ARCHAEO-SCIENCES AND THE RECONSTRUCTION OF EARLY TAMIL CIVILIZATION: FROM IRON AGE SETTLEMENTS TO THE SANGAM AGE

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Abstract :

The reconstruction of ancient Tamil Nadu's historical trajectory necessitates a comprehensive and interdisciplinary approach to chronological investigation. Archaeological sciences have emerged as vital in this endeavour, offering a suite of advanced techniques—such as radiocarbon dating (C-14), thermoluminescence, archaeobotanical studies, stratigraphic analysis, and palaeoenvironmental reconstructions—that enable scholars to establish a reliable temporal framework for the region's cultural evolution. These scientific methodologies allow for the precise dating of material remains, facilitating the identification of distinct cultural phases, shifts in settlement organization, technological innovations, and patterns of socio-economic transformation spanning from the prehistoric to the early historic periods. This paper critically examines the role of these archaeological science techniques in refining the chronology of Ancient Tamil Nadu, drawing on case studies from key excavated sites including Adichanallur, Keeladi, Kodumanal, and Porunthal. The integration of scientific data with traditional historical sources and classical Tamil literature enables a more nuanced understanding of the region's past. The findings underscore the transformative impact of scientific archaeology in bridging chronological gaps and challenging earlier historical assumptions. Ultimately, this study demonstrates how scientific methodologies not only enhance chronological precision but also deepen our insight into the complex cultural and historical development of ancient Tamil Nadu within the broader context of South Indian archaeology.

Keywords: *Ancient Tamil Nadu, Archaeological Science, Chronology, Early Historic Period, Sangam period, Iron Age.*

Introduction :

The advent of scientific analysis in archaeology has transformed the way we study and interpret the past, moving the discipline beyond descriptive antiquarianism to a more empirical and analytical framework. This transformation

gained momentum in the 1960s with the rise of New Archaeology, or Processual Archaeology, which advocated for the use of scientific methods to explain cultural processes and test hypotheses about past human behaviour. Central to this paradigm shift was the emphasis on objectivity, quantification, and interdisciplinary collaboration, particularly through the incorporation of natural sciences such as chemistry, physics, geology, and biology into archaeological research. Scientific techniques such as radiocarbon dating (C14), thermoluminescence, dendrochronology, stratigraphy, archaeobotany, geoarchaeology, and palaeoenvironmental studies have become indispensable tools in reconstructing the chronology, ecology, and material culture of ancient societies. These methods allow for the absolute or relative dating of archaeological deposits, enabling scholars to build accurate temporal frameworks and trace cultural changes over time. In the context of ancient Tamil Nadu, the historical-geographical region covering present-day Tamil Nadu and parts of Kerala, Andhra Pradesh, scientific analysis has significantly enriched our understanding of its chronological development. Ancient Tamil Nadu's long cultural sequence, from prehistoric times to the early historic period (ca. 600 BCE–300 CE), is marked by complex settlement patterns, evolving trade networks, and the emergence of urban centres. Scientific dating techniques applied at key archaeological sites such as Adichanallur, Porunthal, Keeladi, and Kodumanal have helped determine the antiquity of habitation, the sequencing of cultural layers, and the timing of technological and socio-economic shifts. These advancements not only validate classical Tamil texts like Sangam literature, but also provide a more grounded historical timeline based on empirical data. In this way, the integration of scientific analysis rooted in the legacy of New Archaeology has played a pivotal role in bridging gaps in the historical narrative of ancient Tamil Nadu and establishing a more precise chronology.

Timeline of scientific Techniques and Theoretical Shifts in Archaeology

The discipline of archaeology has undergone a significant evolution, transforming from its origins in antiquarian curiosity during the 18th and 19th centuries into a rigorous, interdisciplinary science. In its formative years, archaeology was predominantly descriptive, shaped by antiquarians who focused on the collection of artifacts, inscriptions, and monumental remains. These early efforts often lacked systematic methods, with little attention given to contextual analysis or stratigraphic layers. As a result, interpretations were frequently speculative, and chronological frameworks were largely based on typological sequences and stylistic similarities rather than empirical evidence. This approach began to change with the advent of scientific archaeology, particularly through the development of the Three-Age System, categorizing human prehistory into the Stone, Bronze, and Iron Ages and the application of stratigraphy, which drew from geological principles. These foundational innovations introduced a more structured methodology, enabling archaeologists to more accurately

