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HISTORY OF METALLURGY & ANCIENT IRON SMELTING

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Metal has been a critical technological and economic resource in all historical societies. Studies in the pattern of ancient settlement proved that they had characteristic technological systems which were connected to their environmental resources. Even before the metallurgical properties of metals were discovered some iron ores such as haematite (Fe_2O_3), limonite ($2Fe_4O_3.3H_2O$) and goethite ($Fe_2O_3.H_2O$) were used as red, brown and yellow pigments by the lithic society.[1] The factors of archaeological findings suggests, man's natural attraction for colour sensation led to important steps in the evolution of technology and the use of such pigment might be the preliminary stage leading to the metallurgy.[2]

Around 3000 BC the settlements which were based on copper and bronze had established in Asia Minor, India and China. But, the most significant innovation from a technological point of view was the use of iron. Iron technology has probably been started in Asia Minor around 3000 BC.

The knowledge of iron technology might be spread other parts of the world after 2000 BC. According to archaeological evidence found from so far, the Mesolithic in Sri Lanka was superseded by the protohistoric early iron age.[3] The absence of an intervening Neolithic or Chalcolithic[4] may be attributed to ecological factors, the heavy soils of the island clothed in rain forests being difficult to work with Neolithic technology.[5] Other reasons might be during the Mesolithic period, iron technology was introduced to island from somewhere or the idea was started to practice indigenously by accident.

There are numerous references in ancient chronicles like the ***Mahavansa, Thupavansa, Pujavaliya*** and inscriptions, to use of gold, silver, lead, copper and iron in Sri Lanka from Early Historic times onwards. Archaeological explorations and excavations carried out in various parts of the island confirm such written evidence and the records of the metallurgical knowledge of our ancestors. The earliest known date for iron smelting, 10th century BC was established through C_{14} dating of an archaeological context from Aligala, Sigiriya.[6] It is thought likely that this technology was started at some point in time during or before the 9th century BC. The results yielded from the excavations in the Anuradhapura Citadal area have confirmed this evidence futher.[7]

It is important to examine whether Sri Lanka had an indigenous metal technology and if so, what the characteristics of such a technology may have been. The record of the metallurgical knowledge of our ancestors is essentially incomplete due to the scarcity of research material published on archaeometallurgy.[8] The study on pre-modern iron production in Sri Lanka seems to have started in the 19th century.

Early description and investigations such as those of John Davy,[9] Ondaatje,[10] Coomaraswamy[11] and Hadfield,[12] have indicated that Sri Lanka iron and steel occupied a significant place in the South Asian iron technology complex. Hadfield takes a prominent place among the early investigators of Sri Lankan Archaeometallurgy. In his studies on the samples of iron and steel from Sigiriya, he recorded that the iron masters of ancient times had known the art of 'quenching'[13] tostrengthen steel. These sample artifacts were made of pure iron. The outer surfaces had a high carbon content. He states that those iron masters who produced these artifacts had a knowledge almost as advanced as that of the iron masters of modern times. Hadfield's studies drew attention to the fact that case hardening or cementing,[14] the method of carbonizing wrought iron[15] and quenching were used to produce hard cutting edges. Like earlier observers, Hadfield was struck by the fact that traditional iron and steel production in Sri Lanka was of a very high standard.

In the late 1980's important breakthroughs in the archaeological investigation of this subject were made by the Postgraduate Institute of Archaeology (PGIAR)- in collaboration with the Swedish Board of National Antiquities, under the Settlement Archaeology Research Collaboration Project (SARCP) in the Sigiriya-Dambulla region[16] and by the Archaeological Department working in collaboration with a British team at Samanalavava on the bank of the upper Walave river.[17] However, in addition to these two sites, the remains of iron smelting furnaces unearthed at Ridiyagama (under the Department of Archaeology and the French Mission of Archaeological Co-operation) in 1995,[18] and the existence of iron slag mounds throughout the island, bear evidence that this technology was widespread.

