatic zones characterized to a large extent by the latosol-reddish-brown earth and by the monsoon scrub jungle/monsoon forests (Panabokke 1979 : 232; Gaussen *et al*, 1968; Seneviratne 1984 : 238-240; 1986). Proto-Historic habitation layers and burials in fact show an extremely low occurrence of iron implements, which are also inferior in technology to the products of the subsequent period (Deraniyagala 1972 b : 152; Begley 1981 : 77-78; Seneviratne 1984 : 272-275). The identifiable objects are the knife, blade, arrowhead, nail and (probably) a plough-coulter (*AsAnR* 1957 : 30-31; *AsAdR* 1965-66 : 104; Deraniyagala 1972 b : 152; Begley 1981 : 77-78; Seneviratne 1984 : 272-275).[5] The probable borrowing of the metal technology by the indigenous Mesolithic people of Sri Lanka from the intrusive Megalithic-BRW culture may have been another reason resulting in the limited range of objects as well as the undeveloped stage of this technology during the Proto-Historic period (*ibid.* 283-286).

Such implements were sufficient to harness the micro environment and to thrive on a multi-resource broad spectrum

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5. The reverse is true of Peninsular India, where the Megalithic assemblage has a wide range of artefacts, which include household objects, agricultural implements and weapons (*vide* Rea 1902-03 : 131-139; Banerjee 1965 : Table 2). In addition, these objects were of a superior craftsmanship and quality. For instance, the iron objects from Adichchanallur urn-burials were wrought from a particularly pure metal having a fibrous texture and a 25% carbon content (Leshnik 1974 : 63). The inclusion of carbon is known to give additional strength to iron.

subsistence economy. For instance, weapons were useful to hunt animals and to clear the monsoon scrub jungle for swidden cultivation. These forest tracts can be cleared without much effort by using fire. Evidence from Peninsular India indicates that limited paddy cultivation can also be conducted under a restricted use of iron or without developed methods of irrigation.[6] In general, tribal and semi-tribal societies operate within a simple or limited technology suitable for the functioning of a subsistence economy (Sahlins 1968; 1978; Vidyarti et Rai 1977 : 97-116).

A more extensive reclamation of the existing forest tract probably became a necessity only during the Early Historic period, when better-produced iron implements were demanded to extend agriculture and to open up new habitations[7] to supplement an expanding demographic situation.[8] Implements of iron were also required in specialized crafts as well as for other domestic and utilitarian tasks (Parker 1909 : 552-559); Deraniyagala 1972a; 1972b : 153-154). It is also evident that a

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6. Remains of rice have been reported from the urn-burials at Pomparippu, while rice husk was found within the Proto-Historic habitation layers at Anuradhapura (Deraniyagala 1972b : 159). However, stratigraphic evidence and the locational character of several megalithic sites may indicate that these pre-date some of the reservoirs situated in their vicinity (Begley 1981 : 64-65).

7. An Early Brahmi inscription specifically mentions the beginning of a new settlement in the North Central area by *parumaka* chieftains (Paranavitana 1970 : No. 269).

8. "In a region where this critical level of density has not been reached, people may well be aware of the existence of more intensive methods of land use and they may have access to tools of a less primitive kind; still, may prefer not to use such methods until the point is reached where the size of the population is such that they may accept a decline of output per man-hour" (Boserup 1965 : 41).

wider use of steel may have infused greater efficiency to the metallurgical tradition during the Early Historic period.[9]

Resource Zones

The foregoing raises several questions in relation to resource zones, variations in the raw material and the nature of its utilization and also the technology associated with resource use.

As for resource use, Begley holds the view that the low occurrence of iron implements at Pomparippu (an Iron Age burial site) is due to a scarcity of this raw material, though she does not rule out that iron implements were interred less because their symbolic representation had by now lost its significance (1981 : 78). Contrary to Begley's view, there is sufficient evidence to indicate that the Early Iron Age communities derived raw material in the form of haematite (Fe_2O_3) and limonite ($Fe_2O_3nH_2O$) with relative ease, and perhaps to a lesser extent, magnetite (Fe_3O_4).

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9. Surface explorations at the Early Historic habitation site at Kollan-kanatta (Kudiramalai) revealed heaps of conch shell waste. The shell was apparently sliced with a wire saw (Deraniyagala 1972a : 3), which may indicate the existence of specific implements for specialized crafts. Chank, sawn off in the same manner, may be seen at sites such as Mantai and Kantarodai and also within the Proto- and the Early Historic context in the Southern Deccan e.g. Maski (Foote 1914 : No. 2783; 1916 : Pl. 41). It is reported that to this day the chank-cutters of Bengal use wire blades in their craft (Hornell 1914 : 55). In addition, Kollan-kanatta also yielded iron/steel chisels, used for boring wedge-holes in stone (Deraniyagala 1972a 7, fig. 3RI), and similar implements were found at Tissamaharama (Parker 1884 : 38). Specialized implements of iron/steel, belonging to the Early Historic, Early and Late Mediaeval periods, were unearthed during the recent excavations at Polonnaruwa, Anuradhapura, Abhayagiriya and Sigiriya (*vide* Prematilleke 1982a; 1982b; Wikramagamage 1984; Bandaranayake 1984).

It is suggested that the Mesolithic people of Sri Lanka were aware of different colours present in certain mineralized stones and soils/sands, leading to the use of haematite, limonite molybdenum, mica, graphite, blue clay and Kaolin as pigments for ritualistic purposes and cave art (Deraniyagala 1971 : 38).[10] The continued exploitation of mineral stones by the succeeding Proto-Historic community and their interaction with the Mesolithic people, may have revealed areas possessing mineralized soils and stones that could be exploited and worked under the existing technology.

Particular soil-regions in the north west, north central and in the Jaffna peninsular contain ferruginous gravel below the red/brown earth formation (Cooray 1967 : 149-151; Dahanayake et Jayawardana 1979 : 433-440). It is suggested that the reddening in the brown earth is due to the existence of necessary oxidizing conditions for the formation of red haematite (*ibid.* 440).[11] Soil samples from certain localities in Puttalam, Mannar and Jaffna indicate that in the clayey

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10. It is believed that the idea of using haematite or red ochre for ritualistic purposes was transmitted to South Asia from Africa during the Pre-Historic period (Dart 1974 : 309-320). The Post Harappan Chalcolithic folk of the Kayatha culture in Central India used haematite to prepare the red colour used on the Buff-painted ware. Excavations at Kayatha yielded chunks of used haematite (Dhavalikar 1979 : 231; *vide* Sahi 1986 for details). Recent excavations (1986) at the Fahien Cave at Horana (Sri Lanka) revealed Mesolithic skeletal remains covered with red ochre.

11. This striking feature of the soil in the North-West was known to the early communities. The copper/red colour present in the soil was the basis for naming this region Tambapanni (*Dv.* IX.30; *Mv.* VII. 40-42). On the opposite coast, the primary river in the Tirunelveli District (Tamil Nadu) is traditionally known as Tamraparni. Interestingly enough, the red loam is a dominant feature in the soil of this region too. Some however hold the view that the name Tamraparni (for this river) derives from the (Dravidian) *tan porunai*, i.e. 'cool clear water' (Champakalakshmi 1975-76 : 120).

fraction of the brown earth limonite is present, and in the red earth haematite is dominant (*ibid.* 437-38). Traces of ancient iron-smelting in this soil region have been revealed at Mantai, Kantarodai and at several ancient sites in the Jaffna peninsular (Boake 1887 : III; Carswell et Prickett 1984 : 52, 65; Pieris 1919 : 68; Begley 1967 : 25; Seneviratne 1984 : 272-73).