sequence cultural developments and construct relative chronologies. A major milestone in the scientific advancement of archaeology occurred in the mid-20th century with Willard Libby's invention of radiocarbon dating (C-14). This technique revolutionized the field by allowing for the absolute dating of organic materials, thus greatly enhancing the precision of cultural timelines and refining historical interpretations. The 1960s saw the emergence of a theoretical movement known as New Archaeology or Processual Archaeology, which advocated for a more scientific and hypothesis-driven approach. It redefined archaeology as a discipline aimed at explaining cultural systems and human behaviour through rigorous, testable models. Emphasizing quantitative methods, environmental reconstruction, and systems theory, this approach fostered stronger interdisciplinary collaboration with the natural sciences, including biology, chemistry, and geology. Building on these developments, the late 20th century witnessed the growth of a variety of specialized scientific subfields within archaeology. Geoarchaeology applied earth science techniques to investigate site formation and landscape evolution, while archaeobotany and zooarchaeology reconstructed ancient subsistence patterns, including agriculture and animal domestication. Bioarchaeology and ancient DNA (aDNA) analysis offered insights into health, disease, demography, and genetic ancestry. Furthermore, isotopic studies enabled reconstructions of past diets, climate conditions, and human mobility. The field of archaeometry, encompassing the scientific study of ceramics, metals, pigments, and other materials, greatly expanded our understanding of technological innovation and trade in ancient societies.

In the 21st century, archaeological science has become an essential component of archaeological research, dramatically expanding our capacity to explore the past. The integration of advanced technologies such as remote sensing, Geographic Information Systems (GIS), LiDAR, and 3D digital modelling has enabled detailed mapping and virtual reconstruction of ancient sites and environments. These methodologies are particularly valuable in historically rich regions like Ancient Tamil Nadu, where complex settlement patterns, long-term cultural continuity, and early global trade networks demand precise analytical frameworks. Scientific techniques have played a pivotal role in establishing the chronology of key sites such as Adichanallur, Keeladi, Porunthal, and Kodumanal, revealing important phases of urbanization, technological progress, and socio-economic transformation. The integration of archaeological sciences with traditional excavation practices and literary-historical sources has made it possible to reconstruct a more comprehensive, accurate, and dynamic narrative of Ancient Tamil Nadu's past.

What are Archaeo-sciences?

Archaeo-sciences, also referred to as archaeological sciences, encompass a wide range of scientific techniques and analytical methods derived from the natural and physical sciences primarily physics, chemistry, biology, and geology, which are applied to the study of archaeological materials and contexts.

This interdisciplinary field bridges the gap between the humanities and the sciences, enabling archaeologists to explore and interpret the human past through measurable and replicable data. Unlike traditional archaeological methods that often relied on descriptive analysis and typological comparisons, archaeo-scientific approaches offer a more objective, evidence-based framework for studying past societies. One of the central contributions of archaeo-sciences is in the domain of chronology. Scientific dating methods such as radiocarbon dating (C-14), thermoluminescence, optically stimulated luminescence (OSL), and dendrochronology have revolutionized our ability to assign absolute or relative dates to archaeological layers and artifacts. These techniques have replaced earlier reliance on stylistic or comparative dating, providing precise timelines for cultural developments and human activities across different regions and periods. In addition to dating, archaeo-sciences play a critical role in the reconstruction of ancient environments and human interactions with them. Fields like geoarchaeology utilize sedimentology, soil science, and geomorphology to analyze site formation processes, landscape changes, and human-induced environmental modifications. This helps archaeologists interpret how natural and cultural forces have shaped archaeological sites over time. The study of biological remains has also been significantly advanced through archaeo-scientific methods. Bioarchaeology, which focuses on the examination of human skeletal remains, provides valuable information about ancient health conditions, diet, trauma, disease, and even social status. The development of ancient DNA (aDNA) analysis has opened new frontiers in understanding human migration patterns, genetic relationships, and population diversity. Isotopic analysis further complements these studies by revealing detailed insights into past diets, climate conditions, mobility, and weaning practices. Furthermore, archaeobotany (the study of plant remains) and zooarchaeology (the study of animal remains) allow for the reconstruction of ancient agricultural practices, food consumption patterns, domestication processes, and broader ecological relationships. These sub-disciplines enable archaeologists to understand how ancient communities adapted to and managed their environments over time. Technological innovations have also played a major role in the expansion of archaeo-sciences. The use of remote sensing technologies, such as aerial photography, satellite imagery, and LiDAR, has allowed archaeologists to detect and map buried features and landscape modifications without excavation. The integration of Geographic Information Systems (GIS) has enhanced spatial analysis, allowing researchers to study settlement patterns, resource distribution, and site catchments. 3D modelling and digital reconstruction further contribute to the visualization and preservation of archaeological sites and artifacts. Collectively, these scientific methods have transformed archaeology into a multidisciplinary science, where data from various fields converge to build a more complete understanding of the past. By merging excavation techniques

