# ANTIQUITY OF IRON

*Recent radiometric dates from Tamil Nadu*

**GOVERNMENT OF TAMIL NADU**
**DEPARTMENT OF ARCHAEOLOGY**

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**K. Rajan**
**R. Sivanantham**

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**M.K. STALIN**
*Chief Minister of Tamil Nadu*

# FOREWORD

As the archaeological investigations undertaken for more than half a century in Tamil Nadu to identify and map the potential industrial sites that were actively involved in metallurgy, gemstone cutting, boat building, pearl fishing, textile production and glass making met with encouraging results. These results were treated as specific inputs to understand the exact role played by each technology in shaping Tamil society. Long survivals of these industries, irrespective of vast industrialization, induced the authors to record and document this traditional craftsmanship as they had a direct bearing in understanding the history of science and technology. This technological advancement had a direct bearing on trade, both internal and international and overall social and economic development. The Sangam literature and foreign accounts elaborate on the existence of iron metallurgy, gemstone cutting, pearl and chank fishing and many other technological aspects in the early historic period. The technological know-how and social developments are interrelated. It interacts directly with society and decisively shapes it.

Therefore, understanding the significance of resource zones that sustained the pre-industrial metallurgical operations is one of the critical factors in the development of a society. The utilization of a particular raw material in the production of luxury, prestige, utilitarian or ritual items was conditioned by the supply and demand-based factors such as the functional value of the item, the level of material development in society, direct or indirect access to strategic resources, the possession of suitable technology for resource extraction and production including the existence of an exchange mechanism facilitating the movement of raw material and finished products.

Thus, the Government of Tamil Nadu felt it was necessary to bring traditional technological wealth through target-oriented archaeological explorations and excavations. The recent scientific dates encountered in the excavated sites at Adichchanallur, Sivagalai, Mayiladumparai, Kilnamandi, Mangadu and Thelunganur demanded a fresh look at earlier assumptions. Now the introduction of iron is securely placed in the first quarter of the $4^{th}$ millennium BCE i.e., our antiquity of iron pushed back to 5300 years. We are glad to place recent evidences obtained through sustained efforts of the archaeologists to the general public to measure and appreciate the cultural heritage of this great nation.

**(M.K. STALIN)**


SECRETARIAT,
CHENNAI-600 009.

DATE 02.01.2025

## THANGAM THENNARASU

*Hon'ble Minister for Finance, Environment &*
*Climate Change & Archaeology,*


# FOREWORD

The high level of Indian metallurgical and technological skill achieved since ancient times has been reflected in our artefacts. The iron pillar standing without any process of rustication in the open air for centuries at Qutub Minar in Delhi, the impressive beams used in temple architecture at Konark and the famous Dhar pillar are some of the specimens reflecting the high level of technological skill obtained by our forefathers. These material evidences received much greater attention from the Europeans particularly to steel as a prelude to the Industrial Revolution. European interest in Indian iron dates from the Graeco-Roman period, or more correctly, the Hellenistic-Roman period. Initially, the focus was concentrated on the date of the introduction of iron and technical aspects. All the investigations resulted in fixing the date around the $2^{nd}$ millennium BCE. However, The recent investigations carried out at Adichchanallur, Sivagalai, Mayiladumparai, Mangadu, Thelunganur, and Kilnamandi demanded a fresh look at earlier assumptions. The scientific dates securely placed the introduction of iron in Tamil Nadu in the time bracket of 2953 BCE and 3345 BCE. The Government of Tamil Nadu felt it was a breakthrough in the relentless pursuit of understanding the cultural and technological advancement in the field history of science and technology. Above all, the metallographic analysis carried out on the sword collected from Thelunganur in Mettur taluk of Salem district throws fresh light on the origin of high-carbon steel in south India. The introduction, adaptation, production and expansion of iron and steel had wider implications for our social development. The direct linkage between iron technology and urbanisation needs to be studied very closely. In the same way, the control over the mode of production, distribution, absorption, and technology played a significant role in shaping society. The pride in understanding the achievement of our forefathers in every aspect of social and technological life is important to take corrective measures and to plan our future. I congratulate all the scholars, scientists and field archaeologists involved in this momentous and monumental task.

(THANGAM THENNARASU)

**T. UDHAYACHANDRAN, I.A.S.,**

*Principal Secretary to the Government of Tamil Nadu,*
*Finance Department and Commissioner of Archaeology*

# FOREWORD

The study of the history of science and technology is one of the fascinating subjects in the field of archaeology. The development of science and humans' ability to manipulate or transform science into technology is a captivating moment in the long human history. Science and technology serve as a catalyst in cultural, social, economic, and political development. The conceptual theories and application of those theories into practice are considered science and technology in the academic world. The technology part of human history received much attention among archaeologists to unravel the technology-based human development. Among various technologies, iron technology received special attention due to its exponential impact. The search for the origin, growth and spread of iron technology remained a speculative part of human history. Initially, it is believed that iron technology originated in Asia Minor around the first millennium BCE and moved over to other parts part of the world rapidly as part of technological diffusion. This diffusion-based unicentric theory is challenged and many scholars advocated a multicentric approach. Every nation deployed their scientific forces in identifying the antiquity of iron and India is no exception to this programme. Several metallurgists and archaeologists tried hard to establish the origin of iron in India and safely placed them around the 2$^{nd}$ millennium BCE based on the material evidence unearthed in archaeological excavations. The Tamil Nadu State Archaeology Department is also actively involved in this herculean task of locating and identifying the early use of iron in Tamil Nadu. The recent excavations conducted at Kilnamandi, Mayiladumparai, Adichanallur and Sivagalai provided an encouraging result. The series of scientific dates obtained for the samples collected from various archaeological investigations placed the antiquity of iron in Tamil Nadu in the time bracket between 2953 BCE and 3345 BCE. We are glad to place these recent evidences to the academic world for their scrutiny through this publication. I do hope, the academic community will read the monograph *Antiquity of Iron - Recent radiometric dates from Tamil Nadu* with a critical mind and provide encouraging words and constructive suggestions for the future course of action. I take this opportunity to congratulate all the archaeologists for making every effort and pride in establishing the glorious past of this nation.

# EXPERTS COMMENTS...

## Prof. DILIP KUMAR CHAKRABARTI

*Padma Shri Awardee*
*Emeritus Professor*
*South Asian Archaeology*
*Cambridge University*

The discovery is of such a great importance that it will take some more time before its implication sinks in. My initial response is that some Harappan sites of the period should contain iron and that the report of iron from the Harappan context at Lothal makes logical sense in light of the present discoveries. Further, the early second millennium BCE dates of iron from Ganga valley sites like Malhar suggest that there was a network of iron technology and its distribution during that period. We should try to obtain a clear picture of this network. Meanwhile, we congratulate the archaeologists responsible for this discovery.

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## Prof. OSMUND BOPEARACHCHI

*Emeritus Director of Research*
*French National Centre for Scientific Research, Paris*
*Former Adjunct Professor*
*Central and South Asian Art, Archaeology and Numismatics*
*University of California, Berkeley*

It was with great passion that I read the brochure on the *Antiquity of Iron - Recent radiometric dates from Tamil Nadu,* written by two eminent Indian scholars. It is eloquently written based on scientific methodology. All the major iron smelting sites are documented with the help of precise maps. The dating is based on radiocarbon dating analyses carried out by Beta Analytic, considered to be one of the most reliable laboratories in the world, and on the High Probability Density Range (HPD) method, which assigns relative probabilities to the calibrated range(s) generated. The new dating proposed in the book radically alters the old chronology.

The chapter on the ‘global context’ analyses the dates established to date for iron technology in Egypt, Anatolia, China, Central and Western Europe, Northern Europe and Northern Scandinavia. Radiocarbon dating drastically modifies the chronology of the first iron smelting furnaces in Tamil Nadu. This booklet also provides an update on furnace types, comparing them with ancient archaeological data and recent finds in a more accurate archaeological context. One of the most interesting sections of this study is on ultra-high-carbon steel dating back to the 13th-15th centuries BC. We know that the first signs of real steel production date back to the 13th century BC, in present-day Turkey. The radiometric dates seem to prove that the Tamil Nadu samples are earlier. The analytical tables, photographs of recent archaeological excavations and discoveries are much appreciated additions. The authors have thus achieved their aim of recording, documenting, describing and contextualising the history of iron smelting technologies and their dating in ancient Tamil Nadu.

## Dr. RAKESH TEWARI

*Former Director General*
*Archaeological Survey of India*

About twenty-five years ago, early evidence of iron technology dating to c. 1800 BCE was found at several sites in Uttar Pradesh (North India). The quality of these artefacts led to the suggestion that iron technology might have originated in the 3rd millennium BCE. Today, this hypothesis is supported by a series of scientific dates. These dates, mostly around 2500 BCE, correspond to iron artefacts discovered at various archaeological sites in Tamil Nadu, South India. It is a turning point in Indian archaeology. These dates establish the earliest antiquity of iron technology in India and worldwide. It shows that an independent civilisation, evolved and developed in Tamil Nadu, based on its distinguished features and technologies, flourished in Tamil Nadu during the third millennium BCE, in a far distant area from the contemporary Harappan Civilisation of northwestern South Asia. The efforts in this regard contributed by the Tamil Nadu State Archaeology Department are commendable.

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## Prof. K. PADDAYYA

***Padma Shri Awardee***
***Emeritus Professor and Former Director***
***Deccan College, Pune***

The antiquity of iron in India is a long-debated topic. For a long time, it was ascribed to the beginning or early part of the 1st millennium BCE and then the evidence from sites in Rajasthan and UP stretched it to the second millennium. The new evidence from Tamil Nadu now takes it further backwards to the mid-3rd millennium. The dates from Sivagalai sites are very important, more so when these are on different materials and assayed by more than one laboratory. Tamil Nadu Department of Archaeology has kept up its tempo in field archaeology and has carried out several excavations during the last two decades, covering the Neolithic phase and Iron Age. This work has brought to light interesting additional features of both these phases. All credit to the Tamil Nadu Government!


## Dr. P.J. CHERIAN

*Former Director*
*Kerala Council of Historical Research*


The recent scientific dating of iron technology in Tamil Nadu, revealing sophisticated metallurgical innovations as early as the 3rd millennium BCE, is a groundbreaking discovery—not only for South India or the Indian subcontinent but for the world. This finding challenges long-held assumptions about human cognitive and technological development, urging a re-evaluation of established narratives.

Since Gordon Childe's influential framework divided human history into the Palaeolithic, Mesolithic, Neolithic, Chalcolithic, and Iron Ages, this sequence has been widely regarded as definitive. Yet, is it time to reconsider this linear categorization? Human cognitive and cultural evolution has never followed a uniform or universal trajectory. Technological and material advancements have emerged in diverse and often unpredictable ways, shaped by distinct local resources, environments, and interactions.

The complexity of human history—and the cosmos itself—resists such rigid simplifications. At a minimum, we must recognize that approximations and chronological sequencing often overlap, revealing intricate patterns of continuity and discontinuity, with phases that are sometimes ruptured or fragmented.

Tamil Nadu's multidisciplinary and collaborative approach to exploring the deep past offers a valuable model. By combining rigorous scientific inquiry with a deep respect for indigenous knowledge, it inspires hope for fostering a more inclusive and nuanced understanding of history—and for building a future rooted in open-mindedness and care for generations to come.

Hearty congratulations to the Tamil Nadu State Archaeology Department for the evidence-based and scientific reconstruction of the lost past, setting a benchmark for archaeological excellence.

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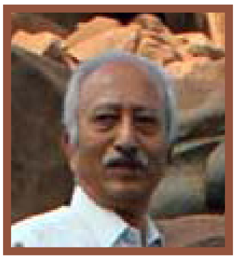
## Prof. K.P. RAO

*Honorary Professor, University of Hyderabad*
*Former Director*
*Department of Archaeology and Museums*
*Government of Andhra Pradesh*


Armed with a batch of scientific dates for iron, Prof. K. Rajan and his team clearly succeeded in changing the existing general perception of 'Chalcolithic' always before Iron Age. They succeeded in proving that in some parts of south India Iron technology was mastered coeval with the copper/bronze technology in western Deccan and beyond in the northwestern parts of India. This work containing large number of scientific dates, most of them ranging between 3000 BCE and 1500 BCE is certainly going to provide ready references for the scholars engaged in the study of Early Iron Age. This work will certainly bring sea change in our understanding of Early Metallurgy in India.




## Prof. **RAVI KORISETTAR**

*Adjunct Professor*
*National Institute of Advanced Studies, Bengaluru*
*Honorary Director*
*Robert Bruce Foote Sanganakallu Archaeological Museum, Bellary*
*Professor of Archaeology, Karnatak University, Dharwad*


The last decade's intensive archaeological excavations and the dating of cultural strata through multiple chronometric dating methods have posed a challenge to the long-held conventional trajectories of copper and iron technologies. The new dates for the well stratified and dated sites falling in the time range from the late third millennium BCE to 600 BCE have led to an inversion of cultural sequences from Copper Age to Iron Age and Iron Age to Early Historic in Tamil Nadu. Furthermore, the dating of Damili (Tamil Brahmi) to 600 BCE has posed yet another challenge to the long held view of the introduction of the Brahmi to south India during the period of Ashoka Maurya and after. These developments are as exciting as tantalizing and have provided hard evidence relating to the temporal and spatial diversity of the beginning of the Iron Age and the transition to Early History across the Indian subcontinent. Another significant contribution of Tamil Nadu archaeological investigations is the emergence of high-carbon crucible steel or wootz steel and unprecedented technology that has origins in south India and was much sought after steel in ancient India and beyond in western Asia and Europe. The quality of iron ore in the greenstone belts of south India played an important role in the early rise of high-quality iron and steel. We will be not surprised if more surprises are in store for us in the future compelling us to rethink traditional or established cultural trajectories.

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## Dr. **ALOK KUMAR KANUNGO**

*Indian Institute of Technology, Gandhinagar*
*Adjunct Associate Professor*
*Flinders University, South Australia*


This eye-opening monograph brings the antiquity and chronology of material science in general and Iron in particular of Tamil Nadu to the forefront with a series of AMS dates analysed in half a dozen Radiocarbon laboratories, of contextual finds from more than a dozen archaeological sites. It has established the fact that there was no cultural vacuum between the Neolithic and Early Historical periods of south India and reconfirmed how the natural resources have been the catalysts to the advancement of our knowledge system. It also opened a new research area to work, i.e., why copper and iron did not cross the Vindhya from north to south and vice versa in the 3rd and up to mid-second millennium BCE. Finally, this has opened up the subject for an interdisciplinary study on pyro-technology, elemental composition, isotope, metallurgical, furnace engineering, invention and innovations, and experimental study to bring the Iron Age Civilization of South India to the academic syllabuses.


## Prof. **SHARADA SRINIVASAN**

*Padma Shri Awardee*

*Professor, National Institute of Advanced Studies, Bengaluru*


The more systematic and laudable efforts of TNSDA to excavate and send specimens from a range of sites for dating to a range of laboratories both internationally and nationally and using a range of techniques from C-14 dating to OSL has yielded interesting results with growing and significant evidence suggesting some of the earliest dates for the emergence of iron in Tamil Nadu. This also fits with the growing evidence for the early development of high-carbon steel and wootz steel. The study of the other associated metal finds such as high-tin bronze also assumes significance to unravel the overall status of metallurgy.

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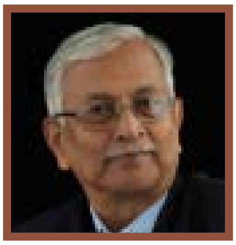



## Prof. **RABINDRA KUMAR MOHANTY**

*Tagore National Fellow*

*Department of Archaeology*

*Deccan College Post-Graduate Research Institute, Pune*


This is heartening to see the evidence of antiquity of emergence of Iron technology and its use in the Indian subcontinent has gradually been pushed back from second millennium BCE as appeared in Northern India to later part of third millennium BCE in South India especially in Tamil Nadu. Glimpse of early evidence of Iron during Indus Valley Civilization has also been debated. Some early dates are also emerging from Central India, Vidarbha region. These multi-regional manifestation of early iron in the subcontinent should be seriously comprehended. Now one has to look for more evidence to bridge the cultural and spatial gaps and also the beginning of such a technological innovation which needed complex procedure. This again needs to be viewed along with cultural assimilation and technology transfer if at all. In these circumstances, it will be prudent to date carbon extracted from iron objects to get a real pragmatic picture. In this regard the present monograph on Antiquty of Iron - Recent radiometric dates from Tamil Nadu brings a new dimension to the Iron Age Research not only in India but in a global context, pushing the claim of Iron Age India much earlier than anywhere else. The efforts of this achievement are laudable. I congratulate Prof. K. Rajan, Dr. R. Sivanantham and his ever-enthusiastic team of researchers from State Archaeology, Tamil Nadu. I am looking forward to see more.

# ANTIQUITY OF IRON

***Recent radiometric dates from Tamil Nadu***

India's journey through her extensive history has been marked by a persistent march of cultural and technological progress across diverse domains, shaped intricately by the unique array of resources found within each geographical locale. Like many other resources and technologies, iron technology played a dominant role in shaping the history of south India, particularly in Tamil Nadu, due to the availability of a sufficient amount of commercially exploitable iron ores. Archaeologists and archaeo-metallurgists are in constant search of establishing the introduction of iron. The extraction of iron from iron ore is considered one of the important technological innovations of humankind. In contrast to copper and bronze tools, iron tools are considered cheaper, durable and more efficient which accelerated agricultural production leading to social and economic development. Therefore, archaeologists and archaeo-metallurgists have always paid greater attention to understanding the iron technology in the world.

Unlike northern India, Tamil Nadu could not experience the proper Copper Age due to the non-availability of sufficient exploitable copper ore. Though a large number of high-tin bronze objects datable to the mid-15$^{th}$ century BCE were collected from the urn burials at Adichanallur (IUACD 23C5689 cal. 1441 BCE) and other places such as Sasthapuram, Adukkam, Sulapuram (Olappatti), Tirumalapuram and Auroville but all of them were unearthed in association with iron objects forcing us to place high-tin bronzes in Iron Age. In general, the smelting of copper is considered a prelude to iron technology. Nevertheless, the recent excavations met with a large number of high-tin bronze objects and all of them are finished products mostly found as grave goods. Irrespective of intensive explorations, the early high-tin bronze production centres are hardly identified on ground in Tamil Nadu. The present evidences suggest that they were imported from outside Tamil Nadu. Further, investigations are needed to characterize the unusual and early finds of high-tin bronzes and whether the sources and/or manufactured were local or external. Thus, the copper might have entered into Tamil Nadu after the introduction of iron.

## IRON AS A METAL

The availability of suitable iron ores like hematite, magnetite, limonite, goethite and laterite containing iron nodules at a convenient distance must have been an important factor for the iron smelting industry. Iron smelting required a high degree of temperature about 1200 -1400 degree Celsius. The entire process starts with the preparation of fuel/charcoal, the furnace, the bellows, fixing of tuyere, wind direction, the time of execution, time taken for the process and finally collection of wrought iron. Commonly occurring natural iron ore are in oxide forms as ferric oxide ($Fe_2O_3$), ferrous-ferric or magnetite ($Fe_3O_4$) and ferric oxy-hydroxide [FeO(OH)]. When the ores undergo a metallurgic process and attain their final form, they are classified based on the presence of carbon. The presence of carbon to the level of (3.8 - 4.7%) is known as pig iron, cast iron (2 - 2.5%) and wrought iron (low carbon steel) 1.5 - 2%. The amount of carbon present in the iron determines the rigidity, flexibility, ductility and toughness of the metal. Increase in carbon presence would increase the rigidity of the metal which results in less flexibility, ductility and toughness. So, wrought iron was primarily preferred by our ancient iron smiths. The most common technique used to reduce carbon percentage in iron is to induce oxygen gas ($O_2$) onto the molten metal which results in the release of carbon into the atmosphere as carbon monoxide (CO) and carbon dioxide ($CO_2$).

# ANTIQUITY OF IRON

## GLOBAL CONTEXT

The earliest iron in the world is known in two forms. The first is iron artefacts made of meteoritic iron, and the second is produced by smelting iron ore. The second form of iron is generally considered the introduction of iron technology in the world due to its mass production. However, nine iron tubular beads (seven from Tomb 67 and two from Tomb 133) made from meteoritic iron collected from graves at al-Gerzeh in northern Egypt of the lower Nile Valley in the year 1911 are considered the earliest known iron artefacts.


