

## **Textures of 'Wootz': Techno-cultural insights on steel, cast iron & ferrous metals in South Indian antiquity**

by  
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### **I. Brief description and objectives**

The book entitled 'Textures of 'Wootz': Techno-cultural insights on steel, cast iron and ferrous metals in Indian antiquity' proposes to provide a technological-cum-cultural overview of the heritage of ferrous metals, particularly high-carbon alloys and steel, in Indian antiquity. A significant theme of the book would be to investigate the intriguing high-carbon 'wootz' steel for which India has been famed in antiquity and which forms an important part of its scientific heritage, from the point of view of exploring its antiquity and properties (with special emphasis on investigations on material from previously undocumented old production sites that were uncovered by the author in Karnataka and Tamil Nadu in southern India.) However, the purpose of proposed book is not so much to write an exhaustive monograph on wootz steel but to locate it a) within a broader canvass concerning Indian ferrous metals over the ages in its developmental aspects (especially from less well studied contexts in southern India) while spanning the gamut of ferrous materials from wrought iron to low carbon and high carbon steel and cast iron b) to explore some of the issues concerning the origins and spread of this technology and c) to integrate a more holistic understanding of the inter-relationship with other craft traditions, decorative or performance arts traditions towards fleshing out the perspective that innovations within the Indic tradition can often be seen to draw from cross-craft interactions with cultural connections across different technological and artistic traditions, augmented by longstanding threads of cultural continuity-with several craft traditions surviving into the present day or at least the recent past.

Thus, to summarise the approach of the book, it would begin by outlining the conceptual framework and then touch upon issues concerning the emergence of ferrous metallurgy in relation to pre-existing craft skills or metallurgical skills: especially from less explored iron age megalithic contexts which may throw light on questions as to whether ferrous metallurgy could have developed independently in the peninsular and southern Indian megalithic contexts as some scholars have debated. The book would then move on to exploring aspects related to the emergence of wootz crucible steel in southern India including some literary accounts on 'wootz' or 'ukku', evidence from production sites concerning the process metallurgy and the story of the use of wootz for production of the artistic patterns of 'Damascus' steel swords. This would be followed by a related but little explored question about the emergence or use of different types of cast irons in Indian antiquity. Further, less well-studied cultural manifestations of iron or steel would be explored ranging from swords used in martial arts, wires for stringed musical instruments, ferrous metals in architecture and other artistic, utilitarian or decorative traditions. Finally, some aspects related to the social history concerning surviving communities of blacksmiths or iron smelters and socio-religious traditions would be touched upon. The time-frame for the proposed book would be about 18 months to 2 years (award granted in June 2003).

### **Justification for the proposed book**

European travellers and geologists such as Buchanan, Percy and Voysey from the seventeenth century onwards have described the production of 'wootz' steel ingots by crucible processes over large parts of southern India including Golconda in Andhra Pradesh, the former Mysore state (in Karnataka) and Salem district in Tamil Nadu. Cyril Stanley Smith (1980) has given an account of the European fascination with 'wootz' steel ingots from southern India and attempts to replicate it for industrial production which spurred the development of metallurgy and metallography in the 18<sup>th</sup>-19<sup>th</sup> centuries, inviting the attention of scientists of the repute of Michael Faraday, inventor of electricity. Studies on some late medieval 'wootz' ingots have shown them to be of high-carbon steel (1-1.5% C), which was a novelty in Europe where only low-carbon steels (less than 0.8% C) had been in vogue. Wootz ingots were also reputed to have been used to make the artistically patterned 'Damascus' swords. Indeed, ancient India deserves a special niche in the annals of western science not only for pioneering the semi-industrial production of metallic zinc and high-carbon steel, but also for indirectly spurring their modern metallurgical advances and metallurgical study in Europe leading to the Industrial Revolution, as pointed out in overviews by the

author with S. Ranganathan on metallurgical heritage of mankind and on wootz steel (Srinivasan and Ranganathan 1997, 1998, 2003 in press).