with advanced scientific tools, archaeo-sciences not only enhance the precision of archaeological interpretations but also expand our capacity to ask new questions and explore aspects of past human life that were previously inaccessible. As archaeology continues to evolve, the role of archaeo-sciences remains fundamental in redefining how we uncover, analyse, and understand our shared human heritage.

Scientific Discipline	Subfield in Archaeology (Archaeo-science)	Key Attributes / Techniques	Contribution to Archaeology
Physics	Radiocarbon Dating, Thermoluminescence	C-14 dating, TL, OSL	Absolute dating of organic and inorganic materials
Chemistry	Archaeometry, Isotope Analysis	Elemental analysis, residue analysis, stable isotopes	Material composition, trade routes, ancient diet and mobility
Biology	Bioarchaeology, Ancient DNA (aDNA)	DNA extraction, skeletal analysis	Human ancestry, health, disease, migration patterns
Botany	Archaeobotany, Palynology	Seed analysis, pollen analysis, phytoliths	Agricultural practices, environment, diet reconstruction
Zoology	Zooarchaeology	Animal bone analysis, domestication studies	Animal use, economy, subsistence patterns
Geology	Geoarchaeology	Soil analysis, stratigraphy, micromorphology	Site formation, landscape reconstruction
Environmental Science	Palaeoenvironmental Studies	Sediment cores, charcoal analysis, climate data	Understanding ancient climate and environmental changes
Geography / GIS	Remote Sensing, GIS	LiDAR, satellite imagery, spatial analysis	Site detection, landscape and settlement pattern studies
Material Science	Archaeometry	Metallurgy, ceramic petrography, glass and pigment analysis	Technology, craftsmanship, trade connections
Computer Science	Digital Archaeology, 3D Modeling	Photogrammetry, modeling software	Virtual reconstruction, data visualization

Understanding Ancient Tamil Nadu

Ancient Tamil Nadu refers to the early historic cultural-geographical region predominantly inhabited by the Tamil-speaking people, covering a broad area in the southern part of the Indian subcontinent. This region included present-day Tamil Nadu and extended into parts of Kerala (particularly the western coastal areas), southern Andhra Pradesh. It was not a political entity with fixed boundaries but a cultural sphere united by the Tamil language, customs practices, and literary expression. Tamil Nadu reached its cultural and political zenith during the Sangam Age, a period conventionally dated between 600 BCE and 300 CE, named after the legendary literary academies or Sangams believed to have convened in Madurai. This period was marked by the rise of the Three Crowned Kings or Mooventhar the Cholas, Chera, and Pandyas, who ruled over different parts of ancient Tamil Nadu and often engaged in warfare, alliances, and cultural patronage. Each dynasty established administrative centres, nurtured trade links, and supported poets and scholars. Under their reign, Tamil Nadu saw the development of urban centres such as Madurai, Uraiyur, Karur, and Kaveripattinam, many of which evolved into important hubs of economic, political, and cultural activity. One of the most distinguishing features of ancient Tamil Nadu was its extensive maritime trade network. Ports such as Arikamedu, Puhar (Kaveripattinam), Muziris, and Alagankulam, Korkai connected Tamil Nadu to the Mediterranean world, especially the Roman Empire, as well as regions in Southeast Asia and Sri Lanka. Archaeological findings such as Roman coins, amphorae, foreign ware, and bead-making industries indicate the volume and sophistication of these exchanges. Tamil Nadu exported items like spices, pearls, ivory, textiles, and precious stones, while importing wine, olive oil, and luxury ceramics. Agriculture thrived due to the region's favourable climate and river systems, supported by a robust knowledge of irrigation techniques, tank-building, and canal systems. The widespread use of iron tools revolutionized agriculture and construction. Specialized crafts such as weaving, metalwork, pottery, and bead-making also developed, leading to a diversified economy. Society in Tamil Nadu was stratified yet dynamic, and there was a notable presence of women poets, merchant guilds, and warrior traditions, as reflected in Sangam poetry. A hallmark of ancient Tamil Nadu's legacy is the Sangam literature, a large body of secular Tamil texts composed by poets and bards under royal patronage. These works not only celebrate kings and heroes but also provide rare ethnographic detail on love, war, politics, nature, ethics, and everyday life. Works like Pattinappālai, Akanāṉūṟu, and Puranāṉūṟu serve as historical documents, offering glimpses into the complex and vibrant civilization of the time. Thus, ancient Tamil Nadu stands out as a significant early civilization of South Asia, characterized by urbanism, literary richness, technological advancement, and a far-reaching maritime orientation, a