An additional source of raw material was also available to the Early Iron Age smelter in the form of nodular iron stone, mainly distributed in the dry zone of Sri Lanka. The primary zone of occurrence of such nodular iron stone is within the areas covered by Puttalam - Kurunegala - Galgamuwa (Cooray 1967 : 178-79), also having a relatively high concentration of Proto- and Early Historic sites. These iron stones can be obtained at the surface level in areas having the exposed crystalline rock formation in the north (e.g. Iranamadu, Mankulàm), and quite prominently in the east and south east sectors of the island. There is an apparent coincidence between the Proto-Historic Megalithic - Black and Red Ware / Early Historic sites and those areas classified in the 1967 soil map (of Panabokke) as 'soils with a high proportion of quartz or iron stone gravel' (see Map). The soil stratification at the Anurādhapura Gedige (Plate I) is described as 'iron stone and quartz gravel...' (Deraniyagala 1972b : 55). The high proportion of iron stone gravel in this soil region was also revealed during the recent excavations at the Abhayagiri *vihāra* complex at Anurādhapura (Wickramagamage 1984). Similarly, the excavation at Pomparippu (Plate II) indicated the stratified occurrence of iron concretions below the surface level (Begley 1981). Evidently the Proto-Historic folk at Anurādhapura worked this nodular iron stone. Excavations at the Anurādhapura citadel revealed limonitic iron-stone nodules in direct association with iron slag from strata 3A and 3B (Deraniyagala 1972b : 152, 155).

There are several iron-stone bearing localities in south east Sri Lanka, and some of these are situated close to the Early Iron Age habitation site at Akurugoda (at Tissamaharama) and the urn burial site at Kataragama. Nodular iron-stone and gravel were extensively found from the habitation levels at Akurugoda (Parker 1884 : 26, 60). It is observed that these"... nodules could be picked out of the underlying decomposed gneiss or gravel, which is extremely ferruginous" (*ibid.* 61).

With the relative development of a communication network during the Early Historic period, these communities may have also had access to larger repositories located in the upper Walawe region, where limonite iron ore is found as "hill-cappings and in the form of scattered boulders of varying sizes at or near the surface" (Harath 1975 : 27). According to observations made by Coomaraswamy, this ore is "generally the nodular haematitie or limonite which arises as a decomposition product of the country rocks and is widely distributed in small quantities" (1908/1956 : 190; Davy 1821/1983 : 13). It is estimated that, of the known iron deposits, 60% are in the Ratnapura district and 20% in the Ambalangoda area (Manicam 1961 : 61). The quality and the ability to work the iron ore found in southern Sri Lanka is described in the following manner: "It is easily smelted, and so pure when reduced as to resemble silver. The rough ore produces from 30 to 70% and on an average fully 50%. The iron wrought from it requires no puddling, and converted into steel, it cuts like a diamond" (Gygax cited in Tennent 1859 : I.30).

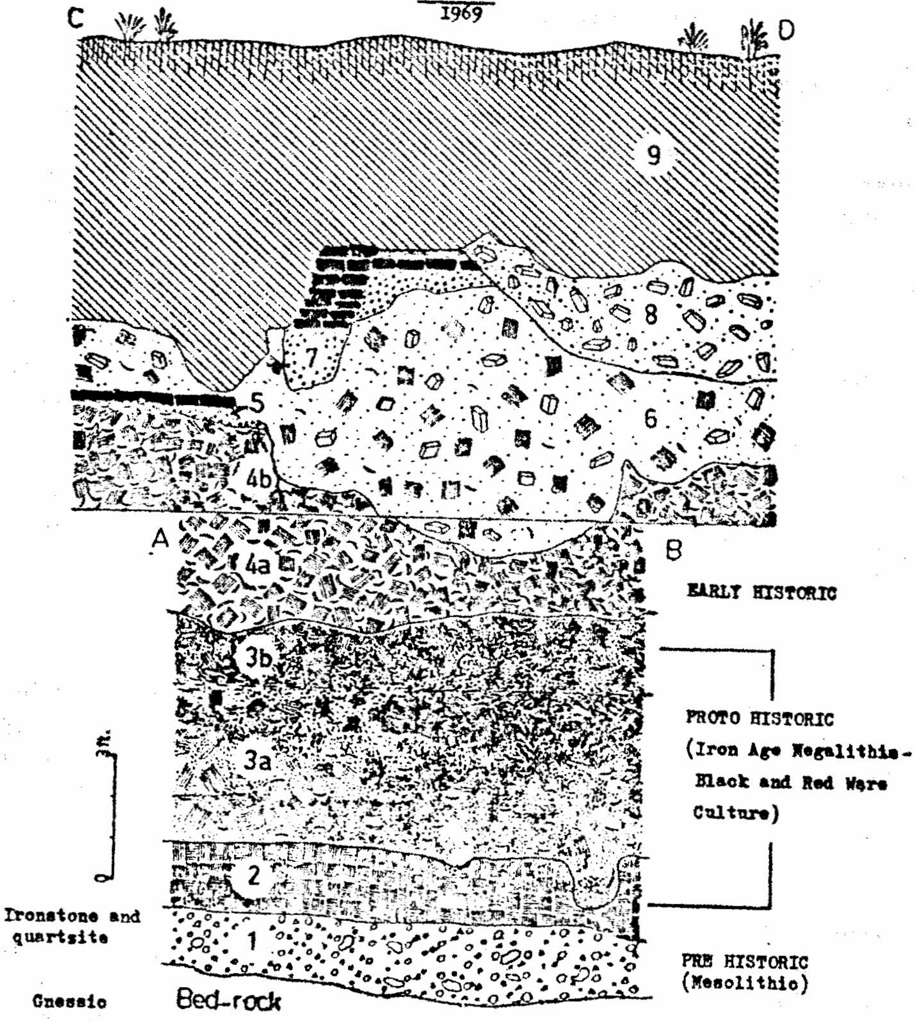
The problem of exploiting magnetite ore in antiquity is an interesting one. The earliest period of its extensive utilization in Sri Lanka is uncertain. A nail from Anurādhapura Citadel Str. 3A (Megalithic) indicated that it was very strongly magnetic (Maliyasena 1986). There is every possibility that some of the iron concretions obtained from this region and used by the Proto-Historic smelters at this site carried a high quantity of iron that may be graded as magnetite. It is in fact noted that at certain resource areas such as Tambakanda, high-grade massive ores occur as concretions in association with low grade pisolitic laterite ore (Pattiarchchi 1961). In addition to the smaller deposits (e.g. Mooloya, Kirimetiya), larger deposits of magnetite can be found in the (Wilagedara) Tambakanda, Panirendawa and at Seruwila, (Herath 1975 : 27-28; Cooray 1967 : III; Jayawardena 1982 : 129-142; Kumar 1982).[12] It is estimated that the

12. *A Preliminary Account of the Iron Ore Investigations in the Wilagedara-Tambakanda Area*, D.B. Pattiarachchi, (Unpublished Report. Geological Survey Department of Sri Lanka. MSS. No. 35).

Plate I

ANURADHAPURA CITADEL (GEDIGE AREA)

SECTION
1969



(S. Deraniyagala. Ancient Ceylon No.2. 1972:56) deposit at Panirendawa contains around 5.6 million tonnes of high grade magnetite (iron 68%)and the ore is found 80-500 feet below the surface level (Kumarapeli 1963). Preliminary investigations at Seruwila indicated the existence of about 7 million tonnes of magnetite and this deposit extends nearly 200 feet below the surface level. The mineralised zone at Seruwila is divided as Block 'C', Arippu and Kollankulam. The earliest reference to this magnetic ore near Trincomalee was made by Davy (1821/1983 : 13). On the basis of slag remains, Coomaraswamy inferred that in certain districts in the hills, magnetite was utilized for Pre-Industrial smelting purposes (1908/1956 : 190). Surface investigations have revealed slag and clay crucibles at Panirendawa (pers. comm. D.E. de S. Jayawardena). Iron slag is also found on the surface of a wide area east of the Buddhist complex at Seruwila (Solheim et Deraniyagala 1972 : 4, 19). The following may establish that, due to certain technological implications involved in the process of production, magnetite may not have been extensively worked during the Proto-Historic period, though the same cannot be inferred for the subsequent periods.

Resource Use and Technology.

At this juncture it is useful to take up certain aspects related to the nature of resource utilization and the technology involved in this process. Resources, in this context, do not exclusively imply raw material, i.e. iron ore. In addition to iron ore, fuel and the form of labour associated with the process of production are integral parts of resource utilization.