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Research and scientific activities presented in this paper, were principally focused on this major 'factory' site at Dehigaha-ala Kanda near Alakolavava village (registered as KO_{14}), identified in 1988 and excavated in 1990 and 1991. This site is situated 8 1/2 Km south-east of the Sigiriya rock. This iron production site which is hidden in deep jungle 1 1/2 Km from Alakolavava village is demarcated on the north and the west by *chena* cultivation, on the east by the Kiri Oya which is one of the major waterways feeding the Sigiriya area. In the Kiri Oya valley alone, there are more than 20 iron production sites. Excavations revealed a series of furnaces and the science slag heap covering a site of nearly 3,750 m^2. Archaeological research enabled the identification of large scale iron production using an advanced bloomery process [24] with magnetite ore (Fe_3O_4) at the site. Pieces of iron slag of various sizes and shapes, slag mounds covered with soil layers and the research carried out bear testimony to the extent of production and the stage of development of the technology.

Systematic excavations conducted over two years in two stages and spread all over the site have resulted in the discovery of several furnaces used in iron production. These furnaces were made by carving the bedrock into an oval shaped pit. In every excavated furnace the front wall was missing. The reason for this may be that the wall had to be broken in order for the spongy iron bloom[20]- which was the final product of furnaces of this type-to be taken out. The front of the furnace

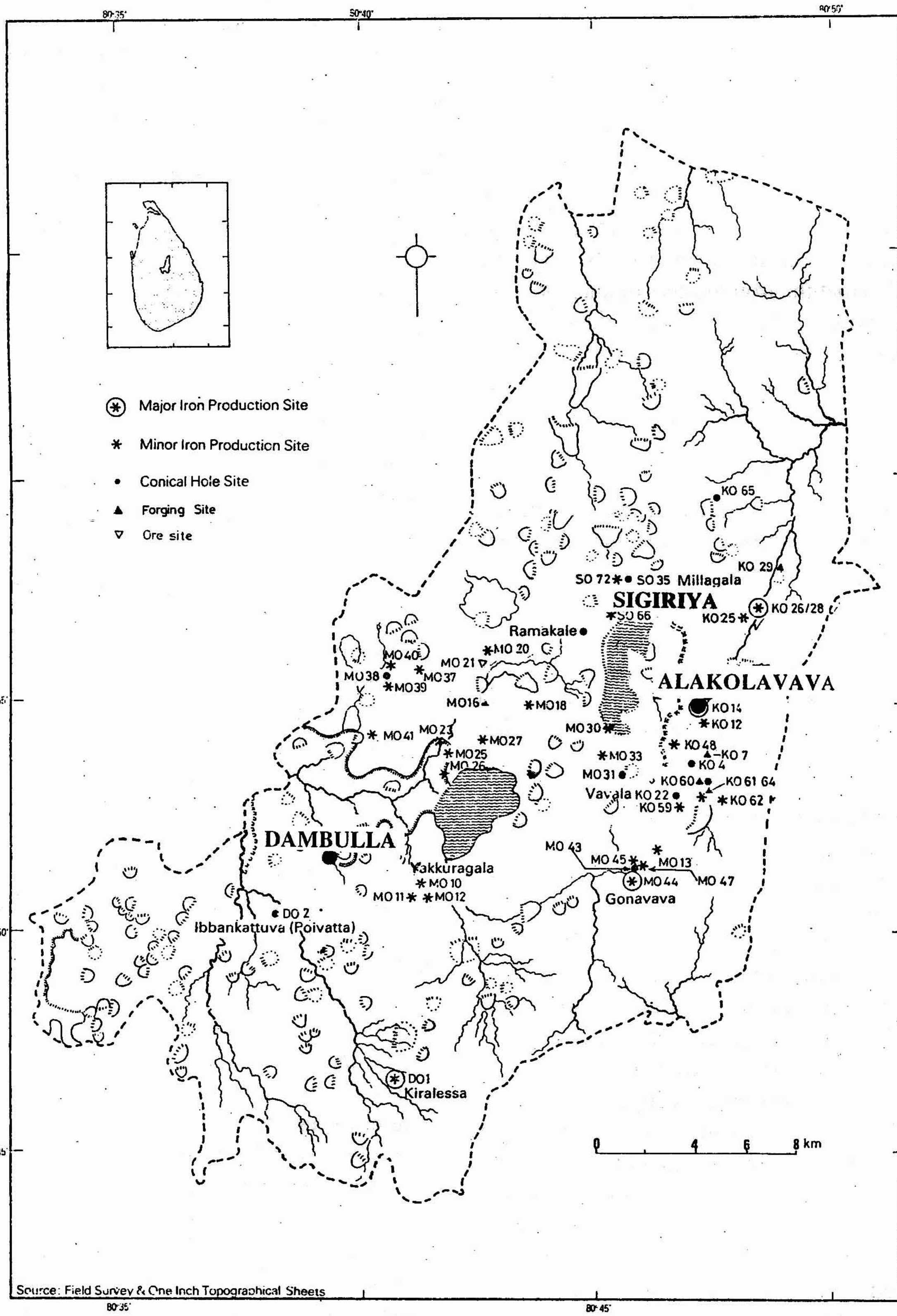

Figure 1: The study region with iron production sites

Iron extraction, the structure of furnaces used and their technological evaluation