*Fig. 1: Iron tubular beads of meteoritic iron found at al-Gerzeh of northern Egypt*

These two tombs are securely dated to c.3400–3100 BCE of Naqada IIC–IIIA period (Stevenson 2009:11-31). These beads were made from meteoritic iron, and shaped by carefully hammering the metal into thin sheets before rolling them into tubes. Scholars believe that metalworkers already had nearly two millennia of experience in hot-work meteoritic iron when iron smelting was introduced (Thilo Rehren et.al., 2013:4785-4792). Since these beads were found in association with elite artefacts made of lapis lazuli, obsidian, gold, carnelian, jasper, quartz, calcite, chalcedony, steatite, faience, garnet, serpentine and with other grave goods such as porphyry bowl, a miniature pink limestone jar, a bird scutiform-shaped palette, an ivory spoon, a flint flake, an ivory comb (?), shells, a jackal canine tooth, a lump of red resin, and nine pottery vessels, scholars propose that these iron beads must be one of the elite goods (Petrie et al., 1912: 16; Stevenson, 2009: 195–196). The recent Neutron-based and X-ray-based analytical methods such as prompt-gamma activation analysis (PGAA), particle-induced X-ray emission (PIXE), neutron radiography (NR), and time-of-flight neutron diffraction (ToF-ND) carried out on three beads confirmed their meteoritic origin. In another instance, a Hittite king from ancient Anatolia (Turkey) seems to have sent an iron dagger to another neighbouring king dated back to the 13th century BCE with an apology note that he could not provide the requested numbers of iron instruments. It demonstrates the cultural and economic value or prestige associated with the meteorite iron which helps to produce desired iron objects directly through smithy with manageable heating out of malleable and ductile nature of iron pallets. Thus, meteorite iron remained the most valuable material till smelting of iron was introduced. Since they are meteoritic iron,  the nature and origin of the earliest iron artefacts made by smelting iron ore or by the processing of bloomery iron have remained a matter of uncertainty and dispute.

The present evidence suggests that the production of iron metal from iron ore only started in the mid-second millennium BCE (Waldbaum 1999) though there are claims of early dates. In Anatolia and Caucasus, the Iron Age began during the late 2nd millennium BCE (c. 1300 BCE). In the Ancient Near East, this transition occurred roughly around the 12th century BCE (1200–1100 BC). The date of c.900 BCE, c. 800 BCE, c. 600 BCE and c.500 BCE are considered the beginning of the Iron Age respectively in China, Central and Western Europe, Northern Europe and Northern Scandinavian Europe (Miller et.al., 1994:1-36; Alpern 2005:41-94; Muhly 2003:174-183; Stuiver 1968:45-58) (Fig. 2).

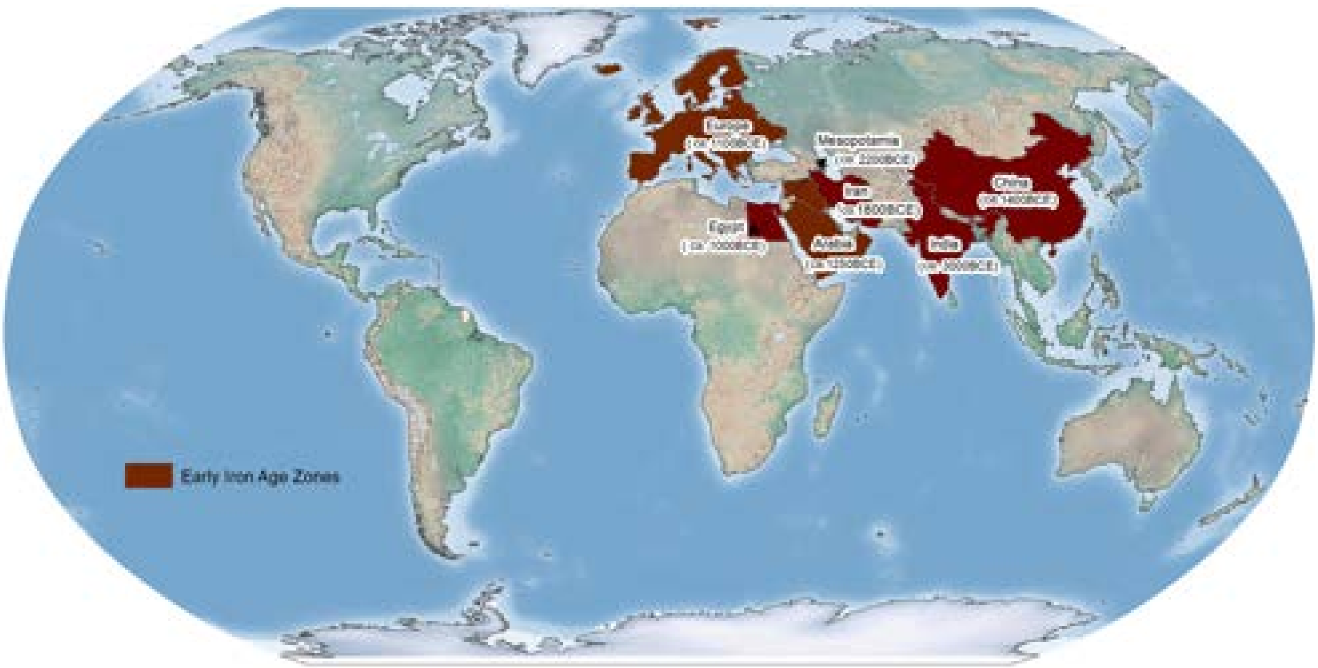



*Fig. 2: Early Iron Age zones*

These dates led to the assumption that iron was first produced in the Anatolia region during the Hittite regime and the technology diffused to other parts of the world. This hypothesis is constantly questioned and debated in the academic world. Unlike copper which requires around 1000°C, iron needs above 1200°C which probably delayed the iron smelting process. Iron tools were made in Central Anatolia in very limited quantities about 1800 BCE and were in general use by elites during the New Hittite Empire (1400 – 1200 BC). It is believed that the diffusion of this technology around the world happened after the 12th-11th century BCE (see Chart 1).

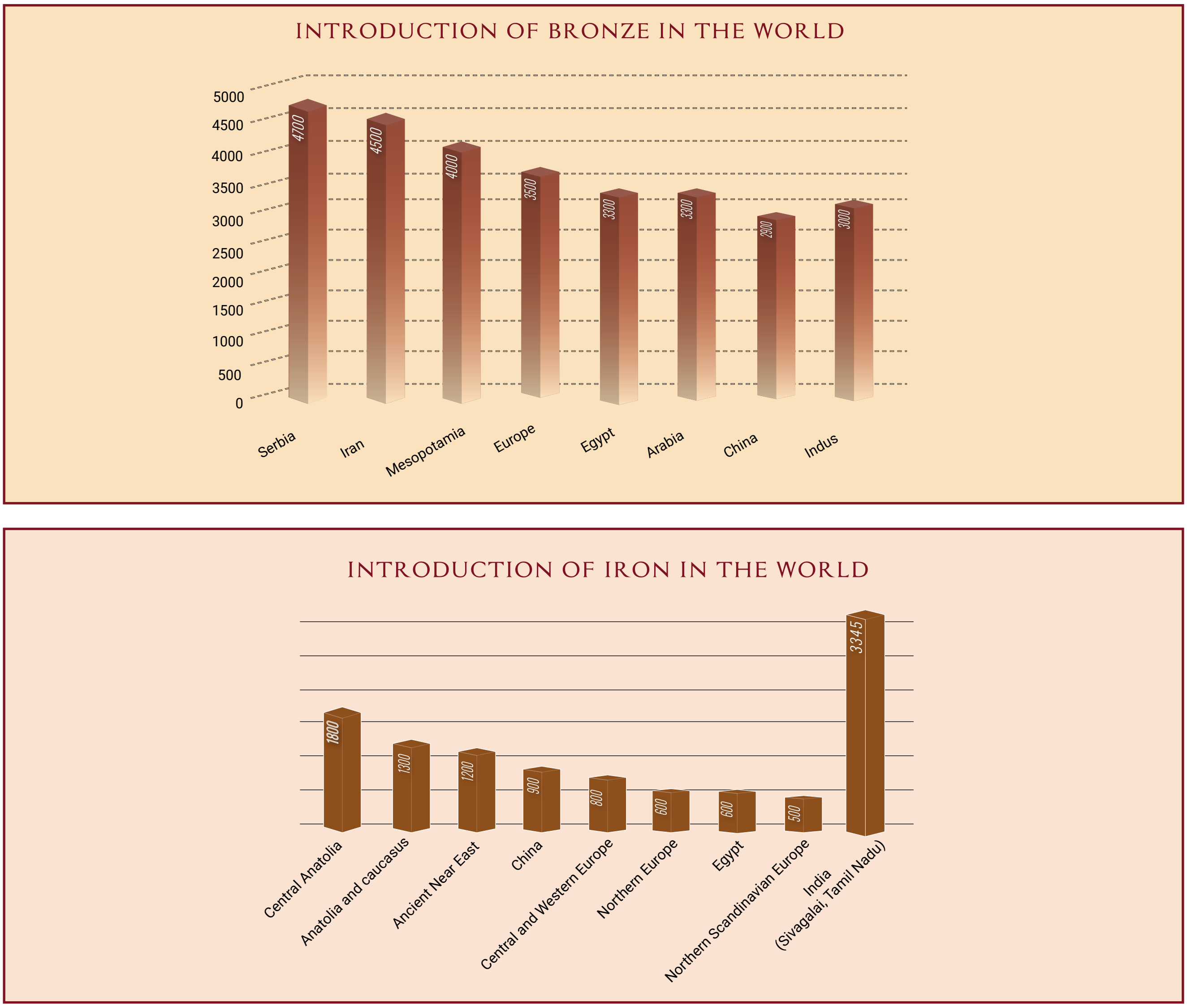



*Chart 1: Timeline of Early Bronze and Iron*

# INDIAN CONTEXT

The art of utilizing iron is considered one of the most important technological innovations in human history. It was instrumental in transforming an agrarian self-sufficient economy into a surplus one which led to population growth, the emergence of multiple clan-based societies and the emergence/development of several other associated factors. To be precise the iron technology induced the rapid socio-economic development of the ancient people. Therefore, the introduction of iron in a particular region is considered one of the important factors in human development.

Thus, the academic debate on the introduction of iron in India has been dealt with for long. The date of the introduction of iron moved from 1100 BCE down to the 2nd millennium BCE over time due to the tireless efforts of various scholars (Table 1). Thus, the series of radiometric dates obtained from different ecological zones of the subcontinent placed the introduction of iron in India to the 2nd millennium BCE (Seshadri 1955:38-41; Sundara 1973:239-251; Deo 1973:131-137, 1991:189-198; Possehl 1988:169-196, 1994; Moorti 1994; Rajan and Yathees Kumar 2013:279-295) (Fig. 3; see Chart 2). The recent excavations and chronometric dates obtained for the samples collected from Iron Age graves in Tamil Nadu further revalidated those findings.

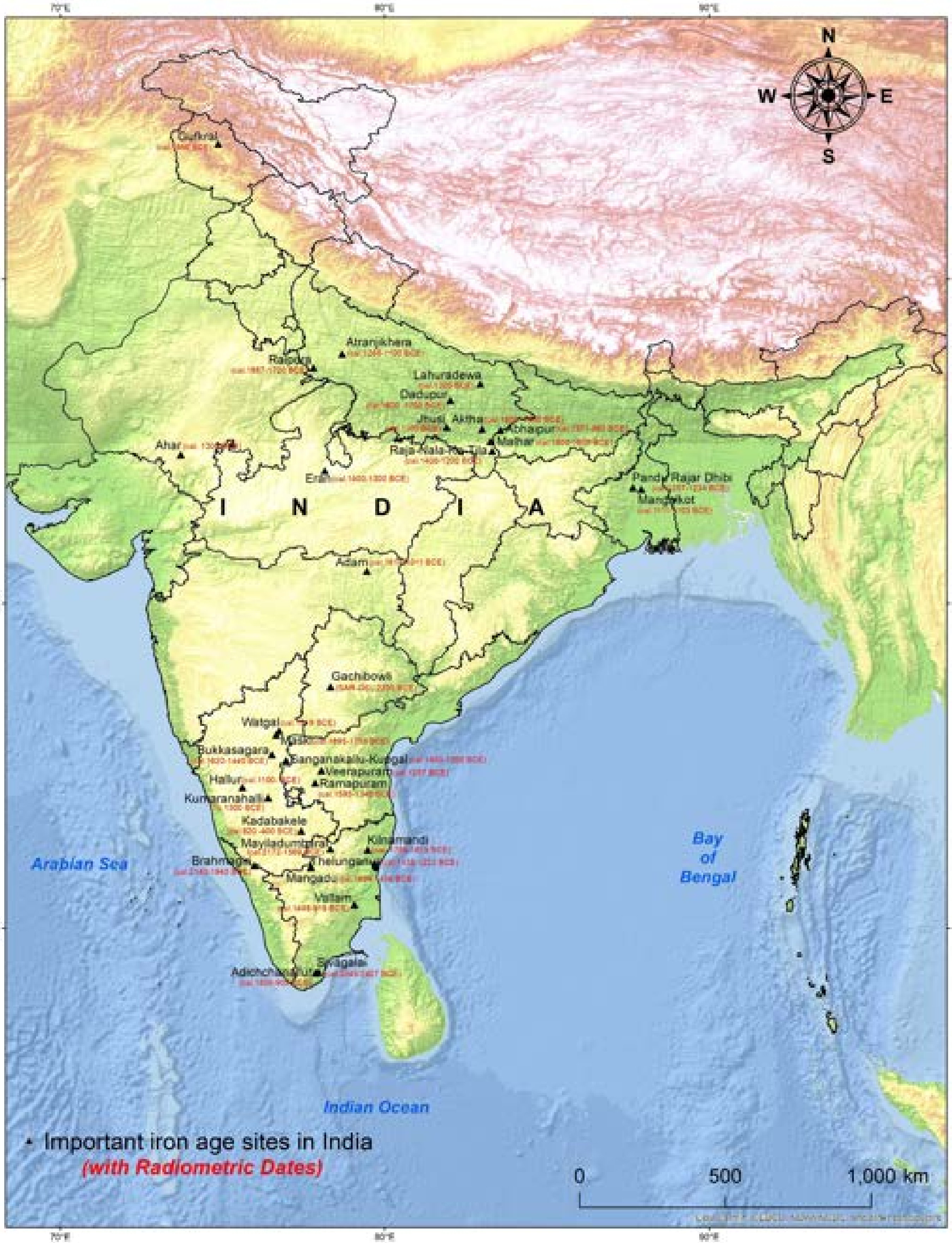
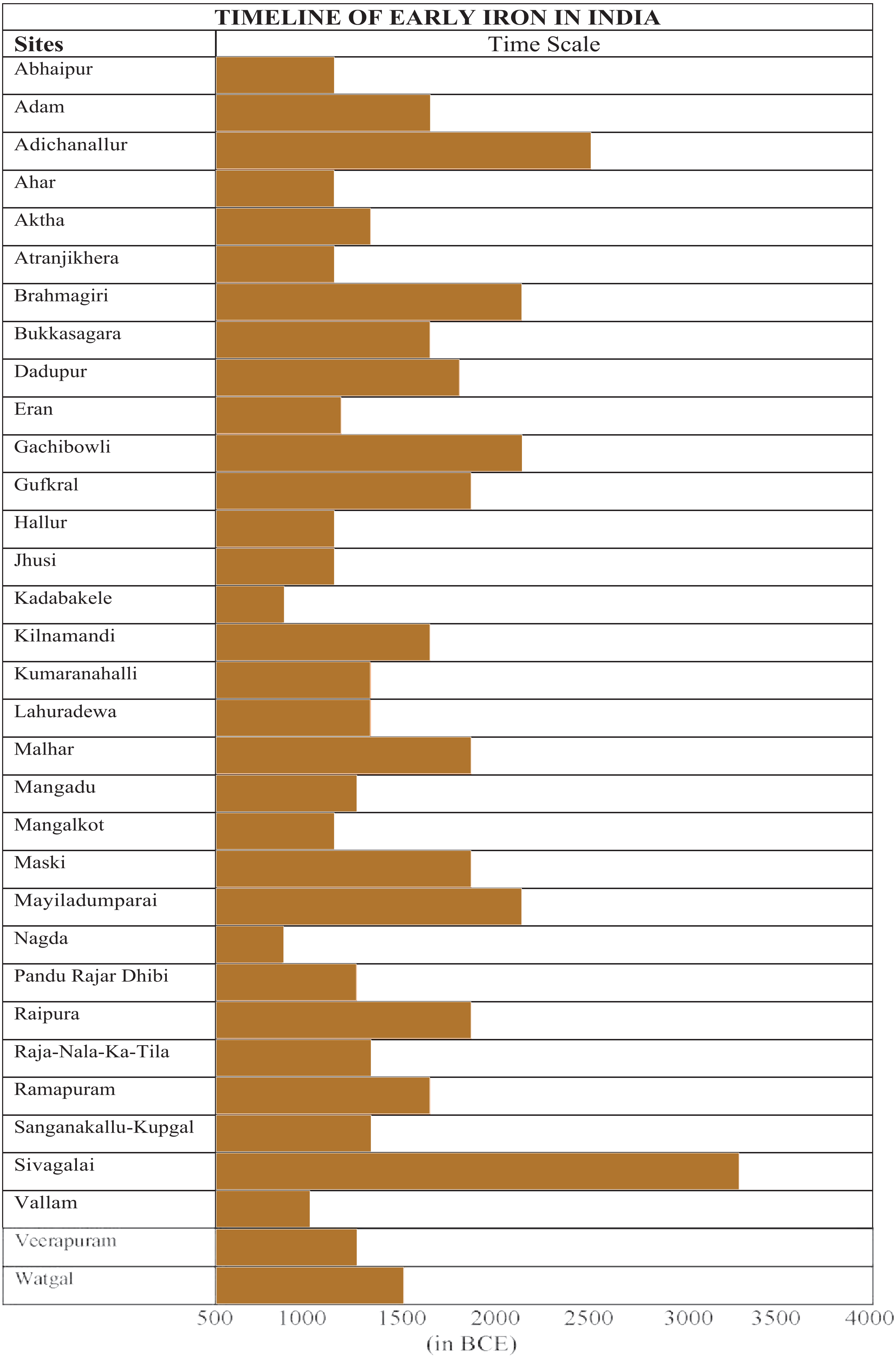



Fig. 3: Early iron yielding sites of India


TIMELINE OF EARLY IRON IN INDIA
Sites
Time Scale
Abhaipur
Adam
Adichanallur
Ahar
Aktha
Atranjikhera
Brahmagiri
Bukkasagara
Dadupur
Eran
Gachibowli
Gufkral
Hallur
Jhusi
Kadabakele
Kilnamandi
Kumaranahalli
Lahuradewa
Malhar
Mangadu
Mangalkot
Maski
Mayiladumparai
Nagda
Pandu Rajar Dhibi
Raipura
Raja-Nala-Ka-Tila
Ramapuram
Sanganakallu-Kupgal
Sivagalai
Vallam
Veerapuram
Watgal
500
1000
1500
2000
2500
3000
3500
4000
(in BCE)

## EARLY IRON YIELDING SITES IN INDIA (EXCLUDING TAMIL NADU)

| S. No | Site | State | Date | $C^{14}$/ $AMS^{14}C$ / TL/OSL | Reference |
|---|---|---|---|---|---|
| 1 | Abhaipur | Uttar Pradesh | cal.1371-980 BCE | $C^{14}$ | Tewari 2003: 536–544; Tewari et.al. 2002:54–62 |
| 2 | Adam | Maharashtra | cal.1614-1011 BCE | $C^{14}$ | Nath 2016 |
| 3 | Ahar | Rajasthan | ca. 1300 BCE | $C^{14}$ | Sahi 1979:366 |
| 4 | Aktha | Uttar Pradesh | cal.1800 -1450 BCE | $C^{14}$ | Tewari 2003: 536–544; Tewari et.al. 2002:54–62 |
| 5 | Atranjikhera | Uttar Pradesh | cal.1265-1100 BCE | $C^{14}$ | Gaur 1997 |
| 6 | Brahmagiri | Karnataka | cal.2140-1940 BCE | $AMS^{14}C$ | Morrison 2005:257-262 |
| 7 | Bukkasagara | Karnataka | cal.1620-1440 BCE | $AMS^{14}C$ | Johansen 2014:256-275 |
| 8 | Dadupur | Uttar Pradesh | cal.1800 -1700 BCE | $C^{14}$ | Tewari 2003:536-544 |
| 9 | Eran | Madhya Pradesh | ca.1400-1300 BCE | $C^{14}$ | Tewari 2010:81-97; Tripathi 1995:58-63 |
| 10 | Gachibowli | Telangana | 2200 BCE | SAR-OSL | Thomas et.al., 2008:781-790 |
| 11 | Gufkral | Jammu and Kashmir | cal.1850 BCE | $C^{14}$ | Tewari 2003:536-544; Rao 2018:129-144 |
| 12 | Hallur | Karnataka | cal.1100- BCE | C14 | Nagaraja Rao et.al., 1971; Fuller 2007:755-778 |
| 13 | Jhusi | Uttar Pradesh | cal.1100 BCE | C14 | Tewari 2003:536-544 |
| 14 | Kadabakele | Karnataka | cal.820 -400 BCE | $AMS^{14}C$ | Sinopoli 2011:377-387 |
| 15 | Kumaranahalli | Karnataka | 1300 BCE | TL | Agrawal and Joshi 1990:219-234 |
| 16 | Lahuradewa | Uttar Pradesh | cal.1300 BCE | $C^{14}$ | Tewari 2003:536-544 |
| 17 | Malhar | Uttar Pradesh | cal.1800-1600 BCE | C14 | Tewari 2003:536-544 |
| 18 | Mangalkot | West Bengal | cal.1111-1103 BCE | C14 | Tewari 2003:536-544 |
| 19 | Maski | Karnataka | cal.1895-1756 BCE | $AMS^{14}C$ | Bauer and Johansen 2015:795-806 |
| 20 | Nagda | Rajasthan | Cal. 885-580 BCE | $C^{14}$ | Agrawal 2003; Tewari 2003:536-544; Chakrabarti 1992 |
| 21 | Pandu Rajar Dhibi | West Bengal | cal.1257-1234 BCE | $C^{14}$ | Tewari 2003:536-544 |
| 22 | Raipura | Uttar Pradesh | cal.1867-1720 BCE | $AMS^{14}C$ | Vibha Tripathi 2014:1010-1016 |
| 23 | Raja-Nala-Ka-Tila | Uttar Pradesh | cal.1400-1200 BCE | $C^{14}$ | Tewari 2003:536-544; Tewari 2010:81-97 |
| 24 | Ramapuram | Telangana | cal.1595-1345 BCE | $C^{14}$ | Tewari 2010:81-97 |
| 25 | Sanganakallu-Kupgal | Karnataka | cal.1400-1200 BCE | $C^{14}$ | Korisettar 2014 |
| 26 | Veerapuram | Telangana | cal.1257 BCE | $C^{14}$ | Sastri et.al., 1984; Tewari 2010:81-97 |
| 27 | Watgal | Karnataka | cal.1519 BCE | $C^{14}$ | Devaraj et.al., 1995:57-74 |

## IRON FURNACE

India's importance as a major and early centre of iron production emerged with the geological enumeration of her iron ores, literary and archaeological data and the miscellaneous government reports have mentioned the pre-industrial iron-smelting operations and the production of iron in different parts of the subcontinent. The major types of pre-industrial iron-smelting operations were systematically studied first by John Percy (1864), but the most comprehensive survey of its kind, both in the field of ores, methods and distribution of pre-industrial iron smelting was undertaken by Valentine Ball (1881) in the volume on economic geology as part III of *A Manual of the Geology of India* (Chakrabarti 1992:157). However, the most systematic discussions of the pre-industrial iron smelting processes in India may be found in Percy's *Metallurgy: Iron and Steel.* He describes three basic types of pre-industrial iron smelting furnaces of which the first two types are found in Tamil Nadu (Percy 1864:254-270). A brief description of the first two types of furnaces has been explained to understand the nature of the furnace encountered in the archaeological context at Mullur, Perungalur, Valltirakottai in the magnetite quartzite containing iron and lateritic belt of Pudukottai region and at Chettipalayam, Idyapalyam, Irugur, Kaniyampundi, Nichchampalayam and Kodumanal in magnetite ore-bearing zones of Tamil Nadu.