The ability of the Pre-Industrial smelters of South Asia to meet their requirements from sources other than large deposits of ore, may be considered a crucial factor in resource utilization.[13] However, the exploitation of particular

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13. The primitive smelter in this region "finds no difficulty in obtaining sufficient supplies of ore from deposits that no European iron master would regard as worth his consideration. Sometimes he will break (contd.)

varieties of iron ore tends to correspond to the existing level of efficiency of the smelting technology. In this connection, the composition of haematite and limonite ores gave certain advantages to the Early Iron Age smelter. These are not compact ores. For instance, limonite is very siliceous by nature. In addition, both ores are relatively free from sulphur and phosphorus and may be easily worked by the smelter (Hodges 1965 : 81).[14]

On the contrary, there may have been only a marginal or non-utilization of magnetite ore by the Early Iron Age smelter, due to certain practical difficulties associated with exploiting and working this ore. With the exception of magnetic sand (that is washed down river courses) certain magnetite deposits in Sri Lanka have to be exploited through deep mining. The upper formations of the Panirendawa deposit, for instance, occur nearly 80 feet below the surface level. In addition, the ironstones in this deposit are interbedded with calc-granules and basic rocks in a succession (Pattiarachchi 1961; Cooray 1967 : III). Hence, deep mining is not the most convenient method of extracting raw material under such conditions. Further to this, there was no compelling reason on the part of the Early Iron Age smelter to procure raw material through such a time and labour-consuming process of deep mining, unless there was no other

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up small friable bits of quarts-iron-ore schists, concentrating the iron ore by winnowing the crushed materials in the wind or by washing in a stream. Sometimes he is content with ferruginous laterite, or even small granules formed by the concentration of the rusty cement in ancient sandstones" (Elwin 1942 : 30-31).

14. The analysis of a typical haematite found in Sri Lanka (Coomaraswamy 1908/1956 : 190).

SiO_2	-	9.14	H_2O	-	8.40
AI_2O_3	-	9.85	S	-	Nil
Fe_2O_3	-	72.30	P_2O_5	-	.05
FeO	-	.22	P	-	.022
					99.96

source of iron ore available to him. For example, there is a fair occurrence of limonitic float ore on the surface at the Tambakanda magnetite deposit. Similarly, low grade lateritic iron stones can be found as boulders and nodules on the surface at Panirendawa (Kumarapeli 1963). This may indicate that the remains of iron working found at these sites were associated with the extraction and the working of limonite, and not necessarily with magnetite, during the Pre-Modern period.

It is useful to outline some aspects of resource use from neighbouring South India, where the utilization of magnetic sand for smelting purposes was done until the early 20th century in this region (Watt 1890/1972 : 505-507). The native smelters of Coimbatore (in Tamil Nadu) never use solid ore but magnetic sand, which is found in the beds of the surface streams, especially after the rains are over (Nicholson 1898 : II.158). To this day, large quantities of magnetic sand that is washed down the Tambraparni river (Tirunelveli in Tamil Nadu) is used by the native smelter.[15] They also took advantage of the disintegrated mineralized rocks to exploit the ore. This is especially true of the Salem District in Tamil Nadu, which has the largest deposits of magnetite ore in South India. It is found that due to the incipient expansion of the mass, accompanied by the oxidation and hydration of the magnetite, the ore-bearing rock crumbles under the slightest blow, or even between the fingers (Richards 1918 : 31). The iron smelting industry has a tradition going back to the Proto-Historic period in the Salem District. We may however note that deep mining was not unknown in the Southern Deccan during the Pre- and Proto-Historic periods. Some of the mines, worked by the Neolithic and the Iron Age Megalithic communities to exploit the auriferious bands of the Dharwar rocks in the Southern Deccan, on certain occasions reached a depth of 300-600 feet below the surface level (*vide* Allchin 1962; also see Chakarabarti 1985-86 : 65-71).

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15. Iron sand from streams was used in a similar manner by the Pre-Industrial smelters in the Middle East (*vide* Overstreet et Grolier 1980 : 282-311).

There are certain deposits in Sri Lanka that do not require deep mining. The magnetite outcrops at Seruwila, for instance, which vary in height from 3 to 45 feet, are excellent for outcropping (Jayawardena 1982 : 130; Herath 1975 : 28). What is significant about the Seruwila deposit is that, in spite of the facility of convenient outcropping, the ore apparently was quarried for copper rather than for iron. Archaeological, textual and inscriptional evidence strongly suggest a tradition of copper extraction from the copper-megnetite deposit at Seruwila, running well into the Early Iron Age.[16] During the Early Iron Age, the other primary magnetite ore-bearing zones, such as Mooloya and Kirimetiya, located in the low montane region, were too distantly situated from the primary habitation zone in the plains. Within the Proto-Historic context, iron ore may be categorized as a 'weight-gaining object'; hence the natural restriction of its movement to distantly located centres of production in the Dry Zone.[17]

It may be assumed that, within the framework of a limited technology and restricted demand, the Proto-Historic smelter found it more convenient to work the haematite and the limonite ore rather than magnetite. For instance, the copper-magnetite deposit at Seruwila contains sulphide ores such as pyrrhotite (Fe_7S_8) and pyrite/marcasite (FeS_2) (Jayawardena 1982 : 131-132; Yapa 1982 : 25). The existence of such ore formations create practical problems to the primitive smelter. Any sulphur left in the metal tends to affect its working properties. The metal becomes brittle when red hot due to the sulphur content, and as a consequence, it is difficult to forge the metal (Hodges 1965 : 81, 85).

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16. See my forthcoming article on 'The Use of Copper in Sri Lanka during the Early Iron Age' in *Ancient Ceylon No. 7*.

17. Until recently, in the lower montane district of Anantapur (Andhra Pradesh), iron ore was transported on cattle, at times to a distance of 35 miles, from the source to the smithy (*APDG*. Anantapur 1970 : 23). This region has a strong tradition of pastoralism, extending well into the Neolithic period. It is possible that in Sri Lanka cattle may have been used as beasts of burden more extensively during the Early Historic period and after.

In fact, as steel can be obtained even by smelting iron ore containing 50% metal (Kularatnam 1979 : 222), haematite and limonite carried a high utility value over magnetite for the primitive smelter, who operated within a limited technological framework.

The following evidence from India may substantiate the above assumption. Spectrographic and chemical analysis on slag remains (of haematite) from the Early Historic levels at Rajghat (Varanasi) indicate that liquation was achieved at 1180^{o} C. (Bharadvaj 1973 : 395). Similarly, at Dhatwa (Surat), iron slag found within the Early Historic context revealed that the limonite ore was reduced around 1100^{o}C. - 1200^{o}C. (Hegde 1973 : 403). The iron implements unearthed from Proto-Historic Mahurjhari (Vidarbha) were reduced at a temperature around 1200^{o}C. (Gogte 1983 : 74). These smelters had also devised certain other convenient methods of working these ores. Evidence for roasting iron ore can be found at Dhatwa (Hegde *op.cit.*) The application of this method by the Pre-Industrial smelters of Sri Lanka is reported by Coomaraswamy (1908/1956 : 190). Generally the limonite ore tends to contain a fair quantity of water and it is therefore necessary to use the process of roasting, which in turn reduces the water content and carbondioxide in the ore. As a consequence, the iron content in the ore increases and makes it more porous, fragile, easily crushable and suitable for reduction (Hegde 1973 : 403).

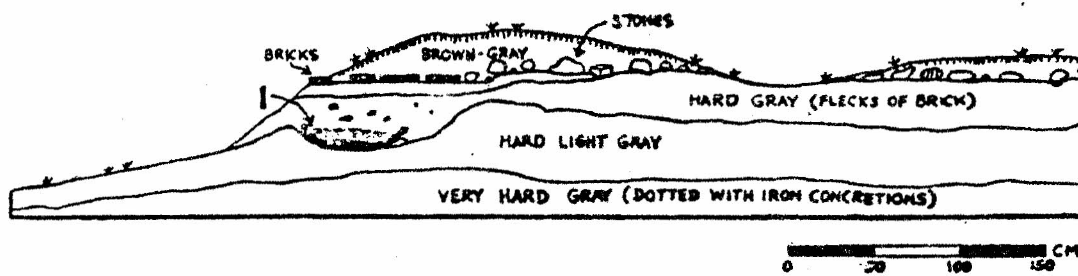
The ability to work limonite or haematite ore cannot be necessarily called a successful technological operation capable of working a highly compact ore such as magnetite. Generally, the reduction of iron ore can be done at 800^{o}C., though iron, produced at 900^{o}C. and below, is extremely porous and cannot be forged (Bharadvaj 1973 : 395). Most iron ores in fact can be melted at 1540^{o}C. for this purpose. It is pertinent to question whether the Proto-Historic smelter in Sri Lanka was technologically equipped with a furnace capable of reaching a temperature of 1800^{o}C. to melt the magnetite ore, or at least reach a temperature of 1200^{o}C. to smelt the ore.