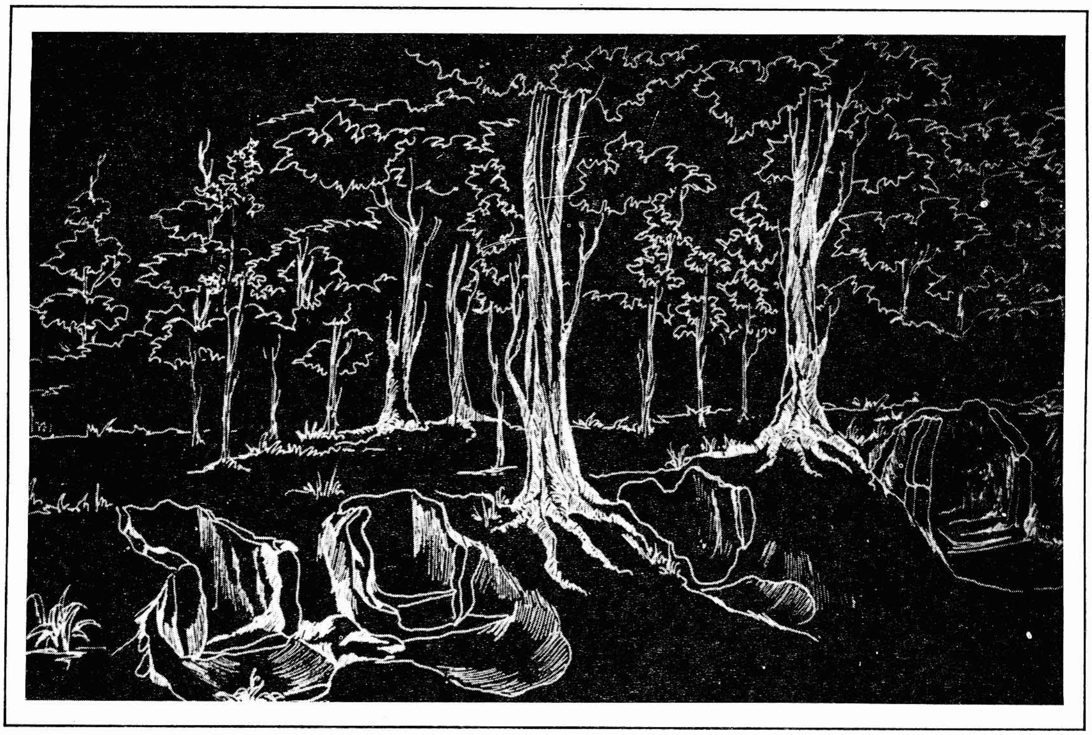

Figure 2: Drawing of series of furnace

shaft probably began from the top of the stone slabs which were used for making of side walls curving inwards.

Starting from the top of the stone slabs, the furnace shafts grew narrower as they increased in height. The height and shape of the shaft had the capability to control the temperature and ensure the strength of the furnace construction. The height of a furnace when reconstructed with the remaining fragments seems to be about 2 m. while the thickness of the side wall was about 20-40 cm. The special feature in the construction of these furnaces, is the carving out of the bedrock to resemble two rounded steps in front of the furnace. This may have been done to facilitate the removal of iron bloom and waste material from the pit afterthe smelting process. The width at the bottom of a furnace was 80-95 cm and the depth (east to west) was 40-60 cm.

Taking the above as well as the height of the furnace in to condideration we can see that the furnaces at Alakolavava were relatively broad. This construction feature also had the capability to control the temperature at a suitable point to obtain a high production activity from the production process.