The first type of furnace, according to John Percy, was the simplest and also the most common. Circular in form, its height varied from 2 to 4 feet. At the bottom, or across the hearth, the width was from 10 to 15 inches, and at the top from 6 to 12 inches. It was made entirely of carefully tempered clay (Fig. 4). The lower part tended to wear way rapidly and was constantly repaired with linings of fresh clay. There were two openings towards the bottom of the furnace – one for removing the cinder, and the other for drawing out the smelted product, or sponge-iron. The second opening was inserted with two earthen pipes, or tuyeres, connected with a pair of bellows. Both the openings were covered with clay before the furnace was lit. The opening for the cinder was generally at the side for the sponge-iron and the tuyeres were in front. The tuyeres, some twelve inches long and an inch in internal diameter, were placed side by side, projecting two to three inches into the furnace, three to four inches from its bottom. If the furnace was newly built, it was first dried by keeping a fire going in it for several hours. The tuyeres were then placed in the position mentioned above, and both the openings at the side and front were sealed with clay. The furnace was half-filled with charcoal and lighted and then filled up to the top. The bellows were applied at this stage. When the charcoal at the top had partly subsided, alternate charges of ore and charcoal were applied till the requisite amount of ore had been introduced. The blast from the bellows was then increased to the maximum and kept constant till the operation was complete. This took four to six hours, during which the cinder was removed from time to time with the help of a small rod or bar through an opening devised for that purpose. But still, for the greater part of time, the cinder remained in the furnace and was removed with the sponge iron, which was taken out at the end of the operation, taking off the front cover. If sufficiently hot, the sponge iron was immediately hammered into a tolerably sound bloom, and if it came out too cold for the purpose, it was reheated and hammered (Percy 1864:254-270).

## KODUMANAL IRON FURNACE

The description found above is well suited to the furnace that was excavated at Kodumanal. The trench laid on the southern edge of the habitation mound yielded a circular base of a furnace 115 cm in diameter at a depth of 65 cm right on the natural soil. The features of the furnace area were distinguished by the white colour, caused perhaps, due to high temperature. Iron slag, burnt clay embedded with slag, tuyere pieces with vitrified mouth and a granite slab were collected near the furnace area. Some of the iron slag, stuck to the wall portion of the furnace had a smooth surface. The presence of a tuyere 15 cm in length,

Fig. 4 : Kodumanal: Iron smelting furnace

6 cm in thickness and a hole of 1.5 cm in diameter suggest that the bellows were used quite nearer to the furnace. The furnace at Kodumanal probably attained a temperature of 1300ºC well above the minimum temperature at which iron oxides can be reduced to iron but substantially below the melting point of the metal. The iron thus produced is still in semi-solid condition as a sponge or raw bloom from which the slag partially drains away, the rest of the slag and gong material is removed by hammering while the stag is still in a fluid state (Tylcote: 1962: 183-4). The absence of postholes, floor level and the mere occurrence of potsherds devoid of other cultural artefacts in the smelting area suggest that the iron smelting was done in an open area on the fringe of the habitation.

Such furnaces with huge iron slag mounds have been noted at Idyapalayam near Coimbatore, Nichchampalayam near Erode and Chettipalayam near Palladam. These three major potential undisturbed archaeological sites need to be probed. These sites are found in association with habitation-cum-burial sites and the archaeological material like russet coated ware, black and red ware, graffiti marks, etc., collected in the habitation mound suggests that these sites are not later than the 5th century BCE.

The second type of furnace, according to Percy, was a cavity made in a bank of clay which was well-tempered. The cavity was cylindrical, fifteen to eighteen inches in diameter, and some two and a half feet deep or high (Fig. 5). At the bottom were two openings facing each other, though to one of which tuyeres were inserted. A row of such furnaces could be made at convenient distances from each other in a bank of clay – a distinct advantage this type offered. The furnace was filled with charcoal and lit in the manner previously described. Alternate charges of ore and charcoal were applied and the bellows kept going at full blast. When a cinder reached a certain height in the furnace, it was tapped with an iron bar inserted through the front opening. The smelted ore was first shaped into a ball with an iron bar introduced from the above, then taken out with tongs through the top again. After the ball was removed the cinder was completely removed by tapping through the front opening. The furnace was then ready for the next charge of ore and charcoal. The lower part of the furnace did not have to be removed (indeed, could not be) for a fresh charge, which saved time and was an improvement upon the first type of furnace. According to Percy, this was 'in fact a small Catalan furnace' (Percy 1864:254-270). An identical furnace is noticed at Perungalur, Vallatirakottai and Suruliappan village. Interestingly, these kinds of furnaces are concentrated in the lateritic belt. These bowl-shaped furnaces differ from the ones found in the magnetite ore-bearing zones where the furnaces are circular and cylindrical in shape.

The third type of furnace, according to Percy, was also a cavity scooped out in the side of a clay mound. Its height on the side was eight to ten feet but inside the furnace was only six to seven feet high, the bottom being two to three feet above ground level. The internal diameter, top to bottom, was eighteen inches square, but a variation of fifteen by twenty-one inches was also known. The front wall was only five to six inches thick and could be removed at pleasure. When it is removed, the furnace presented the appearance of a vertical trench cut in a mound of clay. The base of the furnace was provided with perforated tile of dried clay placed at an angle of forty-five degrees to the back of the furnace.

The base tile or plate was first positioned and cow dung deposited up to a height of twelve inches – four or five inches above the upper edge of the plate. Above this bed of cow dung two earthen tuyeres, at least eighteen inches long, were introduced, almost touching the back of the furnace. The furnace was then partly filled with charcoal, lighted and then filled up to the top. The blast was applied from the front and the man working the bellows sat upon a sort of scaffold two to three feet from the ground. Ore and charcoal were then alternately introduced and the whole operation took twelve to sixteen hours. A considerable quantity of cinder was tapped at intervals during the operation with an iron bar passed through the perforations in the base plate, beginning with the lower holes and then proceeding to the upper ones. The holes through which

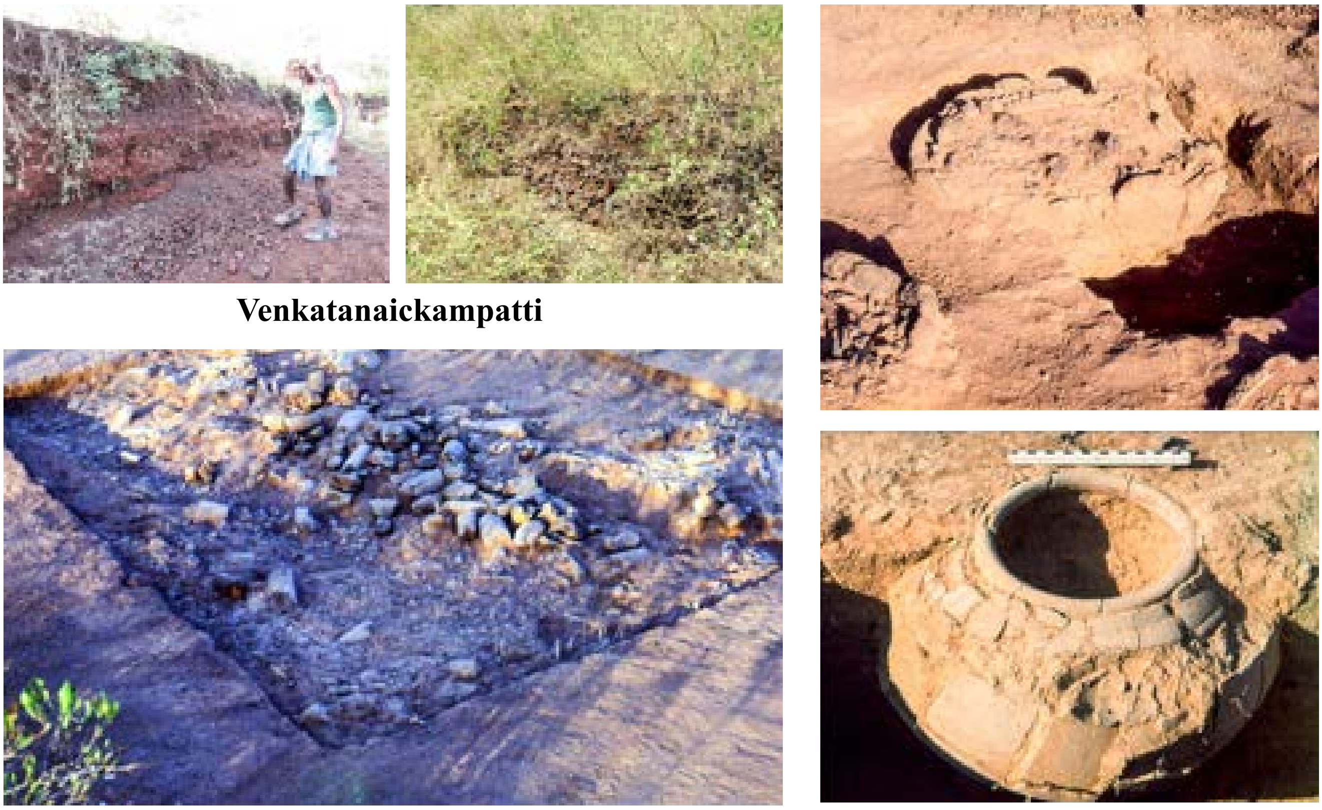
Fig. 5: Perungalur: Iron smelting furnace

the cinder had been drawn were stopped with clay as the iron accumulated at the bottom would otherwise escape. When the iron rose to the level of the tuyeres and the tuyeres were burnt away, the smelting was considered complete. The base plate was then removed with an iron bar and the mass of cinder and iron allowed to fall to the ground. This lump of iron weighed a hundred and fifty to two hundred pounds and was thus too large to be hammered whole. It was therefore cut by means of a sharp-edged sledge so that when cold it could be broken into four pieces. It consisted of a mixture of malleable iron and natural steel, and their proportion depended upon the nature of the ore. It has, however, been pointed out by Percy that, when the object was to produce steel, a large portion of charcoal was employed and a gentle blast applied (Percy 1864:254-270).

The third type of furnace was thus obviously used to make better-grade iron and steel. Such furnaces have not so far been encountered in Tamil Nadu. Probably these furnaces also might have been used but we have not come across them in our investigations. Future exploration and excavation may throw some light on this aspect. However, there are several sites met with furnace material as one observed at Ariyanipatti and Venkatanaickampatti (Fig. 6)

## ANTIQUITY OF IRON IN TAMIL NADU

The recent AMS$^{14}$C and OSL dates obtained from the Iron Age graves at Mangadu, Kilnamandi, Mayiladumparai, Adichanallur and Sivagalai force us to review hitherto-held views on the introduction of iron (Sivanantham, et.al., 2022; Rajan et.al., 2022; Rajan et.al., 2017:52-59; Gnanaraj et.al., 2023:425-432). South India is known for Iron Age sites and Tamil Nadu is no exception to this. More than three thousand Iron Age graves were identified on ground of which 1362 are urn burials, 996 cairn circles, 225 stones circles and 634 habitation-cum-burial sites (Fig. 7). Of them, only a few were excavated and many of them for a brief period yielding limited data. Nevertheless, target-oriented excavations were initiated



**Venkatanaickampatti**

**Ariyanipatti**

Fig. 6: Venkatanaickampatti and Ariyanipatti: Iron smelting area

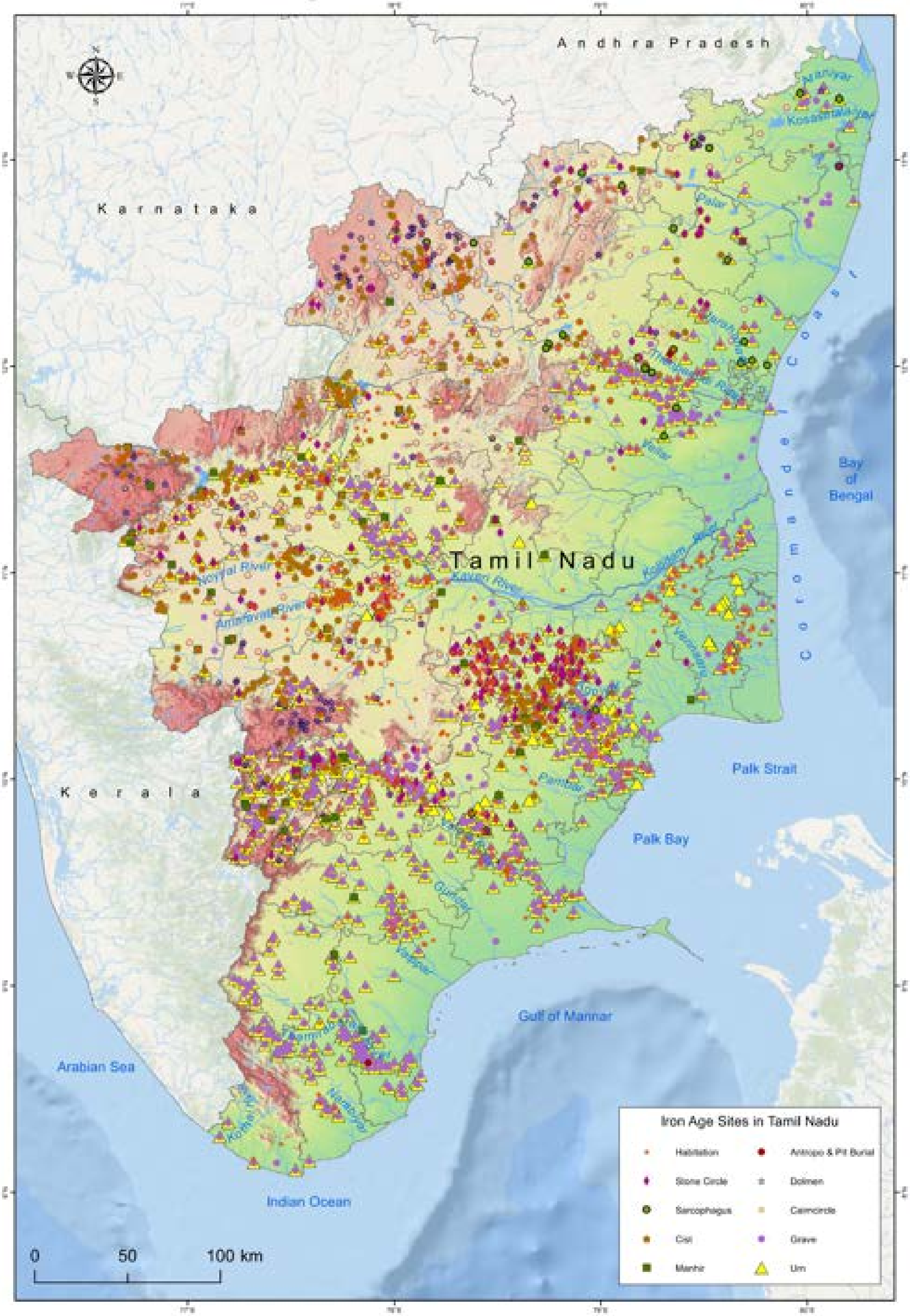



Fig. 7: Iron Age sites in Tamil Nadu

in recent years by the Tamil Nadu State Department of Archaeology, the Archaeological Survey of India and various Universities resulting in some understanding of the Iron Age. A brief account of the early iron-yielding sites of Tamil Nadu may provide a panoramic view of the nature of the Iron Age of Tamil Nadu.

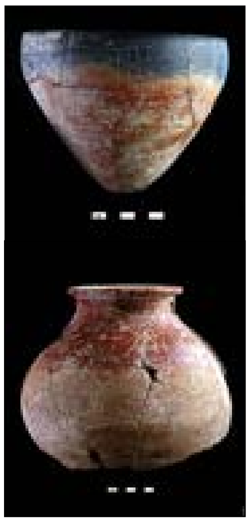
## MANGADU

The sample collected from the iron sword obtained from a disturbed cist burial at Mangadu (11°52′08″N; 77°44′30″E) in Mettur taluk of Salem district provided the conventional age of 1263 BCE (NSF-Arizona AMS Facility AA104114 with the date of 3213 ± 34 BP) and the calibrated age placed between cal. 1604 and 1416 BCE (cal. 3554 - 3366 BP) with a mean value of cal. 1510 BCE (Fig. 8) (Rajan et.al., 2017:52-59; Park et.al., 2019:68-80). For the first time, such an early date arrived and it kindled the interest in iron. Since then, the search for the introduction of iron in Tamil Nadu continued.

*Fig. 8: Mangadu: Iron Age graves-stone circles and disturbed cist*

## KILNAMANDI

The excavations conducted in July-August 2023 at Kilnamandi (12°22′36.11″N; 79°31′24.56″E) in Vandavasi taluk of Tiruvannamalai district of Tamil Nadu met with sarcophagus placed both in a pit (MEG-3) as well as in a cist (MEG-6) (Gnanaraj et.al., 2023:425-432). The sample collected from a stone circle entombing a pit burial with sarcophagus (MEG-3) along with iron objects yielded a conventional date of 1450 BCE and the calibrated date falls between 1769 BCE and 1615 BCE (Beta 666752 with the date of 3400 ± 30 BP) and the mean value goes back to 1692 BCE (Fig. 9). Eventually, it pushed the date of iron a century earlier than Mangadu. Another significance of this AMS$^{14}$C date (1692 BCE) is that a sarcophagus burial was dated for the first time in Tamil Nadu.



Kilnamandi: MEG- 3
Sarcophagus and artefacts

Kilnamandi: MEG- 3
Excavated grave and graffiti inscribed pots

*Fig. 9: Kilnamandi: Iron Age graves (MEG-3) - Sarcophagus placed in a pit*

# MAYILADUMPARAI

The excavation conducted in the year 2021 at Mayiladumparai (12˚26′28.43″N; 78˚20′1.22″E) in Krishnagiri district of Tamil Nadu yielded cultural items such as microlithic tools, neolithic celts, neolithic tool polishing grooves, rock paintings, Iron Age graves, Tamiḻi (Tamiḻ-Brāhmī) inscribed potsherds, memorial stones and trade guild inscriptions covering the time-span from Microlithic times to Late Medieval period (Figs. 10-14). The sample collected from the Iron Age level of the excavated trench (Locality-4, Trench-1) yielding black-and-red ware and iron objects at the depth of 120 cm and 140 cm laid on the hill terrace close to neolithic polishing grooves and rock art yielded two AMS$^{14}$C calibrated dates of 1615 BCE and 2172 BCE (Rajan et.al., 2022). In addition, the ceramics collected from the excavated trenches yielding iron objects match with the ceramics recovered from a pit burial excavated nearby (Fig. 15). Thus, the date of 2172 BCE placed the introduction of iron in the second millennium BCE. This early date was further consolidated with the recent dates of Sivagalai.