Plate - II

Pomparippu Urn-burial Site

SECTION

1970



(V. Begley. Ancient Ceylon No. 4.1981:62)

It is suggested that there is a linkage between advanced pottery kilns and the development of metallurgy (Lamberg-Karlovsky 1974 : 337). On the basis of the qualitative character of the ceramic assemblage from the Proto-Historic context in Sri Lanka, kilns capable of generating very high temperature levels may not have functioned during that period.[18] The ceramics of this epoch belong to the medium paste variety, having a medium/low lustre (Deraniyagala 1972b : 67-105; Begley 1981 : 85; Seneviratne 1984 : 268-272), a clear result of low temperature levels. Better fired fine paste ware having a high lustre emerge during the end-phase of the Proto-

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18. Some Neolithic ware in the Southern Deccan were fired at a temperature ranging from 500°C to 800°C. (Paramasivan 1967 : 249-250). The Russet-Coated Painted Ware, found within the Megalithic context of Peninsular India, was fired under 900°C. (Nayar 1977 : 96). The Megalithic BRW in the Deccan, in certain instances, is well produced and carried a high lustre. It is suggested that the 'polish' (burnishing) on the BRW was achieved through the application of a haematite knob against the surface of the pot as it revolved. While the surface of the pot gives clear red under oxidizing conditions of the fire, clear black is obtained under reducing conditions. The colour of haematite, in firing, changes progressively between 600°C. and 800°C. (*vide* Rawson 1953 : Art. No. 58). The Black Polished Ware, found within the Megalithic context, may have carried the same form of application on its surface, where it enabled the glaze to stand fairly high temperature levels. Chemical analysis shows 13.79% iron oxide in this ware (Plenderlith 1930 : Art. No. 138; also see Gogte et al. 1982b : 72-76 for a study of ferrous/ferric ratio on certain pottery types found within the Proto- and the Early Historic context of South Asia). It is significant that the Northern Black Polished Ware, the Early Historic deluxe ware, of North India also indicate 13% ferrous oxide in its black coating. (Ullah 1946 : 58; also see Rai et Roy 1980-81 : 165-166). The Proto-Historic ceramics of Sri Lanka do not carry signs of burnishing and clearly indicate indifferent firing conditions (Deraniyagala 1972b : 122; Begley 1981 : 85)

Historic period and by the beginning of the Early Historic context in Sri Lanka. We may tentatively infer that efficient furnaces, capable of working the magnetite ore, may not have existed during the Proto-Historic period, and kilns/furnaces capable of generating high temperature levels seem to have come into vogue in Sri Lanka during the Early Historic period.

This evidence may confirm our suggestion about the type of ore more commonly utilized during the Proto-Historic period, where preference was probably given to haematite and limonite over magnetite. Let us take up the case of the Seruwila chalcopyrite-magnetite deposit, which is associated geographically with the primary habitation zone. In addition to its compactness, another great disadvantage of using this magnetite ore to produce iron implements by the Proto-Historic smelter may have been the existence of cobalt in this ore (Jayawardena 1982 : 138). Cobalt can be melted only at 1480^{o}C, which was probably beyond the heat-generating capacity of the Proto-Historic furnace.[19]

We have already suggested the possible use of the Seruwila deposit primarily for copper extraction and not iron during the Early Iron Age. The very occurrence of scattered blocks of magnetite ore with secondary copper minerals in abandoned pits at Seruwila, may indicate that the highly concentrated magnetite was chipped-off in order to separate it from the copper ore (pers. com. Dulip Jayawardena). In this manner, the Early Iron Age craftsmen may have obtained their copper ore from the copper-magnetite deposit at Seruwila without having to use furnaces generating high temperature levels to work the magnetite ore. It is correctly pointed out that the occurrence of iron pyrites during an excavation from a foundry hearth

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19. It is extremely doubtful whether certain ferrous/ferro-alloy minerals were ever worked even during the Early Historic period. For instance, let us take up the case of molybdenum, which was used as a pigment during the Pre-Historic Mesolithic period. Molybdenite (MoS_2) has been reported from Sabaragamuwa (Tennent 1859 : I.31) and Kegalla (Gunaratne 1967 : 55). This is a hard white metal resembling iron or plumbago, and has a very (contd.)

does not necessarily indicate iron smelting, but may have been a result of copper extraction as iron and copper pyrites are commonly found in association (Hodges 1965 : 81; also see Bachmann 1982). There is also a distinct possibility that the utilization of ore from the chalcopyrite-magnetite ore at Seruwila may have given an added advantage to the coppersmith of the Early Iron Age. Spectrographic analysis of copper objects from Anuradhapura Citadel Str. 3A (Megalithic) revealed a relatively high iron content (.84%) in the metal (*vide* Maliyasena 1986). The presence of iron streaks gives additional strength to such copper implements, thus increasing its utility and functional value.[20] Geological observations indicated the occurrence of chalcopyrite in association with magnetite at the Tambakanda-Wilagedara deposit (Pattiarchchi 1961).

The exact nature of the furnace used in Sri Lanka during the Early Iron Age is not known. It is important to bear in mind that the nature of construction was a crucial factor that enhanced the efficiency of the furnace. In 1985 the excavation at the Citadel of Anuradhapura revealed a brick-built furnace from Str. 6 (Middle Historic). This furnace was not exposed due to the limited nature of the excavation. It is suggested that the furnace was probably used for copper smelting (pers. com. S. Deraniyagala 1985) and, as we shall see later, this particular furnace was apparently constructed to generate a high temperature level. The village-based craftsmen may have

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high melting point at 2620^{o}C. Molybdenite has to be extracted by roasting the ore and reducing the oxide level. At present molybdenum is used for special steel and alloys.

20. In this connection we may note the situation that prevailed in Chalcolithic Ahar (Rajasthan, India), where the copper-smiths successfully operated the chalcopyrite ore from the nearby Khetri mines of the Aravalli hills around 1700 B.C. The extraction of chalcopyrites, according to some, was deliberate on the part of Ahar craftsmen. The existence of iron in copper slag (43.89% to 48.26%) and in copper artefacts (1.22% to 6.48%) at Ahar may substantiate the above assumption (Hegde 1969; Sahi 1986).

used light crude furnaces. Such small metallurgical units were in vogue until the early 20th century in Sri Lanka. A Pre-British furnace used for iron smelting emerged from the court yard adjoining the Temple of the Tooth (Kandy) in the course of the 1984 excavations. It is very similar in plan to the light crude furnace from Balangoda described and illustrated by Coomaraswamy (1908/1956 : 191-192). Apparently such light crude furnaces had a low output capacity and, according to the estimate made by Tennent, these were not "capable of smelting more than twenty pounds of ore" (1859 : I.30).

The Megalithic-BRW culture complex in Peninsular India, on the other hand, has yielded sufficient evidence on the type of furnace used during that epoch. The recent excavations at Naikund in Vidarbha yielded "a circular clay-built furnace, bottom measuring 30 cm. diameter, 30 cm. in height, tapering in profile and with clay tuyeres. Clay bricks were laid one above the other, with the convex and concave side surfaces interlocking each other. A lot of tapped slag, cinder and iron ore was also found just nearby the furnace" (Deo 1982 : 29; also see Chakrabarti 1981-83 : 83). This structure is (C-14) dated to the 6th century B.C.