The maximum production which can be obtained out of raw material used, generally depended on the ability to control the reduction conditions in the furnace. Heat is the most important factor of the iron smelting process. The heat generated by an ordinary charcoal fire may reach up to 700^0 C. The furnace, therefore, should have facilities either of natural draught[21] or forced draught[22] to raise the required high temperature for the smelting process. A natural draught of air through a furnace is induced by a high chimney. A forced draught furnace will have provision for anair blast blown in by bellows[23] through a tuyere.[24]

The primitive bellow was made of two large inverted terracotta pots covered with an animal skin. The more developed blown through one blow pipe but in larger furnaces four or even more bellows were provided[25] In the furnaces excavated at Alakolavava pressure marks on the lower parts of the back walls, indicate the use of aforced draught which must have been blown by bellows.

It must be mentioned here that unlike at Alakolavava it is believed that the smelters at Samanalavava used the monsoon winds that lashed across the region at a velocity of 70 km per hour from April to August as a natural draught.[26]

There is evidence or the iron masters of Alakolavava on same occasions used eight tuyeres at a time for one furnace. This was a very special arrangement used for controlling the heat which was essential for the success of the production process. And they also had the ability to avoid cold zones and distribute the air equally to all parts of the furnace.

Analysis reports have shown that the composition of the clays used in the furnace walls and the tuyeres are different at Alakolavava. It is clear that the tuyeres were made of a type of clay which was capable of withstanding much higher temperatures than the furnace walls.[27]

Iron or used and its contribution in the bloomery furnace system

Generally, iron smelters have used haematite and limonite for primitive bloomery furnaces. This is due to the difficulty of reducing very dense iron oxide in a bloomery furnace.

Figure 3: Two furnaces seen from the west Tuyere, bellows and air supply system

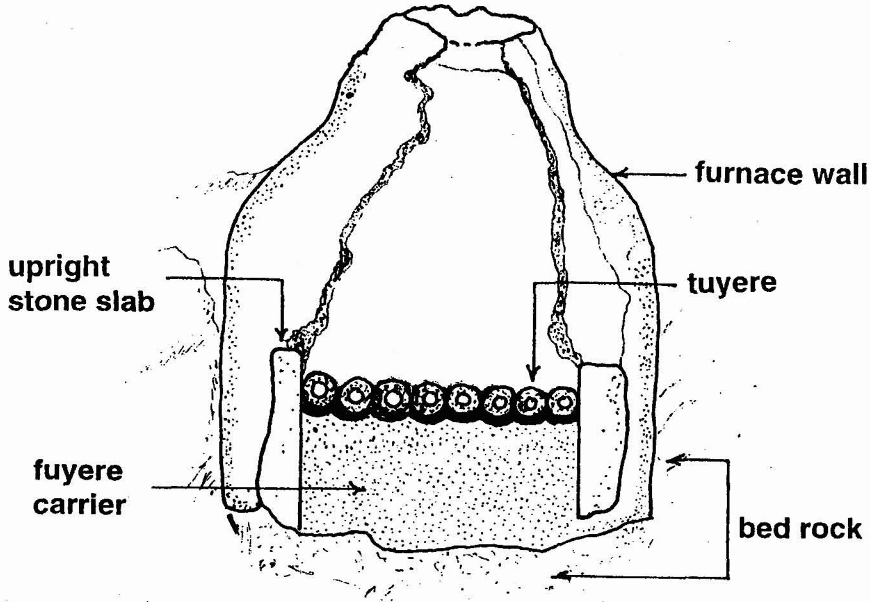

Figure 4: Reconstruction Drawing of well preserved furnace (Furnace no. 27) at Dehigaha-ala kanda

The use of magnetite in bloomery furnances has so far been identified only in a few exceptional cases. Modern archaeometallurgists assume that the dense magnetite ore would be difficult to reduce with this technique.

However, in view of the iron ore fragments found around the boulders at the site and from around the furnaces and attached to the iron slag at the Alakolavava excavation site, it seems that magnetite had been used for this bloomery process. Chemical analyses have shown that the average percentage of iron oxide content in these magnetite grains is 98[27].

According to chemical analysis the slag samples from Alakolavava consisted of a fayalite (Fe_2SiO_4) compound and a lower iron oxide content when compared with slag samples from other production sites which were situated around the area. This indicates that the yield at that site has been very high.

