PIONEERING METALLURGY

THE ORIGINS OF IRON AND STEEL MAKING IN THE SOUTHERN INDIAN SUBCONTINENT

TELANGANA FIELD SURVEY
INTERIM REPORT 2011

G Juleff, S Srinivasan and S Ranganathan

Published by
National Institute of Advanced Studies
Indian Institute of Science Campus
Bengaluru – 560012

Tel: 080-22185000 Fax: 080-22185028
Email: admin@nias.iisc.ernet.in

ISBN 978-81-87663-53-9

Designed and produced by Seán Goddard, University of Exeter

Printed by
Navabharat Enterprises
Seshadripuram
Bengaluru

UKIERI
UK-India Education
and Research Initiative

NATIONAL INSTITUTE OF ADVANCED STUDIES

UNIVERSITY OF EXETER

CONTENTS

MESSAGES

The National Institute of Advanced Studies, Bangalore and Exeter University have been the recipients of a prestigious Indo-British research grant under the UKIERI scheme monitored by British Council. UKIERI was initiated in 2006 with the aim of enhancing educational links and capacity building between institutions in India and UK. 'Pioneering metallurgy' has lived up to the mandate of UKIERI in the ways it has set out —through the mechanisms of research interactions and exchanges between faculty, students and staff in the two institutions— to not only throw new light on interesting research problems in archaeology, archaeological science and heritage studies, but to also take the level of engagement between the two partnering institutions and associated bodies to a higher level of international cooperation. In particular, the project has sought to throw more light on the Telengana region which, while it may today be one of the industrial backwaters of India, once supported one of the most remarkable pre-industrial scientific activities of its time of iron and steel making. It is hoped that awareness is also raised for the need to preserve and present this scientific heritage as an educational and cultural resource and we also wish our local partners in the region continued success. The project has also been a substantial effort for NIAS in terms of logistics of mobilisation, management and exchange of resource personnel not only at an international level and also within the country to various remote sites, and its success gives further impetus to its efforts and aspirations for wider national and international engagement.

Professor V. S. Ramamurthy
Director, National Institute of Advanced Studies, Bangalore

Funded by the UK-India Education and Research Initiative, the 'Pioneering Metallurgy' project brings together researchers from NIAS and the University of Exeter, and effortlessly crosses the humanities/science divide. In many ways it is a shining example of what can be achieved through interdisciplinary and international collaboration. The project has not only involved cooperation between a few senior academics, but has also has seen commitment from a number of early career scholars and post-graduate students. This strength in depth provides solid foundations for future cooperation between NIAS and the University of Exeter.

Professor Sir Steve Smith,
Vice-Chancellor, University of Exeter

ACKNOWLEDGEMENTS

The authors wish to acknowledge and thank the many people who have made contributions to the project and this volume.

In India: VS Ramamurthy , S Settar (NIAS); Hema Thakur, Kishore Bhat (NIAS research scholars and Telangana Field Survey team); Srinivas Aithal, Gayathri, KS Ramakrishna, Sheela Karunakaran, (NIAS staff); Sajeev Krishnan, CP Rajendran (Centre for Earth Sciences, Indian Institute of Science, Bangalore); Bharat Dixit , P Padaikathan (Dept of Materials Engineering, Indian Institute of Science, Bangalore); B Chandrashaker, V Ganga Rao (Osmania University, Hyderabad, research scholars and Telangana Field Survey); T Suresh, A Rajendar, G. Prabhakar, K Ramesh, P Anil Kumar, G Rajesh, Ramachandar (Central University, Hyderabad, research scholars and Telangana Field Survey); Dr. M. Satyanarayana (Headmaster, High School, Konasamudram); Mattela Gangharam, (blacksmith, Ibrahimpatanam) Mandalogi Gangaram (blacksmith, Konapuram Village); British Council, New Delhi; Archaeological Survey of India; Director, Department of Archaeology and Museums, Govt of Andhra Pradesh

In UK: Alan Outram, Bruce Bradley, Seán Goddard, Jo Hatt (Archaeology Department, University of Exeter); Jess Collins, Brice Girbal and Alice Lowson (Archaeology Department, University of Exeter and Telangana Field Survey); Robert Fairhurst and Steve Pendray (Camborne School of Mines, University of Exeter)

PRINCIPAL AUTHORS

Gill Juleff
Archaeology Department, University of Exeter (g.juleff@ex.ac.uk)

Sharada Srinivasan
National Institute of Advanced Studies, Bangalore (sharasri@gmail.com)

S Ranganathan
National Institute of Advanced Studies, Bangalore (rangu2001@yahoo.com)

CONTRIBUTORS

Jens Andersen
Camborne School of Mines, University of Exeter, Cornwall (J.C.Andersen@ex.ac.uk)

Marc Cox
UKIERI Pioneering Metallurgy project (University of Exeter) (mantonycox@gmail.com)

Brian Gilmour
Research Laboratory for Archaeology, University of Oxford (brian.gilmour@rlaha.ox.ac.uk)

Smriti Haricharan
National Institute of Advanced Studies, Bangalore (smriti.march.forth@gmail.com)

S Jaikishan
SLNSA Oriental Degree College, Dharmapuri, Andhra Pradesh (dr.sjai@gmail.com)

NS Nalini
National Institute of Advanced Studies, Bangalore (arnalinins@gmail.com)

Tathagata Neogi
UKIERI Pioneering Metallurgy project (University of Exeter) (tathagata@live.co.uk)

Ioana A Oltean
Archaeology Department, University of Exeter (I.A.Oltean@ex.ac.uk)

MB Rajani
NIIT University, Neemrana, Rajasthan (rajanihf@gmail.com)

S Suwas
Dept of Materials Engineering, Indian Institute of Science, Bangalore (satyamsuwas@materials.iisc.ernet.in)

PHOTOGRAPHS

Unless otherwise stated, all photographs used in this volume are from the project archives

INTRODUCTION

The Project

This British Council funded project under the UKIERI scheme (2009 to 2011) brought together a group of researchers who share many years of experience in the study of South Asia's rich archaeometallurgy and who also share a passionate desire to understand and communicate India's contribution to the history of science and early pre-eminence in the production of ultra high-carbon steels of the finest quality. This project, entitled 'Pioneering metallurgy: origins of iron and steel making in the southern Indian subcontinent', has set itself on the trail of vanishing evidence for pioneering ferrous metallurgy in the Telengana region of Andhra Pradesh, which was once a 'technological hub' of the pre-industrial world.

Partners

The Indian and UK lead Investigators are Dr Sharada Srinivasan of the National Institute of Advanced Studies (NIAS), Indian Institute of Science Campus, Bangalore, and Dr Gill Juleff of Exeter University, UK. Prof S Ranganathan, also of NIAS, Bangalore, as Core Investigator on the project. All three have made seminal contributions to the subject of crucible steel through research papers and books. Drs Juleff and Srinivasan have PhDs in archaeometallurgy from the Institute of Archaeology, University College, London, the former having worked previously particularly on archaeological surveys and experimental reconstructions related to understanding iron metallurgy in Sri Lanka, while the latter has been engaged in archaeometallurgical studies related to south Indian bronzes, metallic heritage and crafts including ferrous metals. Prof Ranganathan has had five decades of experience as a leading materials scientist and has worked on advanced materials such as quasicrystals and metallic glasses at the Indian Institute of Science. He has been interested in archeometallurgy ever since he met Prof Cyril Stanley Smith at the Sorby Centennial meeting in Sheffield in 1963. He has been actively collaborating in archaeometallurgical studies with Dr Sharada Srinivasan since 1996.

In addition, two investigators joined the team by invitation as key researchers. Dr S Jaikishan of the National Degree College, Dharmapuri, in the heart of the Telangana field survey area is a senior researcher on the project, having enthusiastically documented numerous sites in the region. Dr Brian Gilmour of Oxford has worked extensively on the subject of early iron and steel, especially from Persia. Other members of the research team were drawn from the staff and research student communities at both host institutions.

Research setting

The project has sought to explore the challenging frontiers between science and archaeology. It aimed to study an important chapter in the history of science and technology; that is the early development of iron and steel metallurgy and India's contribution to the evolution of technology. Southern India is well known for its artistic metalware, including for example its magnificent Chola bronze statuary, but what has been less well reflected in the annals of the history of science is that parts of this region made pioneering contributions to world developments in iron and steel metallurgy during both the first and second millennia AD, if not even earlier.

One clue to the scale and impact of this past industry could be found in travellers' accounts of the late historic and colonial periods which refer to a huge trade in steel ingots from inland provinces such as Golconda, to ports in West Asia where they were used to make edged weapons, most notably fine Damascus blades. Regions in Andhra Pradesh such as Telangana still bear testimony to this large scale activity. Vast heaps of slag and the waste products of metallurgical processes can still be seen across the landscape. Despite the unprecedented pre-industrial efflorescence of metallurgy in the region in an era preceding the well recognized role of centres such as Sheffield and

Pittsburgh, northern Telangana is today one of the backwaters of India. Little is known about this rich heritage of scientific history and as a result few efforts have been made towards its preservation.

The Telangana Field Survey and analytical studies

A major objective of Pioneering Metallurgy has been to carry out field survey in Northern Telangana, using a range of archaeological methods to gather and integrate a diversity of information relating to iron and steel production both in the distant past and within living memory. Firstly, a record was made of sites and locations that were related to iron smelting and crucible steel production, generally indicated by the presence of debris from metallurgical processes such as slag heaps. It was found that many of these are in fact being destroyed at a rapid rate either to make way for roads, or cultivation and clearance, or the slag waste itself being exploited for construction material. Secondly, the surviving practices of local blacksmiths and testimony of the metal-working artisans were recorded to understand the traditional skills and knowledge base of the region. Indeed, many of these practices are also dying out with blacksmiths being increasingly marginalized in an era of mass production and globalization.

From the perspective of archaeological science, the project is using GPS and geo-spatial techniques to record for posterity the positions and landscape settings of 245 locations surveyed on the ground over a period of six weeks in 2010. Through the mechanism of the UKIERI supported exchange visits a comprehensive database of this archaeometallurgical survey is being prepared as a permanent archive of the archaeological record of the area and as a monograph for publication.

The field team take a break from their survey work to celebrate Holi

Synthetic and analytical interpretations on the nature of the metallurgical activity, its extent and the types of technological processes are being made drawing on this central database of information. Scientific studies on the characterization of materials are also being attempted in collaboration with various partner institutions including Indian Institute of Science, Camborne School of Mines and the Research Laboratory for the History of Art and Archaeology, Oxford. In connection with scientific studies for the project, Dr Srinivasan was able to spend a valuable 6 weeks working with the group headed by Dr Jens Anderson at the Camborne School of Mines, University of Exeter in Cornwall, to explore the use of EPMA to analyse samples from the Telangana field survey.

Project progress

Smriti Haricharan of NIAS teaching an undergraduate class at Exeter in October 2011

Overall, the project has progressed well, not only in terms of new directions of research but also with respect to issues of education and management of heritage. It has also contributed to capacity building at both the collaborating institutions, helping to build bridges between faculty and students with research synergies. Through the Indo-UK exchange element many first time travellers to each other's countries have had novel experiences ranging from the urban to rural Indian setting for the British visitors, and for the Indian visitors the exposure not only to the great world museums in British cities but also the well kept heritage sites in the countryside. Indian colleagues have contributed to undergraduate teaching of Indian Archaeology at Exeter and Exeter personnel have reciprocated in Bangalore. Equally valuable, the quiet exchange of experiences and aspirations from two sides of the world after long, hot and dusty days in the field has helped to form lasting bonds between fellow researchers.

Societal impact and implications for education

In terms of impact, an important element of the dissemination plan is that, apart from addressing the research community, the project is concerned to highlight the need for preservation and promotion of the unique scientific heritage, cultural diversity and traditional skills of the region. This includes awareness of vestiges of built heritage in Telengana, reflecting its vibrant worldwide trade in the past. In this sense the project has potential for long term societal significance. In terms of education, the project has had significance. For example, it was found in schools in Konasamudram, one of the core villages of the survey, that local children were only partially aware of their own heritage but had a hunger to learn about the material that many of their houses were built upon. Information from the project will be available to be used by local educators. The use of the practice of scientific archaeology and experimental archaeology itself to create a more imaginative educational environment and novel ways to engage with materials and ideas is also one that the investigators have been exploring as part of their UKIERI activities and related dissemination efforts.

Academic outputs and research impact

A range of research papers has been presented at conferences with good representations at international venues. These have included such high profile venues as the World of Iron conference at the Natural History Museum, London (2009), the international conference on the Beginnings of the Use of Metals and Alloys at NIAS, Bangalore (2009), the international South Asian Archaeology conference (SOSAA) in Colombo (2010), INSAPVII at the Bath Royal Literary and Scientific Institution, UK, (2010), CISAC, Stanford (2010) and at the Annual Meeting of the Iron and Steel Institute of Japan, Hokkaido, (2010). More than a dozen papers have been presented with a number also in press. Lectures have been delivered in the UK, India, USA and Japan. An Exeter-NIAS Seminar was organized in February 2010, which was attended by a Deputy Vice-Chancellor of Exeter, Prof Neil Armstrong, and from which further links between Exeter and NIAS were forged. As an example, in February 2011 a joint Exeter-NIAS workshop in Experimental Archaeology was held at NIAS under the guidance of Prof Bruce Bradley of Exeter.

Industrial and commercial implications

While the project was not conceived in terms of industrial and commercial implications, the subject of high grade, high-carbon wootz steel is one that has generated considerable interest in top scientific laboratories around the world. This has been in terms of exploring the relevance for modern materials and the significance of replication efforts for developing a better understanding in relation to modern metallurgical research. Thus, the project feeds into this overall effort which has industrial potential, tapping into the interests of steel companies such as Arcelor Mittal and Tata-Corus.

A delegation from NIAS visit the University of Exeter in June 2011

The significance of wootz steel to the history of materials science

Sharada Srinivasan and S Ranganathan

Introduction

The melting of steel proved to be a challenge in antiquity on account of the high melting point of iron. In the 1740s Benjamin Huntsman successfully developed a technique of producing steel that allowed it to be made on a much larger commercial scale and was credited with the discovery of crucible steel. However, Cyril Stanley Smith brought to wider attention an older tradition of crucible steel from India, i.e. wootz or Damascus steel, which he hailed as one of the four metallurgical achievements of antiquity. Known by its anglicized name, wootz from India has attracted world attention. Not so well known is the fact that the modern edifice of metallurgy and materials science was built on European efforts to unravel the mystery of this steel over the past three centuries.

Wootz steel was highly prized across several regions of the world over nearly two millennia and one typical product made of this Indian steel came to be known as the Damascus swords. Figure 1 shows a splendid example of the sword of Tipu Sultan. Wootz steel as an advanced material dominated several landscapes: the geographic, spanning Asia, Europe and the Americas; the historic, stretching over two millennia as maps of nations were redrawn and kingdoms rose and fell; and the literary landscape, as celebrated in myths, legends, poetry, drama, movies and plays in western and eastern languages including Sanskrit, Arabic, Urdu, Japanese, Tamil, Telugu and Kannada. South Asian steel held sway over the religious landscapes through trade and other interactions of Hinduism, Buddhism, Zoroastrianism, Judaism, Islam and Christianity. This is unique as no other advanced material can display this multi-faceted splendour.