Cylindrical furnaces, assignable to the Megalithic culture, have also been observed near the 'Ash mounds' at Mudigal in Andhara Pradesh. These furnaces, covered over and above by lumps of iron slag, "are made of *muram* mixed with earth" (Reddy 1976 : 19).[21] Rami Reddy's investigations at Palavoy in Andhra Pradesh revealed yet another interesting furnace belonging to the Megalithic culture from the 'Ash Mound' at that site. The furnace in this case was located within the 'Ash Mound', where it revealed vitrified ash lumps arranged in a row, with domed-shaped roofs and the vertical columns of burnt cow-dung at intervals, and also remains of slag and ironstone (*ibid.* 25-26). Further exca-

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21. Until recently, conical or cylindrical furnaces were used by the primitive smelters of Chotanagpur (Elwin 1942 : 181). The Agaria smithy, in fact, has no walls and becomes almost entirely enclosed with mounds of waste slag and coal as the work continues (*ibid.* 177).

vations may reveal a typical furnace assignable to the Early Iron Age of Sri Lanka, and it is bound to shed more light on the dynamics of inter-regional transfer of technology.

The efficiency of the furnace cannot be gauged only by the ability to generate a high temperature, but also by its capacity to maintain the temperature at a consistent level. It appears that even in India the Early Historic smelter was unable to maintain a consistent level in the temperature. For example, liquation was achieved by the Early Historic smelters at Rajghat (Varanasi) by reaching a temperature of 1180°C. They however could not maintain the consistency of the temperature level, and as a consequence much of the iron was lost in the slag. Two slag samples from Rajghat indicated 74.43% and 72.12% iron content, thereby reflecting the high percentage of iron lost in the process of production (Bharadvaj 1973 : 394-403). A similar situation was observed at Dhatwa (Surat), where much of the iron was lost in the slag due to reduced temperature level (Hegde 1973 : 403).

The net result of this situation is the high degree of wastage involved in the total process of production. Iron implements (made of haematite), unearthed from the Megalithic-BRW context at Naikund (Vidarbha), revealed that the Proto-Historic smelter had utilized 1 kg. of iron to obtain 350 gr. of pure iron, and about 10 kg. to 12 kg. of iron to derive 3.0 kg. to 4.2 kg. of pure iron (Gogte et al. 1982 : 71).[22] Though similar tests have not been performed on iron

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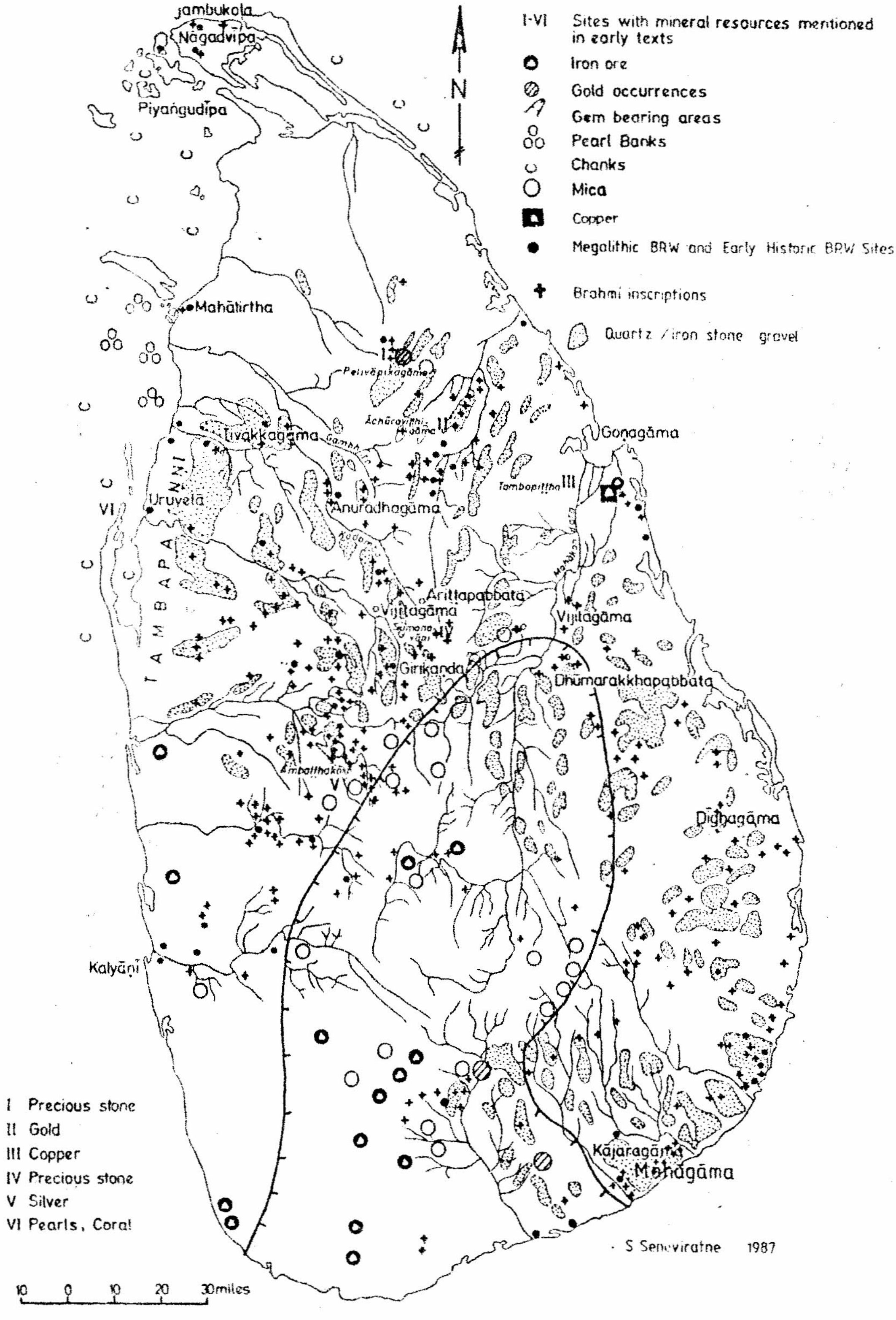
22. The Chanda tribe in Madhya Pradesh utilizes 182 tonnes of haematite ore to extract 40 tonnes of rough iron. For the whole season (5 months) they work 910 tonnes of ore to derive 200 tonnes of rough iron (Elwin 1942 : 214-215). In these regions, even at present, Magnetite, containing 72% of metal, yields only 15% of its weight of bar iron (*ibid.* 194). It is interesting to note that chemical analysis of some of the iron objects manufactured by the contemporary iron smelting tribes of Chotanagpur closely tally with the pre-Christian iron objects of North India, though they differ considerably in terms of physical properties. (Bharadwaj 1979 : 165; also 161, Table 45).


N
I-VI Sites with mineral resources mentioned in early texts
Iron ore
Gold occurrences
Gem bearing areas
Pearl Banks
Chanks
Mica
Copper
Megalithic BRW and Early Historic BRW Sites
Brahmi inscriptions
Quartz / iron stone gravel
Jambukola
Nāgadvipa
Piyaṅgudipa
Mahātirtha
Tivakkagama
Uruvelā
TAMBAPANNI
Anuradhagāma
Gonagāma
Arittapabbata
Vijitagāma
Vijitagāma
Girikanda
Dhūmarakkhapabbata
Dighagāma
Kalyāni
Kājaragāma
Mahagāma
I Precious stone
II Gold
III Copper
IV Precious stone
V Silver
VI Pearls, Coral
10 0 10 20 30miles
S Seneviratne 1987

slag found from the Early Iron Age context in Sri Lanka, an analysis of slag remains from Tambakanda (period not known) indicated a high content of ferrous iron i.e. 56.69% (Patti-archchi 1961 : Table 2). Tennent notes that the 19th century smelters of Sri Lanka at times used up to 20 pounds of ore to obtain 7 to 10 pounds of good metal (1859 : 1.30). It may be noted that Tennent made these observations in areas having high quality haematite and magnetite, in central and south-west Sri Lanka.

Steel.

The process of making native steel in Peninsular India and Sri Lanka is the Wootz method.[23] It is locally known as *urukku* (Tamil) / *ukku* (Kannada) in South India, and *vane* (Sinhala) in Sri Lanka. The Tamil Sangam texts of South India, which belong to the Early Historic period, use the term *eḵku* for pointed or sharp weapons of steel (*Kuṟun* 312; *Puṟam* 308.4-5; *TL* 1926 : 1.iii. 507).

