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Archaeometric Perspectives on Cord-Marked Pottery: Provenance, Technology, and Cultural Connections in Northeast India

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Abstract

The present study discusses the archaeometric characteristics of Neolithic cord-marked pottery recovered from the Myrkhan archaeological site in the East Khasi Hills District of Meghalaya, Northeast India, dated to 1885 to 1765 Cal. BCE. Cord-marked pottery represents a significant component of the Neolithic cultural tradition of eastern and northeast India, and provides important evidence for understanding prehistoric ceramic technology, cultural interaction, and settlement practices. In this study, selected potsherds were analysed using X-ray Diffraction (XRD), Fourier-Transform Infrared Spectroscopy (FTIR), and Energy-Dispersive X-ray Spectroscopy (EDX) to evaluate their mineralogical composition, elemental characteristics, firing conditions, and raw material provenance. The analyses reveal that the pottery assemblage is mineralogically and chemically heterogeneous, comprising quartz, kaolinite, feldspars, haematite, hornblende, ilmenite, and other accessory minerals in varying proportions. Quartz was identified as the dominant mineral phase in most samples, suggesting either naturally self-tempered clay or intentional addition of siliceous inclusions during paste preparation. The predominance of silicon, aluminium, iron, and potassium, together with comparatively low calcium content, indicates the use of non-calcareous aluminosilicate clays derived from locally available geological sources, probably associated with piedmont and weathered granitic deposits of the Khasi Hills region.

FTIR and XRD results indicate that the pottery was generally fired under oxidising conditions at moderate temperatures ranging between approximately 500°C and 800°C. The occurrence of haematite is consistent with the reddish colouration of the ceramics and suggests open firing or simple kiln technology. The presence of organic residues and hydrated mineral phases further indicates the possible use of organic tempering materials and minor post-depositional alterations.

The study demonstrates that the Myrkhan pottery assemblage represents a locally produced Neolithic ceramic tradition characterised by technological adaptability, selective raw material utilisation, and moderate firing technology. The observed stylistic and technological similarities with cord-marked pottery traditions of Northeast India and Southeast Asia likely reflect processes of cultural interaction and technological diffusion.

Introduction

Cord-marked pottery constitutes an important cultural marker in the study of early agrarian societies in India. Characterised by impressions of twisted cords or vegetal fibers on vessel surfaces, this ceramic tradition is commonly associated with early sedentary communities and the development of Neolithic ceramic technologies. In India, cord-marked pottery has been reported from several regions, particularly the Northern Vindhyas, the Ganga Valley, eastern India, and Northeast India (Sharma and Mandal 1980; Misra 2001). Owing to its widespread occurrence, it represents a distinctive component of the Neolithic-Chalcolithic ceramic tradition of Northeast India. Cord-marked pottery has been documented from the states of Bihar, Jharkhand, Odisha, and West Bengal, as well as from the northeastern states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, in both Neolithic and later cultural contexts.

In Northeast India, cord-marked pottery represents one of the defining features of the Neolithic cultural assemblage. Important occurrences have been reported from sites such as Daojali Hading and Sarutaru in Assam (Sharma 1967; for review see- Hazarika 2017), where cord-marked pottery occurs alongside stone axes, shouldered celts, and quadrangular adzes. The corded pottery from Daojali Hading has been dated to 2.7 ± 0.3 ka (Singh and Sharma 2017). Cord-impressed pottery was also documented from the Neolithic site of Sarutaru and the post-Neolithic site of Marakdola in Assam (IAR

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1968-69). In Manipur, the Neolithic sites of Nongpok Keithelmanbi and Napachik yielded both cord-marked and carved-paddle pottery along with associated lithic assemblages (Singh 1981; Singh 1991). A charcoal sample from Nongpok Keithelmanbi provided an age of 4460 ± 120 BP, whereas thermoluminescence dating of pottery from Napachik suggested an age of approximately 1450 BCE. In Nagaland, the site of Ranyak Khen has been dated between 6410 and 6290 BP (Jamir 2014). Similarly, the sites of Lawnongthroh and Myrkhan in Meghalaya have yielded abundant cord-marked and carved-paddle pottery associated with shouldered celts, tanged axes, stone knives, and iron implements. Excavations at Lawnongthroh during 2013-14 yielded radiocarbon ages ranging from 2960 ± 30 BP to 1640 ± 30 BP, whereas the dominant cord-marked pottery assemblage at Myrkhan has been dated to approximately 3500 ± 30 BCE (Mitri and Neog 2016).