culture that left a deep and lasting impact on Tamil identity and heritage. For a long time, Sangam literature was considered by many scholars to be relatively late, perhaps composed or compiled in the early centuries CE. This skepticism was largely due to the absence of corroborating archaeological or epigraphic evidence that could firmly anchor the texts in an earlier historical context. However, the decipherment of Tamil-Brahmi script in the mid-20th century, especially the discovery of the Jambai inscription in Tamil Nadu, marked a turning point in our understanding of the antiquity of Sangam literature. The Jambai inscription, dated to the 1st century BCE, mentions "Satiyaputo Atiyan Nedumaan Anji", a name that exactly matches a chieftain praised in the Puranānūru, one of the canonical Sangam anthologies. This discovery provided concrete epigraphic evidence that linked a historically attested individual with the literary tradition, pushing the origins of Sangam poetry back several centuries. As a result, the Sangam corpus began to be viewed not merely as a literary creation of later times, but as a genuinely early historical resource reflective of the socio-political and cultural landscape of ancient Tamil Nadu.

Role of Archaeo-Sciences in Understanding the Chronologies and Cultures of Ancient Tamil Nadu

Archaeo-sciences have become essential tools in reconstructing the historical and cultural landscape of ancient Tamil Nadu, spanning from the Iron Age to the Sangam period. Scientific methods such as radiocarbon dating, stratigraphic analysis, ceramic typology, archaeobotany, and geoarchaeology have enabled more precise chronological frameworks and deeper insights into the region's cultural complexity. These interdisciplinary approaches help decode the material remains of ancient settlements, shedding light on urbanization, craft production, trade networks, and everyday life. Excavated sites like Keeladi, Adichanallur, and Kodumanal exemplify how archaeo-scientific investigations are transforming our understanding of Ancient Tamil Nadu's early civilizations and their contribution to South Indian history.

- **Mangadu**

In a pivotal study, an iron sword excavated from a disturbed cist burial at Mangadu, Mettur taluk, Salem district was subjected to Accelerator Mass Spectrometry (AMS) dating at the NSF–Arizona facility (Sample ID: AA104114). The to a date range between 1604 and 1416 BCE. This positioned the artifact among the earliest scientifically dated iron objects in Tamil Nadu, offering valuable insights into the antiquity of iron technology in South India. (Rajan et.al., 2017:52-59; Park et.al., 2019:68-80). Subsequent analyses of the sword and associated iron artifacts employed X-ray fluorescence (XRF) to determine elemental composition, and utilized Scanning Electron Microscopy (SEM), Electron Backscatter Diffraction (EBSD), and Optical Microscopy (OM) for structural imaging. Furthermore, X-ray

Diffraction (XRD) and Energy Dispersive X-ray Spectroscopy (EDS) facilitated phase identification. These advanced archaeometallurgical investigations demonstrated that the Early Iron Age inhabitants of Mangadu and nearby Ambal had knowledge of iron alloy processing techniques such as forging and hammering. Notably, the presence of Widmanstätten structures indicated controlled cooling practices, consistent with the production of advanced steel, marking a high level of metallurgical sophistication for the period (Comparative Microstructural and Elemental Analysis of Iron Artefacts from Kaveri Valley Archaeological Sites, 2023).

- **Kilnamandi**

The excavations carried out in July–August 2023 at Kilnamandi in Vandavasi taluk, Tiruvannamalai district, Tamil Nadu, unearthed notable mortuary features, including a sarcophagus burial situated within both a pit (MEG-3) and a cist (MEG-6), an uncommon configuration in South Indian megalithic contexts (Gnanaraj et al., 2023: 425–432). A charcoal sample collected from the stone circle over the pit burial (MEG-3), found in association with iron objects, underwent Accelerator Mass Spectrometry (AMS) analysis at Beta Analytic Laboratory (Sample ID: Beta-666752). The results yielded a calibrated radiocarbon date of approximately 1692 BCE. This discovery is of considerable importance, as it predates the previously earliest known iron usage at Mangadu (ca. 1510 BCE) by nearly a century. Significantly, this also represents the first instance of a sarcophagus burial in Tamil Nadu being scientifically dated, offering a crucial chronological benchmark for understanding mortuary practices and early iron metallurgy in the Early Iron Age of South India.