Some background information related to North Indian and South Indian steel may be useful in this context. There is evidence that the iron smelters of North India were familiar with carburization (case hardening/quenching) around 600 B.C. (Bharadvaj 1979 : 158). Scholars have drawn our attention to references in the *Suttanipāta* on the method of quenching (*vide* Tripati 1986). The introduction of Wootz to North India

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23. The following description may provide a general idea about the Wootz method. "Wootz is produced from black magnetite ore, bamboo-charcoal and the leaves of certain carbonaceous plants, sealed in a crucible of native clay. Smelting the contents in a charcoal fire with blast air yields a button or regulus of metal, which is alternately melted and cooled again four or five times, until round cakes of 5 inches diameter and ½ inch thick, weighing about 2 lbs. are obtained" (Forbes 1950 : 410; Watt 1972 : iv.503). The crucibles are made of a refractory "red loam mixed with a large proportion of charred rice husk. The wood used was *Cassia auriculata* and the leaves of *Asclepious gigantea*, or if such are not procurable, those of the *Convulvulus laurifolia*" (Watt 1972 : iv.503; Forbes *op.cit.* 438).(contd.)

may have taken place around 200 B.C. (Bharadvaj *op.cit.*). Some of the iron implements from Early Historic North India revealed black slag inclusions, Ferrite grains and Pearlite during chemical and metallographic examinations. This points to the existence of low-quality steel in North India as late as the 2nd century B.C. (*ibid.*; 1981-83 : 143).

It is possible that the Wootz method may have entered Peninsular India along with the intrusive Megalithic culture, probably around 1000 B.C. Archaeometallurgical studies indicate that the finished products, in Peninsular India, reflect qualitative and quantitative disparities, spread both in time and space. This is seen by the relatively less developed stage of steel making during its earliest phase in Peninsular India. Steel implements from the Megalithic site at Tadakanahalli in Karnataka (dated to c. 1000 B.C.) showed the presence of Ferrite and Pearlite structures, including slag inclusuons in the metal (*vide* Agrawal et al 1980-81 ; 98). However, by the end-phase of the Proto-Historic period, the Megalithic smelter-craftsman mastered the steel manufacturing process. For instance, an iron axe unearthed from a 6th century B.C. burial at Mahurjhari (Vidarbha), indicated 99.1% iron, 0.9% carbon and a trace of chromium (Deo 1973 : 77; Gogte 1983 : 74). An iron hoe from Early Historic Dhatwa contained iron up to 99.9% (Hegde 1973 : 402-403). It is therefore not surprising that this locally produced high-quality South Indian steel had a ready market in the Roman Empire during the Early Historic period (*vide* Schoff 1915).

The Early Iron Age smelter-craftsman was able to obtain such pure iron because the temperature of reduction was low (1200°C.) and the reduction was done in solid state and not in the liquid state (Gogte *op.cit.*, 75). Due to the lower absorption of carbon in the lower temperature of the furnaces, the indigenous furnaces produced wrought iron. This wrought iron could be easily transformed into steel through Wootz (Banerjee 1965 : 187).

Pre-Industrial craftsman of Sri Lanka used dried woods of *Cassia auriculata (ranavara)* and *Todelia aculeata (kudu miris)* in association with the crucible for making native steel (Ondaatje 1854 : 40 - appendix).

Ethnographic studies clearly record the existence of regional varieties of Wootz in Peninsular India during the British period (for details, *vide* Bronson 1986). These variations were in turn conditioned by the ecology, raw material, labour and the quantitative demand for steel. It is quite likely that this regional variation may have well existed during the Early Iron Age.

An additional feature in the development of steel manufacturing was the use of the layering technique at an early date in Peninsular India. An iron axe at Tedakanahalli was a compact bar, having high content carbon layers on both the sides, with low carbon sheets in between (Agrawal et al. 1980-81 : 99). This method not only saved time for the smith but also gave the tool a strong working surface (*ibid.*). This bar was folded and hammered, to get the desired shape and length, consequently resulting in the distribution of carbon all over the implement (*ibid.*). The Chotanagpur iron-smelting tribes heat the metal for 3-4 hours, and then the hot metal is worked on a stone anvil. It is believed that stone siliconizes the skin of the metal, and as a consequence the iron does not rust easily (Leuva 1963 : 148).

Some of the iron implements unearthed from the Proto-Historic context at Anuradhapura may have been made of steel. Metallurgical studies related to these artefacts are currently in progress. However, it is very clear that, unless improved elements of iron and steel was used, it may have been extremely difficult to fashion drip-ledges on caves of hard granite during the Early Historic period. The tradition of steel-making therefore may have prevailed and continued from the Proto-Historic period. The excavator in fact remarks that at Anuradhapura the Early Historic assemblage "contains the highest concentration of iron artefacts and they appear to be more sophisticated than those from the preceding strata" (Deraniyagala 1972b : 155). The iron tools unearthed by Parker at Akurugoda (Tissamaharama) can be categorized as better manufactured implements of steel belonging to the Early Historic period (Hadfield 1918 : 103).

The availability of improved furnaces generating higher temperature levels may have been an important factor augmenting the production of quality steel at an enhanced scale. It is suggested that the early 20th century Balangoda smelter, who produced (Wootz) steel with an iron content as high as 99.77% (*vide* Coomaraswamy 1908/1956 : 193), may have reached a furnace temperature-level around 1400°C. to obtain such high quality steel (Maliyasena 1986). Though Hadfield's study related to the iron and steel objects from Sigiriya (5th Century A.D.) indicates that the craftsman of that time was aware of carburized steel (Hadfield 1918 : 103-104), the technological tradition of case-hardening or quenching in Sri Lanka may well have an antiquity extending to the Early Iron Age, at least to the Early Historic period. Quenching and tempering is known to give a superior cutting-edge to steel implements (Agrawal et al 1980-81 : 100).

An important contributory factor resulting in better produced iron and steel implements during the Early Historic period may have been the ability of the smelter-craftsmen to achieve high temperature levels through more efficient methods of production techniques. For instance, they devised certain methods to protect furnaces and crucibles from high temperature levels. The 1984 Citadel excavation at Anuradhapura revealed the use of koalin as a binding material for the bricks in the (copper smelting?) furnace unearthed from the Historic levels. Kaolin, which is the pure form of hydrated silicate, not only loses water on heating but also has a high sinter and melting point (1770°C.).[24] Further to this, in the process of native steel-making, cementation/carburization is done at a temperature above 900°C. (Hodges 1965 : 83). Chemical analysis on crucibles used for this purpose in India indicate that quartz component in the clay had been converted to mullite and that the temperature reached was 1250°C., and in certain cases 1470°C. (Rao 1982 : 470). Terracotta crucibles, unearthed from the Abhayagiri excavation at Anuradhapura, show vitrified outer surfaces (Wikramagamage 1984 : 84-86), suggesting that these crucibles had been subjected to high temperature levels. The occurrence of well-fired Black and Red Ware within the Early Historic context may further indicate that improved methods of using furnaces prevailed during this period.

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24. Crucibles of Kaolinitic clay were used in Peninsular India for steel making during the British Period (Bronson 1986 : 36).

Therefore it is not an exaggeration to state that the utilization of improved implements of iron and steel provided a tremendous technological fillip to work the hard gneise. It introduced more advanced methods of architecture, hydraulic engineering, an extension in agriculture and also initiated greater political integration in the post 2nd century B.C. period.

Fuel

The efficient utilization of iron is dependent upon another crucial factor. The availability of fuel and the type of fuel capable of producing the required degree of temperature are vital determinants in this context. Perhaps the most common type of fuel used by the Pre-Industrial smelters of South Asia were charcoal, wood, dung and paddy husk.