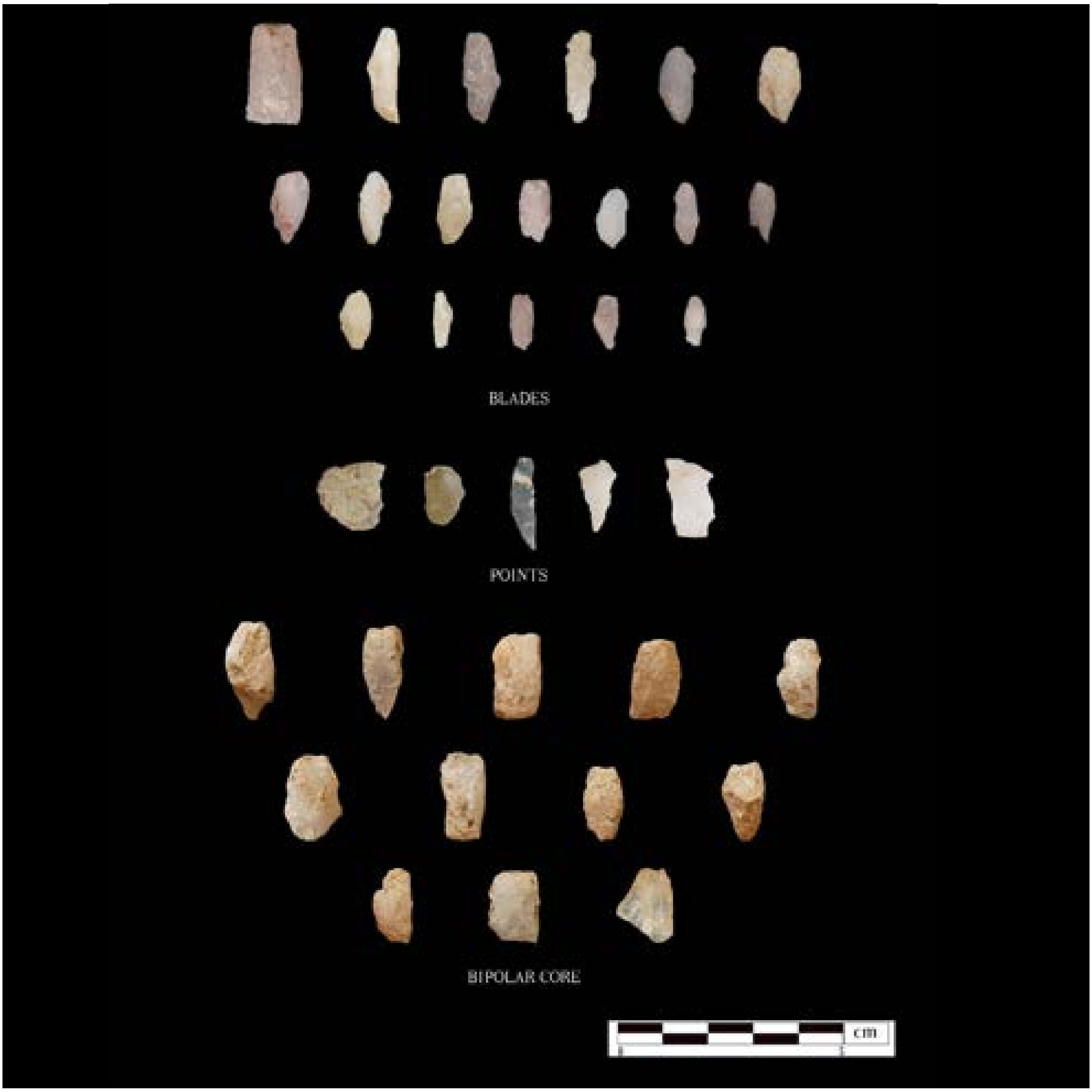
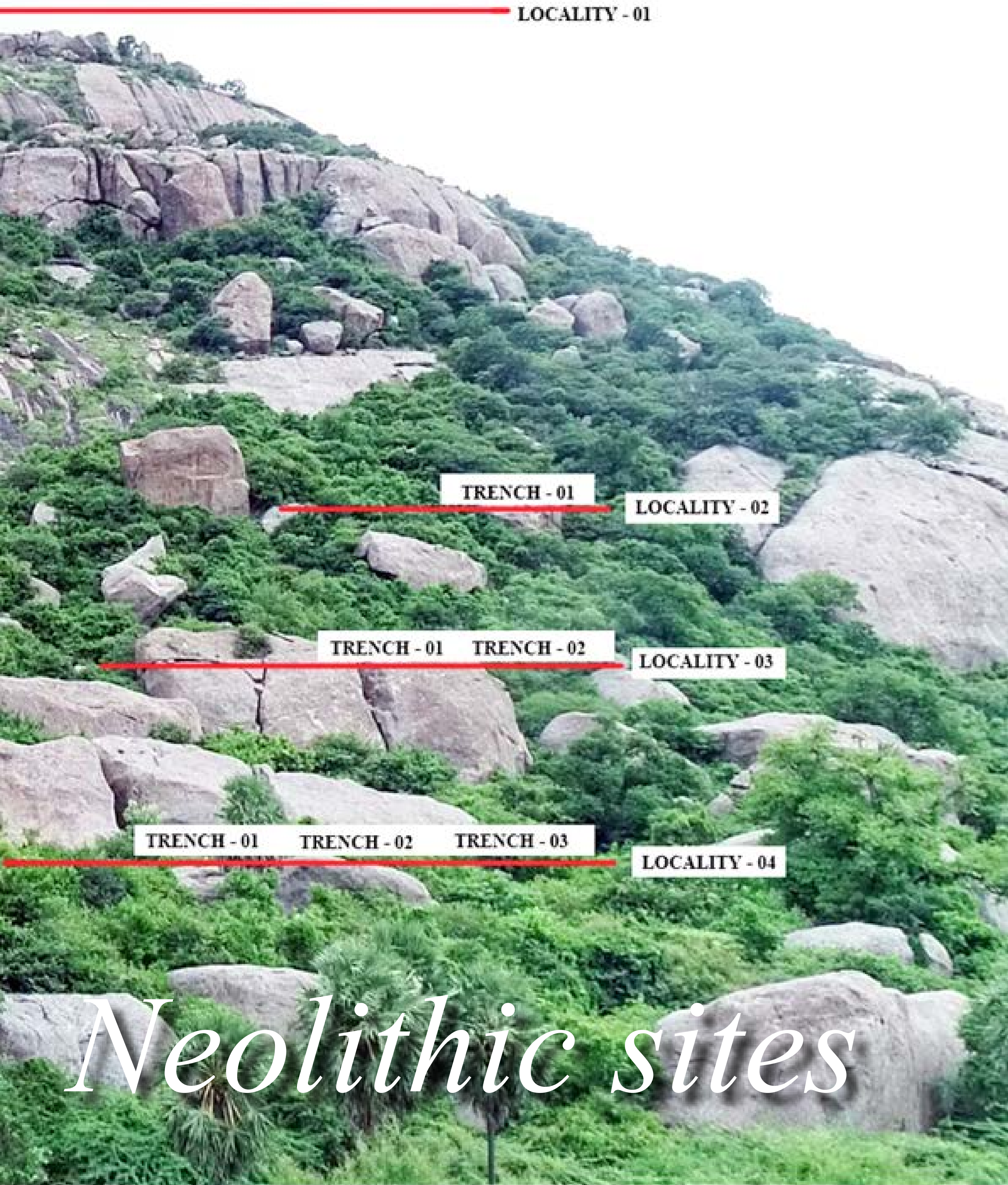



*Fig. 10: Mayiladumparai: Microlithic tools*

Fig. 11: Mayiladumparai: Neolithic grooves

TRENCH - 01

# *Mayiladumparai:*




# Neolithic sites

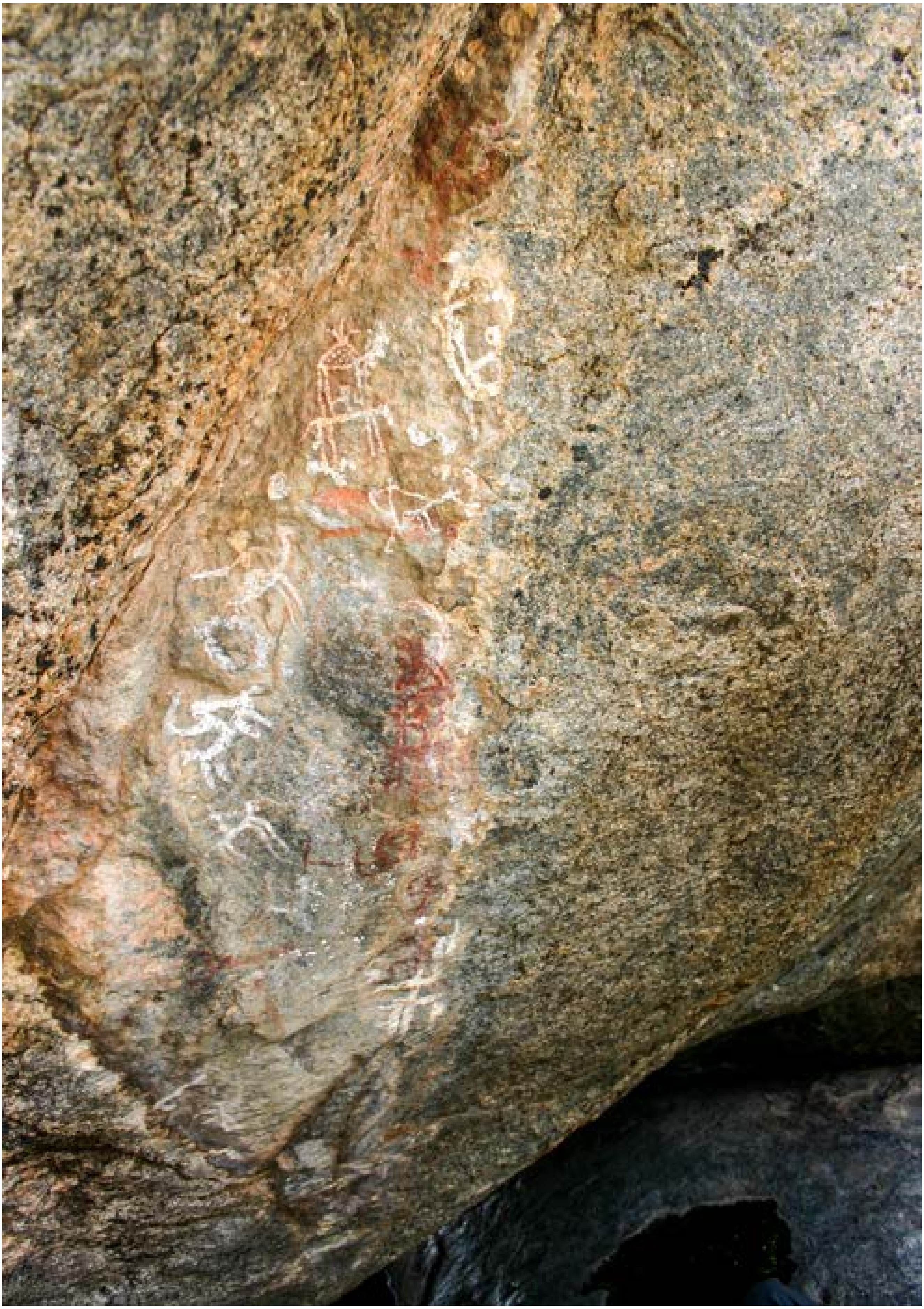


Fig. 12: Myiladumparai: Rock paintings

Fig. 13: Myiladumparai: Excavated Iron Age graves and iron objects

*Fig. 14: Mayiladumparai: Arial view of Iron Age graves*

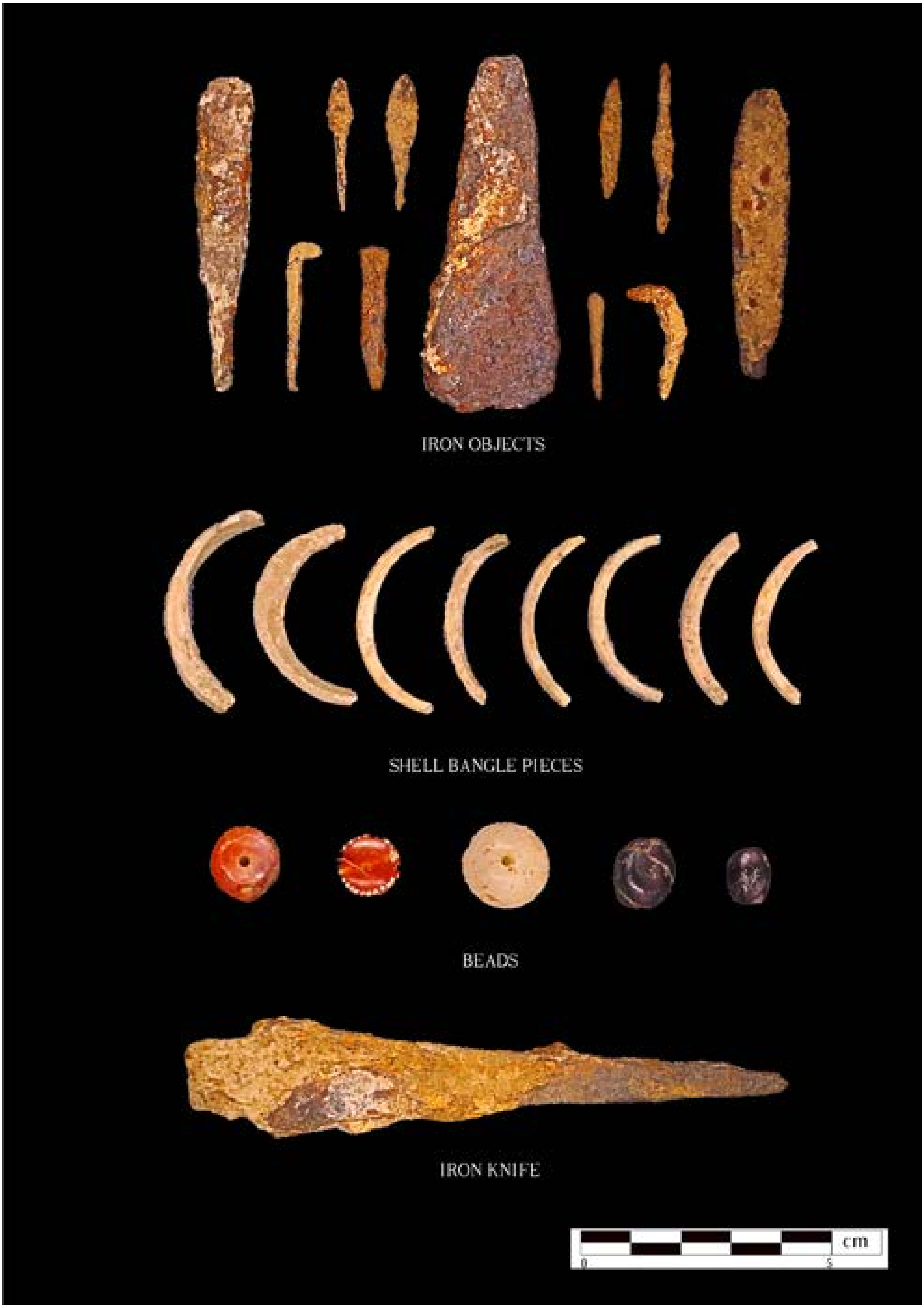



Fig.15_Mayiladumparai_artifacts

# ADICHANALLUR

The famous urn burial site Adichanallur (8° 37′47.6″ N; 77° 52′34.9″E) is situated on the right bank of the river Tamirabarani (Fig. 16). It lies about 4 km west of Srivaikuntam, 24 km southeast of Tirunelveli and 9 km west of Korkai, the ancient port city and capital of Sangam Age Pandyas. The graveyard is referred to as parambu meaning dry elevated mound encompassing an area of 125.04 acres on both sides of the Tirunelveli – Tiruchendur highway (Fig. 17). Since its discovery by F. Jagor of Berlin in 1876 and subsequent excavations by Alexander Rea in 1902-04, the site developed as a well-known iconic site (Rea 1915:1-49). T.Satyamurthy of ASI re-excavated the site in 2004-2005 and again the excavation was initiated in 2021-22 by Arun Raj of ASI (Satyabhama 2020; Satyamurthy 2007:55-66; Arun Raj et.al., 2023:1-10; Arun Raj et.al., 2023a), Tamil Nadu State Department of Archaeology also initiated excavations both in the habitation mound and in the graveyard in the years 2021-22 and 2022-23. Keeping in view of the archaeological, geospatial and scientific data, the entire site/mound is divided into three localities namely Locality- A, B and C and the excavations initiated in all these three localities (Figs. 18-20). The excavated objects include finely made pottery in various kinds such as black-and-red ware, red ware, black polished ware, and white painted black-and-red-ware. The metal objects exposed in the graves include swords, knives, spears, arrowheads, tridents, etc (Fig. 21). The ornaments in bronze include such as bangles, rings, decorated stands, etc. Most of the skeletal remains are found in a secondary context. The associated findings include a large number of ceramics, a variety of bronze objects, iron objects such as hoe-spades, triple-forded spears, mother goddess, etc. Among the bronze objects, the animals, birds, a mother goddess and gold objects such as rings and diadems are unique to Adichanallur. The uniqueness of the bronze objects, qualitative iron artefacts and divergence of the ceramics led the Archaeological Survey of India to re-excavate the site.

The Iron Age habitation mound covering about 50 acres is identified at two localities using remote sensing and a GIS system. One locality is found within a present Vellur-Adichanallur tank and another within the exciting Adichanallur village. Both the Tamil Nadu State Archaeology Department and the Archaeological Survey of India carried out the excavations in the habitation mound. The habitation cuttings yielded bowls, ring stands, plates, lids, pots, jars of fine verities black-and-red ware, black polished ware, white painted black-and-red ware and red ware. The antiquities such as iron implements and hopscotches are noticed in the seventh layer. Three phases of floor levels are noticed in the top three layers. The excavation conducted by the TNSDA met with 933 graffiti-bearing sherds.

The charcoal sample collected in association with iron object at a depth of 220 cm from layer 4 in the trench (Trench-W17 quadrant 2) laid in the habitation mound at Adichanallur by the Tamil Nadu State Department of Archaeology yielded a conventional date of 2060 BCE (4010 ± 30 BP) and calibrated date of 2517 - 2513 BCE (mean value of 2517 BCE (93.9%) and 2613 BCE (1.5%)). This date pushed the introduction of iron to mid-3rd millennium BCE.