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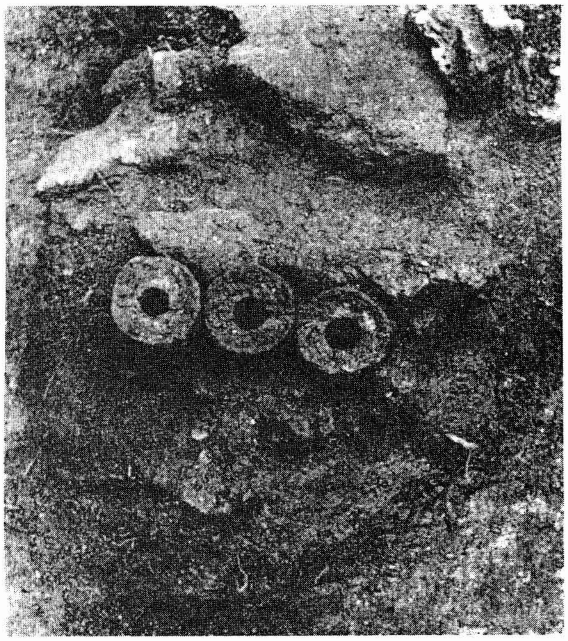

Figure 5: Three tuyeres found with fragment f a tuyere carrier

Dating of the production site.

C_{14} dates[28] indicate that the 'factory' was in operation from about the 2nd century BC to the 4th century AD, a particularly early period for iron production of this scale and quality.

Calibrated age ranges from *cumulative probability,*

one sigma (68.26%). CalibETH 1.5b (1991).

The pottery types found at the site indicate that production was carried out during the Early Historic period (continuing at the site until the 4th century AD). Thus it seems that there had been a well organized iron production system prior to the 5th century AD Kashyapan period which was the main construction phase in Sigiriya city.

However, excavations carried out in the area make it clear that iron production in the Sigiriya-Dambulla area was in existence before the Alakolavava production site and subsequent to the Sigiriya kingdom. Evidence of iron production sites belonging to the post-Kashyapan phase has been found in excavations carried out recently in the outer moat of Sigiriya[29] while evidence has also been found of protohistoric iron production sites in excavations carried out at Aligala prehistoric cave within the citadel of Sigiriya[30] and at Ibbankatuva in the Dambulla area[31]. It is important to note that the protohistoric layer in which evidence of iron production was found at Aligala, was dated to the 10th century BC This is the oldest dating obtained so far for the iron smèlting in the island.

Age Range

Agriculture helped the expansion of the protohistoric settlements in Sigiriya which flourished around the waterways in the area. The emergence of minor irrigation networks which gave rise to large irrigation systems and the food surplus which was the result of that system may have created a favorable background for new technological methods. These factors may have contributed to the emergence of Sigiriya as a suitable location for urbanization.

Therefore, in the light of this and the various excavations conducted around Sigiriya, it becomes clear that even long before the 5th century urbanization, there were iron production and related socio-economic activities in the Sigiriya area. Similarly, a thorough study of ancient economic patterns show that the economic structure of the Raja Rata i.e. the irrigation and agricultural society, was based on iron use.

According to the *National Atlas of Sri Lanka*, hydrated iron oxide, limonite and geothite deposits are found in the Rathnapura and Matara districts, while high grade iron oxide deposits of magnetite are found in the Puttalam District and near Trincomalee.

Title - : Average weight percentage of - Metal O centent in different areas.

WEIGHT%	Fe_2O_3	MnO	SiO_2	Al_2O_3	P_2O_5	TiO_2	MgO	CaO	K_2O
KO 14 1	98.3 98.0	- -	- -	1.3 1.6	- -	0.4 0.4	- -	- -	- -
KO 14 2B	98.6 96.5	- -	0.4 0.3	0.9 0.3	- -	0.1 0.1	- -	- -	- -
KO 14 12B	97.7	-	0.2	1.4	-	0.4	0.3	-	-
KO 14 14B	98.4 98.5	- -	- 0.1	1.1 0.8	- -	0.1 0.1	0.4 0.5	- -	- -
KO 14 14BX	99.0 98.1	- -	0.2 0.2	0.5 1.1	- -	0.1 0.2	0.3 0.4	- -	- -
KO 14 18	97.9 96.7	- -	- 0.2	2.0 2.5	- -	0.1 0.2	- 0.4	- -	- -

Figure 6: Analysis chart of the iron are samples Alakolavava-Dehigaha-ala-kanda (KO 14)

In the 1920s, the archaeologist Hocart observed that the transition from limestone to granite as a building material took place in the 5th century AD. He draws special attention to the use of "square hammered stones" in the constructions of the Sigiriya fortress wall and the cyclopean style stone walls at Mapagala. [32,33] The ability to cut massive blocks of granite of the types mentioned above probably depended on major developments in the production of iron and steel in the Sigiriya hinterland. This finds further support in the quality of the granite carving of the stone thrones in the assembly hall and in the palace on the summit of the Sigiriya rock.