Ethnographic evidence indicates that the Pre-Industrial smelters of Sri Lanka found it convenient to utilize charcoal as a fuel basis (Davy 1821/1983 : 195; Baker 1898 : 50-51; Coomaraswamy 1908/1956 : 191). Charcoal carries several advantages over wood. It is free of water and is more convenient and practical to be used in the kiln/furnace. It is also capable of providing a blast much more severe than wood, and also acts as a flux during smelting. The use of charcoal as fuel therefore results in the reduction of the sulphur content in iron to less than 0.05% in the process of production. In fact chemical and metallographic analysis of iron objects found at Naikund showed a very low sulphur content, indicating the use of charcoal in smelting operations (Gogte 1983 : 74). It is reported that cinder and slag remains from this site revealed clear impressions of charcoal (*ibid.*).[25]

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25. In Peninsular India charcoal continued as the primary fuel type for Pre-Industrial smelting purposes (Elwin 1942 : 121; Leuva 1963 : 147-48). The Agarias use several types of trees, such as *Webbiana*, *Grewia vestita* and *Terminalia tomentosa*, to make charcoal, though they consider *Boswellia serrata* as the best source of charcoal (Elwin *op.cit.*).

It is correctly pointed out that "dry wood, which is made largely of cellulose and lignin...contains a fairly high proportion of water and has a thermal capacity...Damp wood will, of course, give an even lower heat output..." (Hodges 1965 : 166). In better enclosed kilns/furnaces, wood fuel can reach a temperature around 1200°C., though it is likely that such temperature levels can be reached by using wood fuel on open smaller structures, where the heat is proportionately greater (*ibid.*). In Sri Lanka, the cashew tree (*Anacardium occidentale*), which grows on sterile soil in the wet and dry zones, is an excellent type of wood fuel, because it gives a hot and uniform heat (*TA*1897-98 : 205).

It may be suggested that the monsoon scrub jungles in the north west and in the Jaffna peninsula of Sri Lanka, were convenient sources of firewood for the Early Iron Age folk. However, larger trees, capable of providing them with charcoal, had to be obtained from monsoon forests. Such vegetation zones came under a more regular occupation, perhaps during the Early Historic period, which also coincides with more regular and efficient metallurgical operations. It is possible that, even within this vegetation zone, these communities may have been selective in using particular types of trees. Observation and experiment may have led to a discrimination between particular types of wood that had a lesser proportion of water and those types that contained relatively more water.

In the indigenous method of manufacturing iron and steel, the requirement of wood-based fuel in great quantities is a very significant factor in the process of production. It is suggested that the early raw material yielding areas are "most likely to be found, not only where the ore deposit is reasonably superficial, but also where the forest cover was sufficient to provide adequate fuel" (Hodges 1965 : 81).[26]

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26. W. Ruben, in his original study titled 'Eisenschmiede and Damonen in Indian', *Int. Arch. f. Ethnographie*, (Vol. XXXVII, 1939), suggests that the Asur tribe was earlier semi-nomadic, where movements (between a few months and three years) were determined by the availability of ore and fuel (cited in Forbes 1950 : 70 ff.).

According to 19th century estimates, the native smelters of India, who turned out Wootz steel, required 14 tonnes of charcoal to produce 1 ton of finished iron (Watt 1890/1972 : 502). The Chanda of Chotanagpur (India)use up nearly 1½ tonnes of charcoal to smelt 1 ton of ore (Elwin 1942 : 215). The monsoon scrub jungles of Sri Lanka could not provide wood requirements extending to such large proportions. Large quantities of wood were available only within the vegetation zones covered by the monsoon forests and the lowland rain forests.

It is difficult to ascertain to what extent paddy husk was utilized in Sri Lanka as an alternate source of fuel during the Early Iron Age. To this day certain potters in Sri Lanka use paddy husk in their kilns. Excavations at the Anuradhapura Citadel revealed that paddy husk was employed as tempering daub during the Proto-Historic period (Deraniyagala 1972b : 159). In all probability, with the expansion of agricultural activity during the Early Historic period, there may have been an appreciable increase in the utilization of paddy husk as an additional source of fuel. We may note that even at present paddy husk plays a larger role than charcoal in small-scale metallurgical units of South India (Banerjee 1965 : 146, note 10). In Peninsular India the use of loam or clay with charred or uncharred husks as (Wootz) crucible material prevailed until recent times (Bronson 1986 : 36). This is probably because of the convenient availability of husks and because it is capable of retaining the heat and glows much longer than charcoal, due to the high silicacious composition.

Another additional source of fuel used by the Early Iron Age folk may be found in animal dung. The pastoral tradition was a significant component in the multi-resource broad spectrum subsistence pattern that thrived in the arid and in the dry zones of Sri Lanka (*vide* Siriweera 1981; 1982). Especially in areas where the density of the vegetation tends to be low, dung may have been valued as a primary source of fuel by these communities. Though direct evidence is lacking for the use of animal dung by the Early Iron Age metallurgist of Sri Lanka, there is sufficient archaeological evidence to indicate its use as a primary source of fuel in the Deccan by the Neolithic and the Megalithic folk, who operated to a large extent within a pastoral economy.

Burnt dung heaps, (commonly known as 'Ash mounds'), found within the Neolithic and the Megalithic context in the Deccan, have been subject to periodic burning, probably for ritualistic purposes (Allchin 1963). Recent investigations also indicate that some of these mounds were used as sources of fuel as well as in-built kilns/furnaces. It is said that the "particular advantage of dung fuel over wood is that it can act both as a fuel and as a temporary dome to a kiln...cakes of fuel may be laid over a stack of pottery and not allowed to burn out until the very end of the firing. Such a fire, although generically a bonfire, behaves in fact as a kiln" (Hodges 1965 : 165). According to Allchin, the Neolithic ware in the Southern Deccan was fired in a simple bonfire kiln (1960 : 30). It is also suggested that 99% of the ancient pottery was baked in open-fires (Hegde 1977-78 : 110). Recent experiments indicated that "the temperature of an open-fire, using cowdung cakes as the fuel, was found to reach 1000°C." (*ibid.*).

What is more interesting is the utilization of some of these mounds for iron-smelting purposes during the Proto Historic period. The furnace 'built' within the Ash mound at Palavoy is a case in point (Reddy 1976 : 25-26). In all probability these communities used non-magnetite ore. The occurrence of iron slag and haematite ore on the surface in the vicinity of the Ash mound at Kupgal has been recorded by Foote (1916 : 80-81). The temperature-level generated from those dung heaps was sufficient to work non-magnetite ores. Laboratory studies estimate that the formation of vitrified glassy slag at such mounds had taken place under a temperature of about 1200° - 1250°C. (Majumdar et Rajaguru 1966 : 29).

Labour and Production

Archaeological, textual, inscriptional and ethnographic evidence, related to Pre-Industrial metallurgy in South Central Asia, clearly indicate that the metal technology was specialized in character, using simple implements operated by the nuclear or the extended family.

Childe was not incorrect in indentifying the metal-smith as the first expert who became involved in a full-time occupation during the Proto-Historic period (1930 : 4, 10). However, one is uncertain about the full-time involvement of the Proto-Historic smelter-craftsman of Sri Lanka. The very introduction of iron to Sri Lanka from an external region, the apparent borrowing of this technology by the Mesolithic communities, and the limited functional value of iron during the Proto-Historic period, may have restricted the emergence of full-time specialization. Judging by the occurrence of iron ore, iron slag, iron implements, along with copper ore, slag, crucibles and implements of copper within the Proto-Historic levels at Anuradhapura, it may indicate that the metal-smith of that time did not restrict himself to one type of metal but worked different varieties of metal.

Some hint of this situation can perhaps be found in the subsequent period, from the early Brahmi inscriptions, where the iron-smith is called by the term *kabara* (Paranavitana 1970 : XCVIII). Paranavitana derives this term from (Pāli) *kammara* (*ibid.*) Interestingly it is pointed out that "the smiths in old India do not seem to be divided into black-, gold- and silver-smiths, but seem to have been able to work equally well in iron, gold and silver" (Rhys Davids et Stede 1959 : 195). It is therefore possible that, with the greater demand for specialization in different metals, the pre-existing (Proto-Historic) smelter-craftsman i.e. *kabara*, came to be identified with the specialist craftsman involved in the production of iron during the Early Historic period. The early Brahmi inscriptions in fact mention certain other specialists such as the *tabakara* (copper-smith) and *topaśa* (tin-smith) who specifically worked other metals such as copper and tin (*vide* Paranavitana 1970 : No. 351, 370).