As such, more studies have been made on iron in Indian antiquity than on steel. D. P. Agrawal, Bhanu Prakash, V. Tripathi and D. K. Chakrabarti have written on the development of iron metallurgy in ancient India while studies on the famed iron pillar have been made by T.R. Anantharaman, A. K. Lahiri and R. Balasubramaniam. As far as wootz steel is concerned, Thelma Lowe has extensively surveyed and technically studied crucible steel production sites in Konasamudram, while Martha Goodway, Paul Craddock and K.N.P Rao have made studies on the late medieval site of Gathiosahalli recorded by the European travellers. J. D. Verhoeven has simulated the production of Damascus sword blades of high-carbon steel and studied the formation of patterns, while O. Sherby has written on properties observed in ultra-high carbon steels produced under laboratory conditions such as superplasticity. Even so, there is still much to uncover concerning Indian wootz steel, since most studies or accounts of crucible steel production have been made on the late medieval sites or on laboratory simulated high-carbon steels, while all crucible processes need not necessarily have resulted in the production of high-carbon steel. In recent times, evidence for crucible steel production has also emerged from Central Asia and Sri Lanka so that it is relevant to explore and set out the evidence for the antiquity and primacy of the technology of wootz steel within the Indian context.

Amongst present Indian scholars, the author has undertaken significant archaeometallurgical studies on wootz crucible steel by identifying previously unknown sites for crucible steel production at Mel-siruvalur in Tamil Nadu, and Tintini and Machnur in Karnataka as published in Srinivasan (1994) and Srinivasan and Griffiths (1997) which has the potential for increasing the known horizons of wootz steel production in antiquity. Metallographic investigations (ibid.) on metallic remnants in fragments of crucibles from the site of Mel-siruvalur show the clearest evidence from any site yet for the production of high-carbon hyper-eutectoid steel (of about 1.3% C), while the site also shows some nearby evidence for megalithic occupation and is thus being further investigated by the author.

While there has been some focussed research of a high order on certain aspects of crucible steel, this book proposes to explore ferrous metals and 'wootz' from within a broader interpretive framework by viewing technological aspects in relation to cultural aspects. Such an approach has generally not been widely attempted in the overall discourse on metals or materials heritage from India and may serve to redress some of the lacunae in the understanding of Indian ferrous metallurgical heritage. Thus, less well-studied aspects would be incorporated in the book: such as an important question concerning the emergence of cast iron in Indian antiquity. Although cast iron is conventionally thought to have been produced in ancient China and then come much later to wider use in India especially through European intervention there may now be evidence for cast iron from parts of Tamil Nadu going back to the megalithic period (c. 500 BC) as touched upon further in the chapterisation scheme. Other aspects to be touched upon include the developmental aspects of iron metallurgy and insights from the author's own studies on megalithic metallurgy with evidence for skilled use of high-tin bronzes (Srinivasan 1994, 1997) and inter-relationship with iron metallurgy, manifestations of continuing skills in iron and steel metallurgy apart from wootz steel as exemplified by the intriguing flexible swords in the martial art form of Kalaripayattu from Kerala, the knowledge of wire-drawn musical instruments, and decorative or functional uses of ferrous materials and other such cultural or artistic facets. The discernment of threads of cultural or technological continuity and cross-craft contiguities can assume significance in terms of what can be interpreted, albeit cautiously, about the indigenous nature of certain developments or as regards the distinctive trajectory of assimilated forms or technologies within the Indian context.

### **III. Chapterization scheme and Table of contents**

The proposed book would include the following chapters of upto 150-200 pages with photographs and illustrations. The proposed chapterisation scheme is as follows:

#### **Chapter 1:**

Introduction: Exploring paradigms of innovation within the Indic tradition

#### **Chapter 2**

## **Genesis of 'ukku': Insights from megalithic ferrous metallurgy, high-tin bronzes and crafts**

### **Chapter 3**

'Wootz' as high-carbon crucible steel: Evidence from southern India

### **Chapter 4**

**Shades of swords: From 'Damascus' blades to martial arts swords of Kalaripayattu**

### **Chapter 5**

Re-examining the questions of emergence of cast irons in Indian antiquity

### **Chapter 6**

**Ferrous artefacts in decorative, figurative, architectural or musical uses**

### **Chapter 7**

On social history of iron smelting or blacksmithy

### **Chapter 8**

**Conclusions: Making the case for 'wootz' as an Indian innovation**

-Bibliography

-Glossary

-Illustrations and photographs

### **Brief summary of chapters:**

The contents of the proposed chapters are summarised below:

#### **Chapter 1:**

#### **Introduction: Exploring paradigms of innovation within the Indic tradition**

Late scientist C.V. Seshadri, founder-President, Congress of Traditional Science and Technology, who worked on appropriate technology for rural development in India wrote on the 'non-linear' nature of Indian thought processes. Edward De Bono coined the phrase 'lateral thinking' to describe the process of making intellectual and creative breakthroughs by cutting across set patterns or concepts. As such, it seems quite natural that in ancient societies, where empirical observation and knowledge prevail, such 'lateral thinking' and experimentation with different types of materials would have been behind several discoveries. For example, it is believed that the development of copper smelting in Asia Minor or ancient Egypt drew from processes of making faience beads. However, 'lateral thinking' and holistic conceptions seem to have been especially internalized and canonised within the Indic tradition: as seen in the Sanskrit treatise of the *Vishnudharmottara purana* which talks of the interconnectedness between sculpture, painting, dance, music, the fine arts and performing arts. Thus this chapter seeks to explore the background to the development of iron metallurgy, from within the paradigms discussed

above, as to how for example pre-existing craft practices in proto-history could have played a role in contributing to metallurgical developments right from Harappan times to the early historic period ranging from stone, bone, lapidary crafts, glass making and so on. This approach also keeps in mind an exploration of the view expressed by some scholars that there may be reason to consider the indigenous origins of iron metallurgy in the context of megaliths of peninsular and southern India going back to at least around 1100 BC, and sets out to explore whether indeed such a theory of indigenous origins of iron metallurgy is consistent with pre-existing technologies or parameters.

## Chapter 2

### Genesis of 'ukku': Insights from megalithic ferrous metallurgy, high-tin bronzes and crafts

'Wootz' is known to be an anglicised version of 'ukku', the word for steel in south India. The term 'ukku' may derive from 'uruku', used to describe fused or melted metal in Tamil Sangam literature dated broadly from about the 5<sup>th</sup> century BC to 5<sup>th</sup> century AD, while accounts of the Greek Zosimos of the early Christian era suggests that the Indians used crucible processes to make metal for swords, i.e. steel. Pliny's 'Natural History' talks of iron from the Seres which may refer to the ancient south Indian kingdom of the Cheras who are referred to in Sangam texts. While Thelma Lowe, most of all, and others have made crucial studies on the mechanisms of late medieval Deccani wootz production, there still remains much to be investigated and clearly established concerning the antiquity of wootz steel in India and on the identification of ancient artefacts of wootz. It is significant that there are a couple of analyses reported in early excavation reports from some megalithic sites in southern India of iron artefacts with 1-2% carbon (for eg. two javelins from megalithic Andhra Pradesh mentioned in Sundara 1999); however further investigations with micro-structural evidence may be required to ascertain if these can be taken as conclusive evidence for wootz steel. Investigations by the author on a crucible fragment from the megalithic site of Kodumanal (3<sup>rd</sup> century BC) excavated by K. Rajan, Tamil University, found in an iron smelting hearth showed it to be iron-rich without any other significant metal, which did not rule out the fact that it could belong to some kind of ferrous process although as yet no clear evidence of metallic remnants could be found in the crucible (Srinivasan and Griffiths 1997).

Significantly, the author has identified from surface surveys three previously unknown sites for crucible steel production in southern India (*ibid.*). Crucibles from one of these sites, Mel-siruvalur in Tamil Nadu shows clear evidence for the production of a hyper-eutectoid (1.3% C) steel, i.e. a high-carbon steel, probably even by molten carburisation processes at high-temperatures (Srinivasan 1994, Srinivasan and Griffiths 1997). More significantly, the site shows signs of megalithic occupation in the vicinity as independently verified by Sasisekaran (2002) while the author found numerous remains of what appeared to be legs of megalithic sarcophagi in a dried up canal near the dump. (The megalithic period in southern India ranges in different places from the early 1<sup>st</sup> millennium BC to early centuries AD). This site is being further investigated by the author. Other aspects of megalithic iron production to be touched upon include the iron smelting furnace excavated at Naikund, from the Vidharbha megaliths of Maharashtra.

As background, this chapter would also briefly explore whether there are technological parameters within the context of peninsular megaliths which could have supported more advanced metallurgical skills. Previously the Indian subcontinent had not been associated with a more sophisticated bronze working tradition. However, metallurgical investigations by the author established for the first time the use of specialized alloys known as high-tin beta bronzes (which are quenched binary copper-tin alloys bronzes of around 23% tin) to make vessels going back at least to the iron age burials megaliths of the early first millennium BC of the Indian subcontinent which rank amongst the early such alloys known in the world, and which are still made in parts of India such as Kerala by similar processes as reported in Srinivasan (1994b, 1997, 1998a) and in papers written by the author with Ian Glover while at Institute of Archaeology, London (Srinivasan and Glover 1995, 1997). High-tin beta bronzes generally do not seem to have been in vogue in Europe, and indeed the Greek Nearchus (4<sup>th</sup> century BC) mentions that Indians used golden vessels which shattered when dropped which may be interpreted as high-tin bronze, as suggested by Rajpitak and Seeley (1979). What is significant is that the processes of quenching high-tin bronze indicates a general familiarity with heat treatment processes in the megalithic period that could have extended to the knowledge of iron and steel metallurgy. Other evidence for skilled metallurgical activity comes from evidence suggesting that the deepest old gold mine in the world comes from Hutti in Karnataka with carbon dates from timber collected from a depth of about 600 feet from a mine going back to the mid 1<sup>st</sup> millennium BC (Radhakrishna and Curtis 1991).