Fig. 1 The sword of Tipu Sultan

Iron and steel heritage of India

India has been reputed for its iron and steel since ancient times. The Delhi Iron Pillar is a marvellous monument. There are numerous early literary references to steel from India from Mediterranean sources including one from the time of Alexander (3rd c. BCE), who was said to have been presented with 100 talents of Indian steel. Arabs took ingots of wootz steel to Damascus following which a thriving industry developed there for making weapons and armour of this steel, the renown of which has given the steel its name. In the 12th century the Arab Edrisi mentioned that the Hindus excelled in the manufacture of iron and that it was impossible to find anything to surpass the edge from Indian steel. In 1912, Robert Hadfield who studied crucible steel from Sri Lanka recorded that Indian wootz steel was far superior to that previously produced in Europe. Evidence from Kodumanal (c. 3rd century BCE) in Tamil Nadu suggests crucible ferrous processing.

European travellers such as Francis Buchanan in 1807, Benjmain Heyne in 1818, Voysey in 1832 and Josiah Marshall Heath in 1840 observed the manufacture of steel in south India by a crucible process at several locales including Mysore, Malabar and Golconda. By the late 1600's shipments running into tens of thousands of wootz ingots were traded from the Coromandel coast to Persia. This indicates that the production of wootz steel was almost on an industrial scale in what was still an activity predating the Industrial Revolution in Europe. Thus, Konasamudram in Telangana was a world renowned centre to which merchants from Persia and elsewhere flocked long before Sheffield, Pittsburgh and Jamshedpur emerged as steel centres in the modern era.

Indian wootz ingots have been used to forge oriental Damascus swords which were reputed to cut even gauze kerchiefs and were found to be of a very high carbon content of 1.5-2.0% and the best of these were believed to have been made from Indian steel in Persia and Damascus according to Smith. In India, until the 19th century, swords and daggers of wootz steel were made at centres including Lahore, Amritsar, Agra, Jaipur, Gwalior, Tanjore, Mysore and Golconda, although none of these centres survive today.

The role of wootz steel in the development of modern metallurgy

For centuries, iron and steel were thought to be two elements belonging to the ferrous family, just as copper, silver, gold and other metals belong to the non-ferrous family of metals. The recognition that steel is an alloy of iron and carbon came as a result of the chemical assaying of wootz steel in 1774 by the Swedish chemist Tobern Bergman. The Chemical Revolution wrought by Lavoisier received an impetus with the identification of carbon as an element. Indeed, chemistry must in some degree attribute its very origins to iron and its makers.

The development of wootz steel by sheer empirical practice in Southern India, the fashioning of the steel by thermo-mechanical treatments into fierce and beautiful Damascus swords in India and the Middle East with little knowledge of the underpinning science is a remarkable tale in the annals of metallurgy. When this steel was presented to the Western world, scientists in England, France, Russia and Sweden toiled hard and discovered the composition and microstructure and their relation to mechanical properties. This single-minded pursuit of an Eastern technological product by Western scientists —the illustrious names include Michael Faraday, Breant, Anasoff, Belaiew— for over a century created the foundations of modern materials science.

This single-minded pursuit of an Eastern technological product by Western scientists —the illustrious names include Michael Faraday, Breant, Anasoff, Belaiew— for over a century created the foundations of modern materials science.

As studies of wootz progressed it became imperative to establish the phase diagram of the iron-carbon system. The first comprehensive construction is due to Roberts-Austen in 1898. This was the first phase diagram of any alloy ever to be established. Such a diagram made it evident that it is possible to distinguish different products such as wrought iron, plain carbon steels, ultra-high-carbon steels and cast irons on the basis of their composition (Fig. 2). It was also possible to identify various phases such as austenite, ferrite, cementite. The phase reactions such as peritectic, eutectic and eutectoid came to be established. Combination of phases led to microstructures consisting of pearlite and ledeburite. The use of the optical microscope became widespread due to studies of wootz steel.

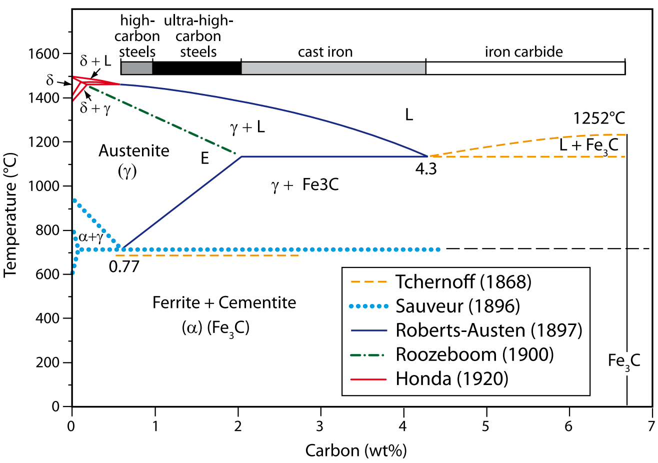


Fig. 2 Iron-carbon (Fe-C) diagram, the first phase diagram of any alloy to be established, by Roberts-Austen in 1898, after whom austenite came to be named. (Courtesy of J Wadsworth)

Deformation and solidification microstructures

Panseri in the 1960's was one of the first to point out that Damascus steel was a hypereutectoid ferrocarbon alloy with spheroidised carbides and carbon content between 1.2-1.8%. Recent studies by Jeffrey Wadsworth and Oleg Sherby have indicated that ultra-high-carbon steels exhibit superplastic properties at warm temperatures and are strong and ductile at room temperatures. The explanation of the superplasticity of the steel is that the typical microstructure of ultra-high-carbon steel with the coarse network of pro-eutectoid cementite forming along the grain boundaries of prior austenite can lead to a fine uniform distribution of spheroidised cementite particles (0.1 mm diameter) in a fine-grained ferrite matrix. John Verhoeven and the blacksmith Alan Pendray collaborated in the production of modern Damascus blades. Verhoeven has proposed that minute amounts of vanadium were necessary to lead to micro-segregation and the formation of banded structures during subsequent processing. Figure 3 shows the banded pattern visible to the naked eye. This texture and its beauty added to the reputation of the Damascus swords.

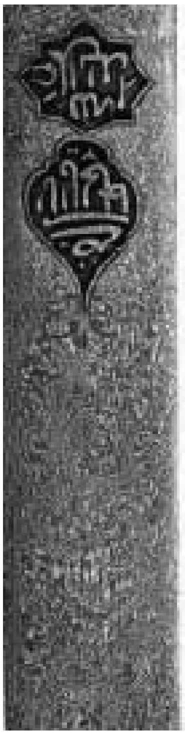
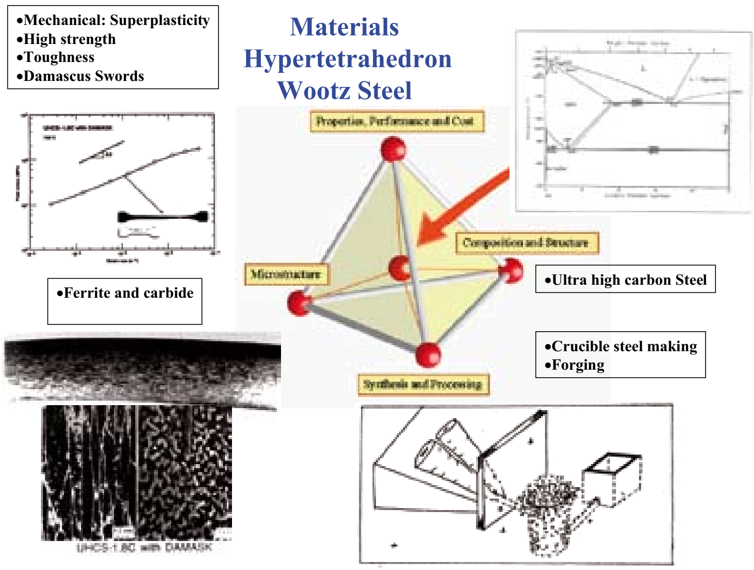


Fig. 3 Ladder pattern (Courtesy of JD Verhoeven)

Materials science tetrahedron and wootz steel

As discussed above, the investigations on wootz steel in 19th century Europe led to the foundations of what we understand today as the central paradigm of materials science. This is based on the idea that the processing of a material leads to a structure, which has a definite combination of properties. This set of properties in turn defines the performance of the possible products that can be made out of these materials. Merton C Flemings and Praveen Chaudhari captured these four defining ideas as the four corners of a tetrahedron. It applies equally well to metals, ceramics, polymers and composites and to materials ranging from sand to steel, nickel to nylon and bone to bronze. It is this powerful generalization that has made materials science a pervasive and enduring concept. The past decade has added one more idea to this quartet of the conceptual framework, namely modelling. As processing, structure and properties become complex, it is possible for us to resort to modelling and simulation. Figure 4 represents such a materials science hyper-tetrahedron for wootz steel. Individual vertices represent processing, structure, properties, performance and modelling. The facets of the Buchanan furnace, the iron-carbon diagram, the microstructure of dendrites in the as-cast state and spheroidised cementite in the forged material, the superplastic elongation, and the Damascene marks are displayed with emphasis on the strong interconnections among them. Materials science came into being due to the investigations into the properties of wootz steel.

Fig. 4 Materials hyper-tetrahedron for Wootz steel (S Ranganathan)



Further reading

Allan, J. and Gilmour, B. (2001) *Persian Steel,: The Tanavoli Collection*, Oxford Universiy Press

Jaikishan, S. (2009) Iron and wootz steel industry in northern Telangana. Telangana Jagrithi, Hyderabad

Juleff, G. (1998) *Early Iron and Steel in Sri Lanka: A Study of the Samanalwewa Area.* AVA-Materialien Bd 54, von Zabern, Mainz

Srinivasan, S. and Ranganathan, S. (2004) *India's legendary wootz steel: An advanced material of the ancient world*. National Institute of Advanced Studies and Indian Institute of Science, Bangalore

Telangana iron and steel: an historical introduction

S Jaikishan

Telangana is one of three geo-political divisions within the state of Andhra Pradesh in South India, along with Rayalaseema and Coastal Andhra. The region of Telangana is the largest at 114,800 km^2, with ten districts including the state capital of Hyderabad. The geographical and cultural landscapes of Telangana are distinctive and impart a sense of unique character. Topographically it lies on the Deccan Plateau, a vast area of central peninsular India made up of basaltic and granitic rocks which host a wealth of minerals including significant deposits of iron ore. The one major river which flows from west to east through the region is the Godaveri (Fig. 1). The landscape is made up of low hills of hard granite boulders surrounded by extensive tracts of cultivated paddy lands and dry cotton and maize crops, and the settlement pattern comprises scattered villages of mixed occupational groups living together (Fig. 2). Northern Telangana, which is the focus of this paper, is made up of four districts; Karimnagar, Nizamabad, Adilabad and Warangal.

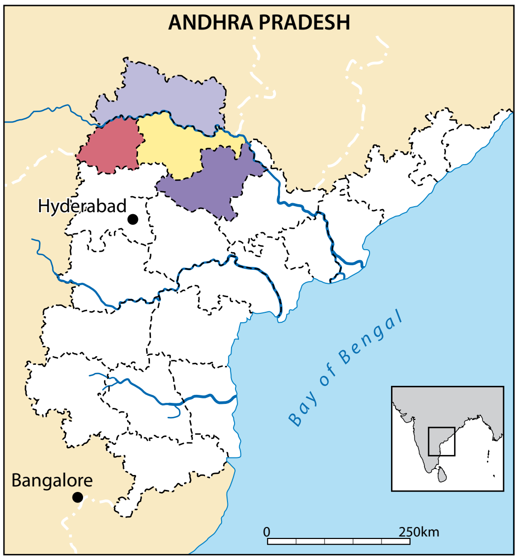


Fig. 1 Andhra Pradesh and the four districts of Northern Telangana

The main purpose of this paper is to give an overview of the general history of the region and the history of iron and crucible steel production from ancient to early modern times in the Telangana region. It is currently difficult to say when iron production in Telangana began but iron objects have been found associated with megalithic burials. The inadvertent excavation of a megalithic burial by a local farmer in the village of Dacharam in Karimnagar district revealed iron implements. At the same time we find evidence, as yet undated, for iron smelting near to this burial site. Iron and steel implements have also been retrieved from excavations at the early Shatavahana site of Kotilingala, dated to 350-80BCE. Kotilingala lies in Velgatur Mandal, Karimnagar district, at a strategic point on the south bank of the Godaveri river. Archaeological excavations were conducted at the site from 1979 to 1983. Some further idea of the potential antiquity of iron smelting can be inferred from the recording of evidence for a coil-built iron smelting furnace at the megalithic site at Naikund in Maharashtra (Deo and Jamkhedkar 1982). Although again

Fig. 2 Telangana landscape of granitic outcrops and cultivated plains

undated, similar coil-built furnace remains have been recorded from smelting sites in Telangana, including the well-preserved site at Buggaram, near Dharmapuri in Karimnagar district. Further perspective on the chronology of megalithic material can be drawn from recent TL dating carried out on the pottery from two megalithic burials within the Hyderabad University campus in Gachibowli which gave dates of 1995 and 2505 BCE (Thomas *et al* 2008, Rao 2010),

A measure of the scale of past iron and steel production activity is conveyed by the results of fieldwork conducted by myself in the four districts of northern Telangana (Jaikishan 2009). In the course of survey over a number of years over 1800 villages have been visited and abundant evidence found for iron smelting, wootz steel manufacture and the forging of iron and steel implements. More than 1100 villages were identified as potential iron and steel manufacturing centres and it is clear that steel usage was and still is prevalent in this region.

Fig 3. Trader's house in Konasamudram. traditional home of the Bhandari family

It is important to set past accounts of iron and steel making and the data from my own survey and the present UKIERI Pioneering Metallurgy project in a broader historical framework. The region was ruled by the native Andhra kings mentioned by Megasthanese in his *Indica,* from their capital at Kotilingala, mentioned above (Shastry 1996). The excavations conducted at Kotilingala by the Archaeological Survey of India yielded several coins of five Andhra kings which Raja Reddy (1984) described as "un-inscribed coins… besides coins of Satavahanas, Samagopa, Gobada, Kamvayasa and Narana". These Andhra kings were contemporary with the Mauryan rulers of the Magadha. The Andhra kingdom was taken over by the Shatavahana rulers in 220 BCE, who established a powerful Empire in South India and ruled up to CE 230.

After Shatavahana rule, the Vishnukundins held sway between the 4th to 6th centuries CE and in the early medieval period the region was occupied by the Western Chalukyas of Badami who ruled till the middle of the 8th century CE (465 to752). The region then went into the hands of the Rashtrakutas, who ruled between CE 752 and 973, with local feudatories, known as the Vemulavada Chalukyas, holding power up to the 10th century. These were followed by the Kalyani Chalukyas from the east and their feudatories, known as the Kakatiyas of Warangal, who occupied the region and established independent rule from the 11th century to the beginning of the 14th century. After the fall of the Kakatiya dynasty in 1323, the region was occupied by Tugluks, Sultans of Delhi. Many local chieftains lead revolts against the new rule, including the Velama Chiefs who seized and retained power for almost a century. After the establishment of Bahamani kingdom at Gulbarga in 1347, the Velamas were overpowered and reduced to subordinate rulers.

Sultan Quli of Hamdan was appointed as a regional ruler of Telangana by Mohammed Shah-III of Bahamani in 1480. Sultan Quli built Golkonda as his capital and became independent in 1518 and following the fall of the Bahamani dynasty established the Qutb Shahi kingdom. The region became prosperous under the Qutb Shahis, with Golkonda becoming famous for its celebrated diamonds in the later medieval period. With the fall of the Qutb Shahi kingdom, *'Nizamath'* (administration) changed to the Asaf Jah dynasty, who ruled continuously up to 1948.