Fig. 16: Adichanallur: Location map

Fig. 17: Adichanallur: Graveyard



**A- Excavated trench**

**B- Excavated um**

**C- Excavated trench**

**D-Excavated urn with cairn packing**

**E- White painted BRW**

*Fig. 18: Adichanallur: Excavated trenches with urn burials*

Fig. 19: Adichanallur: Excavated graves in Locality-B

Fig. 20: Adichanallur: Excavated graves in Locality-C

# IRON IMPLEMENTS LOCALITY – C

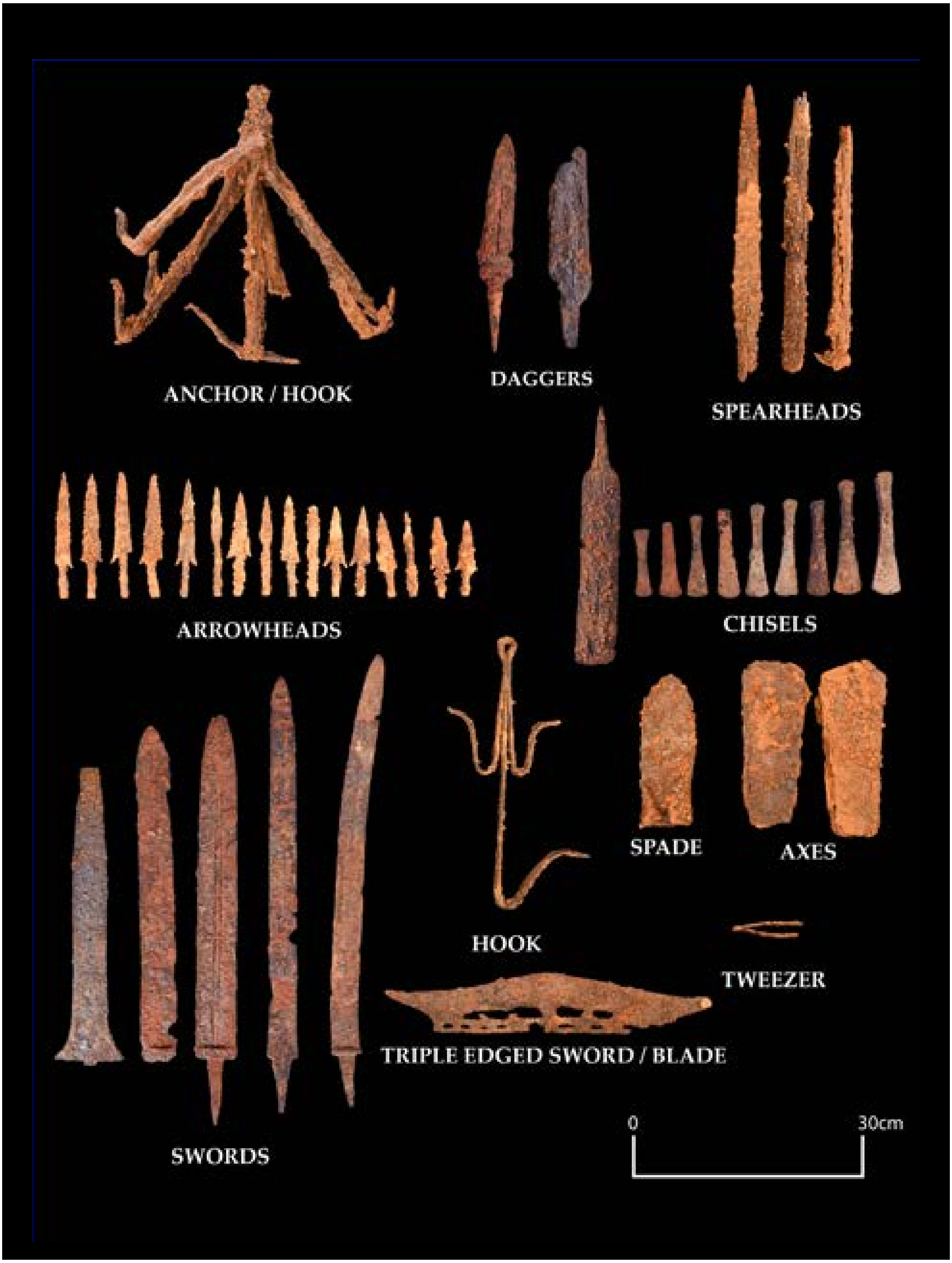



Fig. 21: *Adichanallur: Iron objects (Courtesy: Archaeological Survey of India)*

# SIVAGALAI

Sivagalai (8° 38′19.32″ N; 77° 58′ 41.16″ E), an Iron Age habitation-cum-urn burial site, situated 7 km north of river Porunai (Tamiraparani) about 31 km southwest of Thoothukudi town and 10 km northeast of Srivaikundam in Eral taluk of Thoothukudi district of Tamil Nadu. The famous microlithic site Sayarpuram (popularly called teri sites), the famous urn burial site Adichanallur and the celebrated Early Historic Pandya port Korkai respectively located about 15 km on the north, west and east of Sivagalai (Fig. 22). The Tamil Nadu State Department of Archaeology undertook the excavation in the years 2019-2020, 2020-21 and 2021-22 to bring out the archaeological potentiality of this site (Sivanantham et.al., 2022). The excavations were conducted at eight localities, of which in three localities burials were excavated at Sivagalai, Petmanagaram and Srimoolakarai and the remaining five localities Valappalanpillai-thiradu, Parakiramapandi-thiradu, Chekkadi-thiradu, Aavarangadu and Pottalkottai-thiradu are habitation mounds.

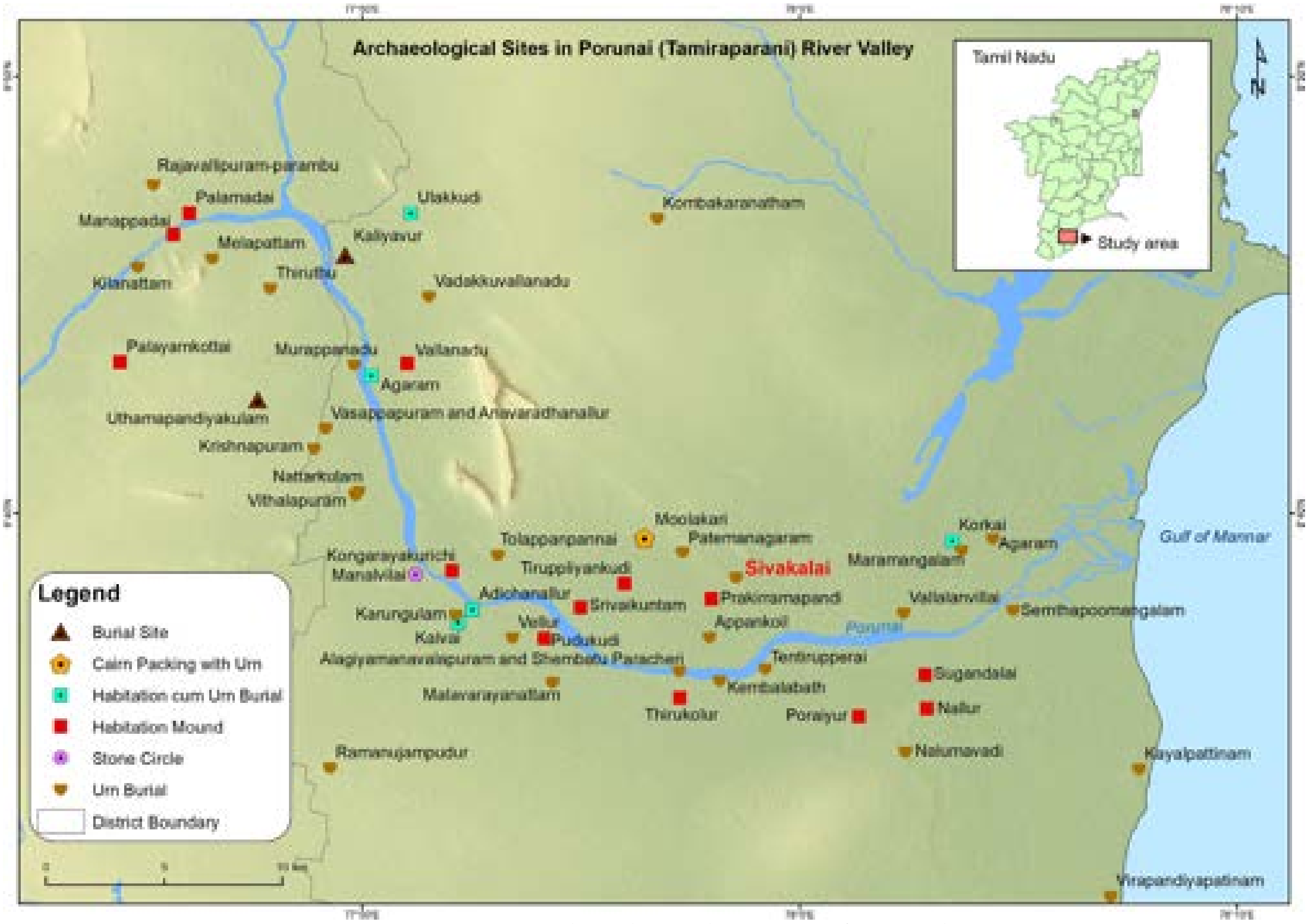



*Fig. 22: Archaeological settings of Sivagalai*

The Iron Age urn burial site, locally called Sivagalai-parambu, with an extent of 500 acres lies northwestern part of the village and the spread of the graveyard extends into the neighbouring villages of Betmanararam and Moolakarai The majority of graves falls at three localities close to the village Sivagalai, Petmanagaram and Moolakarai.

In total, 17 trenches (10x10 m) comprising 39 quadrants were excavated at Sivagalai-parampu (Fig. 23), 3 trenches with 8 quadrants at Petmanagaram and 4 trenches with 16 quadrants were exposed at Srimoolakarai. In total 24 trenches and 63 quadrants were excavated in which 160 urns were exposed. Urns were found both in red ware as well as in black-and-red ware. Out of 160 urns, merely 9 urns are in black-and-red ware and the remaining 151 are of red ware. The red ware urns are chronologically earlier

Fig. 23: Sivagalai-parambu: Excavated trenches

than black-and-red ware urns. The depth of the pit to accommodate the urn depends on the lithology. The maximum depth of the pit is 150 cm and the diameter of the pit is 100-110 cm. The size of the urn varies from large to small with a maximum height of 115 cm, a breadth of 65 cm and a thickness of 4.5 cm. Many of the urns developed a crack due to the pressure of the overlying soil. In a few cases, the lid of the urn was found intact which did not permit to percolation of the soil inside the urn. In a few, the lids were broken and collapsed allowing the soil to fill in the urns. Some of the pits were cut deep into the natural rocky surface and were rested with urns. Ceramics are the predominant grave goods comprising bowls, lids, rings stands and pots made of black-and-red ware, white painted black-and-red ware and black ware accounting for nearly 750 items (Fig. 24). The white painted black-and-red ware is found mostly in graves and very few pieces in the habitation cuttings suggesting its contemporaneity. The iron objects were placed both inside and outside of the urn. Inside, it was placed at the bottom of the urn. More than 85 iron objects consisting of knives, arrowheads, rings, chisels, axes and swords were collected at various levels from both inside and outside of the urn (Figs. 25-27).


*Fig. 24: Sivagalai: White painted black-and-red ware*

*Fig. 25: Sivagalai: Iron swords from graves*

Among the excavated trenches, the urns exposed in quadrants-II and III of trench A2 are interesting. The trench was exposed with three urns (Urn nos. 1-3). The third urn (Trench A2-Urn-3) placed at the centre of the trench was intact with a lid and no soil was percolated inside the urn. Skeletal remains, iron objects and paddy grains were collected from the urn placed at the bottom (Fig. 28). The paddy sample collected from this urn (Urn-3 of Trench A2) was dated back to cal.1155 BCE. Encouraged by this result, charcoal samples were also collected from trench A1 of the habitation mound called Valappalanpillai-thiradu. The samples collected from Trenches A2, C3 and B3 laid in the graveyard were sent for AMS$^{14}$C dates. In total, 5 AMS$^{14}$C dates were received and are taken for analysis. The date of the sample collected from the habitation with Tamiḻi (Tamiḻ-Brāhmī ) inscribed potsherd goes back to 685 BCE (Table-2; S.No.1; Beta 600727). The remaining 4 AMS$^{14}$C dates collected from urn burials with iron objects provided interesting features (Table-2; S.Nos.2-5). The paddy sample collected from an Urn-3 of Trench A2 was dated back to 1155 BCE. **The other three dates falling between 2953 BCE and 3345 BCE yielded iron objects. In this sense, the introduction of iron in Tamil Nadu goes back to the first quarter of the 4$^{th}$ millennium BCE.**

*Fig. 26: Sivagalai: Iron chisels from graves*

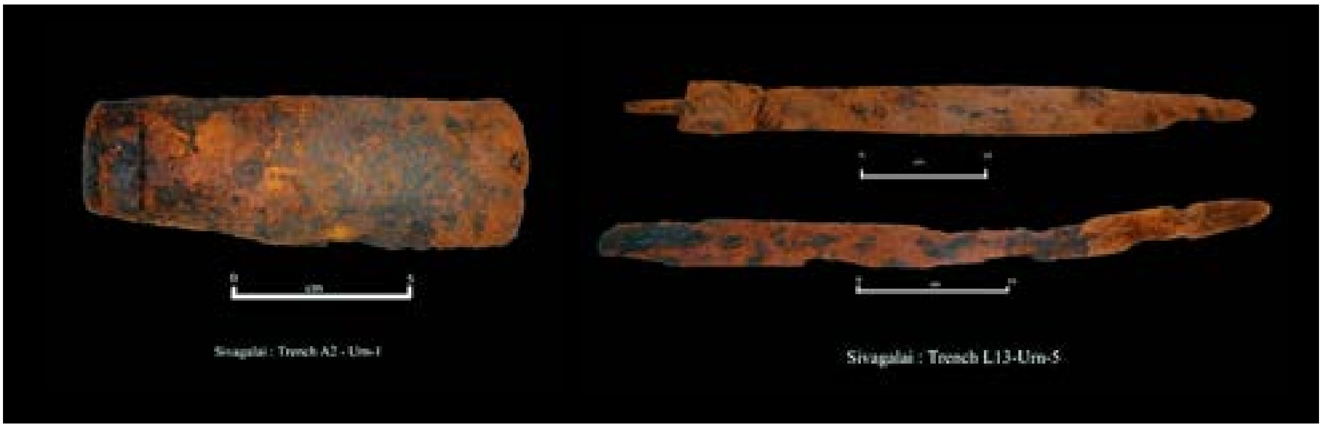



*Fig. 27: Sivagalai: Iron axe and swords from graves*

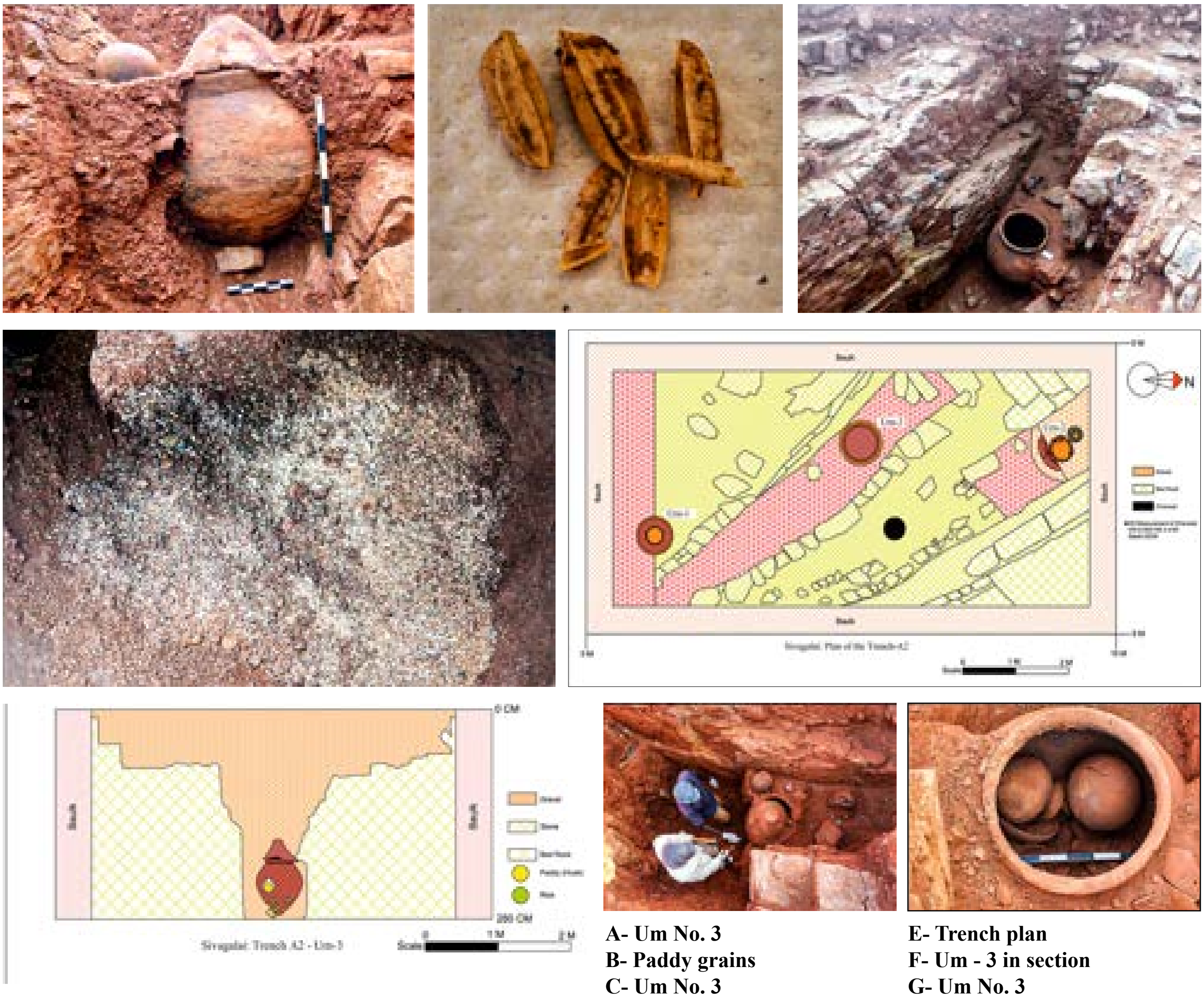
TABLE 2: SIVAGALAI: AMS$^{14}$C

| S. No | Site | Sample No | Trench | AMS$^{14}$C Date | Final age (calibrated AMS$^{14}$C date) | Nature of Sample |
|---|---|---|---|---|---|---|
| 1 | Sivagalai | Beta 600727 | Trench A1/4 Habitation with Tamil-Brahmi inscribed potsherd along with charcoal collected at a depth of 400 cm | 2560+/-30 BP | 685 BCE | Charcoal |
| 2 | Sivagalai | Beta 600726 | Trench A2-Urn-3 | 2950+/-30 BP | 1155 BCE | Paddy |
| 3 | Sivagalai | Beta 583594 | Trench C3/1 | 4300+/-30 BP | 2953 BCE | Charcoal |
| 4 | Sivagalai | Beta 583592 | Trench A2-Urn-1 | 4540+/-30 BP | 3259 BCE | Charcoal |
| 5 | Sivagalai | Beta 583593 | Trench B3-Urn-10 | 4670+/-30 BP | 3345 BCE | Charcoal |

# AMS¹⁴C AND OSL DATES FROM THREE LABORATORIES

Besides, AMS$^{14}$C techniques, it has been decided to obtain the OSL dates from two different laboratories to confirm the dates for the Sivagalai material. Five samples (two ceramic samples and one charcoal sample from Trench A2-Urn-1 and one ceramic sample and one sample of paddy grains from Trench A2-Urn-3) were collected. Of the five samples, three samples were sent to Birbal Sahani Institute of Palaeosciences, Lucknow (Table-3; S.Nos.1), Physical Research Laboratory, Ahmedabad (Table-3; S.No.2) and Beta Analytic Lab, Florida, USA (Table-3; S.No.3) to check the cogency of the date from three different scientific labs (Figs. 29-30). Quite interestingly, the laboratories provided the date of cal. 2459 BCE (S.No. 1 of BSIP/A2-Urn-1), cal. 2427 BCE (S.No. 2 of PRL-A2-Urn-1) and cal. 2590 BCE (S.No. 3 of Beta-A2-Urn-1 - cal.3259). **These three dates are for the samples collected from a single grave (Trench A2-Urn-1). All three dates quite interestingly fall in the middle of the 3rd millennium BCE displaying their consistency.**

Another two samples (ceramic and paddy) collected from the urn burial (Trench A2-Urn-3) were sent to Birbal Sahani Institute of Palaeosciences, Lucknow (Table-3; S.No.4 - BSIP) for OSL date and Beta Analytic Lab, Florida, USA for AMS$^{14}$C date (Table-3; S.No.5- Beta) to check and reconfirm the date. The



A- Um No. 3
B- Paddy grains
C- Um No. 3
D- Paddy grains

E- Trench plan
F- Um - 3 in section
G- Um No. 3
Sivagalai : Trench A2 - Um -3

*Fig.28 Sivagalai_Trench A2_Urn-3*

OSL date of cal. 1284 BCE from BSIP and AMS$^{14}$C date of cal. 1155 BCE from Beta Analytic Lab. were obtained. Interestingly, two kinds of samples (paddy and ceramic) collected from the same urn (Trench A2-Urn-3) provided closer dates but from two different laboratories with two different dating techniques.

In the same way, another two ceramic samples collected from the same urn (Trench L13-Urn-5) were sent to Birbal Sahani Institute of Palaeosciences, Lucknow (Table 3; S.No.6) and Physical Research Laboratory, Ahmedabad (Table 3; S.No.7). The date of cal. 1836 BCE (S.No. 6 of BSIP/L13-Urn-5) and cal. 2450 BCE (S.No. 7 of PRL/L-13-Urn-5) were obtained (Fig. 18). If one takes into account the error values of 363 and 308 respectively for the OSL dates, then, it also provides the same age of cal. 2199 BCE and cal. 2142 BCE (3856 + 363= 4219 BP i.e., 4219 - 2020 = 2199 BCE and 4470 - 308 = 4162 BP i.e., 4162-2020 = 2142 BCE).