## Chapter 4

### 'Wootz' as high-carbon crucible steel: Evidence from southern India

Arab records mention the excellence of Hinduwani or Indian steel while the 12th century Arab Edrisi mentioned that it was impossible to find anything to surpass the edge from Indian steel. Records indicate that Jewish merchants of the 11<sup>th</sup>-12<sup>th</sup> century from Cairo imported iron and steel along with prized metal vessels from southern India. Late medieval observers of the manufacture of wootz steel in India have commented on the process of carburisation of iron to steel in crucibles where a batch of closed crucibles which were packed with a low carbon iron charge were stacked in a large furnace and fired in a long 14-24 hour cycle at high temperatures of not less than 1200°C in a strongly reducing atmosphere (Percy 1860-1880; 773-776). Certainly accounts indicate that by the late medieval period, south Indian wootz steel was reputed to have been used to produce the famed 'Damascus' blades, which have an artistically appealing pattern due to the etched crystalline structure of forged high-carbon steel, of which surviving examples are known from Turkey, Persia, as well as Mughal period and Tipu Sultan era in India. Thus this chapter charts the progress from high technology to high artistry of wootz steel and its metamorphosis into the 'Damascus' blades. This chapter will also briefly touch upon the European interest in replicating wootz steel in the 18<sup>th</sup>-19<sup>th</sup> century and insights into its special properties. This chapter would also summarise the work of recent scholars, including those mentioned in the previous sections, on evidence from production sites for crucible steel.

This chapter would also attempt to place the general process metallurgy of wootz within the context of other Indian technological traditions. To take an example, the nearly sealed crucible process, described in texts like the *Rasaratnasamuchaya* and also used for wootz steel production, is reminiscent of 11<sup>th</sup> century zinc smelting retorts from Zawar in Rajasthan from where the earliest known remains from zinc smelting are found. Lead isotope analyses undertaken by the author on a zinc ingot with a 4<sup>th</sup> century Deccan Brahmi inscription (previously exhibited in Science Museum, London, courtesy Nigel Seeley) corroborated a likely Andhra Deccan provenance, making it one of the earliest known surviving examples of metallic zinc in the world (Srinivasan 1998). Thus one could argue for similarities in the inspiration behind zinc smelting and crucible steel production. The closed-crucible process is still used in a traditional process of making mirrors of a specialised 33% high-tin delta bronze alloy investigated by the author from Aranmula, Kerala (Srinivasan and Glover 1995). The use of iron or steel tools in crafts (such as icon making or granite stone carving still practised in Tamil Nadu), is also one that has not received much attention and may throw some light on technological interdependences.

## Chapter 5

### Shades of swords: From 'Damascus' blades to martial arts swords of Kalaripayattu

This chapter would begin by summarising some of the studies on the replication and properties of Damascus swords and ultra-high carbon steels. The 'Damascus' blades, so-called after one of the sword production centres, can be clearly identified as having been made of high-carbon 'wootz' steel due to the etched crystalline structure resulting wavy patterns (and from which the book draws its name, textures of wootz). However, far less is known about other types of traditional Indian swords and implements as to whether they were made from wootz or high-carbon steel or other processes. Whereas Mughal armoury has generally been much better documented, this chapter would also attempt to touch upon lesser known aspects about Indian armoury such as the Telengana swords, Tipu Sultan armoury and Tanjore armoury from southern India. Another neglected area that this book proposes to emphasise and explore in greater detail is the use of swords and weapons in several martial art traditions in India. These include the various sword blades used in the Kalaripayattu tradition of Kerala including intriguing flexible sword blades. Studies by Zarrelli suggest that the Kalaripayattu tradition may go back to the martial traditions of the Tamil Sangam era of the early centuries AD and is linked to the Tamil *siddha* form of medicine. Their relevance to ritual or performance art and insights from the *Natyasastra*, the ancient treatise on Indian dramaturgy, may also be touched upon briefly.