Returning to more localised evidence for iron and steel making, it is interesting to note that most of the village names are etymologically identified in the regional language, Telugu, as terms relating to iron ore, iron slag, iron smiths, iron furnace

Fig. 4 Combinded crucible body and lid fragment, steel ingot and traditional steel-maker's tongs (author's collection)

and iron manufacturing. For example *Inumu* in Telugu means iron and *Dindurthi, Inukurthi, Induoor* and *Indurthi* are all villages named after iron. *Chityamu* means slag or scum of melted metal and villages named after this include *Chityala, Chittapuram, Chittlapenta* and *Chittemula*. *Kammari* means blacksmith and *Kammaripeta, Kammaripally, Kammarashala* and *Kammarala* are all villages presumably linked with this profession. Finally, *Kolimi* means furnace and *Kolimkunta, Kolimiyala, Kodimayala* are village names related to furnaces. Other village names recorded refer to ever-burning furnaces, dried cakes of slag or the soft stone of the iron ore.

Iron ore was available everywhere in this region. Ore occurred in cap type deposits on the tops of hills and hillocks. Lowe (1990) observed that "the upper surface of all outliers with iron-rich laterititic hard-caps are above 600m". Thevenot (1949) commented "the mines are mere holes at a depth of a man". Local accounts indicate that iron ore was collected and pulverized to powder then washed with water to clean out the clay and dust particles. Sometimes, in the rainy season, the iron ore was collected from stream beds. Cleaned iron ore was sold in every market and traders used to sell it in the streets.

In a number of Arab accounts the terms *hindvi* and *teling* swords are used, referring to swords which were highly prized and manufactured using Deccani wootz. The word *teling* is possibly a reference to Telugu and, therefore, to a sword obtained from Telugu-speaking smiths. (Feuerbach *et al* 2007). Toussaint (2002) notes that all Dravidian languages possess a word for steel, e.g. *uruku, ukku, karugu, urku, ukku,* many of which mean either 'melt' or 'dissolve'. Many scientists, archaeometallurgists and historians have discussed wootz steel from the Deccan region, spanning from Maharastra to Tamil Nadu, however, on present knowledge, it is in northern Telangana that we see the most intense evidence for sustained production from potentially the early historic period to the 19th century. This suggests that a particular wootz steel culture exists, with wootz material being part of the day to day life of the people.

One of the key sites in the area, the village of Konasamudram in Nizamabad district, was clearly a centre of production and marketing. There are references to this village in travel and trading accounts from the late historic period. The present village is built on a large heap of used crucibles and the waste from production is clearly visible on the surface. Konasamudram has become synonymous with crucible steel and has attracted the attention of modern-day researchers as well as travellers in the past. Craddock stated that "the most famous region of steel production by co-fusion [of wrought and cast iron] is in the Nizamabad District of Andhra Pradesh... One of the most important sites was Konasamudram which was visited in 1820s by the English traveller, H.W. Voysey" (Craddock 2007).

The use of locally produced crucible steel extended into everyday artisans' tools, and still today recycling of old crucible steel for use in implements is popular. The best example of this is in the making of toddy tappers' knives

My own study has underlined that this village was a nucleus of wootz steel production. Despite many surrounding villages also being producers of large quantities of steel they were not mentioned by any of the travellers or in contemporary literature. Konasamudram was mentioned by Tavernier in his 'Travels in India'. (2001) and another traveller, Thevenot (1949), said "the best steel was produced at 'Konasamudram' near Nirmal in Nanded District". Most of the marketing and trade in wootz was centralised in this village. Still standing in the centre of the village is an old dilapidated trader's house of the *Baniya* trading community belonging to the Bhandari family (Fig. 3). Voysey (1832) describes how Haji Hassan, a Persian trader, having failed to get his required order of wootz ingots at Indur, came to Konasamudram. Indur was the major marketing town, its original name might be Inumoor, or iron village. It lies in Nanded district and is the present district headquarters of Nizamabad.

Lord Egerton of Tatton, in his 1896 book on Indian and Oriental Armour (2001), stated that "In Elgundel there is the manufacture of swords, daggers, and spearheads from the steel obtained there. At Lingampilly, in the same district, barrels for pistols and matchlocks are prepared in the following manner: bits of old iron are formed into rods the thickness of a man's finger, which are then twisted; three or four of these are joined lengthways, another band of iron of the same breadth and one-third of an inch thick is welded to this, and both are formed in to a band which is twisted and afterwards beaten into a solid cylinder, which is bored by a hard steel chisel". The two places he mentions are in present-day Karimnagar district of Telangana.

Wootz ingots were produced in different sizes and weights, as per the requirements of the weapon or item to be made out of the metal. They were produced to order, with production requirements changing from time to time. The difference in the sizes and shapes of the ingots was significant and could vary from 100 grams to 20 kilograms in weight (Fig. 4). Crucibles from some sites, including the large smelting and steel-making complex at Parsurampalli in Warangal district, were very small and might have produced not more than 50 grams of steel. Three ingots in my own collection weigh 400 grams, 1500 grams and 2000 grams. The use of locally produced crucible steel extended into everyday artisans' tools, and still today recycling of old crucible steel for use in implements is popular. The best example of this is in the making of toddy tappers knives (Fig. 5).

Fig. 5 Toddy tapper's knives (longest example 25cm, author's collection)

This summary provides only a glimpse of the wealth of evidence from historic sources and from the locality itself. There is a need for critical regional studies with prime importance being given to chronology and dating. There is also particular need for detailed survey of original documentary evidence from this region.

Telangana Field Survey: aims, methods and outcomes

G Juleff and B Gilmour

Introduction

The overarching aim of the Pioneering Metallurgy project at its outset was to understand the technological and cultural origins and development of iron and steel production in southern India. To address this aim the objective has been to investigate the archaeometallurgical record in a variety of forms, from production landscapes and sites to artefacts and technological debris, using a range of methods including field survey, ethnographic survey, morphological classification of debris and scientific analysis of materials.

While crucible steel production sites have been identified in Tamil Nadu, Karnataka and Andhra Pradesh, offering a wealth of potential landscapes for investigation, the choice of northern Telangana as the focus of project activities arose from the convergence of previous research and logistical opportunity. Northern Telangana, as is described elsewhere in this volume, comprises the four districts of Adilabad, Nizamabad, Karimnagar and Warangal, bisected by the course of the Godaveri river. The region is now regarded as remote rural Indian heartland and is dominated by scattered agricultural villages. Its role in the past as a major centre of iron and steel production is recorded in historical accounts and field investigations in the 1980's by Thelma Lowe of Berkeley University began the effort to record the physical remains of this industry. The first author here had the good fortune to visit the area briefly with Lowe and was profoundly struck by the scale and diversity of technological evidence and the excellent preservation of

The region is now regarded as remote rural Indian heartland and is dominated by scattered agricultural villages. Its role in the past as a major centre of iron and steel production is recorded in historical accounts

Fig. 1 The survey team examine a slag heap in a teak forest at Gondagudam (location 13-2-10(15))

many of the sites. In more recent years the publication of the sustained investigations of Dr S. Jaikishan (2009) has brought the archaeometallurgical record of Northern Telangana to a wider audience. Thus, through his generous offices, the project established a field base at Dharmapuri, the small home-town of Dr Jaikishan and the six-week Telangana Field Survey took place in the first quarter of 2010.

The aim of the survey was to characterise the archaeometallurgical landscape of the area in terms of the nature and range of technologies present; the spatial and temporal distribution of variations in technology and scale of production; and the contextual relationship between metallurgy and settlement distribution and character. The 12-person team that carried out the survey was led in the field by Dr Brian Gilmour, an authority on the subject of wootz and crucible steel (2006) (co-opted from the Research Laboratory for Archaeology, University of Oxford), plus Dr Jaikishan himself, postgraduate students and researchers from Exeter University and NIAS, and students of Dr Jaikishan's College in Dharmapuri.

Methods

The methodological strategies adopted for the survey are presented here in some detail as a potential template for similar future fieldwork. First and foremost it is important to emphasize that the purpose was not to explore for new sites but to visit known sites and locations to carry out recording and sampling. Occasionally, however, in the course of the work new locations were identified. The survey focussed primarily on a core area of c. 30km diameter, centred on Dharmapuri and straddling both banks of the Godaveri river. Survey was extended up to 100km distance from the centre to incorporate specific known locations. The strategy followed can best be described as reconnaissance-style survey and was based primarily on experience gained by the first author during similar field surveys in Sri Lanka (Juleff 1998). Systematic transect-walking was not undertaken but daily traverses by vehicle and on foot were recorded using GPS. Data was gathered simultaneously by all team members in field notebooks using a continuous expansive narrative approach. The narrative began with the departure from base camp each day and recorded routes travelled, significant landmarks, landscape features, changes in land use and agriculture, village settlements and individuals encountered in the course of a day (Fig. 1). Where sites of interest, including all sites associated with iron and steel production, were encountered these were recorded as 'locations' and identified by a 'date/location' number, using the date followed by a sequential number specific to that date, e.g. 1-2-10 (1) or 5-3-10 (4). This avoided assigning 'site' status at the outset and the consequential early preclusion of data deemed as 'non-site' status. It also allowed multiple loci within a settlement or larger metallurgical complex to be recorded separately rather than being subsumed within a general account of the whole. This also ensured that sites and site names did not become synonymous and interchangeable with village names. As an example of this, the village of Konasamudram has long been synonymous with crucible steel manufacturing and as is thus widely regarded as a crucible steel site. Our traverses within and around the

Fig. 2 Survey traverse through Konasamudram, with multiple locations marked by GPS points both within and on the outskirts of the village

outskirts of the village recorded a number of locations associated with both smelting and crucible steel (Fig. 2). Without further analysis of the data it is not clear whether these locations operated contemporaneously or contiguously, or were chronological distinct episodes. By maintaining them as separate location records the possibility of fine resolution in the analysis stage is preserved. Similar situations were repeated throughout the survey.

Fig. 3 Tools of the trade - field diary, handheld GPS and GPS log

Date/location records encompassed all forms of evidence including sites of metal-working activity, geological features, buildings or structures, find-spots, observation points or persons interviewed. All date/locations were recorded with GPS points and photographs, and where useful, with sketch maps and plans (Fig. 3). In addition to details pertaining to locations, samples of geological material and technological debris were collected and extended notes recording interviews and conversations with individuals encountered were recorded, these are described elsewhere in this volume (Cox and Haricharan and Neogi and Jaikishan).

At the end of each day in the field the information in team members' field notebook was amalgamated and transcribed into a single project diaries using the same narrative approach. The resulting field records, while expansive and perhaps arguably old-fashioned, are comprehensive and readily accessible (being non-digital). They are reinforced by digital GPS and photographic datasets and, with the added use of satellite images, it is possible to recreate the events and progress of each day of the survey.

Observations on survey progress

In the course of the six-week survey 33 days were spent in the field and in that time 245 locations were recorded (Fig. 4). An interim synthesis of the data and discussions of its implications is given elsewhere in this volume and only broad observations are made here. The time spent at each location varied considerably from several hours to perhaps just ten minutes but, with an average of more than 7 locations recorded per day and few locations being re-visited, the level of coverage can be treated as reconnaissance rather than in-depth. This however is mitigated by team members focussing on different areas of recording, e.g. sample collection, sketch planning, photography, measured records, interviewing etc. To maximise time in the field, camp duties (washing and labelling samples, transcribing field notes, classifying technological debris) were carried out in the evening or by team members alternating days in the field with days in camp.

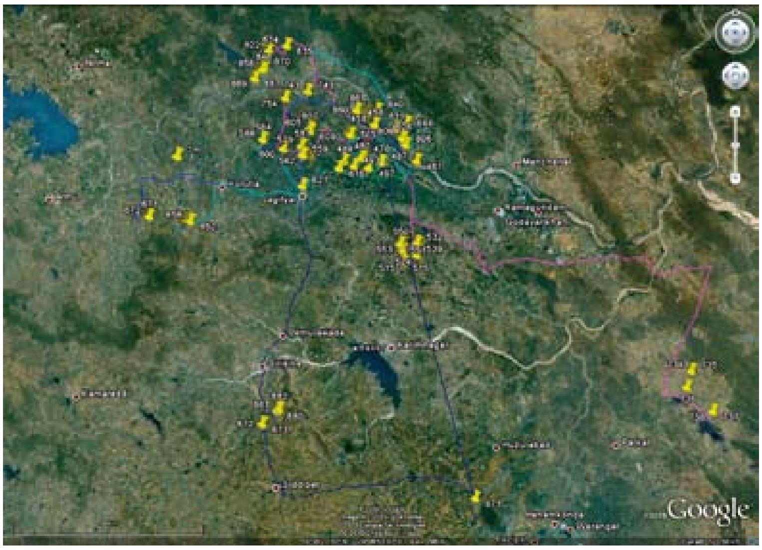


Fig. 4 GPS location points and traverses mid-way through the survey, demonstrating the core area and the extended reconnaissance surveys

The locations recorded encompassed a wide range of categories including general geological features; mineral extraction; locations with direct association with past metallurgy (slag and crucible deposits); historic settlements; individual structures such as temples, fort bastions, manor houses; and locations with ethnometallurgical associations, e.g. operational smithies and interview settings. Close attention was paid to recording the condition of metallurgical locations and assessments were made as

Fig. 5 Many sites were found to be recently damaged or destroyed by land clearance activities. This site was being bull-dozed on the day of the survey visit.

Fig. 6 Many of the best preserved sites lay in forest reserve areas

to whether technological debris was *in situ* or had been re-deposited from elsewhere. In a great many cases material was deemed to be *in situ* but had suffered significant disturbance, mostly commonly in very recent times. It was alarmingly evident that many deposits that had been in primary, undisturbed condition when Lowe carried out her field surveys are now being bulldozed to create agricultural land or quarried away for construction material (Fig. 5). The best preserved locations are those that are and always were remote from settlements in forested areas (Fig. 6) and deposits within settlements are either highly disturbed or secondary, as in the occurrence of slag and crucible fragments liberally embedded in the mud used to construct house and compound walls (Fig. 7).

Within the core area, intra-location narrative recording captured landscape data on topographical associations. For example, relationships between settlements and features such as ore-bearing hillocks or routeways connecting villages and ore deposits or isolated smelting or steel production locations. Attention was also paid to recording place-names, including names of hills, streams, road and river crossings as well as village and hamlet names. Survey beyond the core area was used to visit locations of well-known metallurgical activity to collect comparative material and test the long-range continuity of site types and patterns observed in the core area. The extended survey will also provide pointers to future areas for investigation.

Outcomes

On completion of the survey it was clear that the archaeological record of Northern Telangana is dominated by a complex history of iron and steel production, which in turn is dominated by locations where iron smelting took place. Crucible steel manufacturing takes a central position in the record and occurs both as a stand-alone activity and in

Fig. 7 Past metal-working within settlements is often evidenced by slag and crucible fragments embedded in house and compound walls. While this is recorded as secondary deposition it is rare that the mud used in building construction travels far from its point of origin.

close association with iron smelting. Primary classification of the technological debris indicated significant variation in technological processes, especially with regard to iron smelting. However, chronological resolution of technological variations was far less apparent. The archive that the team took with them when they departed from Dharmapuri consisted of written records in the form of field diaries and notebooks, interview transcripts and debris classification sheets; digital GPS logs and a body of technological debris for further analysis. The treatment of this material during post-survey analysis is reported later in this volume.