Although cord-marked pottery has been extensively reported from various Neolithic sites across eastern and Northeast India, most previous studies have primarily focused on morphological characteristics such as vessel form, decoration, colour, and clay texture. Detailed archaeometric investigations aimed at understanding raw material selection, mineralogical composition, and firing technology remain limited for the Neolithic ceramic traditions of the region.

Technologically, cord impressions may have strengthened vessel walls and improved surface grip, reflecting adaptation to utilitarian requirements. From a cultural perspective, cord-marked pottery exhibits affinities with Neolithic ceramic traditions of Southeast Asia, supporting hypotheses of trans-regional interaction and migration (Higham 2002). The widespread distribution of this pottery tradition across the Brahmaputra Valley and adjoining hill regions further reflects the diffusion of Neolithic lifeways, including agriculture and sedentary habitation.

In Northeast India, where cord-marked pottery represents a defining component of the Neolithic cultural complex, archaeometric analyses from sites such as Daojali Hading, Sarutaru, Napachik, Nongpok Keithelmanbi, Ranyak Khen, Barapani, and Sawmer (Sharma 1967; IAR 1968-69; Singh 1981; Singh 1991; Jamir 2014; Basa and Mohanty 2015) indicate the use of locally available ferruginous and non-calcareous clays mixed with organic tempers such as husk and vegetal matter. These ceramics were generally produced using handmade techniques and fired at relatively low temperatures, mostly below 800° C, without significant vitrification (Singh *et al.* 2018). Petrographic studies further reveal considerable variability in ceramic fabrics, suggesting differences in clay procurement strategies and pottery-making traditions among Neolithic communities despite typological similarities in cord-marked wares (Singh *et al*. 2023). Singh (2017) further emphasised that archaeometric analyses can help reconstruct regional interaction networks and technological choices by identifying mineral inclusions and firing technologies.

In the present study, cord-marked pottery recovered from the Neolithic site of Myrkhan in the East Khasi Hills district of Meghalaya was investigated using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and energy-dispersive X-ray spectroscopy (EDX). The study aims to evaluate the mineralogical composition, firing conditions, and technological characteristics of the pottery in order to reconstruct manufacturing practices and assess its cultural affinities within the broader Neolithic framework of Northeast India.

Site and Inhabitants

The site of Myrkhan (25° 32′ 40.01″ N; 91° 48′ 34.06″ E; 1552 m ASML) was explored and excavated in 2016 and is presently in the preliminary stage of archaeological investigation. Situated on a hilltop within the Meghalaya Plateau, the site lies about 1.1 km east of the Umiam River. It overlooks the eastern gorge of the Umiam stream, which flows across much of the northern Khasi Hills before joining the Brahmaputra River in Assam (Fig. 1).

Archaeological investigations at Myrkhan have revealed a substantial quantity of unfinished lithic tools and extensive flake debris, indicating intensive lithic manufacturing activities. Lithic flakes and associated artefacts are distributed over an area of nearly 3 km² surrounding the site. A particularly dense concentration of archaeological materials, including lithic flakes, stone artefacts, and related remains, was documented along the southwestern margin of the present settlement area. Some of these remains appear to have been exposed through recent agricultural activities carried out by local inhabitants.

Archaeological explorations across the Khasi and Jaintia Hills have identified numerous Neolithic sites characterised by broadly similar lithic assemblages and typo-technological characteristics. Such similarities suggest the existence of a shared technological tradition among Neolithic communities inhabiting the central Meghalaya Plateau. Excavations conducted at sites such as Lawnongthroh and Myrkhan have yielded stone tools, potsherds, and other household artefacts from archaeological contexts (Mitri and Neog 2016). As these sites are scientifically dated, the recovered material culture provides important evidence for examining the relationship between archaeological traditions and the broader genetic-linguistic affiliations of the ethnographic populations of the Khasi-Jaintia Hills.

The available archaeological evidence suggests that Myrkhan functioned as a lithic workshop or factory site during the Neolithic period. Excavations have yielded a large assemblage of artefacts, including numerous potsherds associated with habitation activities. The ceramic

