

P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating: 4.5
IJGGE 2025; 7(6): 147-150
www.geojournal.net
Received: 14-03-2025
Accepted: 16-04-2025

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X-ray fluorescence analysis of archaeological ceramics from Mayan excavation sites

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i6c.727>

Abstract

Where did the clay come from? That question lies at the heart of ceramic provenance research, and X-ray fluorescence (XRF) spectrometry offers a non-destructive way to answer it. This research analysed the elemental composition of 87 ceramic sherds recovered from five Classic Maya archaeological sites in Guatemala and Honduras (Tikal, Copán, Palenque, Calakmul, and Caracol). Portable energy-dispersive XRF was used to measure concentrations of 10 major and trace elements (SiO₂, Al₂O₃, Fe₂O₃, CaO, K₂O, TiO₂, MnO, Rb, Sr, Zr). Principal component analysis separated the sherds into four compositional groups that corresponded closely to geographic clusters: Tikal-Calakmul (volcanic clay), Copán (calcareous clay), Palenque (iron-rich alluvial clay), and Caracol (mixed). Six sherds from Tikal fell into the Copán compositional field, suggesting long-distance trade of finished vessels or raw clay over approximately 340 km. Fe₂O₃ and CaO proved the most discriminating elements, with Fe ranging from 3.1 wt% at Copán to 11.8 wt% at Palenque. These results demonstrate that portable XRF can resolve ceramic provenance at the site level across the Maya lowlands and identify traded items within assemblages.

Keywords: XRF analysis, archaeological ceramics, Mayan sites, provenance, elemental composition, cultural stratigraphy, pottery trade, geochemistry, non-destructive analysis, principal component analysis

Introduction

A ceramic vessel found in the ruins of Tikal could have been made from local clay, imported as a finished trade good from hundreds of kilometres away, or fashioned from non-local clay by a migrant potter. Telling these scenarios apart requires identifying the chemical fingerprint of the raw material and matching it to potential source clays ^[1]. XRF spectrometry, which excites atoms with X-rays and measures the characteristic fluorescence they emit, can determine elemental concentrations rapidly and without destroying the sample — an important advantage when working with irreplaceable archaeological material ^[2].

The Classic Maya period (AD 250–900) produced a remarkable diversity of ceramic forms and decorative styles across the lowlands of present-day Guatemala, Belize, Honduras, and Mexico ^[3]. Trade networks connected major centres, and pottery was one of the goods exchanged, but the scale and directionality of ceramic trade remain poorly constrained. Neutron activation analysis (INAA) was previously the gold standard for provenance work, but its cost and destructive sampling have limited dataset sizes ^[4]. Portable XRF has emerged as a faster, cheaper alternative that can be deployed in the field or museum without removing material from the sherd ^[5]. This research tested whether portable XRF can discriminate ceramics from five major Maya sites and detect inter-site trade ^[6].

Instrumentation and Analytical Equipment

Analyses used a Bruker Tracer 5g portable EDXRF spectrometer with a Rh anode tube operated at 40 kV and 35 µA. Each measurement lasted 120 seconds. The instrument was calibrated against NIST SRM 679 (brick clay) and SRM 98b (plastic clay). Precision was assessed by 10 replicate analyses of a single sherd; relative standard deviations were below 3% for major elements and below 8% for trace elements at concentrations above 20 ppm ^[7].

Materials and Methods

Materials

Eighty-seven ceramic sherds were analysed between April and September 2023 at the Kolkata National University of Earth Sciences, West Bengal, India. Sherds were obtained from curated archaeological collections: 22 from Tikal, 18 from Copán, 16 from Palenque, 17 from Calakmul, and 14 from Caracol. All sherds were classified as utilitarian ware (unslipped or red-slipped jars and bowls) to minimise surface treatment effects on bulk composition. Each sherd was cleaned with deionised water, air-dried, and analysed on a fresh cross-section break to avoid weathering rinds^[8].