TABLE 3: A COMPARATIVE STUDY OF THE AMS14C AND OSL DATES FROM SIVAGALAI

| S. No | Site | Sample No | Trench | Radiometric age (BP for OSL is 2020 CE) | Error age ± (years) | Calibrated radiometric age (in BCE) | Method | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | Sivagalai | BSIP | A2-Urn-1-Ceramic sample | 4479 BP | 358 | 2459 BCE | OSL | All three dates are from the samples taken from the same urn but with different laboratories and methods. |
| 2 | Sivagalai | PRL | A2-Urn-1 Ceramic sample | 4447 BP | 402 | 2427 BCE | OSL | |
| 3 | Sivagalai | Beta 583592 | A2-Urn-1 Charcoal sample | 4540 BP | 30 | 3259 BCE | AMS$^{14}$C | |
| 4 | Sivagalai | BSIP | A2-Urn-3-Ceramic sample | 3304 BP | 561 | 1284 BCE | OSL | Two dates for the samples taken from the same urn but of different methods |
| 5 | Sivagalai | Beta 600726 | A2-Urn-3-Paddy sample | 2950 BP | 30 | 1155 BCE | AMS$^{14}$C | |
| 6 | Sivagalai | BSIP | L13-Urn-5-Ceramic sample | 3856 BP | 363 | 1836 BCE | OSL | Two dates for the samples taken from the same urn but from different laboratories. |
| 7 | Sivagalai | PRL | L13-Urn-5-Ceramic sample | 4470 BP | 308 | 2450 BCE | OSL | |
| 8 | Sivagalai | BSIP | L13-Urn-2-Ceramic sample | 3929 BP | 334 | 1909 BCE | OSL | |
| 9 | Sivagalai | BSIP | L13-Urn-8-Ceramic sample | 4008 BP | 411 | 1988 BCE | OSL | |
| 10 | Sivagalai | Beta 583594 | C3/1-Charcoal sample | 4300 BP | 30 | 2953 BCE | AMS$^{14}$C | |
| 11 | Sivagalai | Beta 583593 | B3-Urn-10-Charcoal sample | 4670 BP | 30 | 3345 BCE | AMS$^{14}$C | |

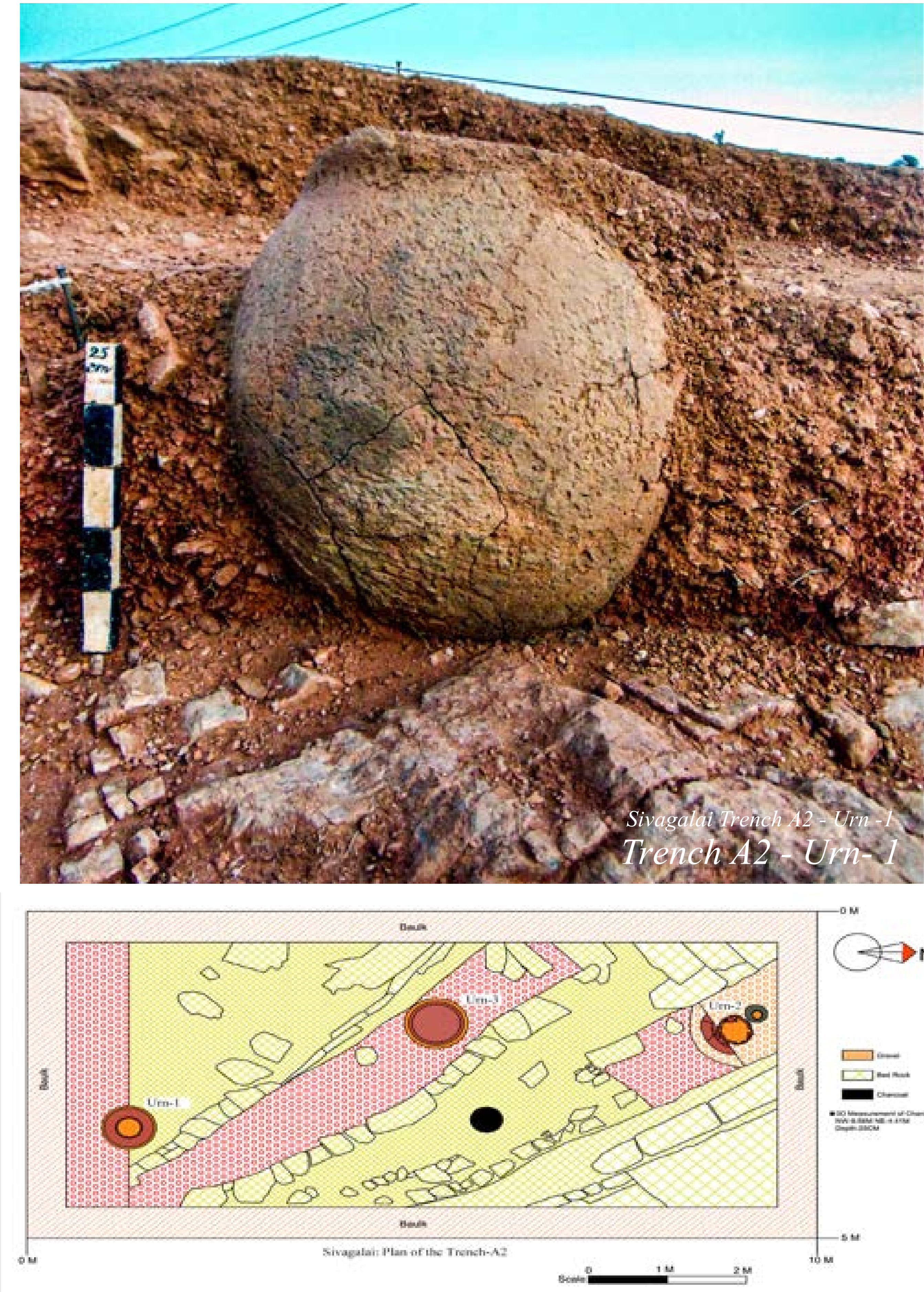
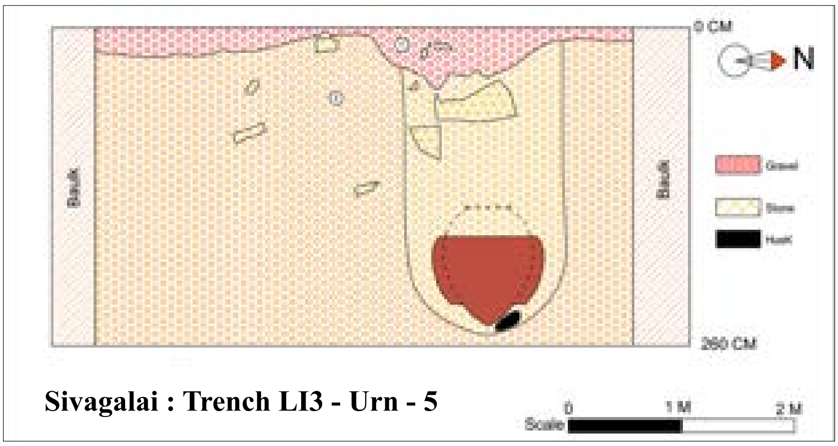



Fig. 29: Sivagalai: Urn no. 1 exposed in Trench A-2

A

B

C




D

**A - Urn No.5**

**B - Paddy grains**

**C - Paddy grains**

**D - Urn in section**

*Fig. 30: Sivagalai: Urn no. 5 exposed in Trench L-13*

| TABLE 4: EARLY IRON YIELDING SITES OF TAMIL NADU (A COMPARATIVE STUDY OF THE AMS$^{14}$C AND OSL DATES) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| S. No | Site | Institution | Sample No | Context | Radiometric age (in BP; BP for OSL is 2020 CE) | Error age +/- (years) | Final calibrated radiometric age (in BCE) | Method |
| 1 | Vallam | Tamil University | PRL-1109 | Habitation - Charcoal | 2980 BP | 30 | 1030 BCE | AMS$^{14}$C |
| 2 | Adichanallur | ASI | IUACD# 23C5693 | Locality-B; Urn No. 13 Paddy | 2840 BP | 54 | 1052 BCE | AMS$^{14}$C |
| 3 | Sivagalai | Tamil Nadu State Archaeology | Beta 600726 | Trench-A2-Urn-3 | 2950 BP | 30 | 1155 BCE | AMS$^{14}$C |
| 4 | Adichanallur | ASI | IUACD# 23C5692 | Locality-C; Urn No. 38 Paddy | 2947 BP | 46 | 1257 BCE | AMS$^{14}$C |
| 5 | Mangadu | Pondicherry University | AA 104114 | Grave-Iron object | 3213 BP | 34 | 1263 BCE | AMS$^{14}$C |
| 6 | Sivagalai | Tamil Nadu State Archaeology | BSIP | A2-Urn-3 Ceramic | 3304 BP | 561 | 1284 BCE | OSL |
| 7 | Adichanallur | ASI | IUACD# 23C5689 | Locality-C; Urn No. 7 Millet | 3155 BP | 40 | 1384 BCE | AMS$^{14}$C |
| 8 | Mayiladumparai | Tamil Nadu State Archaeology | Beta 620258 | Habitation-Charcoal | 3310 BP | 30 | 1569 BCE | AMS$^{14}$C |
| 9 | Kilnamandi | Tamil Nadu State Archaeology | Beta 666752 | Meg. 3 Charcoal | 3400 BP | 30 | 1692 BCE | AMS$^{14}$C |
| 10 | Sivagalai | Tamil Nadu State Archaeology | BSIP | L13-Urn-5 | 3856 BP | 363 | 1836 BCE | OSL |
| 11 | Sivagalai | Tamil Nadu State Archaeology | BSIP | L13-Urn-2 | 3929 BP | 334 | 1909 BCE | OSL |
| 12 | Sivagalai | Tamil Nadu State Archaeology | BSIP | L13-Urn-8 | 4008 BP | 411 | 1988 BCE | OSL |
| 13 | Mayiladumparai | Tamil Nadu State Archaeology | Beta 620259 | Habitation Charcoal | 3310 BP | 30 | 2172 BCE | AMS$^{14}$C |
| 14 | Sivagalai | Tamil Nadu State Archaeology | PRL | A2-Urn-1 | 4447 BP | 402 | 2427 BCE | OSL |
| 15 | Sivagalai | Tamil Nadu State Archaeology | PRL | L13-Urn-5 | 4470 BP | 308 | 2450 BCE | OSL |
| 16 | Sivagalai | Tamil Nadu State Archaeology | BSIP | A2-Urn-1 | 4479 BP | 358 | 2459 BCE | OSL |
| 17 | Adichanallur | TNSDA | Beta – 709374 | Habitation, Layer-4, 220 cm, charcoal | 4010 BP | 30 | 2522 BCE | AMS$^{14}$C |
| 18 | Sivagalai | Tamil Nadu State Archaeology | Beta 583594 | C3/1-Urn | 4300 BP | 30 | 2953 BCE | AMS$^{14}$C |
| 19 | Sivagalai | Tamil Nadu State Archaeology | Beta 583592 | A2-Urn-1 | 4540 BP | 30 | 3259 BCE | AMS$^{14}$C |
| 20 | Sivagalai | Tamil Nadu State -Archaeology | Beta 583593 | B3-Urn | 4670 BP | 30 | 3345 BCE | AMS$^{14}$C |

Besides, the charcoal samples collected from the two urns (Trench L13-Urn No.2 and 8) yielded a date of cal. 1909 BCE and cal. 1988 BCE (Table 3; S.Nos.8 and 9). Another two samples collected from trenches C3/1 and B3-Urn-10 respectively provided the date of 2953 BCE and 3345 BCE (Table 3; S.Nos.10 and 11).

To date, 20 samples have been collected in the cultural context yielding iron objects and were dated using two different scientific methods (13 AMS$^{14}$C and 7 OSL) from five different scientific laboratories namely Beta Analytic, Arizona University Lab., Inter University Accelerator Centre (IUAC, New Delhi), Birbal Sahni Institute of Palaeosciences (BSIP, Lucknow) and Physical Research Laboratory (PRL, Ahmedabad) for the samples collected from Sivagalai, Adichanallur, Kilnamandi, Vallam, Mayiladumparai and Mangadu (Table 4). **The date of 2500-3000 BCE has been taken as a mid-range value although two dates fall even in the early part of the 4$^{th}$ millennium BCE (Beta 583592-Trench A2-Urn-1-3259 BCE; Beta 583593-Trench B3-Urn-3345 BCE).**

Further, it may not be out of context if one discusses ultra-high carbon steel and high-tin bronze objects recovered from various archaeological sites of Tamil Nadu. The ultra-high carbon steel and high-tin bronze reflect the advanced metallurgical skill attained by contemporary artisans as early as the 13$^{th}$-15$^{th}$ century BCE. The production of ultra-high carbon steel is considered as an advanced stage of iron technology which developed over the years after the introduction of iron. To date, the high-tin bronze artefacts and steel objects in Tamil Nadu were collected mostly from Iron Age graves indicating these were introduced after the introduction of iron.

## HIGH TIN BRONZES

The smelting of copper and bronze is considered as prelude to iron and steel. The Bronze Age is generally placed before the Iron Age in the world context (Fig. 31).The significant artefacts, particularly high-tin bronze objects, gold diadems, iron objects and variety of ceramic assemblages were unearthed from the Locality-C of Adichanallur. Several high-tin bronze objects found to be binary (alloys of copper and tin) include rings, sieves, bowls, lids with deer knobs and bowls having three long stands with surrounding decorated birds (Fig. 32).

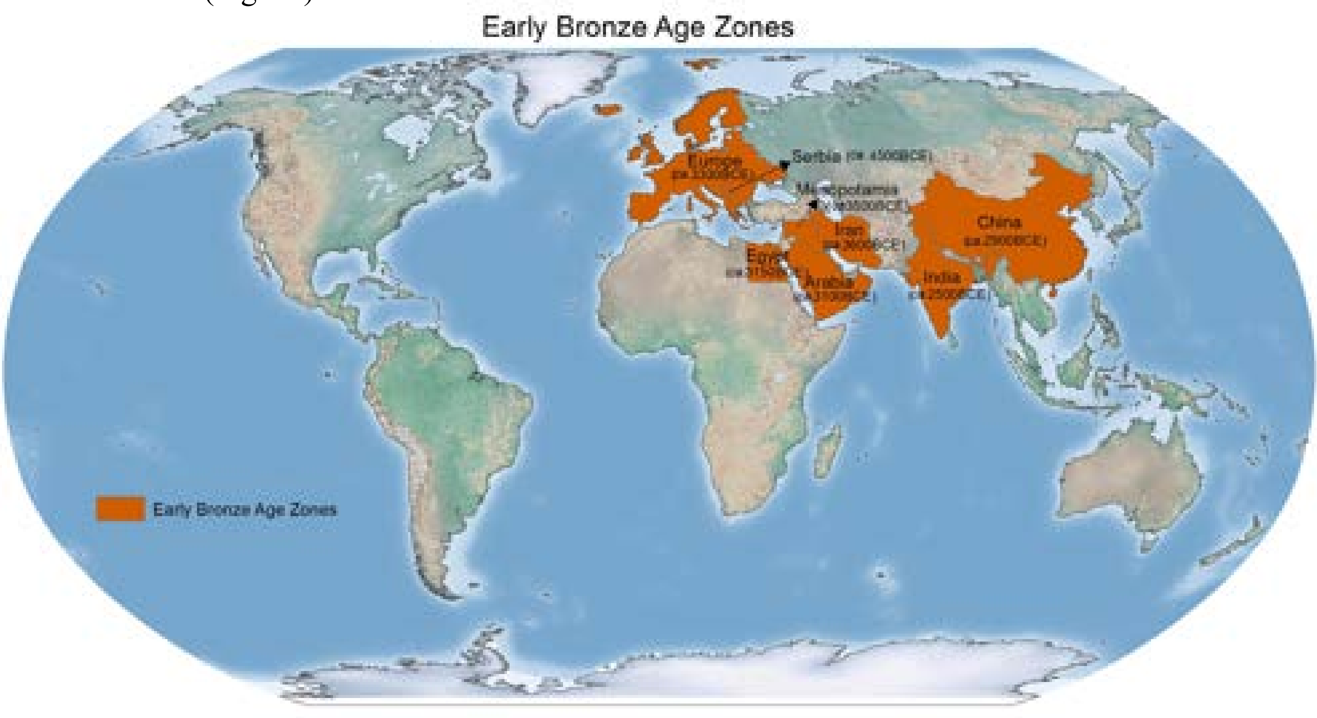



Fig.31_Bronze_world


Fig. 32: Adichanallur: High-tin bronze objects (Courtesy: Archaeological Survey of India)

Among other artefacts, gold diadems or Fillets and a gold ring are the significant ones. Iron implements include swords, knives, spades, spears, arrowheads, spear heads, chisels, hangers, etc. Paddy and the millets are some of the important items recovered from the grave. The quality of the artefacts, the quantity of the grave goods, the nature of the rituals, the location of the graves and the scientific dates indicate that they began to bury their departed soul on the river banks as early as the 15$^{th}$ century BCE. One of the important findings is the high-valued high-tin bronze objects such as double-fish, ring stand, tripod stand, sieve, bowl, lid with deer knob, miniature jar, bangle, etc.,

Among the 20 AMS$^{14}$C dates (ASI -14 and TNSDA-6), three AMS$^{14}$C dates for the samples collected two from the graves and a third one from the habitation cuttings provided the calibrated date of 1149 BCE, 1441 BCE and 1757 BCE respectively (Table 5). The samples collected from Locality C-Urn no. 7 and Urn no. 38 yielded high-tin bronze objects.

TABLE 5: AMS$^{14}$C DATES OF ADICHANALLUR

| S. No | Site | Inst. | Sample Number | Locus | Material | Conven-tional Age in BP | Conven-tional Age in BCE | Calibrated Age |
|---|---|---|---|---|---|---|---|---|
| 1 | Adichanallur | ASI | IUACD #23C5692 | Locality B-Urn-38 | Paddy | 2947 ± 46 | 997 BCE | 1149 BCE (95.0%) |
| 2 | Adichanallur | ASI | IUACD# 23C5689 | Locality C-Urn-7 | Millet | 3155 ± 40 | 1205 BCE | 1441 BCE (83.5%) |
| 3 | Adichanallur | TNSDA | Beta - 583589 | ADC1- 003 Habitation | Charcoal | 3470 ± 30 | 1520 BCE | 1757 BCE (86.1%) |

The excavations conducted by the ASI and TNSDA at various points of the graveyard yielded excellent bronze objects with varied compositions of tin such as low, high and super-high tin bronze artefacts. The low-tin bronze materials containing around 10% tin (Sn) in copper (Cu) are called α- bronzes, the high-tin bronzes constituting 20 - 25% tin (Sn) are designated as (α + β) bronzes or simply β bronzes and the tin having 30% or more are considered as γ bronzes by metallurgists.

The non-destructive X-ray Fluorescence Analysis (XRF) analysis carried out by the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam and the team lead by Sharada Srinivasan of National Institute of Advanced Studies, Bangalore on copper bowls, strainers and flower stands, suggest the presence of above 80% copper and 15% tin validating the existence of high-tin bronze. The XRF Analysis carried out on a toy dog recovered from Urn-27 (ZG16/Q-1) in the year 2022 showed that it is a binary bronze with 90% copper and tin at 7%. The analysis of one of the thick bronze rod fragments gave copper of 25%, tin of 48%, iron content of 21 %, trace lead of 0.6% and zinc of 0.8%. The portable XRF machine gave a reading of about 89% copper and 7-8% tin with trace iron of about 3%. The preliminary investigations carried out on the above bronze objects indicate and reconfirm that the bronze objects hold a high-tin percentage as reported from Sivagalai and Adichanallur excavations (Srinivasan 2024:78-89).


Fig. 33: Sasthapuram: Disturbed graves and the high-tin bronze artefacts


*Fig. 34: High-tin bronze objects from other sites of Tamil Nadu*

Incidentally, the preliminary investigations carried out at Sasthapuram located on the western side of the Tirunelveli-Kanniyakumari National Highway near Sirumalinji village in Nanguneri taluk of Tirunelveli yielded high-tin bronze bowls from a disturbed urn spread out on the northern side of the Vempudaiya Sasthakoil (Fig. 33). The bronze object of Sasthapuram yielded as high as 36.83% of tin. Besides Adichanallur, such high-tin bronze artefacts were recovered in several Iron Age and Early Historic graves in the places at Adukkam, Sulapuram, Auroville, Kodumanal, Sivagali and Thirumalapuram suggesting its utility and widespread (Fig. 34). The copper hoards consist of copper antennae swords collected from Appukallu, Ramanathapuram and Anaimalai probably are made of high-tin bronzes but their metallurgical analysis is yet to be made and confirmed.

The availability of high-tin bronzes at Adichanallur, Sivagalai and Sasthapuram in 15th century BCE and ultra-high carbon crucible steel in the 13th century from Thelunganur and Mangadu clearly supports the existence of iron technology prior to steel and they are aware of the metallurgical and technological skill in handling various type of metals.