- **Adichanallur**

Adichanallur, situated on the banks of the River Tamiraparani in Thoothukudi district, Tamil Nadu, lies approximately 9 km west of the ancient port town Korkai. First brought to scholarly attention by F. Jagor of Berlin in 1876, the site was extensively excavated by Alexander Rea between 1902 and 1904 under the Archaeological Survey of India (ASI). Subsequent re- excavations by T. Satyamurthy (2004–2005), and renewed efforts by the ASI in 2021–2022, along with parallel investigations by the Tamil Nadu State Department of Archaeology (TNSDA) during 2021–2023, have revealed significant insights into Iron Age cultural complexity. In a landmark scientific breakthrough, charcoal samples from Adichanallur underwent Accelerator Mass Spectrometry (AMS) radiocarbon dating at Beta Analytic Laboratory, Florida, yielding calibrated dates ranging from 905 BCE to 696 BCE, confirming early Iron Age activity (ASI Press Release, 2019; The Hindu, July 2019). In a more recent excavation by TNSDA, a charcoal sample collected from layer 4 (depth 220 cm) in Trench-W17 quadrant 2 of the habitation mound found in association with iron implements produced a conventional date of 2060 BCE, suggesting the possibility of a pre-Iron Age cultural horizon. Ceramic

typology studies using techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) have revealed varied clay sources and firing technologies, indicating an advanced ceramic production system (TNSDA Report, 2022; Indian Archaeology: A Review). Archaeo-botanical and isotopic analyses of rice husks and organic residues within burial urns, carried out by the Birbal Sahni Institute of Palaeo-sciences (BSIP), Lucknow, point to an agro-pastoral subsistence economy focused on millet and rice cultivation (BSIP Report, 2023). These findings, taken together, underscore the transformative role of archaeo-sciences ranging from radiometric dating to isotopic and material analyses in reconstructing the socio-cultural and technological frameworks of one of ancient Tamil Nadu's most pivotal early historic settlements.

- **Melaperumpallam**

The archaeological site of Melaperumpallam, situated near Poompuhar in the Mayiladuthurai District of Tamil Nadu, serves as a vital key to reconstructing the cultural and trade dynamics of Early Historic and Sangam period Tamil Nadu, thanks to its integration of archaeo-scientific methodologies. Excavations led by Dr K. Rajan in the early 2000s uncovered diverse artefacts such as black-and-red ware, Roman ceramics, and amphora fragments, all of which strongly point toward active participation in Indo-Roman maritime trade networks (Rajan, 2008). A notable scientific intervention at the site was the application of Optically Stimulated Luminescence (OSL) dating, employed to determine the last exposure of pottery and sediments to sunlight. The analysis yielded a chronological range spanning the 2nd century BCE to the 2nd century CE, which coincides with the height of Tamil maritime exchange with the Roman world during the Sangam era (Rajan et al., 2017). This dating supports the artefactual evidence for robust commercial activities during this period. Further, the excavation yielded carbonised remains of rice and millet, alongside marine fish bones, pointing to a diversified agro-maritime economy. These biological samples were sent to the Birbal Sahni Institute of Palaeosciences (BSIP) in Lucknow for palaeobotanical and isotope analysis. The isotope studies, particularly on faunal dental enamel, revealed that some animals had dietary signatures consistent with inland regions, suggesting a pattern of inland-to-coastal exchange networks (BSIP Report, 2003). Additionally, the discovery of brick-built structures interpreted as possible warehouses prompted geoarchaeological analyses, including micromorphological studies and soil chemistry tests. These investigations revealed evidence of intermittent flooding, consistent with the site's deltaic location near the Kaveri River, thus shedding light on environmental adaptations and site management strategies in antiquity (Rajan et al., 2008). Complementing these studies, ceramic petrography and chemical analyses (notably X-Ray

Fluorescence (XRF) and thin-section petrography) were conducted on both amphora fragments and local pottery. These analyses enabled scholars to distinguish imported ceramics, particularly those of Roman Mediterranean origin, from indigenous wares based on their mineralogical and compositional characteristics (Krishnan & Rajan, 2011). The identification of Roman amphora types, typically used for transporting wine and oil, further underscores Melaperumpallam's function as a key entrepot in the broader transoceanic exchange network of the Early Historic period.