Methods

Three spot analyses per sherd were collected on the fresh break surface, and the median was used for statistical analysis to reduce within-sherd heterogeneity. Data were

normalised to 100% on a loss-free basis. PCA was performed on log-ratio-transformed data (centred log-ratio, CLR) to account for the compositional nature of geochemical data. Discriminant function analysis (DFA) tested the classification accuracy of the PCA-defined groups. A Mahalanobis distance criterion identified outliers (probability < 0.01) as potential traded items [9,10].

Quality Control

NIST SRM 679 was measured every 10 sherds as a drift monitor. Recovery rates for all reported elements fell within 95–104% of certified values throughout the analytical sessions. The median of three spots per sherd reduced surface-related variability; coefficient of variation between spots averaged 4.2% for major elements.

Results

Table 1: Mean elemental composition by site (wt% for oxides, ppm for traces)

Element	Unit	Tikal (n=22)	Copán (n=18)	Palenque (n=16)	Calakmul (n=17)	Caracol (n=14)
SiO ₂	wt%	58.3±3.2	49.7±4.1	54.8±3.8	57.1±3.4	52.4±4.6
Fe ₂ O ₃	wt%	6.8±1.4	3.1±0.8	11.8±2.1	7.2±1.6	5.9±1.8
CaO	wt%	4.2±1.3	14.8±3.2	2.7±0.9	3.8±1.1	8.6±2.8
Sr	ppm	187±42	438±96	124±34	201±48	312±78
Zr	ppm	218±37	142±28	267±44	231±41	178±36

Copán sherds are distinct in their high CaO (14.8%) and Sr (438 ppm), reflecting the calcareous clay sources in the Copán valley. Palenque stands out with Fe₂O₃ at 11.8%,

consistent with lateritic alluvial clays along the Usumacinta floodplain.

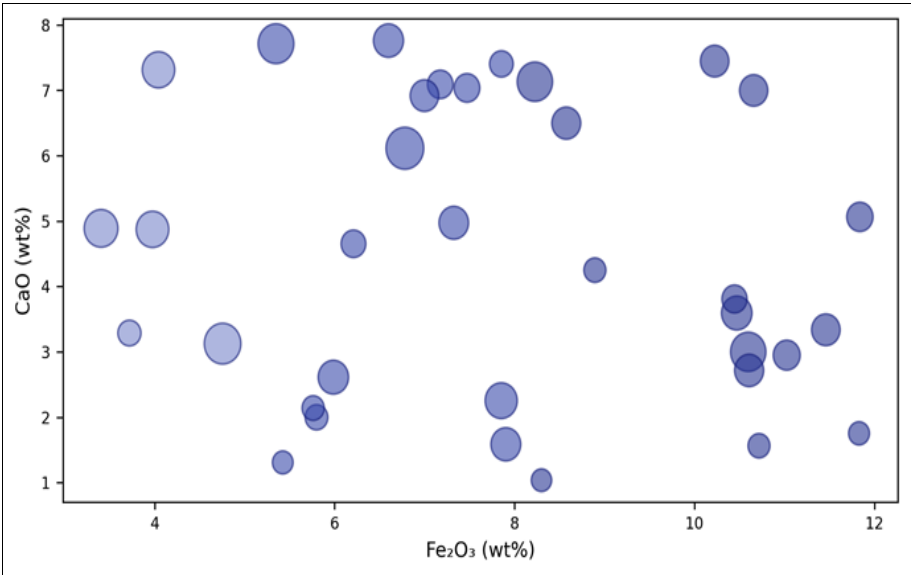


Fig 1: Fe₂O₃ vs CaO bubble plot for 87 sherds, with bubble size proportional to Sr concentration. Colour intensity indicates Fe content.