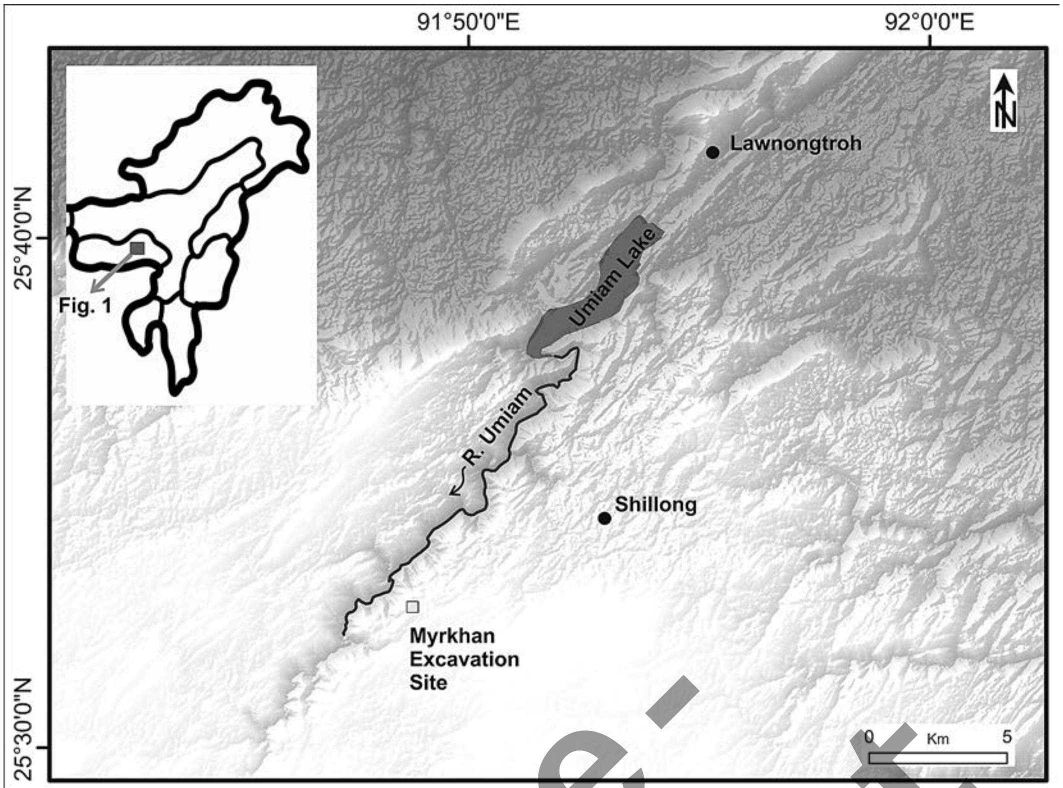

Fig. 1: Location of the Myrkhan excavation site in the East Khasi Hills District of Meghalaya

and lithic assemblages together provide important evidence for Neolithic settlement patterns, technological practices, and the cultural development of early agricultural communities in Northeast India.

The Khasi Hills of the central Meghalaya Plateau are predominantly inhabited by Khasi-Pnar communities, who belong linguistically to the Mon-Khmer branch of the Austro-Asiatic language family (Diffloth 2005). Genetic studies further indicate significant affinities between the populations of these hills and the Munda and other Austro-Asiatic-speaking groups of Southeast Asia (Chaubey *et al*. 2011). These linguistic and genetic associations enhance the archaeological significance of the Khasi-Jaintia Hills for understanding prehistoric population dynamics and cultural interactions in Northeast India.

The material evidence recovered from Lawnongthroh-1 and Myrkhan-1 exhibits the characteristic features of the Neolithic cultural tradition of the Khasi-Jaintia Hills. Excavations at Lawnongthroh-1 were conducted during 2013-2014, whereas investigations at Myrkhan-1 are still in the preliminary stage. Although analysis of the cultural materials from Lawnongthroh-1 has been substantially completed, ongoing investigations at Myrkhan-1 have already provided a broad understanding of the site's cultural composition. Comparative analysis of the archaeological materials from both sites has enabled the identification of similarities and variations in their cultural assemblages. The archaeological data generated from these excavations contribute significantly to understanding the Neolithic cultural traditions of the Khasi-Jaintia Hills within the broader framework of the central Meghalaya Plateau.

Materials and Methods

Excavation of the Site

Prior to the large-scale excavation, two trial trenches (2 × 2 m) were excavated to a depth of approximately 80 cm in order to examine the stratigraphic profile and assess the archaeological potential of the site. Following site mapping, a 20 × 20 m grid layout was established for systematic excavation (Fig. 2). Horizontal grid-based excavation was subsequently carried out across the site, and a total of 11 trenches were opened during the first phase of excavation at Myrkhan. Trench T5, located at the highest point of the site, was designated as the datum point. Trenches situated north of T5 were labelled sequentially as T + 1, T + 2, and so forth, whereas those located south of the datum point were designated as T − 1, T − 2, and so on.