Telangana field survey: macro-morphological analysis of technological debris

M Cox and S Haricharan

Introduction

The technological debris collected during the 2010 Telangana survey forms one of the key project datasets and its macro-morphological analysis is an integral component of the post-survey treatment of the data (Fig. 1). The aim of this analysis is to increase our understanding of the nature of the technological processes represented at the locations recorded during the field survey. This includes at a primary level the identification of both smelting and crucible steel refining, and at a more detailed level, variations in these processes. By assessing and comparing assemblages of technological debris from individual locations a composite picture of the technology carried out within this landscape can be achieved.

The methodology adopted for the macro-morphological analysis can be broken into three stages. The first stage focuses on how data and material were collected in the field. The second concerns the data gathered during the initial classification of collected

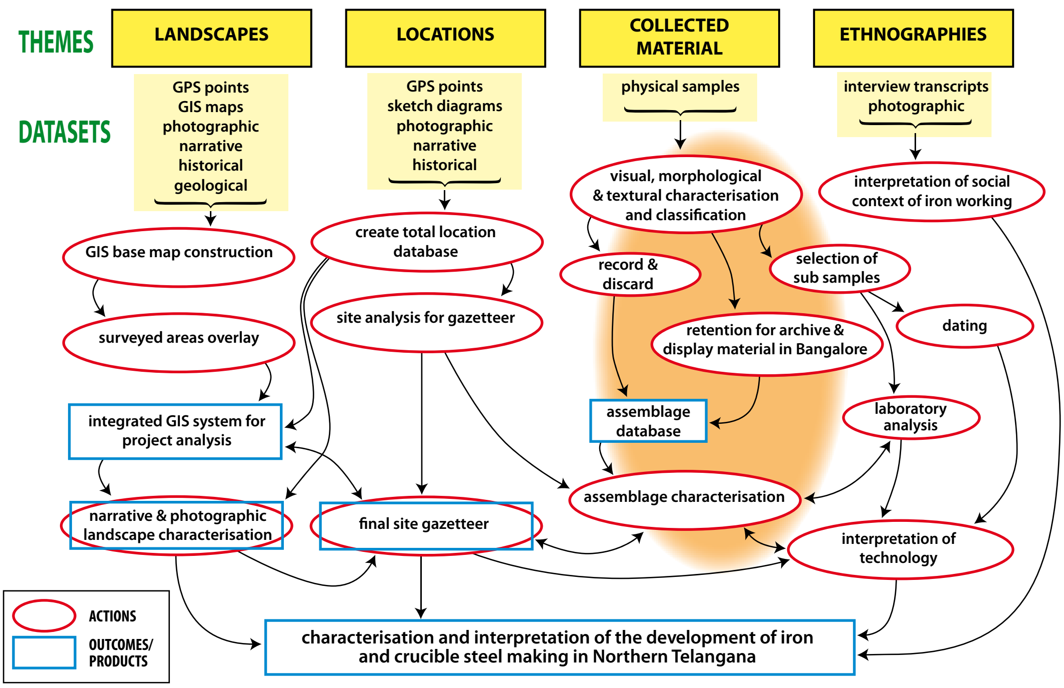


Fig. 1 Schematic approach to the post-survey treatment of key datasets

material at the survey base in Dharmapuri, Telangana. The information recorded through this classification formed the foundation dataset for subsequent analysis. The collected material consisted of waste components, e.g. fragments of slag, ore, metal and refractory material, such as tuyeres, crucibles and furnace walls. This debris provides direct evidence of the smelting and refining processes that once took place in this landscape. All the material collected was characterised and records created, and a proportion of sub-samples from each assemblage retained for further analysis. The retained samples were moved to the National Institute of Advanced Studies (NIAS), Bangalore, where the third stage of macro-morphological analysis took place in which a detailed comparative study of diagnostic material was made in order to detect major and minor variations in character at a survey-wide level as well as define technological groups.

Sample collection in the field

The totality of the collected material from the survey, including pottery, soil samples and technological debris, weighed over 1500kg. Technological debris, in the form of slag, refractory and geological material, was by far the largest component.

The locations examined during field survey were originally identified by Dr S Jaikishan, who had conducted explorations in the region over the past ten years (Jaikishan, this volume). A reconnaissance-style field survey strategy was followed and in the course of recording locations of interest technological and geological (possible ore and raw materials) samples were collected from the ground surface. Locations were plotted using GPS and notes on the depositional character of technological debris, for example, whether undisturbed slag heaps or dispersed scatters of material, were taken by survey team members, along with observations on landscape context and setting, particularly proximity with geological features (Fig. 2).

All the material collected was assigned to date/location records. In order to achieve an unbiased collection regime, bulk samples of material with multiple fragments from one point within each site were collected. The totality of the collected material from the survey, including pottery, soil samples and technological debris, weighed over 1500kg. Technological debris, in the form of slag, refractory and geological material, was by far the largest component. In some instances, in addition to bulk representative samples, distinctive selected samples were collected such as near-complete examples of consistent forms or fragments that indicated potential variations in technology. All the collected material was first washed and then weighed and sorted by material type, e.g. slag, refractory, geological etc..

Fig. 2 Collecting samples in the field

Primary classification of technological debris

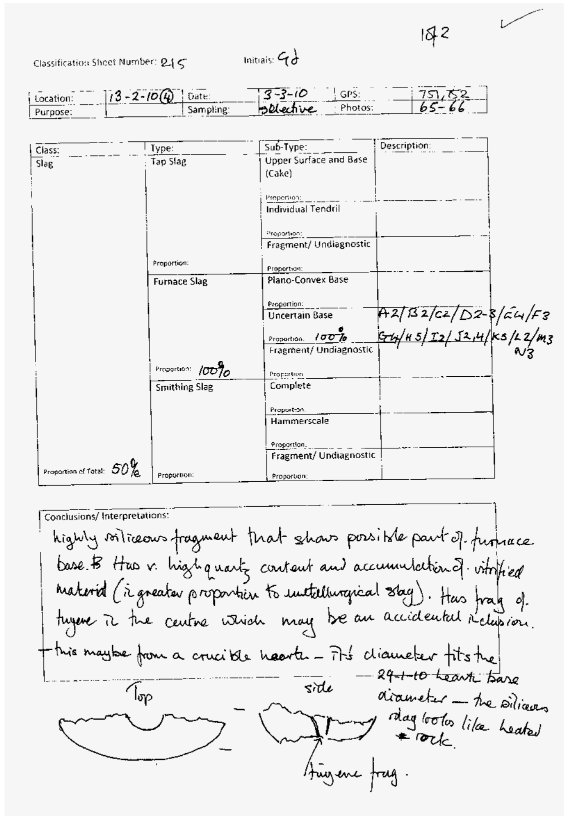
In order to gain an understanding of the industry as a whole, the sample material was initially assessed on a location by location basis. This process began in the field at Dharmapuri, where the material collected during fieldwork was simultaneously classified and recorded. Each location sample was laid out and photographed as a whole to provide a record of the assemblage being described through classification. The classification scheme was devised to allow rapid recording through visual examination. Given the volume of the samples, recording each fragment individually would have been impractical, hence samples were recorded as groups of similar material. This methodological approach mitigated the time constraints imposed by being in the field but allowed an overview of sample sets from each site (Fig. 3).

Fig. 3 An assemblage of material from one location laid out for photo-recording and classification

The aim of the classification scheme was to record sufficient detail to allow the identification of correlations, comparisons and groupings of shared attributes across the entire collected assemblage. The classification sheets were arranged in a hierarchy that first defined the material by class, the four classes being geological, slag, metal and refractory material. Once sorted by class, the date/location number, GPS points, date and preliminary interpretation of the material were recorded. The percentage figure recorded at each level of classification is a qualitative measure of the proportion of the sample within a class, type or sub-type. The type and sub-type levels record specific and distinct morphological forms.

For example, the classification sheets for the slag included 'type' (e.g. tap slag, furnace slag or smithing slag) with 'sub-type' (e.g. plano-convex base, individual tendril etc). Similarly, the classification sheets for refractory material had 'type' (e.g. furnace wall, tuyere or crucible) and 'sub-types' which refers to various components of the complete artefact such as lid or body sherd. The classification of the geological and metal samples followed a similar format. The lowest level of the classification scheme describes attributes and variants for each class of material. These attribute-variants are recorded by alphanumerical 'descriptors' and a large array of descriptors are possible for any class of material. Under the slag classification scheme, shape is attribute 'A' and shape variants are assigned numeric descriptors such as 1 plano-concave, 2 plano, plano-convex, 3 convex, 4 concave-convex and 5 amorphous. Thus, a fragment of furnace slag might be recorded as: A3 (plano-convex), B1 (very large) and C2 (thick) (Fig. 4).

Fig. 4 Example of a slag classification record compiled in the field



1&2

Classification Sheet Number: 215 Initials: Gd

Location:	13-2-10(4)	Date:	3-3-10	GPS:	751, 752
Purpose:		Sampling:	selective	Photos:	65-66

Class:	Type:	Sub-Type:	Description:
Slag	Tap Slag	Upper Surface and Base (Cake) Proportion:	
		Individual Tendril Proportion:	
	Proportion:	Fragment/ Undiagnostic Proportion:	
	Furnace Slag	Plano-Convex Base Proportion:	
		Uncertain Base Proportion: 100%	A2/B2/C2/D2-3/E4/F3 G4/H5/I2/J2,4/K5/L2/M3 N3
	Proportion: 100%	Fragment/ Undiagnostic Proportion:	
	Smithing Slag	Complete Proportion:	
		Hammerscale Proportion:	
Proportion of Total: 50%	Proportion:	Fragment/ Undiagnostic Proportion:	

Conclusions/ Interpretations:
highly siliceous fragment that shows possible part of furnace base. Has v. high quartz content and accumulation of vitrified material (i greater proportion to metallurgical slag). Has frag of tuyere in the centre which may be an accidental inclusion.
+ this maybe from a crucible hearth – it's diameter fits the ~~29-1-10~~ hearth base diameter – the siliceous slag looks like heated * rock.

Top side

tuyere frag.

A similar method, with different descriptors, was followed for the other categories of material. Over 425 classification records were compiled by hand in the field. These were subsequently transferred to a spreadsheet format. In digital form it is hoped that the data will allow a degree of analytical and statistical interrogation and a first experimental examination of the data using cluster analysis is being developed. The work has yet to be completed but it may be possible to detect patterning in the data in relation to locations and site types that are not apparent from the field evidence.

Assemblage analysis

The classification methodology used made it possible to gain useful qualitative data using a typological approach to recording the large body of collected material. Once the material had been classified most of the technological debris could be left behind at the survey base in Dharmapuri. The retained samples, transported to NIAS to be kept as reference material amounted to approximately 25% of the total technological debris classified.

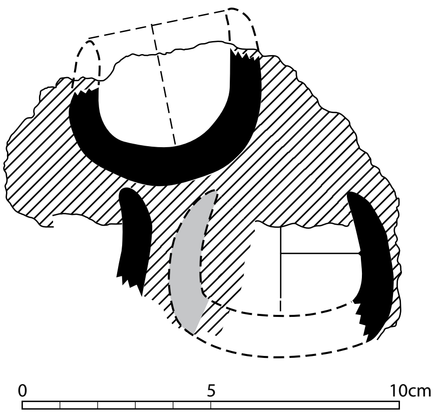


Fig. 5 Measured drawings of important typological material for the archive and publication

At NIAS, the third and final macroscopic analysis allowed a more expansive approach to characterising the material, free from the confines of the classification system used in the secondary analysis. The aim here was to record more in-depth information using a narrative approach based on observation of features and comparison with other survey-wide material.

Through this final part of the study, a more inter-site and technology specific analysis could take place, looking at groups of material and following lines of inquiry beyond the location-specific recording. Detailed visual examination was carried out to determine and isolate particular technologies and industrial processes. Closely related site assemblages were studied as a whole, along with prominent or recurrent diagnostic features, to piece together the processes that may have produced a particular combination of debris types. The characterisation process became more subjective and features such as average furnace diameters, crucible forms and sizes, refractory fabrics, furnace wall construction and thickness etc. were considered and noted in discursive descriptions. This process meant assemblages could be deconstructed and technological groupings identified. Diagnostic components within assemblages could be correlated with similar material from other locations across the survey.

Fig. 6 Photograph showing a ceramic furnace wall sitting on a much vitrified, reusable stone plinth

At this final stage of assemblage analysis measured drawings and additional photographs were made of the diagnostic material, especially tuyeres, crucibles and furnace remains. Unique and recurring diagnostic examples were selected and drawn to illustrate typological groups (Figs 5 & 6).

The end-product of the macro-morphological analysis is a dataset consisting of 425+ classification records representing the material collected during fieldwork. The same data, recording the material by type, sub type and attributes, has been transposed to a digital format for statistical analysis. In addition, the retained reference material in storage in Bangalore represents an archive of technological debris available for further study. Future work will correlate and integrate the technological groupings identified with site distribution patterns arising from the post-survey analysis of the location database and eventual site gazetteer.

Telangana Ethnometallurgical Survey: an interim report

T Neogi and S Jaikishan

Introduction

As an integral element of the Telangana survey of 2010 a systematic ethnometallurgical survey was undertaken. The aim was to record as far as possible the presence, lives and working practices of the last generation of working rural blacksmiths and descendants of iron smelters. Towards the end of the field season an opportunity also arose to study and document the Mammayee festival, which is the traditional annual rejuvenation festival of the blacksmith community of the region dedicated to their goddess, Mammayee. The data that was gathered during this component of the field survey represents a valuable ethnoarchaeological tool to study the effect of social organisation, culture and tradition of the rural blacksmiths of the Telangana region and understand their approach to metals as a whole and iron in particular, as reflected through their technological choices and style. This report discusses the ethnographic records and observations made and the methodology followed during the ethnoarchaeological survey.

Methods

The methods used fall into two broad areas; the collection of ethnographic data in the field and the subsequent archive collation and interpretation of the data.

Collecting ethnographic data in the field involved interviewing blacksmiths in their residences or work-spaces. Non-blacksmiths, including village elders, toddy tappers, owners of land containing slag or crucible heaps were also interviewed to gather knowledge or memory of past smelting as well as smithing. Among a total number of twenty interviews conducted and recorded, eleven are with traditional blacksmiths, including one itinerant blacksmith. In many cases the survey team encountered blacksmiths by chance while surveying a nearby slag or crucible heap. In other cases the local villagers would lead the team to the blacksmith's quarters. The interview process (Fig. 1) began by asking the blacksmith if he minded talking to us about their work. We found all of them very interested and enthusiastic to talk about their trade. With the consent of the blacksmith, each interview was conducted around a set but

Fig.1 A field interview with a blacksmith (centre) and the authors

Fig. 2 Working blacksmith in Sekalla village

flexible format of topics (to ensure consistency) including; the blacksmithing tradition of his family and the village; memory about past smelting and smithing; kinds of tools produced or repaired; target market and clients of the manufactured products; remuneration system; source of raw materials; apprenticeship process and the future of traditional blacksmithing from their perspective. Interviews were conducted in Telugu with Dr Jaikishan and G Prabhakar acting as translators. The interview process included making detailed hand notes as well as video recording. Although the knowledge and memory of traditional iron ore smelting technology is sketchy, some interesting recollections were obtained. Lachaiah, an octogenarian from Sekalla village recollected the smelters using round furnaces to smelt the iron ore obtained from a nearby hill. He further added that the iron obtained was used for production of agricultural implements and that the smelters and the blacksmiths were the same people. Other childhood recollections of the village elders (including senior blacksmiths) include the memory of playing near a smelting furnace with bellows, as well as recollections of blooms left for cooling in open fields. These recollections, however, come from the final days of iron smelting in the region and therefore it could be deduced that smelting was done on a very small scale at that time and served extremely localised requirements. It is also highly probable that the smelters were increasingly taking to blacksmithing, which was more profitable than the declining smelting industry. The recollection of Lachaiah of the smelters being the blacksmiths themselves might be situated in this scenario. Also, the important revelation that the farmers bring raw materials in the form of scrap iron to the blacksmith might be the survival of an age-old practice of bringing raw iron from the smelting community to the blacksmith. Most of the blacksmiths were sceptical about future generations taking up blacksmithing as a livelihood. Apart from this, blacksmiths were also observed and recorded in their work (Fig. 2), and measured sketch plans (Fig. 3) were made of their working spaces for potential comparison with archaeological evidence.