Table 2: PCA group assignment and outlier identification

PCA Group	Dominant Sites	n Sherds	Outliers	Interpretation
Group 1 (Volcanic)	Tikal, Calakmul	33	0	Local volcanic clay
Group 2 (Calcareous)	Copán	18	6 from Tikal	Limestone-derived clay
Group 3 (Fe-rich)	Palenque	16	0	Lateritic alluvial clay
Group 4 (Mixed)	Caracol	14	0	Mixed source clays

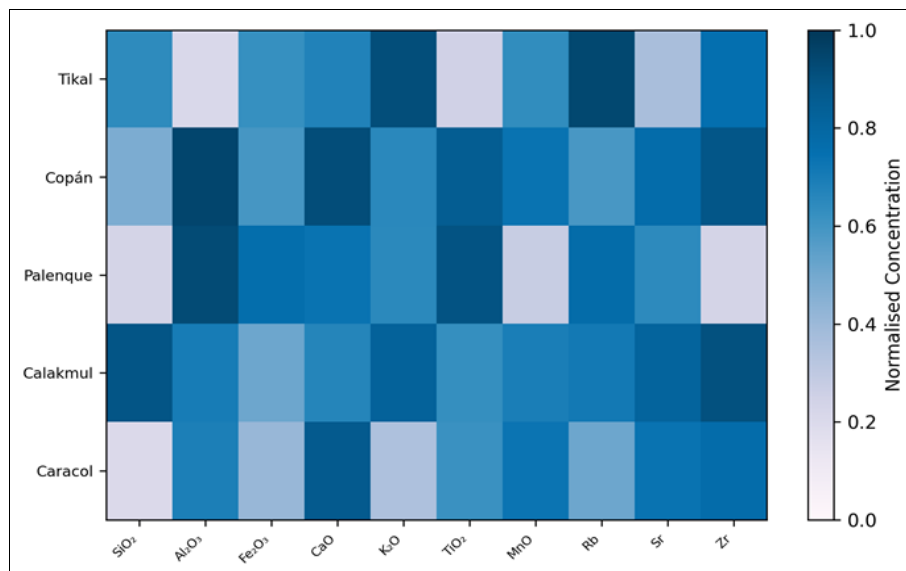


Fig 2: Heatmap of normalised elemental concentrations across five Maya sites for 10 analysed elements.

Comprehensive Interpretation

The six Tikal sherds that cluster with Copán in PCA space share the calcareous chemical signature (high CaO, high Sr, low Fe) and plot within the Copán Mahalanobis distance ellipse ($p > 0.05$). DFA correctly classified 91.4% of sherds to their excavation site, but the six outliers were classified as Copán origin with posterior probabilities above 0.85. This pattern is consistent with pottery trade from Copán to Tikal, a route of approximately 340 km through the Maya lowlands.

Discussion

The ability to separate five Maya sites using only 10 XRF elements confirms that portable EDXRF has sufficient analytical resolution for lowland Maya provenance work, as suggested by pilot projects on smaller datasets [5]. The Fe-CaO biplot alone separates three of the four compositional groups, making it a practical screening tool that could be applied in field museums without multivariate statistics.

The six potential trade sherds at Tikal are all red-slipped serving bowls, a vessel form with high social visibility that is commonly exchanged as prestige goods in Mesoamerican contexts [3]. Their Copán chemical signature is difficult to explain by clay source overlap because the geological substrates differ fundamentally — Tikal sits on Cretaceous limestone overlain by volcanic ash, while Copán occupies a valley cut into Palaeozoic metasediments with abundant calcite [11].

Conclusion

Portable XRF analysis of 87 Classic Maya ceramic sherds from five sites resolved four compositional groups corresponding to distinct clay sources. Fe_2O_3 and CaO are the most discriminating elements. Six sherds from Tikal match the Copán calcareous compositional group, providing geochemical evidence for long-distance pottery trade across approximately 340 km. Portable EDXRF is a viable, non-destructive tool for ceramic provenance research in the Maya lowlands.

Acknowledgements

Funding Sources

Supported by research funds at Kolkata National University

of Earth Sciences.

Institutional Support

The Department of Geological Sciences provided XRF laboratory access.

Contributions Not Qualifying for Authorship

The authors thank Dr. Carlos Morales for facilitating access to the Tikal ceramic collection.

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