Sample Collection

A total number of 1402 potsherds were recovered from four different stratigraphic units of the excavated pit. The

Fig. 2: (A) and (B) General view of the trenches exposed during excavation displaying occupation layers

sizes of the pottery fragments vary from medium to very small. Based on the type of impression, the potsherds were divided into two categories: (1) cord-marked and (2) carved paddle. Different types of impression patterns were visible in the upper surfaces of both the pottery types. These patterns are zigzag, crisscross, horizontal or vertical (Fig. 3). Apart from these two types of potsherds, a few other potsherds with plain surface were also found, though the number of these plain potsherds is less than the other two types. About 655 potsherds were recovered from layer 1,340 potsherds from layer 2, 333 potsherds from layer 3, and 48 potsherds from layer 4 (Table 1).

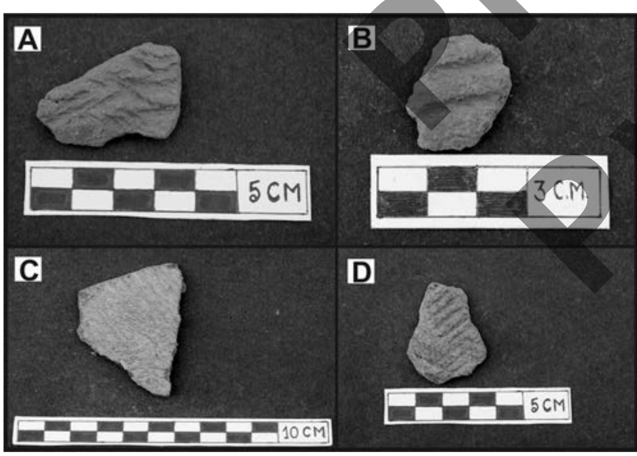

Fig. 3: (A), (B), (C), and (D) Cord-marked pottery sherds recovered from the excavation, showing variations in the pattern of impressions

Analytical Techniques Employed

The analysis of pottery and its description is treated under four heads: physical properties, composition of materials, technique, and style. During the first phase of excavation, a number of potsherds along with other artefacts were obtained.

X-ray Diffraction (XRD)

X-ray diffraction (XRD) is widely used for the identification and characterisation of crystalline mineral phases in archaeological ceramics. In ceramic studies, XRD provides important information on mineral composition, firing conditions, and technological processes associated with pottery production (Stanjek and Häusler 2004). The technique identifies minerals based on their crystalline structures (Zussman 1977). In the present study, potsherds collected from different trenches and stratigraphic depths were analysed using XRD to determine their mineralogical composition.

The potsherds were carefully hand-ground into fine powder using an agate mortar and pestle to ensure homogeneity and adequate particle participation during diffraction analysis. X-ray powder diffraction patterns were recorded using a TTRA III Rigaku X-ray diffractometer with Cu Kα radiation (λ = 1.5406 Å). Diffraction data

Table 1: Detailed classification of potsherds based on the surface design and depth

Depth (cm)	Cord-Marked	Carved paddle	Plain Ware	Unidentified	Total no. of sherds in each layer
0-20	306	170	54	125	655
20-30	138	83	31	88	340
30-40	136	92	27	78	333
40-50	32	3	4	9	48
Total	612	348	116	300	1376

was collected over a 2θ range of 5°-75° with a step size of 0.02° and an appropriate scanning rate. The mineralogical composition of the samples was identified using standard XRD interpretation procedures.

Fourier-Transform Infrared Spectroscopy (FTIR)

Fourier-transform infrared spectroscopy (FTIR) is widely used to identify functional groups and mineral phases in archaeological ceramics through the interaction of infrared radiation with the sample material. In ceramic studies, FTIR analysis provides important information regarding clay composition, mineral transformations, and firing conditions (Velraj *et al*. 2009). The technique also helps identify crystalline and amorphous phases present within the ceramic matrix (Smith 2011; Margaris 2014).

FTIR spectra of the pottery samples were recorded using a Bruker Alpha FTIR spectrometer employing the KBr pellet technique over the wavenumber range of 4000-400 cm^{-1}. The powdered samples were mixed with KBr in a weight ratio of 1:20 and pressed into pellets for analysis. Each spectrum was obtained using multiple scans under ambient laboratory conditions. The obtained spectra were analysed to identify characteristic absorption bands and corresponding mineral phases using standard reference data and available literature.

Energy Dispersive X-ray Spectroscopy (EDX)

Energy Dispersive X-ray spectroscopy (EDX) is an analytical technique used for the elemental analysis or chemical characterisation of a sample. It shows the presence of elements in a sample along with its percentage. As a type of spectroscopy, it relies on the investigation of a sample through interactions between electromagnetic radiation and matter, analysing X-rays emitted by the matter in response to being hit with charged particles.