## ULTRA - HIGH CARBON CRUCIBLE STEEL

The high-carbon crucible steel technology is considered one of the finest achievements of South India. In 1722, the French scholar R.A.F. de Reaumur wrote in his memoir on methods of recognising defects and good quality in steel (Sisco 1956:176). In 1795, Pearson, the Englishman, attempted to identify the manufacturing process of steel and wrongly concluded that it was manufactured directly from ore (Pearson 1795:345). However, it was learned that wootz steel is never formed directly from the ore, but by the fusion of fragments of small bars of malleable iron, in a crucible with woody carbonaceous matter (Mushet 1840:662). This led to the accumulation of data on the process of manufacture of wootz from different parts of India. Among the scholars like Benjamin Heyne and E.H.Voysey, Francis Buchanan's work A Journey from Madras through the Countries of Mysore, Canara and Malabar published in three volumes in 1807 stood as a comprehensive work on this subject. The superiority of the steel over other metals led them to serious scientific analysis and metallurgists made an attempt to identify the properties of the steel and attempted to imitate them. Dr. Murray Thompson of Roorkee Engineering College, U.P. informed Alexander Cunningham after analysing the sample of Delhi pillar received from him that it was a pure malleable iron of 7.66 specific gravity (Cunningham 1871:169 -170). Subsequently, Dhar pillar and Konarak beam were discovered (Smith 1897:143 -146; Graves 1912:187-202). Till then, it was considered bronze or some kind of mixed metal. The pillar erected as early as the 4th century caught the attention of the metallurgist, as it has been standing almost rust-free since then. Robert Hadfield's metallographic analysis in 1912 on the Delhi pillar and his material proof of 7% carbon is probably the first material proof of steel from the early Indian context (Hadfield 1912:134-172). Since then, the origin and diffusion of iron and steel have been studied in India. The different phases of the research on this aspect have been discussed extensively in Indian literature (Banerjee 1965; Chakrabarti 1992).

The wrought iron, steel, cast iron and pig iron are differentiated based on carbon content. The iron consisting of 0.15% carbon is considered as wrought iron, 0.15% to 2% as steel, 2% to 4% as cast iron and more than 4% as pig iron. There are two methods in the manufacturing of steel namely the carbonization method and the decarbonization method. In the first method, the carbon is added to the wrought iron if the carbon content is less than 2%. In the second method, carbon is removed from cast iron which normally carries more than 2% carbon. These processes are being carried out with the help of crucibles. Therefore, it is called crucible steel or "wootz steel". The term wootz is the anglicization of the Tamil word ekku or Kannada/Telugu ukku. The presence of 1.5 to 2.0% of carbon in the iron is considered high-carbon steel. The Kodumanal and Mel-Siruvalur findings in Tamil Nadu could be cited as the finest examples of crucible

*Fig. 35: Kodumanal: Crucible furnace used for making steel*

steel (Srinivasan 2007: 673–96). The Wootz iron is known for its durability and the ability to be flexible and tensile. It was due to the presence of Vanadium (V) in the Indian iron ores as the mafic (Magnesium-Iron) igneous rocks are abundant in the subcontinent. Through trade contacts, this technology was carried to the Middle East and ancient Europe. The well-known Damascus blades were manufactured using this technology.

The introduction of iron and high-carbon steel are interrelated as the latter is the reflection of the advanced level of iron technology. If one knows the date of introduction of steel then naturally the antiquity of iron falls before this date. The investigations carried out on material from Konasamudram, Nizamabad district, Andhra Pradesh (Lowe 1990: 237–250; Voysey 1832:245–247) and Gatihosahalli in the Chitradurga district of Karnataka (Freestone and Tite 1986:35–63) have shown the existence of specialised, standardised and semi-industrial production techniques dating from at least the late medieval period. Sharada Srinivasan came across a previously unrecorded archaeometallurgical site in Mel-Siruvalur, in Sankarapuram taluk of Kallakurichi district, Tamil Nadu (Srinivasan 2007: 673–96). Kodumanal yielded a crucible furnace with high-carbon steel and was firmly dated to 6th century BCE (Rajan 2016:399–416) (Fig. 35). The high carbon steel at Kadebakele in Karnataka yielded a secured date of 880-440 BCE (Srinivasan et.al., 2009:116-121). Identification of these production centres supports the idea that wootz steel production was relatively widespread in South India. The evidence of ultra-high carbon steel, popularly called crucible steel or wootz steel, surfaced at Thelunganur and provided a new insight into the antiquity of steel in south India.

Thelunganur (77° 44′31″ E; 11° 54′ 06″ N) lies 10 km north of Kolaththur, in Mettur taluk of Salem district, Tamil Nadu (Fig. 36). The graveyard site (80 ha.) consist of more than 500 graves situated on the right bank of the river Kaveri in the midst of a cluster of burial sites namely Mangadu, Korapallam and Pannavadi. It met with three type of graves, namely cist burial, urn burial and pit burial entombed with a cairn circle indicating the existence of three different forms of ritual/faith systems. In one of the disturbed burials, two polished stone tools, iron objects and a good number of black-and-red ware and black ware were collected. An iron sword in a better state of preservation was collected from a disturbed pit containing urn enclosed with a capstone. The metallographic analysis carried out on this sword revealed that it was made of ultrahigh carbon steel whose carbon concentration is 0.9 -1.3% based on weight fraction (Rajan et. al., 2017:52-59; Park et.al 2019:68 - 80). The carbon samples collected directly from the hilt and blade of the sword yielded two AMS$^{14}$C dates 2900 - 2627 BCE (4208 ± 35 yrs. BP) and 1435 - 1233 BCE (3089 ± 40 yrs. BP) (Table 6). The two dates with a wide chronological gap pose a great problem in understanding the nature of the sword. Whether the hilt and other parts of the sword were made separately and fused at a later date is a moot point to be discussed. However, the sample collected from the sword obtained in the grave at Mangadu (the nearest site) assigned the date between 1604 - 1416 BCE (3213 ± 34 yrs. BP). Keeping in view of these dates, the lower limit of the date (3089 ± 40 yrs. BP or the calendar date between 1435 and 1233 BCE) obtained for Thelunganur sword is reluctantly accepted with a greater amount of reservation. Even if one considers the lower limit of 1233 BCE, the date is so significant in cultural, chronological and technological contexts. At the chronological level, the AMS$^{14}$C date of 13$^{th}$ century BCE obtained for the sword is the earliest date so far obtained for the steel. At the technical level, the sword was made of ultrahigh carbon steel with a controlled microstructure consisting mostly of particles of iron carbide in the ferrite background, which is almost free of non-metallic inclusions (Rajan et.al. 2017:52 - 59; Park et.al 2019:68 - 80).

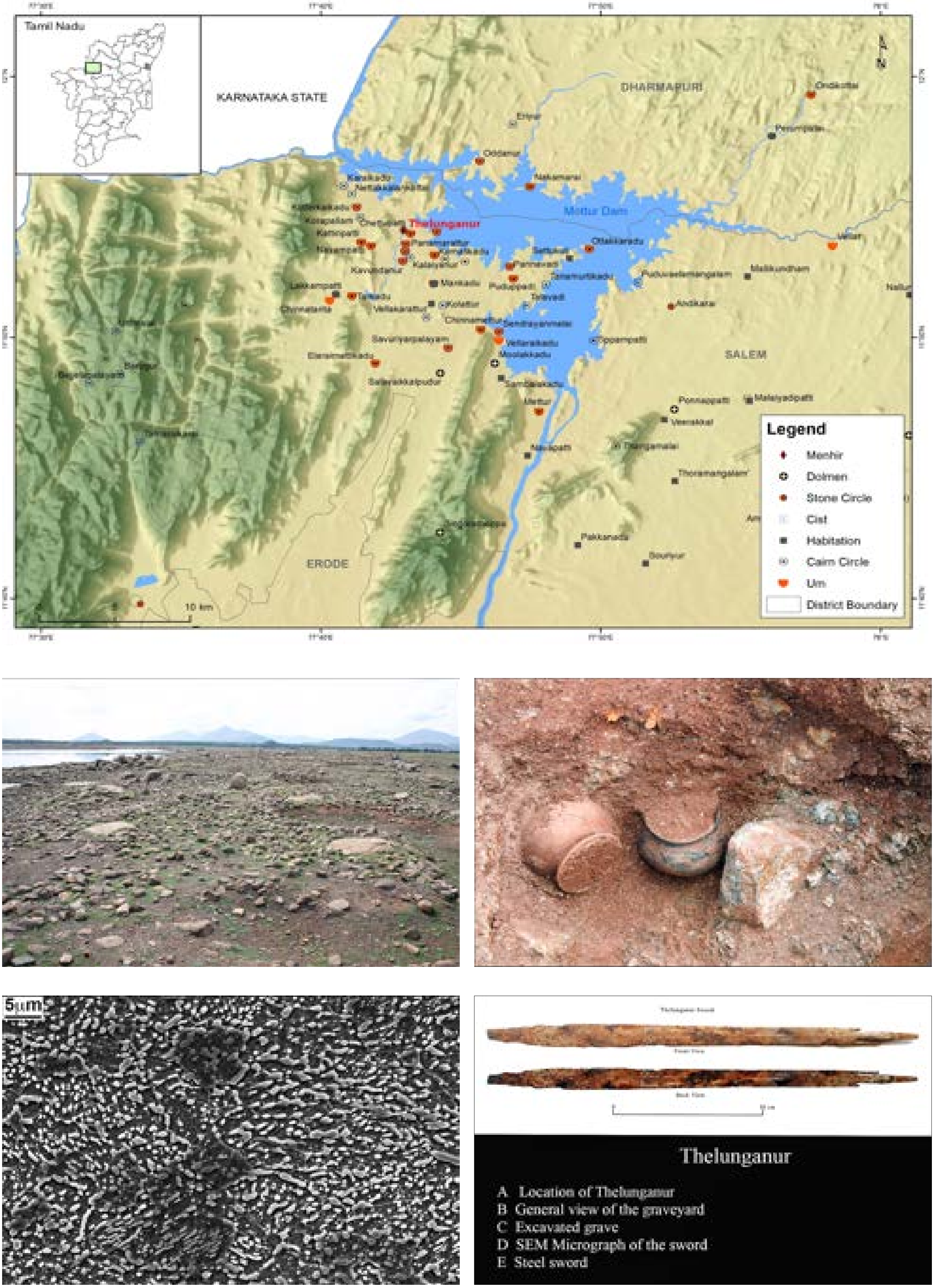



*Fig. 36: Thelunganur: Iron Age graves and swords*

| TABLE 6: AMS RADIOCARBON MEASUREMENTS ON CARBON SAMPLES EXTRACTED FROM THE IRON OBJECTS OF THELUNGANUR AND MANGADU. THE MEASUREMENTS WERE MADE IN THE UNIVERSITY OF ARIZONA'S NSF-ARIZONA AMS FACILITY FOR $^{14}C$ ANALYSIS. | | | | | |
|---|---|---|---|---|---|
| **Artifact** | | **$\delta^{13}C$ (‰)** | **1σ $^{14}C$ age (yrs. BP)** | **95.4%(2σ) cal. age ranges (BCE)** | **Lab Code** |
| Thelunganur Steel sword | Sample #1 | -23.2 | 3089 ± 40 | 1435-1233 | AA99857 |
| | Sample #2 | -31.0 | 4208 ± 35 | 2900 - 2627 | AA104832 |
| Thelunganur arrowhead | | -22.9 | 2835 ± 34 | 1109 - 909 | AA104113 |
| Mangadu iron object | | -25.8 | 3213 ± 34 | 1604 -1416 | AA104114 |

The earlier excavations at Sivagalai, Adichanallur, Mayiladumparai, Kilnamandi and Mangadu indicated the date falls between 2500 BCE and 3000 BCE. as the introduction of iron in south India, particularly in Tamil Nadu.

When cultural zones located north of Vindhyas experienced the Copper Age, the region south of Vindhyas might have entered into the Iron Age due to the limited availability of commercially exploitable copper ore. Thus, the Copper Age of North India and the Iron Age of South India are probably contemporary. Future excavations and scientific dates may further clarify or strengthen the nature of the introduction of iron in India.

Based on the availability of AMS$^{14}$C and OSL dates of 2427 BCE, 2450 BCE, 2459 BCE, 2522 BCE, 2953 BCE, 3259 BCE and 3345 BCE were obtained for the samples recovered from the recent excavations. Therefore, we may securely place the introduction of iron in India, particularly in Tamil Nadu, in the early part of 4$^{th}$ millennium BCE. The metallurgical analysis of iron objects from the excavated sites and future excavations in iron ore-bearing zones may further consolidate or strengthen these findings. Let us hope and wait for future evidences.

Beta Analytic
TESTING LABORATORY

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ISO/IEC 17025:2017-Accredited Testing Laboratory

# REPORT OF RADIOCARBON DATING ANALYSES

| | |
|---|---|
| Ramalingam Sivanantham | Report Date: July 05, 2023 |
| Tamil Nadu Department of Archaeology | Material Received: June 21, 2023 |

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes | |
|---|---|---|---|
| **Beta - 666752** | **KMD1/2023 - 001** | **3400 +/- 30 BP** | IRMS δ13C: -25.3 o/oo |

| | | |
|---|---|---|
| **(93.3%)** | **1769 - 1615 cal BC** | **(3718 - 3564 cal BP)** |
| **( 2.1%)** | **1866 - 1852 cal BC** | **(3815 - 3801 cal BP)** |

| | |
|---|---|
| Submitter Material: | Charcoal |
| Pretreatment: | (charred material) acid/alkali/acid |
| Analyzed Material: | Charred material |
| Analysis Service: | AMS-Standard delivery |
| Percent Modern Carbon: | 65.49 +/- 0.24 pMC |
| Fraction Modern Carbon: | 0.6549 +/- 0.0024 |
| D14C: | -345.09 +/- 2.45 o/oo |
| Δ14C: | -350.85 +/- 2.45 o/oo (1950:2023) |
| Measured Radiocarbon Age: | (without d13C correction): 3400 +/- 30 BP |
| Calibration: | BetaCal4.20: HPD method: INTCAL20 |

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 10 of 21

BetaCal 4.20

# Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -25.3 o/oo)

**Laboratory number** **Beta-666752**

**Conventional radiocarbon age** **3400 ± 30 BP**

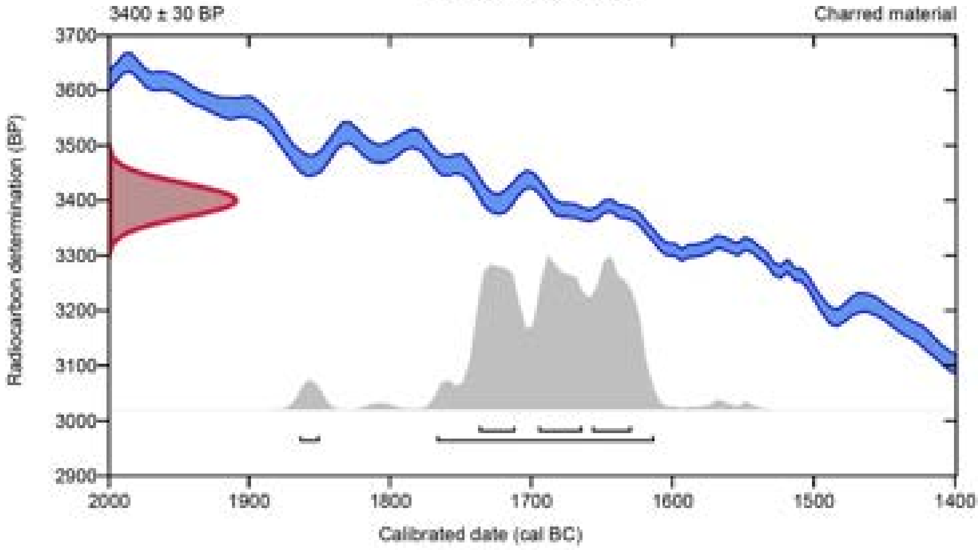
95.4% probability

| | | |
|---|---|---|
| (93.3%) | 1769 - 1615 cal BC | (3718 - 3564 cal BP) |
| (2.1%) | 1866 - 1852 cal BC | (3815 - 3801 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (25.2%) | 1697 - 1666 cal BC | (3646 - 3615 cal BP) |
| (22.1%) | 1659 - 1631 cal BC | (3608 - 3580 cal BP) |
| (21%) | 1739 - 1713 cal BC | (3688 - 3662 cal BP) |

**KMD1/2023 - 001**




**Database used**
**INTCAL20**

**References**


**References to Probability Method**
Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.
**References to Database INTCAL20**
Reimer, et al., 2020, Radiocarbon 62(4):725-757.



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info@betalabservices.com

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# REPORT OF RADIOCARBON DATING ANALYSES

Ramalingam Sivanantham — Report Date: March 14, 2022

Tamil Nadu Department of Archaeology — Material Received: February 28, 2022

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes | |
|---|---|---|---|
| **Beta - 620258** | **MLP1-003** | **3310 +/- 30 BP** | IRMS δ13C: -25.4 o/oo |

| | | |
|---|---|---|
| **(93.9%)** | **1634 - 1504 cal BC** | **(3583 - 3453 cal BP)** |
| **( 1.5%)** | **1669 - 1656 cal BC** | **(3618 - 3605 cal BP)** |

Submitter Material: Charcoal
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 66.23 +/- 0.25 pMC
Fraction Modern Carbon: 0.6623 +/- 0.0025
D14C: -337.71 +/- 2.47 o/oo
Δ14C: -343.45 +/- 2.47 o/oo (1950:2022)
Measured Radiocarbon Age: (without d13C correction): 3320 +/- 30 BP
Calibration: BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 4 of 15

BetaCal 4.20

# Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -25.4 o/oo)

**Laboratory number** **Beta-620258**

**Conventional radiocarbon age** **3310 ± 30 BP**

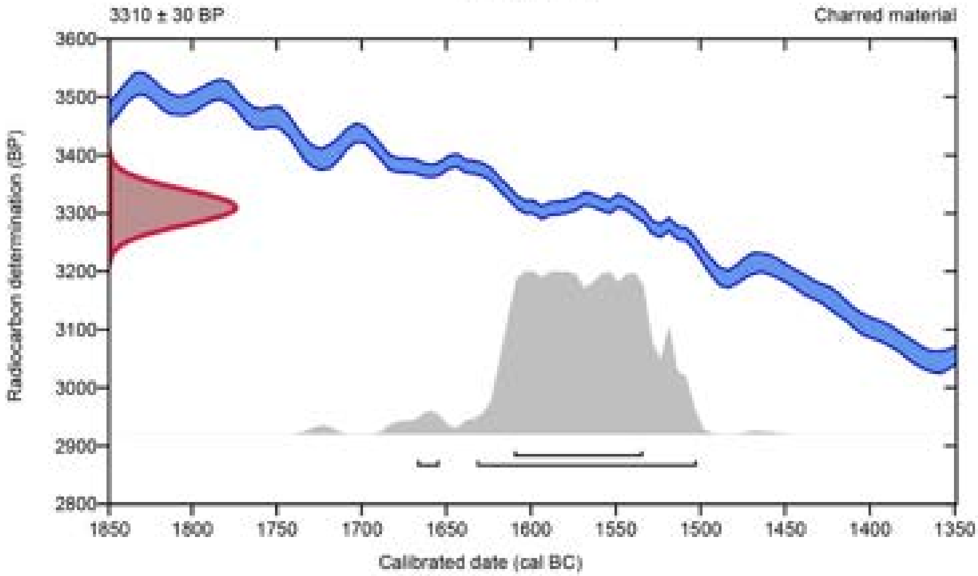
95.4% probability

| | | |
|---|---|---|
| (93.9%) | 1634 - 1504 cal BC | (3583 - 3453 cal BP) |
| (1.5%) | 1669 - 1656 cal BC | (3618 - 3605 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (68.2%) | 1612 - 1536 cal BC | (3561 - 3485 cal BP) |

**MLP1-003**




**Database used**
**INTCAL20**

**References**

**References to Probability Method**
Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.
**References to Database INTCAL20**
Reimer, et al., 2020, Radiocarbon 62(4):725-757.

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CARBON-14 TESTING

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## REPORT OF RADIOCARBON DATING ANALYSIS

Submitter **Sivanantham Ramalingam**

Company **Department of Archaeology**

Received Date **September 12, 2024**

Report Date **October 2, 2024**

Laboratory Number **Beta-709374**

Sample Code **ADC-21-002**

To validate report, scan this QR code on a mobile device or go to https://verify.betalabservices.com and enter the requested information.