The detailed study of the annual festival of the blacksmiths was conducted by visiting the temples of their goddess Mammayee (Fig. 4) on the first day of the festival and interviewing blacksmiths about the preparation and ritual performances. The rituals were observed in four villages (Kalvala, Uploor, Ibrahimpatnam and Konasamudram). Hand-written field notes were supplemented with photographic and video records.

The collected ethnographic data was carefully archived. The interviews and other significant conversations recorded in field notes were initially transcribed in the field by hand into a project interview notebook. In the post-survey collation of data this was transcribed into a digital record. The interviews were then carefully studied and an interview subject checklist prepared in which the numbered interviews were sorted under different headings based on the themes discussed in the interviews,

Fig. 3 Measured sketch plans were made of working smithies

such as raw material source, tools manufactured, remunerations etc. The records made during the Mammayee festival were separately transcribed from hand notes to a digital record and a video and image archive created. The final ethnographic archive consists of five principal datasets —interview transcripts, video records, a manufactured iron tool, festival records and image archive.

The rural blacksmiths of Telangana: some observations

The blacksmiths of the Telangana region, like most of the blacksmith communities of south India, fall within the Viswakarma (the Hindu god of arts and crafts) caste group. The Viswakarma caste in the Telangana region consists of five distinct craft communities; blacksmiths, gold-smiths, bronze-smiths, carpenters and stonemasons or sculptors. Although intermarriage is often practiced among the three metal craft communities, it is not altogether clear whether the matrimonial relations are encouraged with the non-metal craft groups (carpenters and stonemasons). Marriage outside the caste is not encouraged. The Viswakarma caste of the region, including the blacksmith community, wear sacred threads like the Brahmins and a sense of strong inter-caste competition with the Brahmins could be observed in the traditions and taboos of the blacksmith community.

The blacksmith communities frequently occur as close clusters within larger rural settlements, often not very far from the location of a slag or crucible heap. Spatially, their residences and workspaces are situated closer to the residential cluster of the agricultural community, who are their primary clients. The community is stratified according to seniority and is headed, in each village, by a body of elder blacksmiths (consisting generally of three or four senior smiths) who preside over communal meetings, which are generally held on every new moon evening and in the premises of the temple of their goddess, Mammayee. The elder blacksmiths are responsible for making all important decisions regarding community disputes, auspicious and inauspicious days and festivals. In most cases their decisions are deemed as final and unassailable. This intra-community hierarchy and other inter- or intra-community and caste relations are guided and attested by a distinct ritualistic behaviour as well as obligation reciprocation mechanism (Mauss 2009). These could be observed in detail during their annual rejuvenation

Finally, they tie sacred threads on their working implements, which appear to be extensions of a blacksmiths' body and rejuvenated through endowment of divine power and the blessings of the goddess.

Fig. 4 The goddess Mammayee during the annual renewal festival

Fig. 5 Itinerant blacksmith

Fig. 7 Tying the sacred thread on a blacksmith's hammer

festival. Women are strictly prohibited from participating in any aspect of blacksmithing and the cult of their goddess.

As mentioned, the farmers form the immediate clientele for the blacksmiths. The business relationship between these two communities is regulated through a long-standing tradition of oral contract, where the individual farmer agrees to pay a certain amount of grain (normally rice or pulses) to the blacksmith, who in turn has to make or mend as much agricultural equipment as the farmer asks from him. The payment comes in two instalments i.e., after two harvest seasons. This seemed to be a very well established tradition in most of the villages of the region. Apart from some villages which are closer to urban centres or highways, monetary transaction is not preferred. The system of two instalments is strictly followed even during a cash transaction with the farmers. At least one itinerant blacksmith (Fig. 5) was interviewed during the survey. He preferred to accept cash due to the wandering nature of his work.

The blacksmiths manufacture tools exclusively to fulfil the needs of the immediate rural community. It appeared that mass production of the iron implements is not practiced and manufacture or repair is done only on request, probably due to the declining market of indigenously produced items in competition with industrialised products. Consequently, all of them are primarily engaged in repair work rather than manufacture of new tools. Raw materials are generally procured from the market by the farmers, rather than the blacksmiths themselves, in the form of scrap industrial iron, commonly as lorry springs. Charcoal can be purchased from local markets but sometimes the blacksmiths prefer to make charcoal themselves from locally abundant teak wood.

Although the region is rich in ore, smelting is no longer practised and it appears that the knowledge of smelting technology is significantly lost. Some village elders retain some memory of the thriving smelting industry of the past, but the information obtained during the 2010 survey was sketchy and further intensive enquiry is required.

It was observed during fieldwork that the number of working blacksmiths within a village can range widely from three observed in Sekalla to forty-three locally reputed in Uploor. However, overall the number of working smithies is rapidly declining since younger generations are opting for more lucrative trade or placement in the Middle East.

Mammayee Festival

The festival of the goddess Mammayee traditionally takes place in the last eleven days of the Telugu calendar, which normally falls in early March. However, due to poverty among the blacksmiths of the region, the festival was reduced to three days during our visit in 2010. A total number of four villages were surveyed in the course of the festival, and the final day ritual, which coincides with Telugu New Year's Day, was observed in the village of Ibrahimpatnam (Karimnagar district), where the cult of the goddess is still the strongest. On the first day of this festival the blacksmiths cease to work and donate some of their working tools to the nearby Mammayee temple. The blacksmiths do not take non-vegetarian food and cooking must be done strictly within the temple premises. Women are not allowed in the cult performances and all the activities are carried out by the blacksmiths themselves. Although other craft groups of the caste also cease to

Fig. 6 Blacksmith's tools donated to Veera Brahmendra Swami during annual festival

work and worship god Viswakarma in their individual residences, the cult of Mammayee seems to be exclusively followed by the blacksmith community. Along with Mammayee, a local saint, Veera Brahmendra Swami (Fig. 6), is also worshipped. It is believed that this saint functions as the patron saint of the community, rather like St. Clement in parts of England (Sawyer 1884).

On the final day of the festival the blacksmiths gather in the temple before sunrise and prepare food offerings consisting of five principal items (in this case) pulses, rice, maize, coconut and jaggery. The final worship is conducted by the senior blacksmiths, with the senior-most of them acting as high priest, reciting mantras. It was observed that in at least three villages the high priests also operate as goldsmiths as well as being practising blacksmiths. After these rituals, the blacksmiths gather in the temple courtyard and help each other in tying the fresh, turmeric-dipped, sacred thread. Finally, they tie sacred threads on their working implements (Fig. 7), which appear to be extensions of a blacksmiths' body and rejuvenated through endowment of divine power and the blessings of the goddess. This is followed by the inauguration of the smithy in individual workspaces. This is done by hitting the anvil in three sets of five, first by the eldest family member followed by others according to age (Fig. 8). Then, while the eldest smith is required to light the hearth and manufacture an agricultural implement, the next in line operates the fan bellows (hand-turned). Finally, the junior apprentices of the family carry the newly produced implements to the houses of the farmers, who, in turn, are required to offer rice, pulses, turmeric and garlic in exchange for the implements. Thus the long-standing relationship with the farming community is renewed through a ritual contract.

Fig. 8 The first five strikes on the anvil by the senior blacksmith during the annual renewal festival

Conclusion

The above account comprises preliminary observations made during the 2010 Telangana field season. While further in-depth ethnoarchaeological research is required to resolve a detailed picture of the past community and the industry, it is evident that the opportunity remains to gather important social and technological data on past and surviving traditional communities and practices.

Archaeometallurgy in the Telangana region: a GIS approach

Ioana A Oltean, MB Rajani and NS Nalini

Geographic background of the study area

Telangana is located in the middle of the Indian Peninsula on the Deccan Plateau (Fig. 1). This region is divided between the fragmented upland topography of the Eastern Ghats mountains and the relative flatness of rolling peneplains. In the area of the latter, solitary granite relict hills produce stark visual contrast across the landscape. Two major rivers, Godaveri and Krishna, flow eastwards from their source in the Western Ghats of Karnataka and Maharashtra, across Telangana towards their combined delta on the Bay of Bengal coast (Singh 1971). The present study covered the northern part of the Telangana, where the Godavari and its tributaries articulate the natural and living landscape. Except for Parasurampalli some 80km away to the south-east in the Warangal district and Gopalpur 40km south, most of the survey has taken place in a condensed area of some 60km by 70km, with a central core area of c. 30km diameter, along the Godavari valley, mostly within the Adilabad and Karimnagar districts and into the border of Nizamabad district.

Fig. 1 Location of survey area

The study area enjoys a typical monsoon climate and is covered mainly by moist deciduous forests and agricultural fields. The area is occupied by numerous villages of various sizes, with only a few urban centres (Jagtial, Koratla, Lakshettipet, Warangal, Karimnagar, etc.). Today, Telangana represents the northern part of the state of Andhra Pradesh. However, unlike Andhra along the coast and Rayalaseema inland, Telangana has been for some 400 years a part of Hyderabad, an independent kingdom ruled by Islamic Qutb Shahi and Nizam dynasties. The Andhra plateau has been inhabited for several millennia before the current era and with

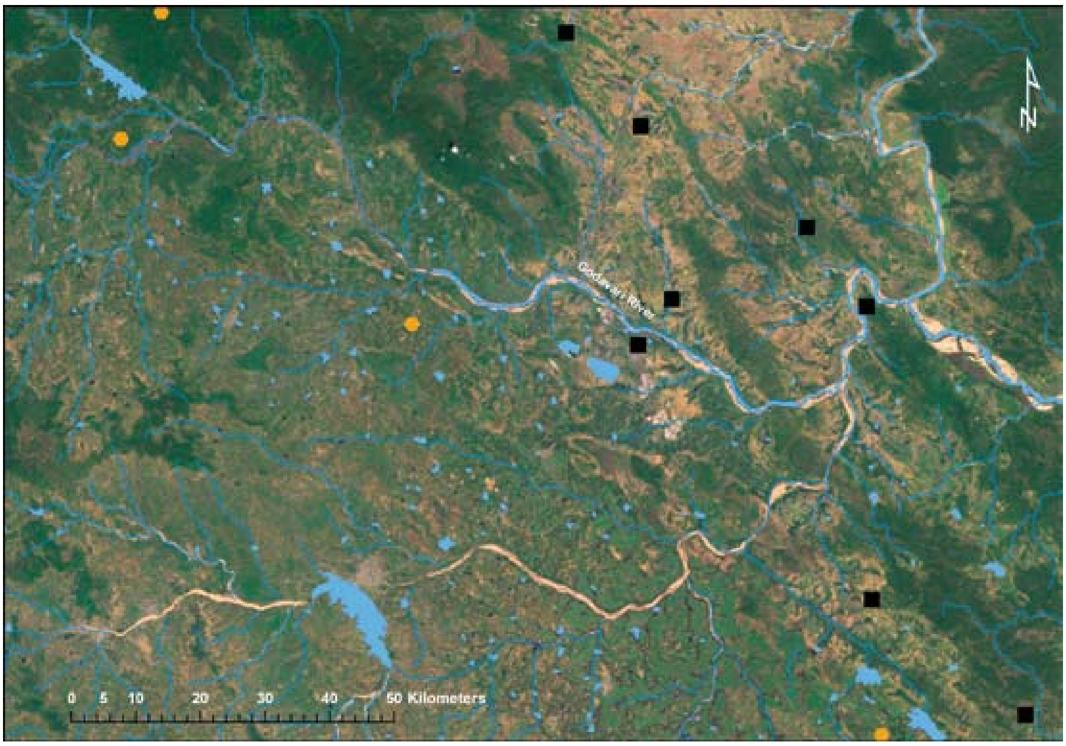


Fig. 2 Location of previously known large iron and coal resources in mid-Godaveri river basin (Iron: orange hexagons; coal: black squares)

some 30 fortified towns and large population by the 1st century CE. However, the region remains until today largely rural with its capital at Warangal since the mid-11th century (Singh 1971). This settlement pattern was noted in Arab accounts of India which also record a rapid demographic increase, from their conquest in the early 14th century, from just under one million to over 3.5 million inhabitants. Since then and throughout the 16th-17th centuries numerous water reservoirs have been constructed across the landscape to irrigate agricultural land and support the growing population.

Although Telangana was in the past connected to distant centres by roads and a postal service (Zaki 1981) by comparison with other areas of Andhra Pradesh it remained a remote and less developed region. Nevertheless, over and above the rich resource for mineral deposits, relevant to the focus of this project and for which the region is renowned, Andhra Pradesh has valuable coal resources (Fig. 2). Although hematite deposits have been identified and the estimated regional resource is up to 51 million tonnes, most iron ore occurs as banded magnetite deposits, with resources of probably as much as 418 million tonnes. The ore occurrence in the Adilabad district is generally associated with Gondwana rocks or quartzites, but within the area surveyed the main ore type is banded hematite quartzite (in Chityal and Kalleda). In Karimnagar, iron ore is contained in the Yerabali ferruginous quartzite. In Warangal, ore comes mostly from Pakhals (where haematite occurs in shales, slates and phyllites intercalated with limestone) and Dharwars (banded magnetite-hematite) (GSI 2006).

The archaeological GIS

Throughout time, humans as individuals and as communities have never lived and performed activities in complete isolation from their natural or cultural environment. The development of Landscape Archaeology allows us to consider past human activity in its spatial context and interpret archaeological evidence scattered across wider landscapes. In recent decades it has produced dramatic changes in our understanding of past cultures and civilizations across the world. Although it had not been applied previously in this region, it is clear that the specific natural conditions in the study area and the wider region had a significant impact on human settlement and the development of early metallurgy in Telangana and a landscape approach to data collection and analysis was appropriate.

