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AMS Dating of Iron Smelting at Zangon Tama site, Sokoto State, Nigeria

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Abstract

The establishment of reliable chronologies remains fundamental to understanding the development and persistence of iron production in Africa. This paper presents Accelerator Mass Spectrometry (AMS) radiocarbon dates obtained from charcoal samples recovered from iron-smelting contexts at Zangon Tama, Sokoto State, northwestern Nigeria. Five charcoal samples associated with slag deposits, furnace remains, and metallurgical debris were calibrated using the IntCal20 Northern Hemisphere calibration curve. The calibrated dates indicate that iron-smelting activities occurred between the late thirteenth and seventeenth centuries CE. The results suggest at least three phases of production: an initial phase during the late thirteenth and fourteenth centuries CE, a principal production phase during the fifteenth century CE, and a later phase extending into the seventeenth century CE. The chronology demonstrates long-term technological continuity and repeated use of the site over approximately four centuries. The study contributes to wider discussions concerning indigenous technological knowledge, technological resilience, and the persistence of iron-smelting traditions in West Africa.

1. INTRODUCTION

Iron production represents one of the most significant technological developments in African history and played a fundamental role in economic, social, and political transformations across the continent. Archaeological investigations over the past several decades have demonstrated that African societies developed diverse and sophisticated iron-smelting traditions adapted to local environmental and cultural conditions [1, 2]. In West Africa, iron production facilitated agricultural expansion, craft specialization, warfare, and long-distance exchange, thereby making a substantial contribution to the development of complex societies.

Despite the importance of iron production in African history, many iron-smelting sites remain undated. Chronological uncertainty continues to limit understanding of the emergence, development, and persistence of metallurgical traditions in several regions of Nigeria. While important chronologies have been established at sites such as the Nok sites, Lejja, Opi, Tsauni (Zaria) and Ife, northwestern Nigeria remains comparatively underrepresented in radiometric studies.

Zangon Tama is one of several iron-smelting sites identified within Sokoto State. Archaeological investigations revealed extensive slag accumulations, furnace remains, tuyere fragments, charcoal, and other evidence of intensive iron production. However, prior to this study, no secure chronology existed for the site.

This paper presents AMS radiocarbon dates obtained from charcoal samples recovered during excavations at Zangon Tama. The objectives are to establish a chronological framework for iron-smelting activities at the site, and situate this chronology within wider debates on African metallurgy and indigenous technological systems.

2. STUDY AREA AND ARCHAEOLOGICAL BACKGROUND

Zangon Tama is located in Magabcin Sarki village, Yabo Local Government Area, Sokoto State, Nigeria (12°42'N 5°02'E; 311 m asl). The site lies 35 km along the Sokoto-Jega-Birnin Kebbi road in Sokoto State, within the Sudan savanna ecological zone (Fig. 1). The region is characterised by seasonal rainfall, open woodland vegetation, and abundant iron-bearing geological formations suitable for bloomery iron production.

Archaeological surveys and excavations revealed evidence of metallurgical activity, including large slag concentrations, furnace wall fragments, tuyere remains, charcoal deposits, and furnace bases. Excavation identified multiple furnace clusters arranged in circular formations. Two principal furnace groups were documented: larger furnaces measuring approximately 75–100 cm in diameter and smaller furnaces measuring between 60–70 cm in diameter [15].

The density of metallurgical remains suggests that Zangon Tama functioned as an important production centre rather than a small-scale household industry. The presence of overlapping slag deposits and multiple furnace structures indicate repeated episodes of iron production over an extended period.

3. ANALYTICAL CONTEXT: ACCELERATOR MASS SPECTROMETRY IN AFRICAN ARCHAEOLOGY

The paradigm governing African archaeometallurgy has evolved significantly, shifting from early diffusionist paradigms toward a rigorous documentation of local innovation, technological resilience, and indigenous knowledge systems. Pioneering work by Schmidt demonstrated that African iron-smelting traditions were not exclusively static mechanical processes but were deeply embedded within complex socio-political, symbolic, and adaptive cognitive frameworks [3, 4]. Contemporary scholarship, including syntheses by Chirikure, illustrates the dynamic nature of these technological systems, which continuously adapted to changing economic inputs and resource availability [5].