Conventional Radiocarbon Age **4010 +/- 30 BP**

Ratio of Stable Isotopes **IRMS δ13C: -23.9 o/oo**

**95.4% Probability Calibrated Range(s)**

| | | |
|---|---|---|
| **(93.9%)** | **2580 - 2465 cal BC** | **(4529 - 4414 cal BP)** |
| **(1.5%)** | **2618 - 2608 cal BC** | **(4567 - 4557 cal BP)** |

| | |
|---|---|
| Submitter Material | Charcoal |
| Pretreatment | (Charred material):acid/alkali/acid |
| Analyzed Material | Charred material |
| Analysis Service | AMS-Standard Delivery |
| Percent Modern Carbon | 60.70 +/- 0.23 pMC |
| Fraction Modern Carbon | 0.6070 +/- 0.0023 |
| D14C | -392.98 +/- 2.26 o/oo |
| Δ14C | -398.39 +/- 2.26 o/oo (1950:2024) |
| Measured Radiocarbon Age | (without d13C correction): 3990 +/- 30 BP |
| Calibration | BetaCal 5.0: High Probability Density Range Method: INTCAL20 |

Results are ISO/IEC-17025 accredited. All work was done at Beta in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1sigma counting statistics. Calculated sigmas less than 30BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 3 of 10

BETA Beta Analytic
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BetaCal 5.0

**Calibration of Radiocarbon Age to Calendar Years**

(High Probability Density Range Method: INTCAL20)

(Variables: d13C = -23.9 o/oo)

**Beta-Laboratory Number** **709374**

**Conventional Radiocarbon Age (BP)** **4010 +/- 30 BP**

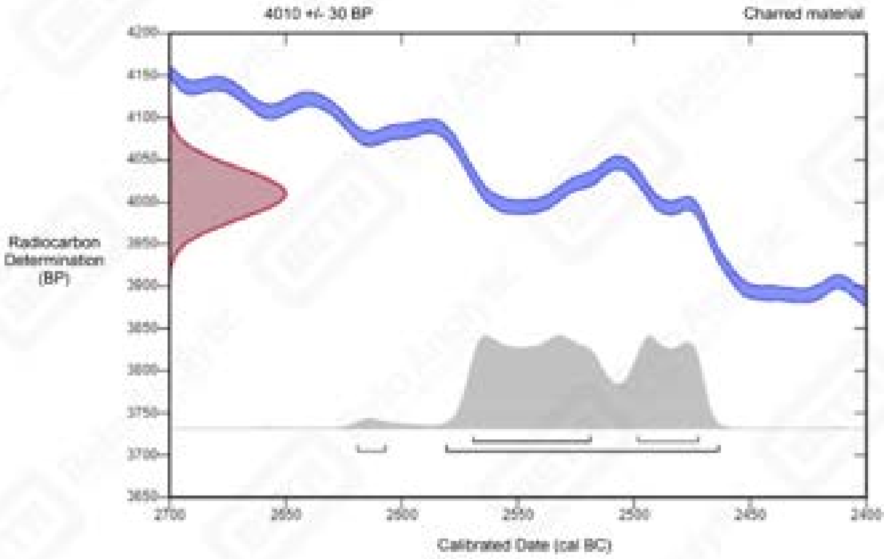
95.4% Probability Calibrated Range(s)

| | | |
|---|---|---|
| (93.9%) | 2580 - 2465 cal BC | (4529 - 4414 cal BP) |
| (1.5%) | 2618 - 2608 cal BC | (4567 - 4557 cal BP) |

68.2% Probability Calibrated Range(s)

| | | |
|---|---|---|
| (45.8%) | 2568 - 2520 cal BC | (4517 - 4469 cal BP) |
| (22.4%) | 2497 - 2473 cal BC | (4446 - 4422 cal BP) |

**ADC-21-002**




**Database Used**

INTCAL20

**References**

**References to Probability Method**

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

**References to Database INTCAL20**

Reimer, et al., 2020, Radiocarbon 62(4): 725-757.

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# REPORT OF RADIOCARBON DATING ANALYSES

Ramalingam Sivanantham — Report Date: February 22, 2021

Tamil Nadu Department of Archaeology — Material Received: February 02, 2021

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes | |
|---|---|---|---|
| **Beta - 583594** | **SGI1-003** | **4300 +/- 30 BP** | IRMS δ13C: -24.2 o/oo |

| | | |
|---|---|---|
| **(80.7%)** | **2939 - 2881 cal BC** | **(4888 - 4830 cal BP)** |
| **(11.3%)** | **3011 - 2974 cal BC** | **(4960 - 4923 cal BP)** |
| **( 3.4%)** | **2969 - 2948 cal BC** | **(4918 - 4897 cal BP)** |

Submitter Material: Charcoal
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 58.55 +/- 0.22 pMC
Fraction Modern Carbon: 0.5855 +/- 0.0022
D14C: -414.50 +/- 2.19 o/oo
Δ14C: -419.51 +/- 2.19 o/oo (1950:2021)
Measured Radiocarbon Age: (without d13C correction): 4290 +/- 30 BP
Calibration: BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 25 of 57

BetaCal 4.20

# Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -23.5 o/oo)

**Laboratory number** **Beta-583592**

**Conventional radiocarbon age** **4540 ± 30 BP**

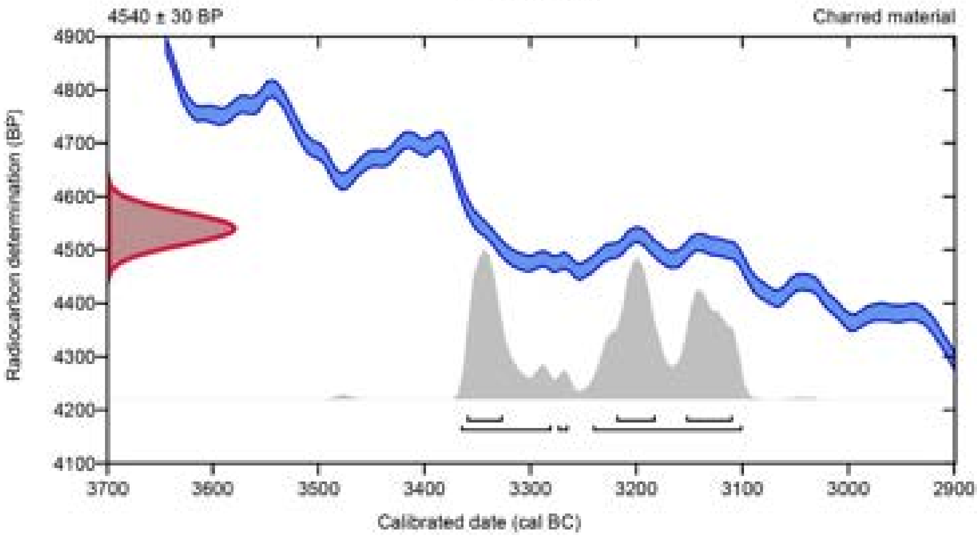
95.4% probability

| | | |
|---|---|---|
| (61.5%) | 3243 - 3102 cal BC | (5192 - 5051 cal BP) |
| (32.4%) | 3368 - 3282 cal BC | (5317 - 5231 cal BP) |
| (1.5%) | 3276 - 3266 cal BC | (5225 - 5215 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (23.4%) | 3221 - 3184 cal BC | (5170 - 5133 cal BP) |
| (23%) | 3362 - 3328 cal BC | (5311 - 5277 cal BP) |
| (21.8%) | 3155 - 3111 cal BC | (5104 - 5060 cal BP) |

**SGI1-001**




## Database used

INTCAL20

## References

**References to Probability Method**

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.

**References to Database INTCAL20**

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## REPORT OF RADIOCARBON DATING ANALYSES

| | | | |
|---|---|---|---|
| Ramalingam Sivanantham | | Report Date: | February 22, 2021 |
| Tamil Nadu Department of Archaeology | | Material Received: | February 02, 2021 |

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes | |
|---|---|---|---|
| **Beta - 583593** | **SGI1-002** | **4670 +/- 30 BP** | IRMS δ13C: -25.4 o/oo |

**(95.4%)** **3519 - 3371 cal BC** **(5468 - 5320 cal BP)**

Submitter Material: Charcoal
Pretreatment: (charred material) acid/alkali/acid
Analyzed Material: Charred material
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 55.91 +/- 0.21 pMC
Fraction Modern Carbon: 0.5591 +/- 0.0021
D14C: -440.86 +/- 2.09 o/oo
Δ14C: -445.64 +/- 2.09 o/oo (1950:2021)
Measured Radiocarbon Age: (without d13C correction): 4680 +/- 30 BP
Calibration: BetaCal4.20: HPD method: INTCAL20

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 24 of 57

BetaCal 4.20

## Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -25.4 o/oo)

**Laboratory number** **Beta-583593**

**Conventional radiocarbon age** **4670 ± 30 BP**

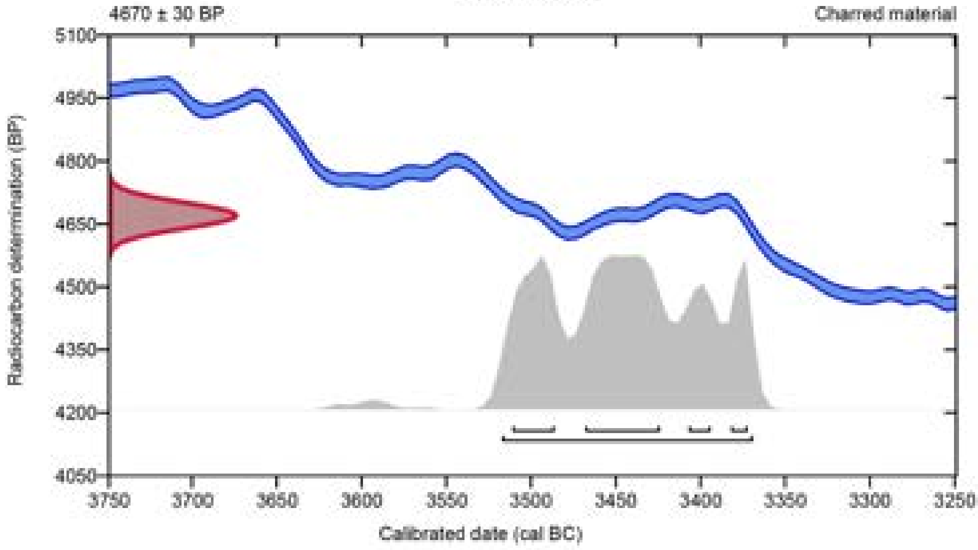
95.4% probability

| | | |
|---|---|---|
| (95.4%) | 3519 - 3371 cal BC | (5468 - 5320 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (34.8%) | 3470 - 3426 cal BC | (5419 - 5375 cal BP) |
| (18.1%) | 3513 - 3488 cal BC | (5462 - 5437 cal BP) |
| (8.1%) | 3409 - 3396 cal BC | (5358 - 5345 cal BP) |
| (7.2%) | 3384 - 3374 cal BC | (5333 - 5323 cal BP) |

**SGI1-002**




**Database used**
**INTCAL20**

**References**

**References to Probability Method**
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## REPORT OF RADIOCARBON DATING ANALYSES

| | |
|---|---|
| Ramalingam Sivanantham | Report Date: February 22, 2021 |
| Tamil Nadu Department of Archaeology | Material Received: February 02, 2021 |

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes | |
|---|---|---|---|
| **Beta - 583594** | **SGI1-003** | **4300 +/- 30 BP** | IRMS δ13C: -24.2 o/oo |

| | | |
|---|---|---|
| **(80.7%)** | **2939 - 2881 cal BC** | **(4888 - 4830 cal BP)** |
| **(11.3%)** | **3011 - 2974 cal BC** | **(4960 - 4923 cal BP)** |
| **( 3.4%)** | **2969 - 2948 cal BC** | **(4918 - 4897 cal BP)** |

| | |
|---|---|
| Submitter Material: | Charcoal |
| Pretreatment: | (charred material) acid/alkali/acid |
| Analyzed Material: | Charred material |
| Analysis Service: | AMS-Standard delivery |
| Percent Modern Carbon: | 58.55 +/- 0.22 pMC |
| Fraction Modern Carbon: | 0.5855 +/- 0.0022 |
| D14C: | -414.50 +/- 2.19 o/oo |
| Δ14C: | -419.51 +/- 2.19 o/oo (1950:2021) |
| Measured Radiocarbon Age: | (without d13C correction): 4290 +/- 30 BP |
| Calibration: | BetaCal4.20: HPD method: INTCAL20 |

Results are ISO/IEC-17025:2017 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

Page 25 of 57

BetaCal 4.20

# Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL20)

(Variables: d13C = -24.2 o/oo)

**Laboratory number** **Beta-583594**

**Conventional radiocarbon age** **4300 ± 30 BP**

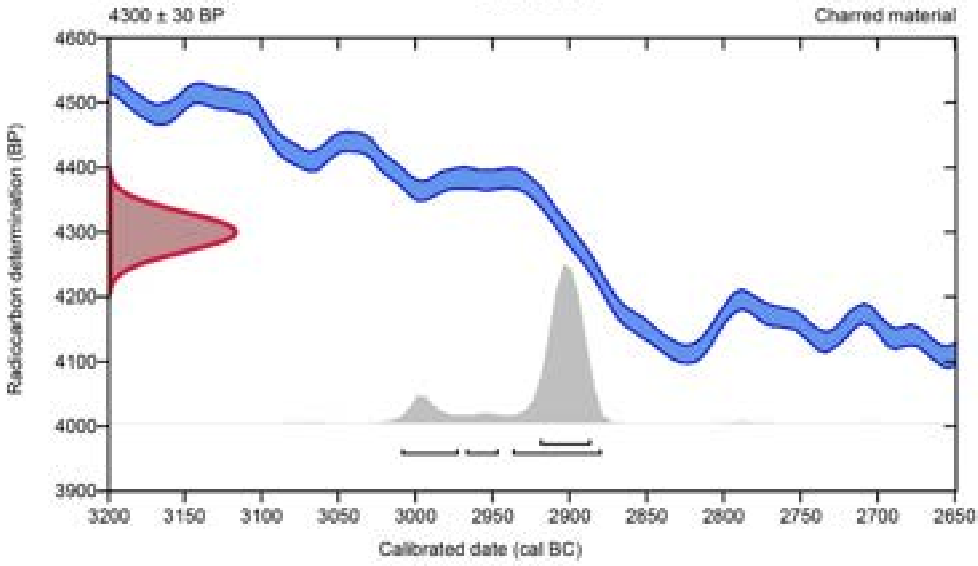
95.4% probability

| | | |
|---|---|---|
| (80.7%) | 2939 - 2881 cal BC | (4888 - 4830 cal BP) |
| (11.3%) | 3011 - 2974 cal BC | (4960 - 4923 cal BP) |
| (3.4%) | 2969 - 2948 cal BC | (4918 - 4897 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (68.2%) | 2921 - 2888 cal BC | (4870 - 4837 cal BP) |

**SGI1-003**

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1946

बीरबल साहनी पुराविज्ञान संस्थान
BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES
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Lucknow-226 007
भारत (INDIA)

(भारत सरकार के विज्ञान और प्रौद्योगिकी विभाग का एक स्वायत्तशासी संस्थान)
(AN AUTONOMOUS INSTITUTE UNDER DEPARTMENT OF SCIENCE & TECHNOLOGY, GOVERNMENT OF INDIA)

संख्या
No. ..................................

दिनांक
Dated ......14.01.2023..........

To

**The Commissioner,**
Department of Archaeology,
Government of Tamil Nadu,
Tamil Salai, Egmore, Chennai 600008

Dear Sir,

Five urn pieces of Sivagalai burial site were dated using luminescence dating method in BSIP, Lucknow. As dose rate measurements are still ongoing, the luminescence ages tabulated below are provisional. The ages are to be understood as this many years ago (since 2019 – sample collection year) the urns were made by firing in the kiln.

| Sl. No. | Institute Name | Sample Code | Age (years) |
|---|---|---|---|
| 1 | BSIP | A2-Urn1_BSIP | 4500±400 |
| 2 | BSIP | A2-Urn3_BSIP | 3300±600 |
| 3 | BSIP | L13-Urn2_BSIP | 4000±300 |
| 4 | BSIP | L13-Urn5_BSIP | 3900±400 |
| 5 | BSIP | L13-Urn8_BSIP | 4000±400 |

Dr. Priyanka Singh and Mr. Ishwar Shukla are working with me on this endeavor.

Thanks,

**Dr. P. Morthekai**
Scientist - D
morthekai@gmail.com / +91 9787952151

भौतिक अनुसंधान प्रयोगशाला
(भारत सरकार, अंतरिक्ष विभाग की यूनिट)
नवरंगपुरा, अहमदाबाद - 380 009, भारत

Physical Research Laboratory
(A Unit of Dept. of Space, Govt. of India)
Navrangpura, Ahmedabad - 380 009, India

14th Jan 2023

To

**The Commissioner**
Department of Archaeology
Government of Tamil Nadu
Tamil Salai , Egmore Chennai 600008

Dear Sir,

Two urn pieces of Sivagalai urns were dated using luminescence dating method in PRL, Ahmedabad. The ages below are tentative as dose rate measurements are still pending.

| Sl. No. | Institute Name | Sample Code | Age (years) |
|---|---|---|---|
| 1 | PRL | A2-Urn1_PRL | 4400±400 |
| 2 | PRL | L13-Urn5_PRL | 4500±300 |

Ms. Malika Singhal is involved in the project under my supervision.

Thanks.

14-01-2023

**Dr. Naveen Chauhan**

Dr. Naveen Chauhan, Associate Professor, AMOPH Division
Office Phone: +91-79-2631-4753, Mobile: +91-8076266801
e-mail: chauhan@prl.res.in

# BIBLIOGRAPHY

Agrawal, D. P., and G.P. Joshi 1990. Iron Objects from South Indian Megaliths (Karnataka) - A Technological Study and Significance, in *Archaeology in Karnataka*, A Sundara and K.G. Bhatsoori (eds.), pp.219–234. Mysore: Directorate of Archaeology and Museums.

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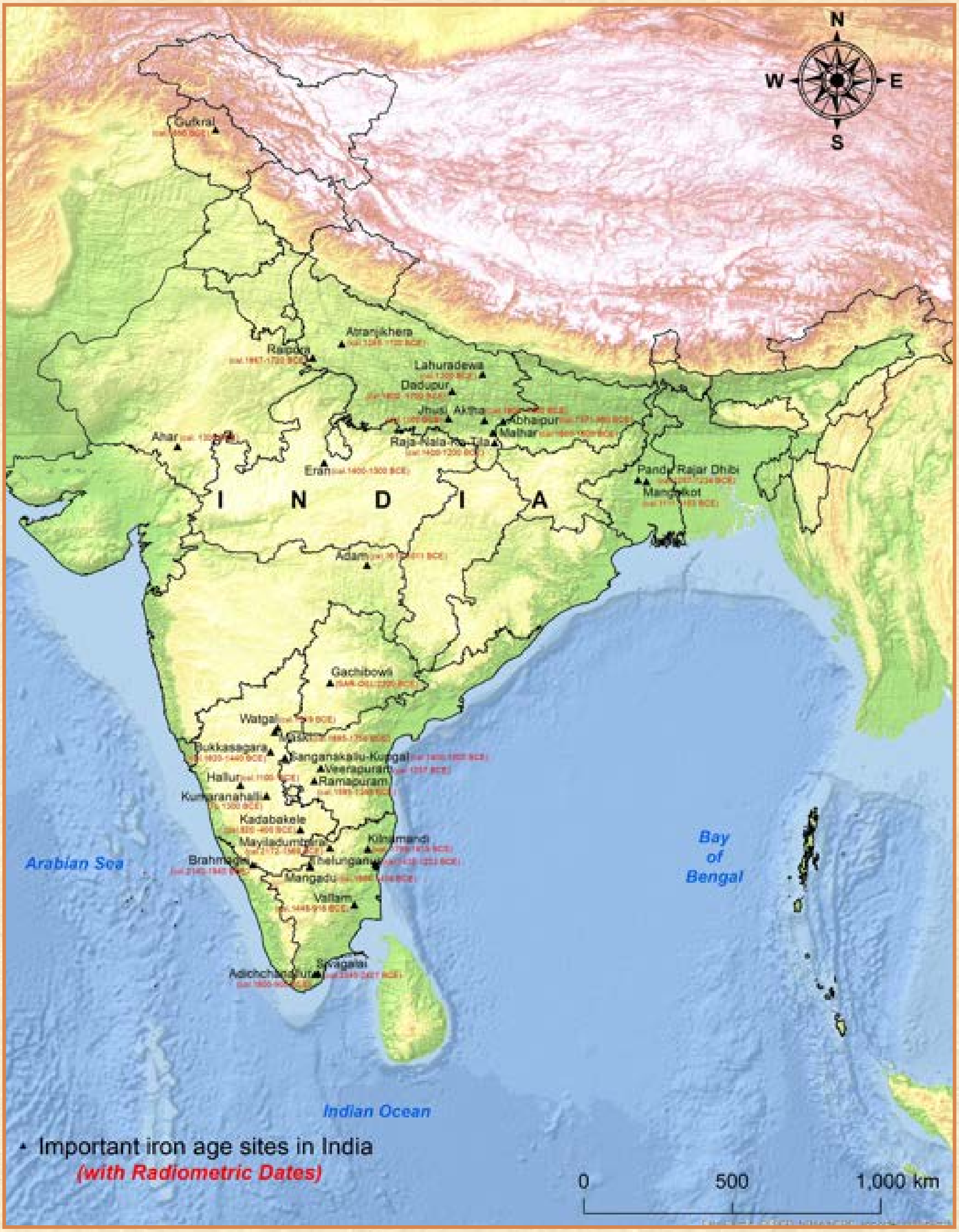
Iron Age Sites with Radiometric Dates

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