A project database and a Geographical Information System (GIS) were built to integrate

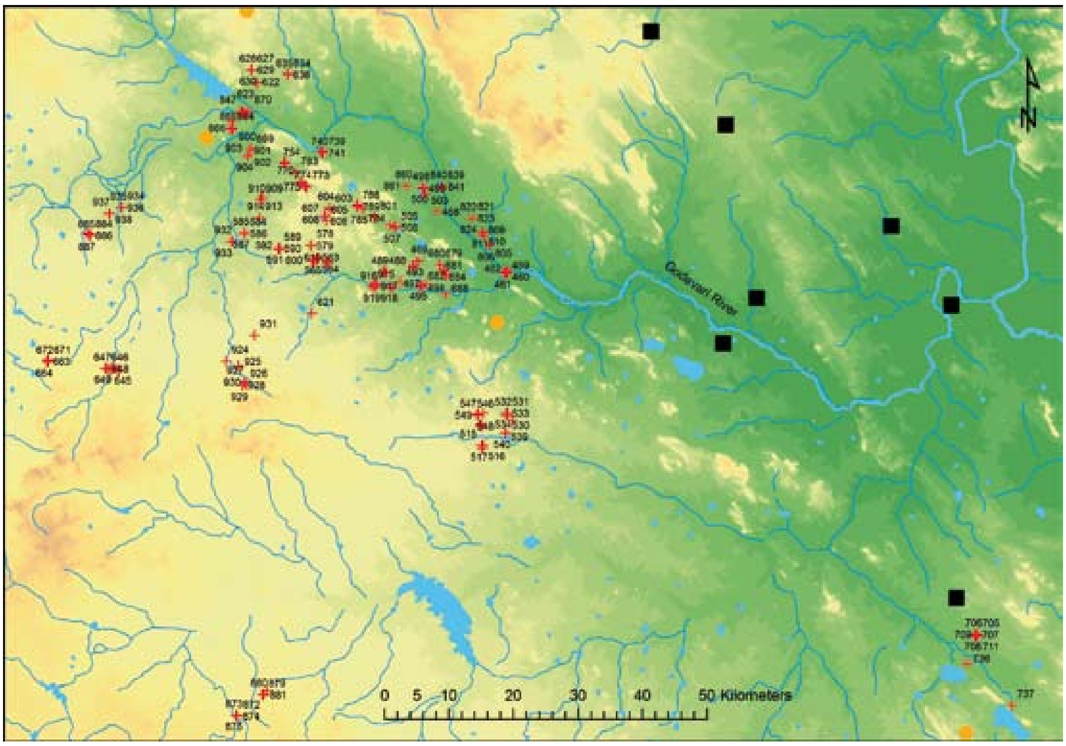


Fig. 3 General topographic context of the GPS survey points (DEM: USGS)

Fig. 4 Modern land-use on IRS_P6 LISS-IV satellite multispectral image (5.8m spatial resolution) of the area around Dharmapuri in false colouring: Blue = band 2 (green 0.52 to 0.59 microns); Green = Band 3 (red - 0.62 to 0.68 microns; Red = band 4 (Near Infrared - 0.76 to 0.86 microns)

field data with various information datasets on the natural and cultural landscape of the study area in order to allow appropriate data management and to perform a variety of spatial analyses and extract new interpretations (Fig 3).

GPS survey data

At the fieldwork stage relevant site locations identified by the project survey team were visited on the ground and data collection included GPS survey using a hand-held device (Garmin E-trex Vista HCX). In each location several GPS points were taken, resulting in a total of 449 separate points. Their identifiers and coordinates were included in the field notes alongside site description and sample recording. Points were downloaded to the computer on a daily basis and organised according to date and location (see figure 2, Juleff *et al*, this volume). Depending on the material identified at each location, preliminary analysis allowed identification of five categories: ore deposits, mining, smelting, processing and crucible sites. These classifications were later dissolved and new classifications emerged as the project progressed and the data were analyzed.

Background datasets

General background information related to the modern natural and socio-cultural environment has relied on a range of available satellite and cartographic sources. Images of the study area from the Indian Remote Sensing satellites (IRS) were made available to the Bangalore-based team (Table 1 and Fig. 4). Full coverage of Survey of India topographic sheets for the area at 1:250,000 is held by project partners with additional material at 1:50,000 available in Bangalore. Also, a variety of satellite and cartographic data freely available over the internet have been downloaded by both Exeter and Bangalore teams and creatively used to supply background information to this study. Separate digital layers for the study area of Elevation Model (DEM) and water bodies at 90m ground resolution were downloaded from USGS (http://www.usgs.gov/). In addition we used free ESRI-user cartographic resources and satellite imagery of sub-metre to 20m ground resolution from Google Earth™.

Table 1: Technical parameters of the IRS satellite imagery

Satellite/Sensor	*Spatial resolution in m*	*Spectral resolution in µm*	*Swath in km*	*Date*
IRS-P6, LISS-III	23.5m	Band 2: 0.52 - 0.59 Band 3: 0.62 - 0.68 Band 4: 0.76 – 0.86 Band 5:1.55 – 1.70	141km	16 Oct 04 13 Feb 05
IRS-P6, LISS-IV	5.8m	Band 2: 0.52 - 0.59 Band 3: 0.62 - 0.68 Band 4: 0.76 – 0.86	24km	20 Jan 06 3 Feb 07 27 Feb 07 14 Mar 04 24 Feb 04
SRTM DEM	90m			

Software

The project design was based on building a project GIS using the market leader ArcGIS software (ESRI). Though this software was available at Exeter, the Bangalore team succeeded in acquiring a license only late, therefore their initial analyses were made using *Geomatica* 10.3 (PCI Geomatics Inc). This is primarily a desktop software package for advanced analysis and processing of raster-type earth observation data such as satellite and aerial imagery, but is able to integrate point data within these analyses and convert to different formats including ArcGIS-compatible shapefiles. GPS waypoints were downloaded and organized through Garmin's MapSource and GPS TrackMaker. In the next step they were brought as text files into Geomatica and in Erdas softwares for viewing the distribution of the five initial location categories against Indian satellite multispectral imagery and the DEM by the Bangalore team.

The 1:250.000 topographic maps, which in Geomatica were not added to data views due to their different map projection and coordinate system from the standard UTM-WGS of the other datasets have been subsequently integrated in Exeter's ArcGIS project file, alongside SRTM data, geo-referenced ground survey information from the project database and ESRI user satellite imagery and cartographic layers. Survey points were also overlaid on Google Earth™ to understand local topography, land-use and site context and, whenever possible, identify any features such as slag heaps, ruined structures or enclosures which may bring additional archaeological knowledge (Fig. 5). An immediate priority will be to bring relevant imagery from Google Earth into the GIS in order to allow feature mapping and advanced possibility for comparison with other datasets.

Fig. 5 Distribution of field survey GPS waypoints and interpretative sketch of extant archaeological features visible on Google Earth GeoEye™ satellite imagery of 5 April 2009 at Buggaram (Karimnagar); the context for what it appeared on the ground to be a series of separate locations for smelting and ore processing is in fact a settlement.

Preliminary observations

Preliminary statistics from the already processed data indicate 183 locations in the study area were categorised as previously involved in metallurgical production, with additional location groups including ethnographic and geological; prehistoric and historical; or single findspots. Although data analysis is not yet complete, location size (small/medium/large) and preservation status (primary/disturbed/secondary) of the various site types identified will be used to characterise the archaeological landscape. The definition of more precise site sub-types based on the technological processes will emerge when the total database has been compiled but preliminary observations indicate a spread of locations with evidence for smelting and crucible steel, sometimes in combination or close proximity (Fig. 6).

Difficulties of data collection in the field do not always allow full appreciation of site complexity. Proximity analysis and clustering patterns of surveyed locations can give indication of potential activity aggregation. In some cases, (e.g. Fig. 5), satellite imagery indicated with certainty that separate locations registered on the ground were part of a single large site.

Most of the smelting and crucible steel sites were found at lower altitudes, whereas ore deposits are higher. Also, most evidence for steel-making crucibles comes from

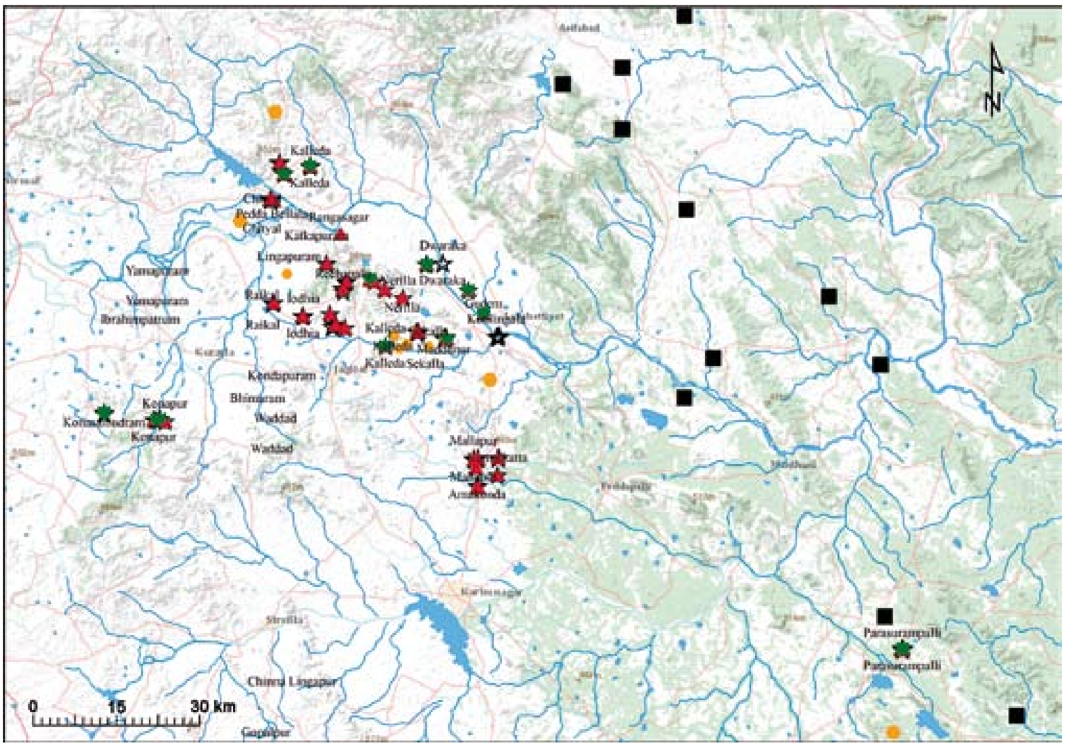


Fig. 6 Distribution of smelting locations (red triangle) and crucible-steel locations in the study area in relation to local topography and resources (larger sites marked by stars).

larger complexes, and across the full dataset there is a tendency towards medium to larger sites. This may reflect the ready visibility of larger sites and thus a bias in the survey. Future work will complete the location database to realise its full utility as an interpretive tool to understand the socio-cultural aspects of iron and steel production in the study area.

Telangana Field Survey: post-survey analysis of field data

G Juleff, Sharada Srinivasan, S Ranganathan, S Jaikishan and B Gilmour

In our attempt to understand the nature of the development of iron and steel-making in Northern Telangana rigorous detailed field recording has given us a number of strong datasets that include evidence on landscapes, environment and geology; settlement character, distribution and histories; technologies; and ethnographies. The data has the potential to provide us with a near-complete picture of the technological development and cultural impact of iron and steel production in the area surveyed and by extrapolation in neighbouring regions. The data has been distilled into four distinct themes; landscapes, locations, collected material and ethnographies, and schematic pathways leading through their treatment to interpretation devised (Fig. 1).

Work on these datasets since the field survey has followed a methodology of systematic digital archiving, deconstruction of the data into component elements and cross-correlation of datasets. The primary products of this process are permanent project archives which will be accessible through a conventional gazetteer of sites and a more

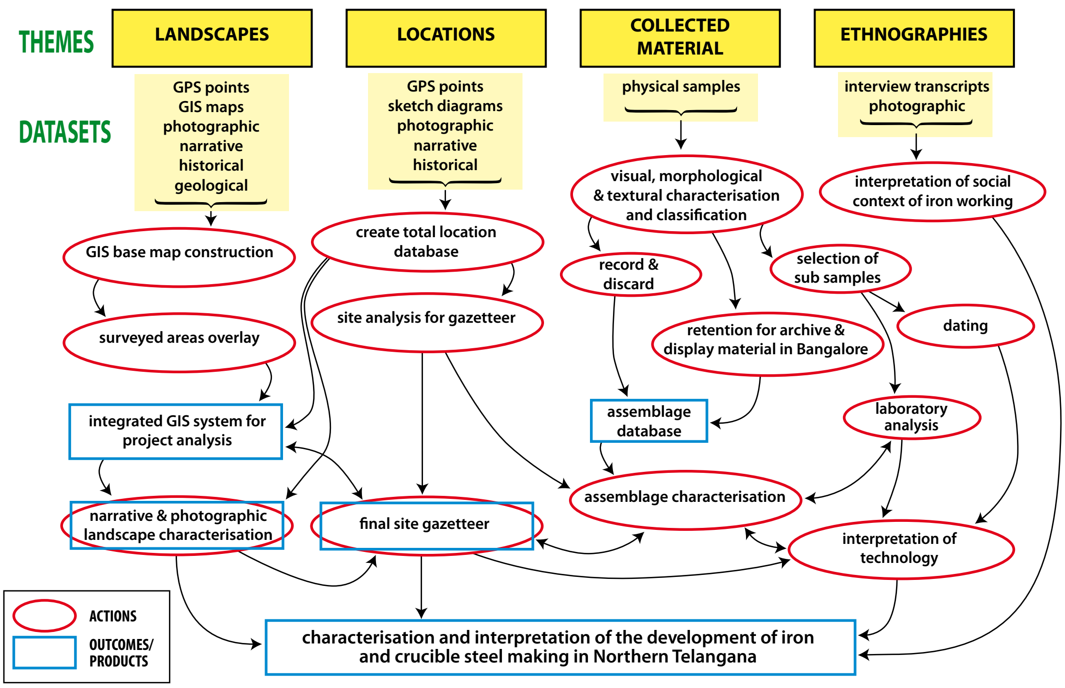


Fig. 1 Schematic approach to the post-survey treatment of data showing progression through the four key themes

interactive GIS system. These in turn will provide material for broad interpretational syntheses of iron and steel production and reconstructions of regional technologies. Here we will describe the methodological approaches adopted in collating and analysing the datasets and summarise some preliminary observations.

Treatment of location data

On returning from the field the primary source of data comprised the hand-written narratives in the project notebooks and diaries, with the supporting GPS logs. The first task was to transpose this into a digital form and create discrete 'location' records. (The treatment of the GPS data has been described elsewhere (Oltean *et al*, this volume).) A proforma location record form was designed onto which information culled from the diaries and other survey archives could be systematically re-ordered to capture four tiers of data: locational and administrative, e.g. GPS positions, district and local place-names, location description, cross-references to project diary pages; site description, including landscape setting, site type and sub-type, size and condition of the site or deposit and general descriptions of features and visible assemblages; sampling level and collected material giving cross-references to sample register numbers; and cross-references to other relevant sources, e.g. photographs, maps, documentary sources and interview records (Fig. 2). The final entry on the form, associated date/location records, provides a first opportunity to identify site groupings based on proximity or shared features or assemblage traits. Information has been added to these forms incrementally and many fields will only be completed on detailed survey-wide analysis. For example, site sub-types have yet to be fully defined, although patterns are emerging from the data. Also, the provision for a new site number will only be used on the final collation of the records into a gazetteer, when some may be amalgamated and some removed, such as records for secondary incorporation of slags in the fabric of a wall in proximity with records for a primary deposit of similar slag within a village compound.