## Chapter 5

### Re-examining the questions of emergence of cast irons in Indian antiquity

An interesting question that has received little attention in India but is related to the development of wootz high-carbon steel is that of whether cast iron was ever made in Indian antiquity. Of course, it is well recognised that

cast iron first came into widespread use in China much before Europe or other parts of the world, where it was widely used by the early christian era for a range of artefacts including some monumental castings. In the Indian subcontinent cast iron is thought to have only come into vogue very much later from the late medieval period; for instance cast iron pillars were used for the first time in architecture in the Mysore palace made in Britain. It is intriguing however, that there are reports of some evidence for production of cast iron with about 6% carbon from a megalithic period twin hearth furnace in Guttur in Tamil Nadu (dated *c.* 500 BC) (Sasisekaran 2002). It has also been observed that some crucible steel processes resulted in the production of white cast iron. Thus, a re-examination would be attempted from within the Indian archaeological record exploring evidence for cast iron artefacts (such as bells) or use of related furnaces which could throw more light on the question of emergence of cast iron in Indian antiquity and serve to confirm or corroborate the preliminary evidence.

## Chapter 6

### Ferrous artefacts in decorative, figurative, musical or architectural uses

This chapter would touch upon the long history of use of ferrous artefacts in a range of non-weaponry contexts as decorative and utilitarian artefacts and links with other arts or crafts. The corrosion resistant Gupta era Delhi iron pillar (4<sup>th</sup>-5<sup>th</sup> century) is the largest known early wrought iron forging, while massive forged architectural iron beams were used in the medieval Konarak and Jaganannath temples in Orissa; these aspects have been written about elsewhere and would only be briefly touched upon in this chapter. However, the use of iron in figurative or decorative contexts is less known which this chapter would delve more into. For example, a tiny ferrous mother goddess figurine was uncovered from megalithic Alangankulam in Tamil Nadu, dated *c.* 1000 BC. India has a rich tradition of stringed musical instruments: from the traditional *veena* used in the Hindu devotional Carnatic music style of southern India, to the Indo-Islamic adaptation of the *sitar* in northern India (which owes its name to the Persian instrument). Accounts suggest that wire for the Persian sitar was traded out of the 15<sup>th</sup> century Vijayanagara kingdom of Karnataka, with the musical stone pillars of Hampi corroborating the kingdom's grasp of the science of music. Other non-weapon utilitarian or decorative uses of iron going back to protohistory would be explored from lampstands, tripods, utensils etc.

## Chapter 7

### Continuing traditions and social history of iron smelting or blacksmithy

This chapter would explore aspects of social history of ferrous metal workers, surviving craft traditions and aspects of continuity and change in relation to caste-based crafts or traditional craft guilds. Traditionally, iron workers belonged to the artisan community known as Viswakarma. *Manu*, who worked in iron is said to have been the first of the five sons of *Viswakarma*, the maker of the universe. Nevertheless, as far as actual social hierarchy goes, today the rural blacksmith has slipped to the bottom of the social hierarchy of artisans. Since the artefacts produced by blacksmiths are utilitarian and often do not receive support as handicrafts, there is a danger of their being marginalised. Thus this chapter proposes to touch upon little known aspects about rural blacksmithy. As far as social history is concerned, there is also an interesting instance of reverence for a metal craftsman in the tale of Munishwara, a metalworking saint to whom there are several shrines in Karnataka. Indeed, from technical investigations the author found evidence for both crucibles related to wootz steel production and copper smelting slags from a shrine to Munishwara in Tintini, indicating that the legend was associated with actual metalworkers. Brouwer has also written on social anthropology of metal crafts in Karnataka. Thus this chapter would illuminate some aspects about social history and continuing traditions.

### Conclusions: Making the case for wootz as an Indian innovation

In recent years, concerted archaeometallurgical studies have brought to light evidence for steel made from crucible processes in parts of Central Asia and Sri Lanka, which also had a skilled iron working tradition, thought to date from the first millennium AD. Although it does not seem to have been clearly established yet if the end products were high-carbon steel this raises issues about the origins of the crucible steel technology vis a vis the Indian evidence. However, this chapter would draw together the information discussed or presented in the preceding chapters to argue that it still remains entirely reasonable to postulate that the technology of high-carbon wootz steel originated and thrived in the Indian peninsula, particularly southern India, and could have spread elsewhere. Apart from the literary and cultural evidence, preliminary archaeometallurgical evidence from south Indian megalithic contexts also suggests that the best case for the origins of high-carbon wootz steel made by crucible processes seems to come from the southern Indian peninsula.

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