It is possible to suggest two vital aspects that are associated with labour and production in Pre-State societies of South Central Asia.

The first is the operation of subsistence economies through a 'simple technology' (Vidyarti et Rai 1977 : 103).

In such situations, "the basic apparatus can be handled by the household groups...implements are homespun...the same interest party can carry through the whole procedure from the extraction of the raw material to the fabrication of the finished goods" (Sahlins 1978 : 79).

The second aspect is the ability of the household (nuclear or extended family), as the unit of production, to control labour and the means of production. In the absence of a controlling authority that allots specific tasks of production, labour is under the control of the household itself, where property rights (cattle, the plot or raw material) are normally held in common "at the level of the family, hamlet, lineage or village" (Harris 1972 : 256).[27]

Archaeological and ethnographic studies indicate that the actual production itself was on a low key. The activities of the Early Iron Age smelter-craftsman was generally conducted at the habitation. The Citadel excavation at Anuradhapura yielded iron, slag, finished products and tools from the Early Iron Age residential areas (Deraniyagala 1972 b : 152). Similar remains were unearthed from the primary habitation site at Kantarodai (Pieris 1919 : 61-62; Begley 1967 : 24) and Tissamaharama (Parker 1884 : 60).[28] Interestingly, the house as well as the smithy was known as *kuḍam* in the Early Historic Sangam texts of South India

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27. The Agarias of Chota Nagpur have no private ownership in the iron ore pits and there is no village ownership. The same area is simultaneously dug by groups, at times arriving from three different hamlets (Elwin 1942 : 176).

28. The 19th century furnace described by Coomaraswamy was located very near to the house occupied by the smelter and his family (1908/1956 : 190). The furnace was situated "beneath the thatched roof of a shed open on all sides" (*ibid*). Similarly, the Agaria smithy has no protecting or enclosing walls (Elwin 1942 : 177). The Agaria smithies are located either within the village or outside among the trees or at times even on a hill-side, the smithy being built into the side of the hill (*ibid*. 177-79).

(*PPTI* 311). There were, however, instances when smelting was conducted near the ore. Several early Brahmi inscription-bearing caves or rock shelters, located in the montane region, show evidence of early iron workings, at times, in association with Early Historic BRW.[29]

The association between some of the iron workings and residential localities suggests the involvement of the household group as the unit of production, especially during the Proto-Historic period. Vestiges of this situation most obviously continued into the Early Historic period. For instance, an Early Brahmi inscription identifies a *kabara* as a *gahapati*, i.e. 'householder' (Paranavitana 1970, No. 301). *Gahapati* (Skt. *gṛhapati*) literally means lord/head.master of the household. It is suggested that, though in its original context *gahapati* implied 'householder', "it could be extended to cover the headship over occupational groups based on the *kula*" (Wagle 1966 : 151-156). In another early Brahmi inscription, a tin-smith (*topaśa*) is called *gahapati*, and in this case his family unit i.e. *kula*, is also mentioned (Paranavitana 1970, No. 370).[30] In any event, the *gahapati* individuals, (an urban and rural based affluent social class) derived their economic strength from agrarian, craft and commercial operations.

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29. Coomaraswamy mentions local iron smelters who visited Nuwara Eliya to work the iron ore found there (1908/ 1956 : 190).

30. The extraction of iron ore requires the collective effort of the family or the resident clan group in the hamlet/village. The smelters of Chotanagpur extract iron ore from the pit with simple mattocks and then the group carries it to the furnace in home-made reed baskets (Elwin 1942 : 174-76). They also collectively gather fuel, i.e. wood for charcoal (Leuva 1963 : 148). It is again the family group that breaks the iron ore into fragments by pounding (*MDG* Salem 1918 : 31; Leuva *op.cit.* 147). Until the final phase of the product, a minimum of two individuals are always involved in the process of production. In the case of the Asur, the head of the family (i.e. father) organizes and delegates production tasks to the family members (*ibid.* 68).

Auxiliary implements, associated with smelting, were familiar to the Early Iron Age smelter-craftsman (Deraniyagala 1972 a : 7; Parker 1884 : 38). It is interesting to note that a cist-burial at Yelleshwaram (Andhra Pradesh) yielded a pair of iron tongs (Khan 1963 : 48, Pl. xiii, A-C.). The *Culavamsa* (88, 98) lists the following objects or implements and tools used by the blacksmiths of Sri Lanka (during the Late Mediaeval period), viz. "bellows, tongs, hammers, sledge-hammers, anvils, sharp saws, axes, hatchets, (wedges) for splitting trees." The Sangam texts also mention the blacksmith's forge, pincers, bellows, blow-pipe and the anvil (Kailasapathy 1968 : 203). The early 20th century native smelters in the Deccan used the identical implements in their craft (*vide* Forbes 1950 : 36; Elwin 1942; Leuva 1963).

The whole process of production (from the collection of ore to the finished product) is an extremely time- and labour-consuming one. This gave the smelter-craftsman little or no time for agricultural activity. Conversely, with the greater demand for iron implements during the Early Historic period, there appears to have been a higher level of specialization and a corresponding hierarcization within the smelter-craft group. Such developments, more specifically, were a consequence of urbanization and social stratification, leading to a greater division of labour within the Early Historic context.

An early Brahmi inscription (1st century B.C./A.D.) from Ganekanda Vihara (Kurunegala district) mentions a *puga* (corporation), where a *kabara* named Nāga functioned as its *anu-jeṭa* (Vice-President) (Paranavitana 1970 : No. 1198). We are able to draw some important inferences from this inscription. Firstly, it is possible to infer that two groups of specialists were involved in this industry during the Early Historic period. They were, namely, the smelter and the craftsman. This specialization may have been more apparent at urban and semi-urban centres. By virtue of his specialization, the craftsman may have enjoyed a relatively higher socio-economic status vis-a-vis the smelter.[31]

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31. In Andhra, during the Ikṣvāku period (3rd - 4th century A.D.) a *chhaya stambha* (memorial pillar) was raised (contd.)

Secondly, the existence of guilds or corporations clearly indicates that the means of production and labour came to be controlled outside the family unit of production, at least at urban and semi-urban centres.[32] It is not impossible that a smaller unit of production, headed by the *gahapati*, may have been incorporated into a larger guild body. We are unaware whether the *puga* in question incorporated only iron-smiths or other specialists as well, though some early Brahmi inscriptions do record the existence of guilds representing only a particular group of specialists (*vide* Paranavitana 1970 : 696a, 1145; 1983 : 105-07).

The production technique and the nature of resource use can be taken up as a study giving direction more specifically to the socio-economic significance of the processes of production during different epochs in Pre-Industrial Sri Lanka.

In Sri Lanka the exploitation of mineral resources, even those varieties known during the Mesolithic period, was purposefully extracted during the Proto-Historic period, and more specifically during the Early Historic period. An increase in the quantitative level of exploitation and utilization of mineral resources seems to be associated with a relative improvement in the technology, a demographic

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at Nagajunakonda in memory of a foreman to coppersmiths (Sircar 1963 : 16-I). *Chhāya stambha* memorials were invariably associated with elite groups at Nagajunakonda during the Ikshvāku period.

32. The Ganekanda Vihara inscription addresses the *Jeṭa* (President) of the corporation as a *cara* or journeyman (Paranavitana 1970 : No. 1198). We are unaware of his specialization. It is not altogether impossible that he too may have been a *kabara*, who travelled from place to place as a master-craftsman. It is interesting to note that an early Tamil Brahmi inscription at Alakarmalai (Tamil Nadu) records a donation made by a *Koḻuvaṇikaṉ* or iron-monger (Mahadevan 1966 : No. 38).

expansion, an extension in the settlement zones and related economic activities, an intensification in the demand for luxury and utilitarian items, and also due to an expansion in the exchange vortex. Another important factor in this connection is the structural transformation in the political institutions, leading to the emergence of 'real authority' in society. This factor may have acted as a strong basis towards a greater integration of natural resources, a more successful and organized control over labour, means of production and the surplus including its distribution during the Early Historic period.[33]

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33. "The treasury has its source in the mines; from the treasury the army comes into being. With the treasury and the army the earth is obtained." (*Kauṭilya Arthaśāstra* 11.12.37).