Throughout the process references to the field archive material have been retained so that it is possible to re-examine the original notes. Under sampling level the annotations S and P record that samples were collected from the location or that a sketch plan was drawn in a field notebook. Of the 245 locations some form of plan was drawn at 123, i.e. 50%, and only at 23 locations were no samples collected. Entries under 'technological debris sheet no.' indicate that material from the location has been described using the classification scheme and 'Ref. material' indicates that physical samples are stored at NIAS in Bangalore (see Cox and Haricharan, this volume). The information compiled

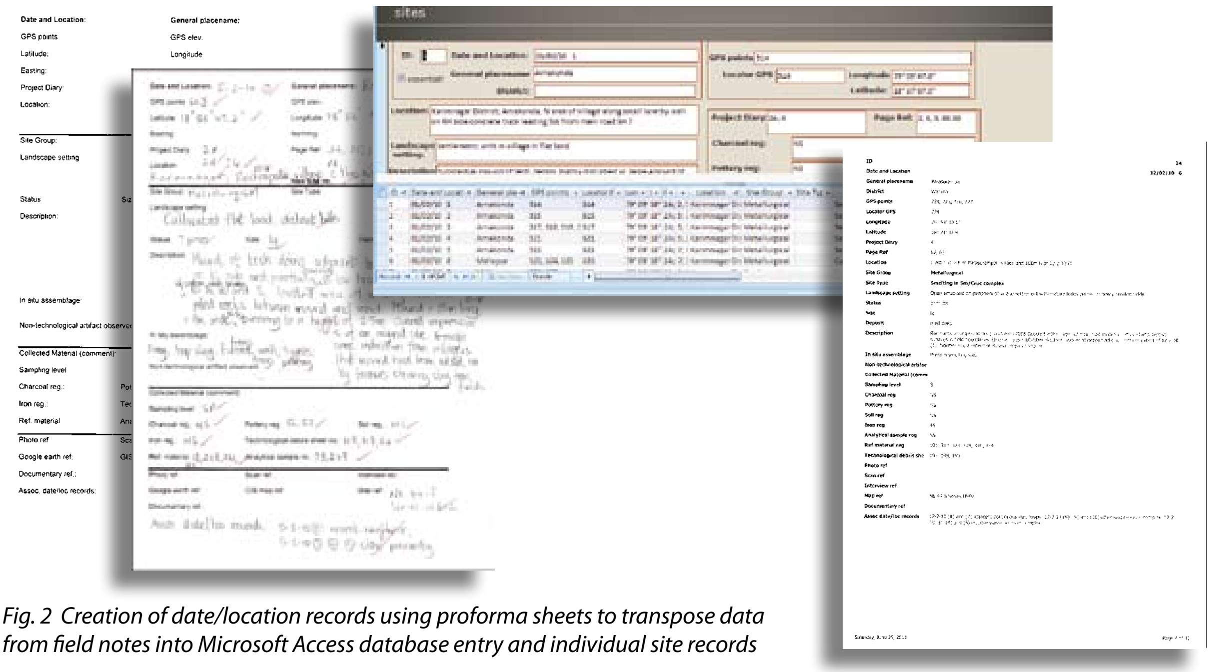


Fig. 2 Creation of date/location records using proforma sheets to transpose data from field notes into Microsoft Access database entry and individual site records

on the location record proforma sheets was then transferred to an Microsoft Access database containing the same entry fields. This, in turn, has been fed into the GIS system established for the project (Oltean *et al*, this volume). Once completed, it will be possible to generate individual site records from the database to form a publishable gazetteer of sites for the survey (Fig. 2).

Preliminary observations on the metallurgical sites

Of the 245 locations recorded, 183 are associated with metal-working and fall within the metallurgical group of sites. The preliminary observations made here relate to this component of the record. Reaching the ultimate project objective of characterisation and interpretation of the archaeometallurgical record of Northern Telangana requires integrating data from both the locations and the collected material datasets and observations here also draw on the macro-morphological analysis of the technological debris (Cox and Haricharan, this volume).

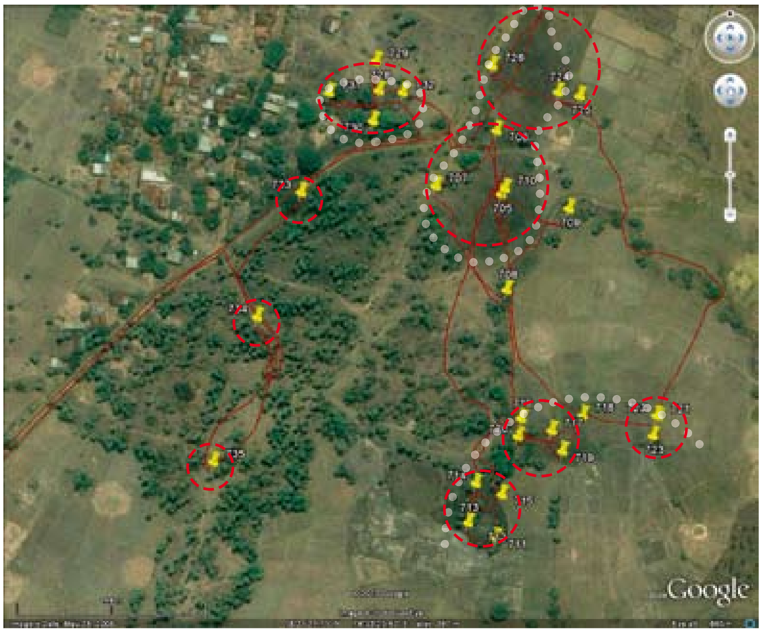


Fig. 3 Parasurampalli, working interpretation of a large smelting and crucible steel complex

By using the system of location records decisions on assigning 'site' status remains open to interpretation. It is clear from the records that frequently locations group together in complex sites made up of separate elements or sub-sites. These separate elements may be differentiated by technological processes, e.g. smelting and crucible steel making, or they may all display the same technology distributed over several loci, as in a group of slag heaps. Determining how the elements within a complex site relate to each other is one of the tasks of interpretation. Is the separation chronological and does it reflect development over time, or is it social and reflects the working practices of different family groups, or does the explanation lie in technological considerations? One example of a large metal-working complex is that at Parasurampalli in Warangal district (Fig. 3). In an extensive area of toddy palm cultivation on the edge of the present village 10 locations were recorded. These included large but badly damaged slag heaps, well-preserved discrete deposits of crucible fragments and possible peripheral scattered spreads of secondary material, which may equally represent remnants of *in situ* slag heaps. Combining macro-morphological data with location data it is possible to propose a division between smelting and crucible steel with the later forming an arc of activity at one extreme of the complex with large-scale smelting occupying a more central position. Several other examples of such complex sites exist.

At site sub-type level technological processes will be the determining factor, with the primary distinction being between smelting, smithing and crucible steel. Without introducing numbers of sites that may later be superseded, it is clear that the overall record is dominated by smelting, with crucible steel sites forming in the region of 20% of the record. Only two possible smithing sites were identified, both small and associated with past settlements. Undoubtedly other smithing sites exist but macro-morphological analysis did not identify typical assemblages. Macro-morphological analysis did however define clear patterns, both in terms of diversity of forms and their distribution, in the technological debris for smelting and crucible steel making. Slags form the largest body of material examined and these are dominated by material derived from furnaces capable of slag-tapping (removing the molten slag from the furnace during smelting). A small number of sites display assemblages that do not include tap slags and slag appears to have cooled inside the furnace. The distribution of both types appears at present to be

Fig. 4 Heap of complete furnace base slags from small diameter furnace

dispersed across the survey area with no identifiable concentrations. One notable site of the non-slag tapping type is that at Buggaram, Karimnagar distrtict (see Fig. 5, Oltean *et al*, this volume). In a small number of cases slags with very distinct persistent morphologies were observed (Fig. 4).

Of the furnaces themselves, only fragmentary material remains in most cases. However, some striking consistencies across the survey can be discerned. Many furnaces are small diameter, <0.75m, and were constructed as detachable shaft structures placed over a permanent basal stone plinth (see Fig. 6 Cox and Haricharan, this volume). These basal stones were prone to heat damage and the fragmentary examples identified all bore heavy vitrification and it is possible that quartz from the granitic stone contributed to the slag forming process within the furnace. Many of these furnace shafts were formed by plastering clay around bundles of reeds or straw as indicated by striated impressions on their internal surfaces. An analogous furnace construction technique is used by the Agaria tribal smelters who are the last people in India to still smelt iron. At a small number of other sites coil-built furnace wall fragments were clearly identified (Fig. 6). One of these sites was Buggaram and possibly reinforces Dr Jaikishan long-held view that this site is one of the earliest in the area by analogy with a coil-built furnace at the megalithic site of Naikund, Maharastra (Jaikishan, this volume).

Fig. 6 Coil-built furnace wall (exterior view)

Tuyeres (the pre-fired clay tubes used to channel air into a furnace) form one of the largest and most visibly prominent components of the technological debris and the material examined divides into three distinct forms. The forms are based on size and range from exceptionally large tuyeres, through medium-size to very small tuyeres. The large tuyeres are thick-walled and parallel-sided and often have an internal bore of >5cm (Fig. 7). They are the smallest group of tuyeres but they occur widely across the survey. In general they are most closely associated with sites where crucible steel making is evidenced but this is not exclusive. The largest group of tuyeres are the medium-sized examples. These can vary considerably in degree of taper, overall length and construction method but overall they are of medium wall thickness, tapering or flaring and can be very heavily damaged by vitrification. Many have large segments of vitrified furnace wall remnants adhering to them and give the impression of high-temperature, dynamic

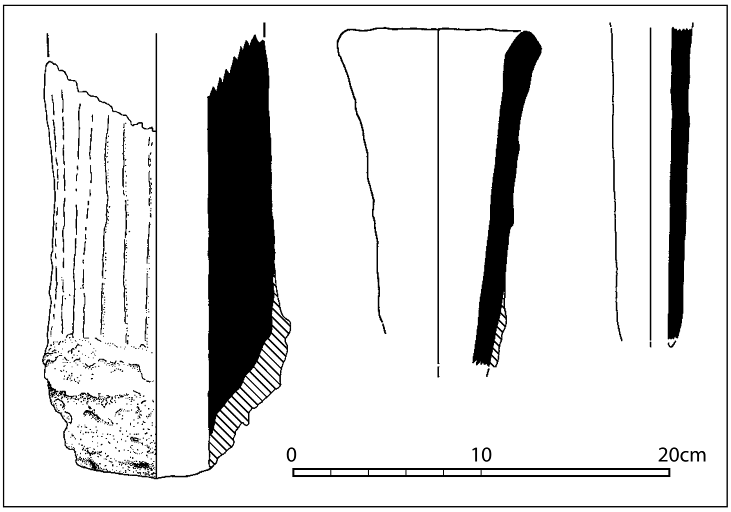


Fig. 7 Examples of the three forms of tuyere found during survey

Fig. 8 Example of large, conical crucible lid showing indentations caused by the tongs used to remove the crucible from the furnace

Fig. 9 Thin-walled crucible. Scale 1:2

processes (Fig. 7). They are predominantly associated with smelting sites. The third group of tuyeres are the very small. While these can vary in size they are all parallel-sided and are less heavily vitrified than the medium-size tuyeres (Fig. 7). Their distribution is not widespread but on the sites where they do occur they appear in abundance. Preliminary analysis suggests they are associated with sites with non-slag-tapping assemblages.

Finally, it has emerged that the crucibles fall into two distinct type groups. The first of these is well known as the material commonly seen at Konasamudram but which occurs on a number of other sites. These crucibles are thick-walled and have disproportionally large conical lids that are luted and fused onto the crucible body. The lids consistently show tong indentations indicating that individual crucibles were handled (removed from the furnace) while still soft (see Fig. 4, Jaikishan, this volume). These crucibles can vary significantly in size and span from c. 3 to 15cm in diameter, but with a clear tendency towards the large end of the scale (Fig. 8). The second and larger group, in terms of site distribution, comprises more standardized small to medium-sized thin-walled crucibles (Fig. 9). The lids of these thin-walled examples are also luted onto the body of the crucibles but they are not of the large conical form. These crucibles are fired in batches stacked into a furnace, as opposed to the Konasamudram type that are handled individually, resulting in clusters of fused crucibles that have to be smashed open to retrieve the ingot material inside (see Fig. 5 Cox and Haricharan, this volume). On present assessment of the data, thin-walled crucibles appear most often to occur at sites or complexes that also include smelting evidence while the thick-walled examples occur at locations dedicated to crucible steel manufacturing.

These crucibles are fired in batches stacked into a furnace, as opposed to the Konasamudram type that are handled individually, resulting in clusters of fused crucibles that have to be smashed open to retrieve the ingot material inside.

The preliminary observations above help to set the agenda for continuing research. Interpreting technological processes from the material requires a substantial component of scientific analysis at microstructural level (Srinivasan *et al*, this volume) and this will in turn begin to correlate the field evidence for certain processes with historical accounts that refer to the mode of crucible steel manufacture, including co-fusion using locally-produced cast iron (Voysey 1832). To set these technologies within a cultural framework the task remains to overlay distribution patterns of the concurrence of the distinctive forms summarised above onto distribution patterns of sites and locations in relation to landscape features, including settlements and known ore deposits. This will require a combination of GIS and statistical analysis as well as other conventional archaeological approaches. The biggest stumbling block to fully understanding the technological and cultural development of iron and steel production in this region is the lack of chronological resolution. This is a problem common to archaeometallurgical sites and landscapes. Despite vigilance during the field survey, little directly datable artefact material was retrieved. Surface samples of pottery were collected but their occurrence is sparse and little systematic study has been made of local pottery forms in Andhra Pradesh and thus their utility for dating is limited. The future route planned will be a programme of OSL (optically stimulated luminescence), possibly augmented by TL (thermo-luminescence), dating of tuyere fragments to give potentially accurate dates for metallurgical sites.

In summary, there is only one conclusion that can be drawn from the work so far which is that there is still much to be done to reach a full characterisation of the archaeometallurgical record of Northern Telangana. Fortunately, it is clear that the body of data collected by the project holds enormous potential to achieve this.

From the macroscopic to the microscopic: some scientific insights

Sharada Srinivasan, S Ranganathan, JC Andersen and S Suwas

Metallographic and metallurgical studies help to give insights into the history of technology of metal artefacts. Debris associated with pre-industrial metallurgical activity is found in piled up mounds at sites which are referred to as slag heaps. Slags refer to the waste or by-products from the process of extraction of metal from the ore by smelting which is a pyrometallurgical process of reduction of ore to metal in a heated furnace. Slags are typically partially vitrified or in a glassy state as a mixture of oxides and silicates with minor remnants of entrapped metal. The lighter viscous slag separates from the metal and is usually tapped out of the furnace, characterised as tap slag. Tuyeres refer to the blowpipes or nozzles used to generate a draught to work the furnace.

In the bloomery process for smelting iron, a solid state iron bloom was produced; whereby the reduction of ore to iron metal took place at a temperature sufficient to reduce the ore and below the melting point of iron. Bloomery iron has a low carbon content, below about 0.04%, and this was used as wrought iron after a smithing process. In the blast furnace however, higher temperatures and more reducing conditions were reached, resulting in the formation of cast iron with higher carbon contents, going up to 2-4%, although this is a more brittle product. Crucible steel has an intermediary composition between wrought iron and cast iron, of about 1-2% carbon, classifying it as an ultra-high-carbon steel and has properties of high ductility for forging and high impact strength, making it highly suitable for weapons. It seems that in parts of southern India crucible steel was produced by a process of carburising wrought iron to hypereutectoid high-carbon steel as described by Srinivasan (1994, 2007) from Mel-siruvalur in Tamil Nadu. This has also been described as the Mysore process at sites such as Gatihosahalli as noted by KNP Rao (1989) and Craddock (1998) and described by Buchanan. On the other hand, crucible steel processes reported from parts of Andhra Pradesh such as Nizamabad are thought to have followed co-fusion or melting together of cast iron and wrought iron to get a steel of intermediate composition as described by Voysey, also known as the Deccani process which has been studied especially by Thelma Lowe (1990). The term wootz derives from the word for steel *ukku*, which may be linked to the Tamil word, *uruku* (i.e. boiling) and such terms may hark back to classical Tamil Sangam literature (c. 300 BCE-300 CE) (Srinivasan 1994).