- **Kodumanal**

The archaeological site of Kodumanal, located on the banks of the Noyyal River in Erode district, Tamil Nadu, plays a crucial role in reconstructing the early historic socio-economic and technological landscape of ancient Tamil Nadu. Under the leadership of Dr. K. Rajan, systematic excavations have uncovered a rich array of artefacts including iron implements, semi-precious stone beads, Roman coins, Tamil-Brahmi inscribed pottery, and industrial debris, which collectively indicate the site's prominence as a multi-craft production centre and trade hub during the Sangam period (Rajan & Yatheeskumar, 2011). To construct a robust chronological framework, charcoal samples collected from metallurgical and habitation layers were subjected to Accelerator Mass Spectrometry (AMS) dating at Beta Analytic Radiocarbon Dating Laboratory, yielding calibrated dates between 4th century BCE and 1st century CE (Rajan et al., 2017). These dates confirm the site's occupation and technological activity during the early historic period. The site is especially notable for its advanced iron and steel production. Archaeometallurgical analyses involving X-Ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM) were carried out on iron slags, tuyeres, crucibles, and finished tools. These tests revealed evidence of carburisation and high-temperature forging techniques, indicative of early high-carbon steel (wootz) production, which was technologically sophisticated for its time (Sasisekaran & Rajan, 2022). Ceramic typology was supported by thin-section petrography and XRF elemental analysis, focusing on varieties such as black-and-red ware, Rouletted ware, and amphora fragments. These analyses revealed both local and exotic clay sources, demonstrating long-distance trade, particularly with the Mediterranean world (Sasisekaran, 2019). The discovery of Roman amphorae fragments further supports Indo-Roman maritime trade links. The site's subsistence patterns were clarified through archaeobotanical and faunal studies. Using flotation techniques, archaeologists recovered charred seeds and husks of rice (Oryza sativa), finger millet (Eleusine coracana), and legumes, which indicate a mixed agro-pastoral economy. Complementary zooarchaeological analysis revealed bones of domesticated cattle, goat, and even marine fish, suggesting that trade networks extended to coastal regions

(BSIP Palaeobotanical Report, 2010). Further insights into site organization and occupational intensity were gained through geoarchaeological analysis. Sediment samples from industrial and habitation areas were tested for phosphate concentration, magnetic susceptibility, and micromorphology. These data provided valuable clues about activity zones, periodic flooding events, and seasonal occupation patterns (Rajan & Yatheeskumar, 2011).

- **Porunthal**

The archaeological site of Porunthal, situated near Palani in the Dindigul district of Tamil Nadu, has emerged as a significant locus for exploring the Early Iron Age and the development of early writing systems in South India, largely due to the integration of various archaeo-scientific techniques. The site garnered national prominence following the discovery of a Tamil-Brahmi inscription on a black-and-red ware pot found in a well-stratified archaeological context—an important milestone in tracing the origins of Tamil script (Rajan & Yatheeskumar, 2011). To establish a reliable chronology, charred rice grains retrieved from the same context were subjected to Accelerator Mass Spectrometry (AMS) dating. The analysis was conducted at the Oxford Radiocarbon Accelerator Unit (ORAU), University of Oxford, yielding a calibrated date of around 500 BCE, thereby placing the inscribed pottery among the earliest evidence of writing in South India (ORAU AMS Report, 2010).To reconstruct the cultural and technological milieu, ceramic typology and petrographic analyses were undertaken. These studies revealed the use of high-temperature firing methods and mineral compositions that paralleled pottery traditions from other regions, indicating the existence of shared ceramic practices, possibly facilitated by long-distance trade or cultural interaction (Rajan & Yatheeskumar, 2011). In parallel, an archaeobotanical study was carried out in collaboration with the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow. Analysis of charred seeds and husks from hearths and pit features revealed the presence of rice (Oryza sativa), pearl millet (Pennisetum glaucum), and finger millet (Eleusine coracana), suggesting a mixed agricultural economy that combined both cereal cultivation and subsistence farming strategies (BSIP Palaeobotanical Report, 2009–2010).Together, these scientific methods have helped establish Porunthal not only as a critical site for understanding early literacy and technology but also as a window into agricultural practices and trade networks of the Early Iron Age in Tamil Nadu.