In West Africa, this capacity to adapt manifested as immense regional variability in furnace engineering and production scales. For instance, deep-time sequences from southeastern Nigeria (e.g., Lejja and Umundu) push the frontiers of iron manufacturing back into the first millennium BCE, with technological continuity spanning nearly two millennia [6, 7]. Conversely, documented chronologies within the West African savanna and Hausaland suggest that while early nodes existed, extensive industrial scaling expanded significantly during the first and second millennia AD, as seen at Yelwa and Tsauni [8, 9].

Methodologically, capturing the fine-grained nuances of this production in archaeological iron-smelting contexts due to the small, fragmented nature of recovered charcoal and the technical challenges of extracting uncontaminated organic material from dense slag matrices.

To overcome these constraints, Accelerator Mass Spectrometry (AMS) has emerged as the gold standard. By utilising a high-energy particle accelerator as an ultra-sensitive mass spectrometer, AMS

directly counts ^{14}C atoms relative to stable carbon isotopes, in milligram-range sample masses while effectively eliminating isobaric interferences. When paired with the refined IntCal20 Northern Hemisphere atmospheric calibration curve, AMS dating provides the temporal resolution needed to resolve rapid technological phases and long-term site continuity [10].

4. MATERIALS AND METHODS

4.1. Sample selection and stratigraphic context

Charcoal samples were systematically sampled from stratified contexts directly associated with primary metallurgical activity (furnace bases, tuyere fragments and slag). The samples were recovered across three strategic excavation units designated Pit A, Pit B, and Pit C. Five charcoal samples showing distinct woody structure and minimal post-depositional weathering were selected for AMS radiocarbon analysis.

4.2. Sample processing

Radiocarbon measurements were conducted at the Tandem Accelerator Mass Spectrometry (TAMS) facility iThemba LABS, South Africa. It is a premier centre for accelerator-based sciences on the African continent. The charcoal samples (assigned identifiers IT-C-4539 through IT-C-4543) underwent standard Acid-Alkali-Acid (AAA) chemical pretreatments [11] to remove mobile humic acids and modern carbonate contaminants. Samples were then combusted under vacuum in the presence of CuO and Ag to yield to CO_2 gas [12] The CO_2 gas was cryogenically distilled and catalytically reduced to elemental C as graphite in the presence of Fe and H_2 at 600° C [13].

The sample graphite was pressed into cathodes and sputtered with cesium ions at a 40 kV cathode voltage to generate a C beam, thereby destroying molecular carbohydrate isobars (such as ^{13}CH and $^{12}CH_2$). High-resolution magnetic and electrostatic analysers subsequently isolated ^{14}C ions against stable ^{12}C and ^{13}C currents. Samples were then run with graphite processed from coal as background. Oxalic Acid II was used as a reference, and a known-age wood sample as control. Data processing followed the protocol of Zoppi [14]

4.3. Calibration and chronological modeling

The resulting conventional radiocarbon ages (expressed in years Before Present, BP) were calibrated into calendar years using OxCal software with the IntCal20 Northern Hemisphere atmospheric calibration curve [10]. Calendar age ranges are reported with 95.4% confidence intervals to ensure statistical reliability for archaeological interpretation (Fig. 2).

5. RESULTS

The AMS data generated by the iThemba LABS are presented in Tables I.