The ethnographic record in the Telengana bears some evidence of its long tradition of skilled metal processing and metal smithy. To get an idea of the kinds of finished metal artefacts found locally, a knife typically used by the community of toddy tappers in the Telengana region, to extract toddy from the palmyra palm, was investigated at the Indian Institute of Science using metallographic and microscopic study. This knife was collected by S Jaikishan and presented to S Ranganathan. Scanning electron microscopy (SEM) was undertaken on a polished cross-section of the blunt edge of the knife as seen in (Fig. 1). This is a back-scattered electron image which gives an idea of the different phases or constituents in the

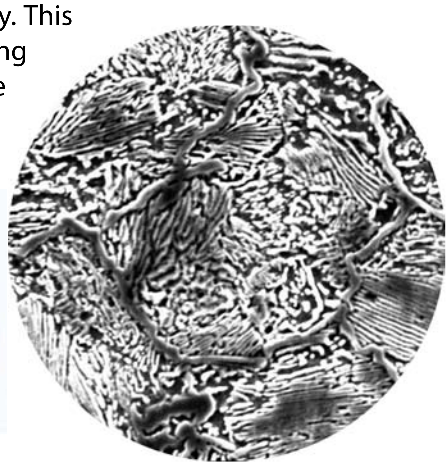


Fig. 1 Broken toddy tapper's knife from Konapuram, Nizamabad district with scanning electron microscopy image of microstructure of blunt edge (Dept of Materials Eng., IISc)

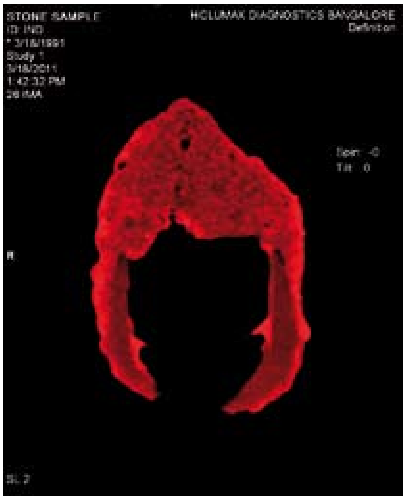


Fig. 2 CT scan slice across a crucible from Konasamudram, used in the production of crucible steel showing distinct layers of lining and luting (Indian Institute of Science, Bangalore)

metal, since the higher atomic number constituents show up brighter. The structure is clearly one of a high-carbon steel showing a network of cementite around hexagonal grains containing a matrix of lamellar pearlite (which is a mix of lower carbon ferrite and higher carbon cementite). The microstructure suggests that the carbon content is about 1-1.5%, with a characteristic structure associated with wootz steel, and such a structure is also found in a nail from Pattanam, (c. 1st century) in Kerala, excavated by KCHR (Srinivasan 2007). The Damascus blade forged of wootz steel has attracted the interest of modern material scientists in topics such as nanotechnology and superplasticity (Ranganathan and Srinivasan 2006).

Sites of crucible steel production can be distinguished by the presence of scattered broken crucible fragments left behind after the fired and intact crucibles were broken to retrieve the steel ingots. A range of analytical techniques were explored to gain more insights into the kinds of end products and the production mechanisms. One such was the medical imaging technique CT scan or Computed Tomography undertaken with the co-operation of Sajeev Krishnan, Centre for Earth Sciences at the Indian Institute of Science. A series of two-dimensional images or slices through a 3-dimensional object (i.e. a tomogram) is obtained. This is useful for non-destructive examination of heterogeneous materials like crucibles. Figure 2 shows a CT scan slice across a crucible from Konasamudram used in the production of crucible steel (location 10-2-10(2)). The different layers in the make-up of the crucible can be seen, including an inner, more homogeneous layer forming the wall of the crucible and an exterior heterogenous layer which forms a luting or covering around the inner layer. The heavily packed lid also has a large cavity in it which may have been the region through which the tongs may have been pierced to get a grip on the crucible, for example to remove the crucible once the firing cycle was completed after the ingot had formed.

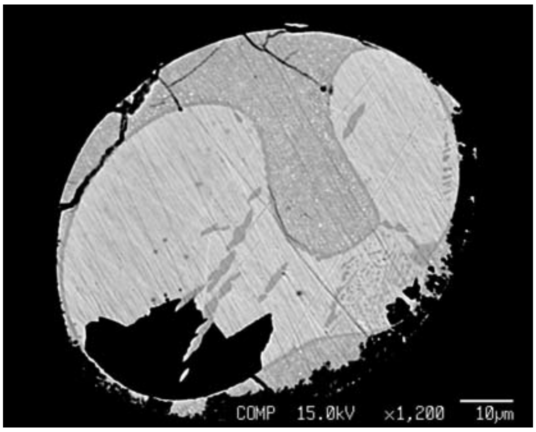


Fig. 3 Back-scatter electron image, using EPMA at CSM, University of Exeter, of green glassy slag from Waddad village showing metallic prills with structures resembling cast iron

An important study has been initiated with the use of Electron Probe Micro-analysis (EPMA-WDS) on some of the slags and crucibles undertaken in co-operation with the Camborne School of Mines (CSM), University of Exeter. In this technique a beam of electrons is fired at a polished metallurgical sample and the characteristic X-rays are analysed. This technique also enabled precise 'spot' analysis of the different phases and constituents. It was possible to analyze the glassy constituents and metallic remnants separately using a programme of separate standards and calibrations for each, one for oxides and the other for metals, and each measuring about 17 constituents including major, minor and traces. From preliminary investigations, one trend that is noteworthy is the growing evidence for the fairly well entrenched pre-industrial use of more efficient high temperature processes as seen from the finds of very 'efficient' slags and crucibles with very little metallic content left behind in them, and the evidence of very tiny globular 'prills' of ferrous metal remnants of less than 10 microns diameter. These suggest that temperatures approaching those needed to make iron molten; the melting point of iron, which is around 1500° C, can be lowered to about 1200° C under highly reducing conditions. For example, figure 3 indicates that glassy green slag from the village of Waddad in the survey area seems to have metallic prills or remnants that resemble the structures of cast iron. The lighter phase seen in the ferrous metal prill contained phosphorus-rich regions of up to 11%; iron phosphide is typically found in cast iron. This specimen also had a high calcium oxide content, up to 25%; limestone is continuously added as a flux in blast furnaces. Although blast furnace

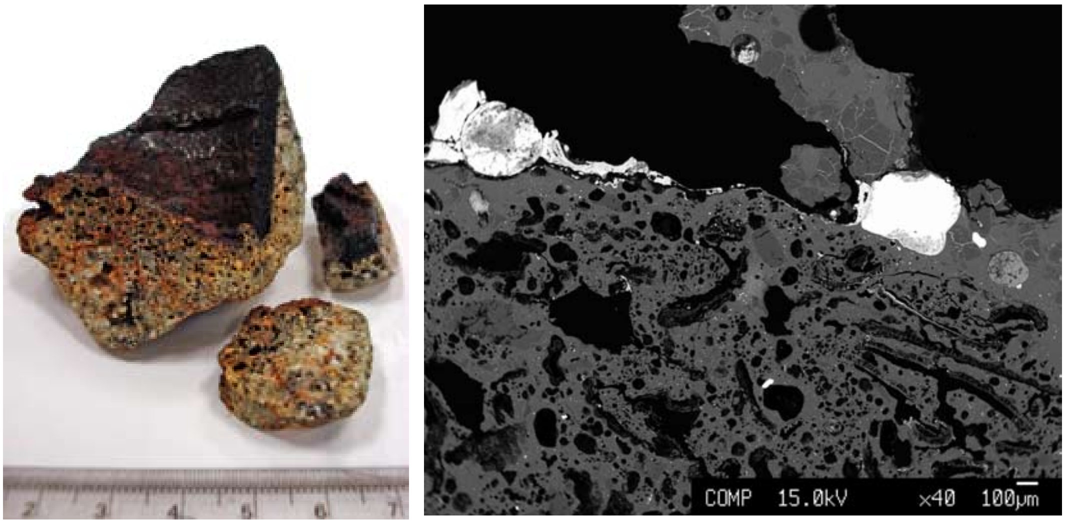


Fig. 4 Fragments of a steel-making crucible with back-scatter electron image of a section (TS-35), undertaken using EPMA at CSM, University of Exeter

technology is typically associated with China, this suggests that the prevalence of this technology in the pre-industrial Indian context may also need to be more thoroughly explored.

Some insights into the making of the crucibles for steel production could also be gained. It seems that the inner wall described before was especially well packed with rice hull relicts. These, when charred, would have contributed to the reducing conditions and refractory properties, being rich in carbon and silicon. In contrast, the outer luting or covering of the crucible had much more of quartz or siliceous fragments which seems to have been intentional to make the outer layer more refractory, as quartz has a high melting point, to enable the crucible to resist melting down. This is a trend also noted in some other studies on south Indian wootz crucible processes mentioned before by Lowe (1990) and Srinivasan (2007). The outer luting in particular in certain specimens was also seen to contain minerals like zircon, or zirconium silicate, confirmed by EDAX, and is reported to be found in sands in Andhra Pradesh, especially beach sands on the east coast. Zircon itself is used in modern metallurgical purposes and is described as a super-refractory material with a very high melting point. Of course, further bulk analysis would be needed to assess the proportion of such minerals in the fabric of the outer luting. Figure 4 shows a section of a crucible from crucible steel production showing entrapped ferrous metal remnants along the lining of the crucible, which is more siliceous and glassy, while the inner wall of the crucible is packed with several charred rice hull relicts in the matrix. Zirconium rich minerals are represented by tiny bright specks. Figure 5 is a dotmap for the relative elemental concentration of silicon across this section highlighting some of these aspects.

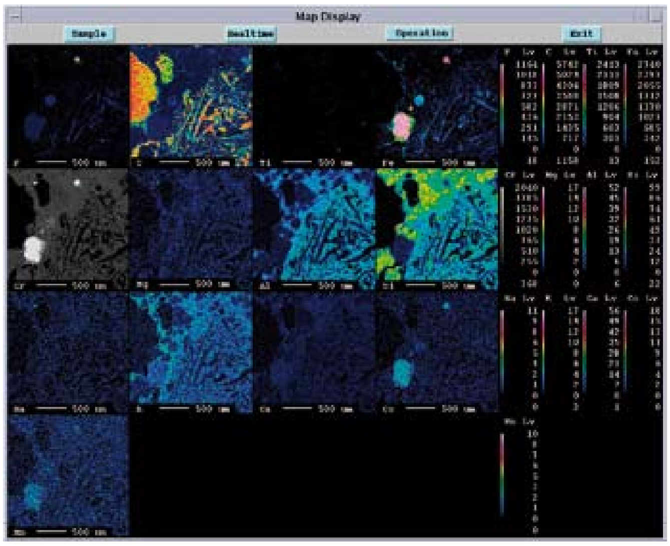


Fig. 5 Elemental concentration maps across section of crucible (TS-35) for P, C, Ti, Fe, Mg, Al, Si, Na, K, Ca, Co, Mn; undertaken using EPMA at CSM, University of Exeter

Further investigations are underway on ore specimens at Camborne School of Mines. Explorations are also being made on attempting to date sediments using Optically Stimulated Luminescence (OSL) dating with five samples collected in collaboration with CP Rajendran, associated with Indian Institute of Science and given to Wadia Institute for study. Investigations are also being made in collaboration with Research Laboratory for History of Art and Archaeology, University of Oxford.

REFERENCES

Allan, J. and Gilmour, B. (2001) *Persian Steel, The Tanavoli Collection*, Oxford University Press

Craddock, P.T. (1998) New light on crucible steel in Asia, *Bulletin of the Metals Museum*, 29: 41-66

Craddock, P.T. (2007) Cast Iron: the elusive feedstock of crucible steel, *Indian Journal of History of Science*, Indian National Science Academy, New Delhi, Vol.42(4): 593-607

Deo, S. B. and A.P. Jamkhedkar. (1982) *Excavations at Naikund, Bombay*: Department of Archaeology and Museums, Govt of Maharashtra

Lord Egerton of Tatton. (1906) (reprinted 2001) *A Description of Indian and Oriental Armour*, New Edition, Asian Educational Services, New Delhi

Feuerbach, A., Balasubramaniam, R. and S. Kalyanaraman. (2007) On the origin of the terms wootz, Hinduwani and Pulad, *Indian Journal of History of Science*, Indian National Science Academy, New Delhi, Vol. 42(3): 377-386

Geological Survey of India, (2006) Detailed information dossier (DID) on iron ores in India, *Geological Survey of India*

Hoyland, R and Gilmour, B. (2006) *Medieval Islamic Swords and Swordmaking: Kindi's treatise 'On Swords and their kinds' (edition, translation and commentary)* Gibb Memorial Trust, Oxford

Jaikishan, S. (2009) *Iron and wootz steel industry in northern Telangana*. Telangana Jagrithi, Hyderabad

Juleff, G. (1998) *Early Iron and Steel in Sri Lanka: A Study of the Samanalwewa Area*. AVA-Materialien Bd 54, von Zabern, Mainz

Lowe, T. L. (1990) Indian iron ore and the technology of Deccani 'wootz' production. *Proceedings, Iron paleo-metallurgy and cultures International Symposium*, Belfort, France (ms)

Lowe, T.L. (1990) Refractories in high carbon iron processing: A preliminary study of Deccani wootz making crucibles, in Kingery, W.D. (ed), Ceramics and Civilization, *The American Ceramic Society*, Pittsburgh, 237-250

Mauss, M. (2009) *The Gift: the form and reason for exchange in archaic societies*, Routledge, London

Rao, K. N. P. (1989) Wootz-Indian crucible steel, *Metal News*, 11, 1-6

Rao, K.P. (2010) Excavations at Gachibowli: A Preliminary Report, Puratattva, *Bulletin of the Indian Archaeological Society*, New Delhi, No. 40

Raja Reddy, D. (1984) Un-inscribed coins of Andhra. *The Numismatic Society of Hyderabad*, Abids, Hyderabad

Ranganathan, S. and Srinivasan, S. (2006) A Tale of Wootz Steel. *Resonance - A Journal of Science Education*, Vol. 11. No. 67-78

Sawyer, F. E. (1884) '"Old Clem" celebrations and blacksmiths' lore' in *The Folk-Lore Journal*, vol. 2(11): 321-329

Shastry, P. V. P. (1996) *Rural Studies in Early Andhra*. VR Publications, Hyderabad

Singh, R.L. (ed.) (1971) *India: a regional geography*, National Geographic Society of India

Srinivasan, S. and Ranganathan, S. (2004) *India's legendary wootz steel: An advanced material of the ancient world*. National Institute of Advanced Studies and Indian Institute of Science, Bangalore

Srinivasan, S. (1994) Wootz crucible steel: a newly discovered production site in South India. *Papers from the Institute of Archaeology*, 5: 49-61. London: University College London

Srinivasan, S. (2007) On higher carbon and crucible steels in southern India: further insights from Mel-siruvalur, megalithic Kodumanal and early historic Pattinam, *Indian Journal of History of Science*, 42.4: 673-95.

Tavernier, J-B. (2001) *Travels in India*, V. Ball (trans), 2nd edition, William Crooke (ed), Munshiram Manoharilal Publishers Pvt. Ltd., New Delhi

Thevenot, J. de. (1949) *Indian travels of Thevenot and Careri,* S. N. Sen (ed), National Archives of India, New Delhi

Thomas, P. J., Nagabhushanam. P. and D. V. Reddy. (2008) Optically stimulated luminescence dating of heated materials using single-aliquot regenerative-dose procedure: a feasibility study using archaeological artefacts from India, *Journal of Archaeological Science*, 35: 781-790

Toussaint, F. (2002) Iron and Steel in ancient India, in Tradition and Innovation in the *History of Iron Making, An Indo European Perspective*. Pande, G. and Jan af Gijerstam (eds), 39-46

Voysey, H.W. (1832) Description of the native manufacture of steel in southern India, *Journal of the Asiatic Society of Bengal*, Vol I: 245-247

Zaki, M. (1981) *Arab Accounts of India (during the fourteenth century)*, Delhi