The Brahmi inscriptions of pre-Christian times, speak of the existence of craftsman in different kinds of metal. They are referred to as *kabara* (ironsmith), *tabakara* (coppersmith) and *topasa* (tinsmith). The word *kabara* derives from the Pali word *kammara*.

Iron Production and Communities

In more recent times the different stages of the iron production process have been associated with particular castes. Those who extracted the iron from the ore were called the ***yammanno*** caste. While the producers of 'steel' or iron tools belonged to the ***navandanno or aachari cast.***

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In folk songs or ***jana kavi,*** handed down from generation to generation which refer to iron producers, a clear distinction is shown between the ***yamanno*** and the ***aachari*** or ***navandanna*** caste. In ancient times the caste system was mainly occupation based. As a result, technology was preserved by being handed down from generation to generation. The caste system in ancient Sri Lanka was developed to maintain the socio-economic systems of the day. This social pattern changed with the advent of foreign rule and as a result the traditional technological know-how was lost under colonialism. Another reason for this decline was cheap steel and iron implements imported from Europe and the inability of the indigenous iron producers to adopt new advance in technology.

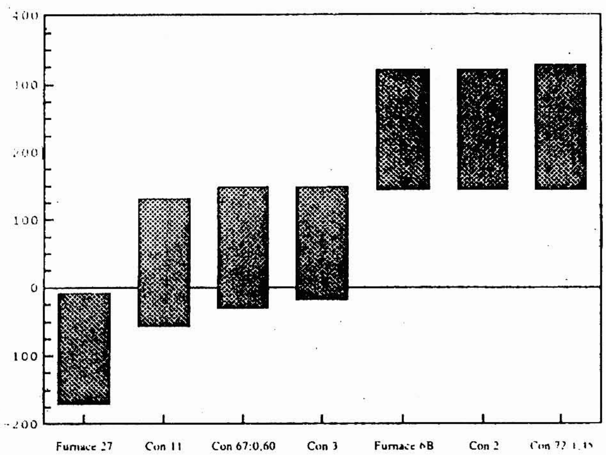

Figure 7: Radiocarbon dates. Dehigaha- ala- Kanda.
Age range

Frequency of production

The approximate volume of iron production can generally be estimated from the amount of slag remaining on the site. However, most of the slags remain buried under soil layers. According to rough calculations, more than 10,000 tons of iron had been produced at the Alakolavava site.

A study of the high technological knowledge possessed by these iron masters, the highly developed furnaces used in the process, the high iron content of the iron ore used, the iron content of slag etc. makes it clear that they were capable of producing very high quality iron relative to the amount of raw material used. The high quality of iron produced, the quality of output and the nature of the organization of production suggest industrial level production for use beyond the Sigiriya-Dambulla region, for local purposes such as agriculture and war, and even possibly for export.

A total of 35 iron production sites including about 5 of similar magnitude have been found in the area. There are some records in neighboring India about the Early Historic site of Kamrej, situated on the banks of the river Tapi which was dated to the same period as the Alakolavava production site. This site was mentioned in a Greek maritime guide ***Peripius Maris Erythraei*** as a coastal trading station engaged in the export of iron to the Red Sea littoral and the Mediterranean region[35].

Wood was used by the ancient iron workers as the main source of fuel in the production process. The ability to do so depended on the natural vegetation. A reduction of wood and ore probably caused the decline of iron production at Alakolavava. In considering ancient production systems, there is evidence to suggest that the distribution of Sri Lanka's natural vegetation, mineral resources and natural fuel played an important role in production processes in any region.

Agriculture helped the expansion of the protohistoric settlements in Sigiriya which flourished around the waterways in the area. The emergence of minor irrigation networks which gave rise to large irrigation systems and the food surplus which was the result of that system may have created a favorable background for new technological methods.

FOOTNOTES:

1. **lithic society** : An old world chronological period started with stone tool technology. The Paleolithic period is the earliest known stone period. Mesolithic is the theoretical phase situated next to the Paleolithic period. The Neolithic is the recent stone period characterized by the development of agriculture with an increasing emphasis on sedentism. Lithic society is described as the society that lived in the stone ages which are mentioned above.