Table 1
AMS RADIOCARBON DATES FROM ZANGON TAMA

Sample	Lab No.	Context	Conventional Age (BP)	Calibrated Date (CE)
Sa1	IT-C-4539	Pit A (20 cm)	525 ± 30	1327–1351; 1394–1442
Sa2	IT-C-4542	Pit B (20–40 cm)	300 ± 45	1472–1665
Sa3	IT-C-4540	Pit C (45 cm)	640 ± 60	1275–1412
Sa4	IT-C-4543	Pit C (50 cm)	495 ± 40	1326–1352; 1393–1460
Sa5	IT-C-4541	Pit C (60 cm)	310 ± 45	1469–1660

The calibrated AMS dates position the operational lifecycle of Zangon Tama firmly between the late thirteenth and seventeenth centuries AD. The chronology begins with sample Sa3 (AD 1275–1412), while the terminal phases of production are captured by samples Sa5 and Sa2, extending well into the mid-seventeenth century (Table 1).

Intriguingly, the stratigraphic column in Pit C exhibits an inverted age-depth relationship. The charcoal sample recovered at an intermediate depth of 45 cm (Sa3) yeilded the oldest date, whereas the deepest sample at 60 cm (Sa5) yielded a significantly younger age profile. This stratigraphic inversion indicates complex site-formation processes. It points to intensive, multi-phase metallurgical activity where older smelting debris was cut into or redeposited during subsequent furnace construction; disturbance in metallurgical deposits; charcoal incorporated into later fills; and differences between the dated charcoal and the actual metallurgical event. Slag-clearing cycles or the “old wood” problem.

6. DISCUSSION

6.1 Chronological range of iron-smelting activity

The calibrated dates place iron-smelting activity at Zangon Tama within a broad period extending from the late thirteenth century to the seventeenth century CE. The earliest dated sample is Sa3 from Pit C at 45 cm depth, with a calibrated range of 1275–1412 CE. Sa1 from Pit A and Sa4 from Pit C fall mainly within the fourteenth and fifteenth centuries, while Sa5 from Pit C and Sa2 from Pit B indicate activity extending into the sixteenth and seventeenth centuries (Table 1).

These dates showed that the Zangon Tama production area was used over several centuries. The available evidence is consistent with repeated or episodic production rather than necessarily continuous operation. The four-century span should therefore be understood as the chronological duration represented by the dated archaeological contexts, not as uninterrupted iron production.

6.2 Stratigraphic relationships and site formation

The dates from Pit C reveal a non-linear relationship between depth and radiocarbon age. Sa3, recovered at 45 cm, produced the oldest determination (640 ± 60 BP; 1275–1412 CE), whereas Sa5, recovered at the greater depth of 60 cm, produced a younger determination (310 ± 45 BP; 1469–1660 CE). Sa4 at 50 cm yielded an intermediate conventional age of 495 ± 40 BP, calibrated to 1326–1352 CE and 1393–1460 CE (Table 1).

This inversion cautions against treating depth alone as a direct chronological sequence at Zangon Tama. It may reflect complex site-formation processes, including disturbance, redeposition, the cutting of earlier deposits by later activity, or the movement of charcoal during repeated furnace construction and slag-clearing episodes. The interpretation should nevertheless remain tentative because the present dataset contains only three dates from Pit C and no independent micromorphological or sedimentological assessment of the deposits.

Although the five dates do not justify a formal statistical phasing model, they provide a useful descriptive sequence. An initial phase is represented by Sa3 and begins no later than the late thirteenth or fourteenth century CE. A second period is represented by the overlapping probability ranges of Sa1 and Sa4 and indicates activity during the fourteenth and fifteenth centuries. A later phase is represented by Sa5 and Sa2, whose calibrated ranges extend into the sixteenth and seventeenth centuries. The evidence therefore supports a long-lived production landscape in which metallurgical activity was undertaken repeatedly over an extended period.

6.3 Implications for technological continuity

The long chronological span represented at Zangon Tama provides an important basis for investigating the persistence and transmission of metallurgical knowledge. Repeated production over several centuries would have required the maintenance and transmission of practical knowledge concerning ore selection, charcoal production, furnace construction, tuyere placement, refractory materials, and control of the smelting environment. The radiocarbon evidence alone does not indicate how this knowledge was transmitted, but it establishes the temporal framework within which technological continuity can be investigated.