- **Keeladi**

The archaeological site of Keeladi (Keezhadi), located near the Vaigai River in Tamil Nadu's Sivaganga district, has emerged as a transformative site in the reconstruction of early historic South Indian civilization. Since the fourth phase of excavation (2018 onwards), are conducted under the supervision of the Tamil Nadu State Department of Archaeology (TNSDA), Keeladi has significantly altered long-held assumptions about

the chronology and cultural complexity of ancient Tamil Nadu. One of the most defining features of this discovery has been the application of archaeo-scientific techniques, particularly Accelerator Mass Spectrometry (AMS) radiocarbon dating. Charcoal samples from stratified cultural layers were analysed by Beta Analytic Radiocarbon Dating Laboratory in Florida (Sample No. Beta-488961) and IISER Pune, with results indicating dates as early as 580 BCE, which challenges the earlier view that Tamil urbanism only flourished after the Mauryan period (TNSDA, Keeladi Excavation Report, 2020). These scientific findings provide the basis for pushing back the beginnings of urbanization in the Vaigai valley. Stratigraphic investigations at Keeladi have revealed well-defined occupational layers characterized by brick structures, burnt brick flooring, and artifactual density, indicating a well-planned and continuously inhabited settlement. Complementing this stratigraphy, ceramic typology and material analysis have contributed to chronological precision. Techniques such as Thermoluminescence (TL) and X-Ray Fluorescence (XRF) spectroscopy were employed to analyze various pottery types, notably Black and Red Ware (BRW), foreign ware and graffiti-marked ceramics. These analyses, documented by Prof. K. Rajan (2020) and others in the Man and Environment journal, point to both advanced local firing technologies and external trade connections, particularly with the Mediterranean and Southeast Asian maritime circuits. Furthermore, archaeo-botanical research, undertaken in collaboration with the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, identified carbonized remains of rice, millet, horse gram, and pulses, indicating that Keeladi was supported by a robust and diverse agricultural economy (BSIP Annual Report, 2020–21). One of the most groundbreaking contributions of archaeo-science to Keeladi's chronology is the identification and analysis of Tamil-Brahmi inscriptions. These inscribed pottery sherds, recovered from lower habitation levels, were studied using digital microscopy and residue analysis. Paleographic studies confirmed that several sherds dated to at least the 6th – 5th century BCE, thus validating literary references found in Sangam literature and earlier epigraphic claims (Mahadevan, 2020; TNSDA Report, 2020). This pushes back the timeline for the use of script and emergence of literacy in Tamil Nadu. Moreover, geoarchaeological surveys conducted by TNSDA in association with university departments employed soil micromorphology, mineralogical profiling, and particle size analysis, to distinguish between natural and anthropogenic sedimentation. These efforts have solidified the interpretation of the site's stratigraphy and confirmed that Keeladi developed through well-defined cultural phases rather than sporadic occupation (TNSDA, 2020). Thin-section petrographic analysis of ceramics from Keeladi enabled researchers to determine both the mineralogical makeup and the firing techniques used in producing various types of pottery, such as black-and-red ware (BRW), red slipped ware, and fine

grey ware. The results demonstrated the use of multiple clay sources and well-regulated firing conditions, reflecting a sophisticated level of ceramic technology. Notably, the presence of fine mineral inclusions and signs of vitrification in several samples pointed to the use of high-temperature kilns, indicative of deliberate and skilled craftsmanship (Rajan, 2019; Pandey et al., 2020). Together, these scientific approaches have reconstructed Keeladi not just as an ancient habitation site but as a well-organized urban centre with distinct cultural, economic, and technological trajectories. The convergence of archaeological methods with disciplines such as geoarchaeology, archaeobotany, epigraphy, and materials science offers a multidisciplinary framework that is essential for reassessing the depth and diversity of ancient Tamil civilization. In light of these developments, Keeladi stands as a key site in reinterpreting the early historic phase of South India, showing that urbanism, script usage, literacy, and international trade were deeply embedded in Tamil society long before the Common Era.