2. Schmandt-Besserat, Denise. 1980, Ocher in Prehistory, ***The coming of the Age of iron***, Theodore A Wertime and James D. Muhly (eds), new Heaven & Yale University Press, London.

3. **iron age** : The theoretical division of the technological stage characterized by the use of iron.

   protohistoric period : the period situated between the prehistoric period and the historic period. According to the Deraniyagala's chronology, the period between 900-600 BC belongs to this period. It is distinguished by the appearance of iron technology and irrigated agriculture (wet rice cultivation) (Deraniyagala, 1990).

4. **chalcolithic period :** The period characterized by the use of copper with stone tools.

5. Deraniyagala, S. 1990, The Proto-and Early Historic Radio Carbon Chronology of Sri Lanka, ***Ancient Ceylon No 12***, Department of Archaeology, Colombo.

6. Karunaratne, P. and Adikari, G. 1994, Excavations at Aligala Prehistoric Site, ***Further Studies in the Settlement Archaeology of the Sigiriya- Dambulla Region***, Bandaranayaka, S. and M. Mogren (eds.) ***PGIAR***, Colombo.

7. Deraniyagala, S.U and Abeyratne, M. 1997, Radiocarbon Chronology of Iron Age and Early Historic Anuradhapura, Sri Lanka: Revised Age Estimate (Unpublished)

8. **archaeometallurgy :** The science which studies ancient metallurgy in its widest sense from its beginning up to the industrial age.

9. Davy, J.1983, ***An account of the interior of Ceylon, and of its inhabitants, with travels in that island,*** Tisara Prakasakayo Ltd, Dehiwela.

10. Ondaatje, W.C. 1854, The Kandyan Mode of Manufacturing Steel, ***Ceylon Almanac and Annual Register,*** Government Printer, Colombo.

11. Coomaraswamy, A.K. 1956 (1908), ***Medieval Sinhalese Art,*** Pantheon Books, New York.

12. Hadfield, R. 1912, Sinhalese Iron and Steel of Ancient Origin, ***Journal*** at red heat into cold water.

13. **quenching or water treatment :** The hardening of steel by plunging it at a red heat into cold water.

14. **case hardening or cementing :** The production of a hard surface on steels by localized heating and quenching of the surface.

15. **wrought iron :** pure iron made by forging (by direct process).

16. Forenius, S. And Solangaarachchi, R. 1994, Dehigaha-ala-kanda (KO 14) at Alakolavava: An Early Iron Production Site with a Highly Developed Technology, ***Further Studies in the Settlement Archaeology of the Sigiriya - Dam bulla Region,*** PGAIR, Colombo

17. Juleff, G. 1990, The Samanalavava Archaeological Survey, ***Ancient Ceylon No 9,*** Department of Archeology, Colombo.

18. Bopearachchi, O and Wijeyapala, W. 1995, The fluvial and maritime trade centers of ancient Sri Lanka. Results of the explorations and excavations conducted by the Sri Lanka-French Archaeological Mission.

19. **bloomery process :** The production method of iron in solid condition directly as the result of a reduction of iron ore.

20. **spongy iron bloom:** soft mixture of iron that has been produced by the bloomery process.

21. **natural draught:** a current of natural air.

22. **forced draught :** a strong current of air produced by bellows.

23. **bellows:** an instrument for producing a strong current of air.

24. **tuyere :** a ceramic tube for blowing air from the bellows into a furnace.

25. Prakash, B. 1990, Scientific Basis and Technology of Ancient Indian Copper and Iron Metallurgy, ***History of Iron and Steel Making in India,*** Kuppuram, G. And K. Kumudamani (eds.), Sundeep Prakashan, Delhi.

26. Juleff, G. 1996, An ancient wind powered iron smelting technology in Sri Lanka, *Nature, International Weekly Journal of Science, vol.379.*

27. Noreus, D. 1994, Chemical Characterization of Ore, Slag and Iron from an Advanced Bloomery Process in the Sigiriya - Dambulla Region, *Monograph on Iron Production,* (unpublished report).

28. **C_{14}** : A dating technique which measures the length of time which has elapsed since any living thing died by analysing the ratio of normal carbon-12 to ratioactive carbon-14 in its remains. This technique is used to date bone, wood, shell, charcoal and other materials which consist of carbon.

29. Bandaranayake, S. (ed.) 1993 ***Site Report, Sigiriya Project,*** (unpublished).

30. Refer number 6.