6.3. AMS infrastructure and archaeological science in Africa

In the context of modern research policy, this study highlights how access to centralised scientific infrastructure drives high-level scientific output within developing regions. Historically, African archaeological and heritage samples were routinely exported to North American or European laboratories for dating, a model that limited local capacity building and institutional equity.

This paper leverages an African, continent-based accelerator facility to achieve the dating chronology. This creates a sustainable ecosystem for African heritage science, showcasing how advanced physics

installations can directly serve humanities and social sciences across national borders.

7. CONCLUSION

This study provides the first AMS dating for Zangon Tama iron-smelting site in Sokoto State, Nigeria. The resulting framework maps an active technological lifecycle spanning from the late thirteenth to the seventeenth centuries CE.

The identification of three distinct production phases highlights long-term technological continuity, engineering resilience, and generations of specialized knowledge transmission in northwestern Nigeria. This collaboration underscores the immense potential of shared African accelerator infrastructures to solve regional empirical questions, bridging the gap between nuclear instrumentation, materials science, and cultural heritage preservation.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Author Contribution

R. Y. wrote the main manuscript text, D. K. prepared figure 2, S. W. provided the laboratory procedures. All authors reviewed the manuscript.

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Data availability

The data may be obtained from the corresponding author upon reasonable request.

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Figures

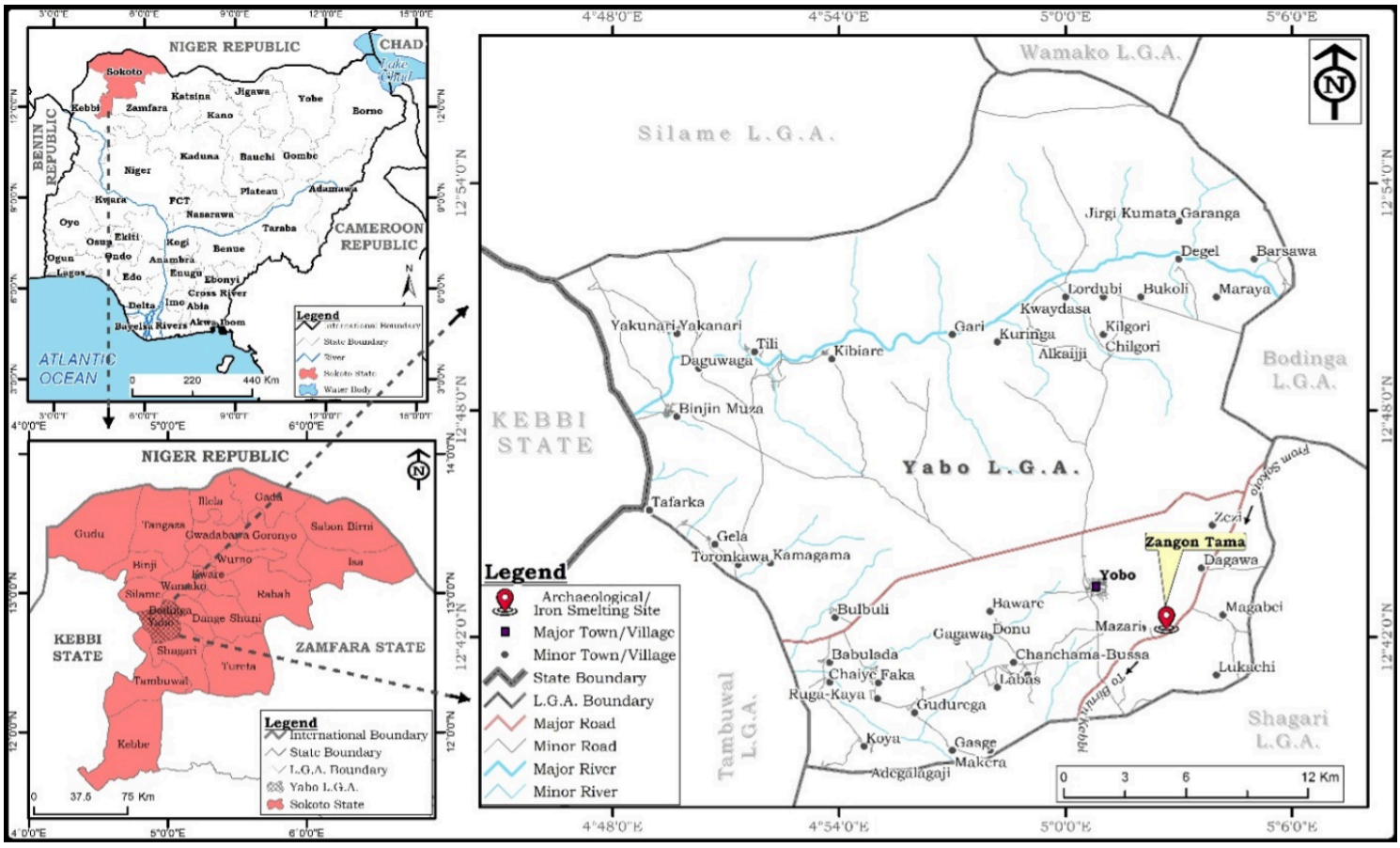


Figure 1

Map of Zangon Tama in Yabo Local Government Area, Sokoto State, Nigeria (Inset: Map of Nigeria and Sokoto State).

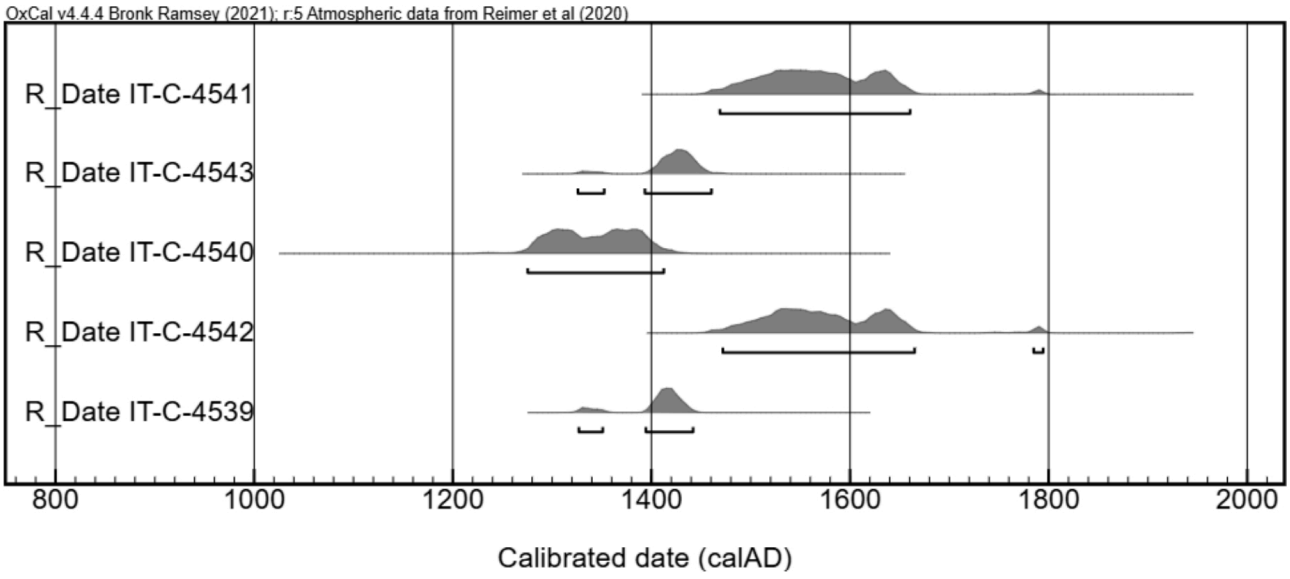


Figure 2

The results of the radiocarbon dating of charcoal samples from Zangon Tama. Intervals of calibrated dates (at 95.4% confidence level) and results using the Bayesian model of Oxcal 4.3.2 and INTCAL13 multiple calibration curves