- **Sivakalai**

Recent excavations at Sivagalai, an Iron Age urn-burial site in Tamil Nadu's Thoothukudi district, have radically revised the timeline of iron usage and early settlement in South India. The In the course of excavations at Sivagalai, a total of 24 trenches and 63 quadrants were opened, leading to the discovery of 160 burial urns. These urns were made predominantly of red ware (151 urns), while only 9 were composed of black-and-red ware. Among the grave goods uncovered, ceramics formed the majority nearly 750 items, including bowls, lids, ring stands, and pots in black-and-red ware, white-painted black-and-red ware, and black ware. Iron artefacts were discovered both inside and outside the urns, often placed at the base within. More than 85 iron objects, including knives, arrowheads, rings, chisels, axes, and swords, were recovered at different levels in and around the urns. Radiocarbon dating using Accelerator Mass Spectrometry (AMS) was conducted at leading laboratories—Beta Analytic (USA), Physical Research Laboratory (Ahmedabad), and Birbal Sahni Institute of Palaeosciences (BSIP, Lucknow). These tests dated charcoal samples associated with the iron implements and paddy grains in the burial urns to between 3345 BCE and 3259 BCE (TNSDA, Antiquity of Iron, 2025). In one instance, ceramic and paddy samples from Urn-3 of Trench A2 were sent to BSIP for OSL (Optically Stimulated Luminescence) dating and to Beta Analytic for AMS14C analysis. The OSL test yielded a calibrated date of 1284 BCE, while the AMS result was dated to 1155 BCE. Despite the different techniques and labs, both samples produced closely aligned dates, affirming their credibility. Significantly, from Trench A1/4 of the habitation site, a potsherd bearing Tamil-Brahmi script was recovered along with charcoal from a depth of 400 cm. This sample, dated to 685 BCE (Sample No: Beta 600727),

Sample ID / Trench Context	Material Dated	Associated Artifact	Lab/ Institution	Calibrated Date	Remarks
Urn Burial – Trench A2	Charcoal (near iron spearhead)	Iron spearhead	Beta Analytic Inc., Florida (USA)	3345–3259 BCE	The earliest confirmed Iron Age artifact in Tamil Nadu; dated from securely sealed context.
Urn Burial – Trench B1	Paddy grain (with iron tool)	Iron chisel fragment	Physical Research Laboratory	~1155 BCE	Indicates iron metallurgy and agriculture co-existed in early Tamil settlements.

predates the previously earliest Tamil-Brahmi script found at Keezhadi (580 BCE), thereby pushing back the known origins of Tamil writing by a century. In the third phase of excavation, 34 burial urns were recovered from a hillock area of the site. These were sent to the Department of Genetics at Madurai Kamaraj University, where Dr G. Kumaresan and his team conducted ancient DNA (aDNA) analysis and further radiometric dating. This interdisciplinary effort marks one of the earliest integrations of archaeogenetics in southern India, enabling researchers to explore population dynamics, ancestry, and lifeways of Iron Age communities in Ancient Tamil Nadu.

The use of archaeo-scientific methods such as AMS dating, OSL, archaeometallurgy, archaeogenetics, and ceramic analysis has been crucial in building a scientifically verifiable chronology and uncovering the complex socio-economic and technological character of ancient Sivakalai. These techniques have elevated the site's importance in the world and established new models for multidisciplinary archaeological research.

Conclusion :

The integration of archaeo-sciences into archaeological research has emerged as a transformative approach in the study of the past, especially in regions with deep cultural and linguistic histories like ancient Tamil Nadu. These scientific methods offer objective, quantifiable data that supplement traditional archaeological interpretations, thereby bridging the gap between material culture and historical reconstruction. The application of techniques such as radiocarbon dating, thermoluminescence, stable isotope analysis, ceramic petrography, residue analysis, and geochemical studies allows archaeologists to establish accurate chronologies, reconstruct ancient technologies, and better understand environmental contexts and human adaptation over time. By providing

precise timelines, archaeo-sciences help determine the antiquity of cultural phases and refine the dating of important transitions, such as the shift from pre-urban to urban societies, or the development of writing systems and literacy. These methods also play a crucial role in verifying the historical authenticity of oral traditions, inscriptions, and literary sources, thus offering a scientific foundation for cultural narratives. Furthermore, the study of ancient subsistence patterns through archaeobotany and zooarchaeology reveals critical information about diet, agriculture, domestication, and trade practices. Such analyses contribute to understanding human-environment interactions, resource management strategies, and the socio-economic organization of past communities. Advances in residue analysis and DNA studies of organic remains are further expanding the ability to reconstruct ancient lifeways with remarkable specificity. In essence, archaeo-sciences enable archaeologists to move beyond surface-level interpretations and toward a more comprehensive, evidence-based understanding of the human past. They not only illuminate the material and environmental dimensions of ancient societies but also play a critical role in validating cultural heritage, preserving identity, and reshaping historical narratives through scientific credibility. This synergy between science and archaeology is vital for building a more accurate, inclusive, and globally relevant understanding of early human civilizations.

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