For EDX data analysis, the experiment is done in a Gemini Field Emission Scanning Electron Microscope (FESEM), which is equipped with a windowless EDS. The powder pottery sample is attached to a metallic holder (aluminium stub) with the help of a carbon tab (double-sided adhesive carbon-conductive tab). The ceramic products need to be covered by a thin conducting surface layer, usually done with gold or carbon in an argon atmosphere. After coating, a uniformly conducting cover is formed, which helps in reducing heating by the electron beam. The prepared sample is placed in the sample holder of the FESEM machine. The energy of characteristic X-rays that is emitted when electrons strike a solid specimen enables the identification of the main elements that were present in the pottery samples (Karapukaityte *et al*. 2006).

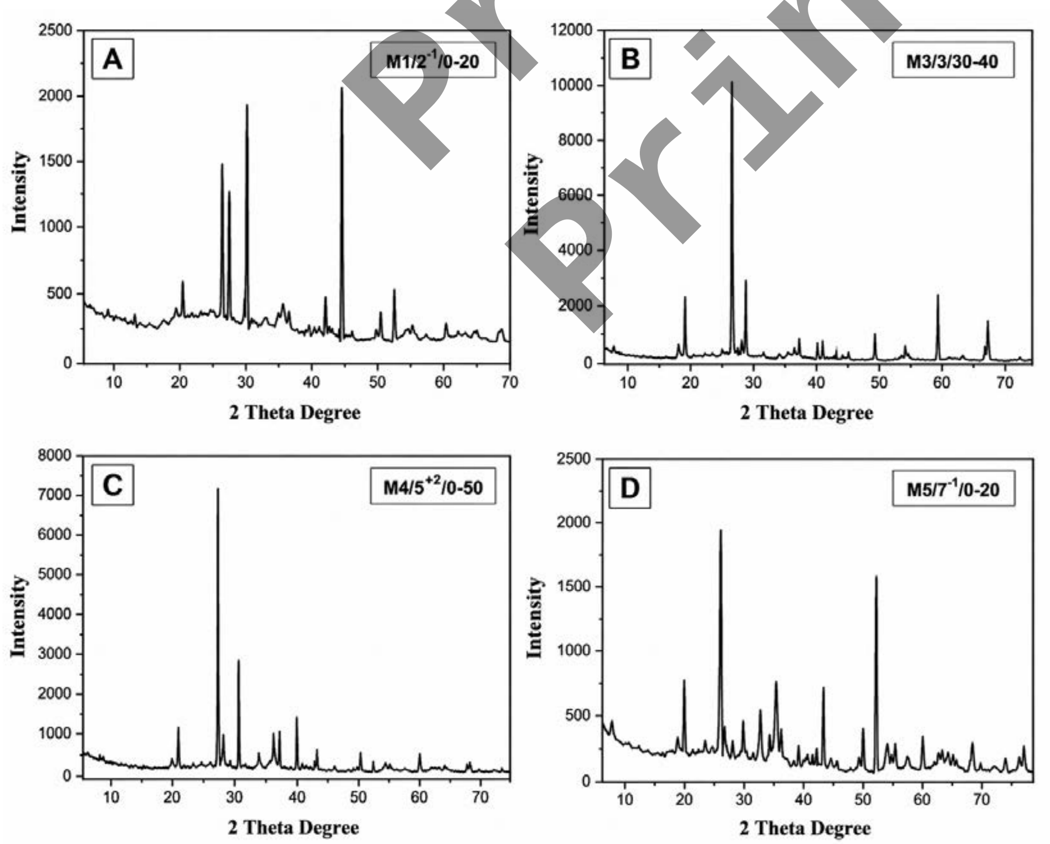

Fig. 4: XRD spectra of Neolithic ceramic samples M1, M3, M4, and M5 shown in A, B, C, and D, respectively, illustrating the mineralogical phases present

Table 2. Details of pottery samples considered in the present study

Sl. No.	Sample name	Layer Depth (cm)	Trench	Colour	Pattern of Design	Thickness of the Sherds (mm)	Length and breadth (mm)	Space between lines (mm)	Type of pottery	Description
1	M1/2^{-1}/0-20	0-20	2-1	Reddish brown/ HUE 5YR-4/4	Criss-Cross	6	L25/B19	3	Cord Marked	Body part, small in size, course ware
2	M3/3/30-40	30-40	3	Strong brown/ HUE 7.5YR- 5/8	Vertical/ Horizontal	5	L23/B20	1.5	Cord Marked	Body part, medium in size, course ware
3	M4/5^{+2}/40-50	40-50	5+2	Dark reddish brown/ HUE 5YR- ¾	Criss-Cross	6	L24/B23.5	1	Cord Marked	Body part, medium in size, course ware
4	M5/7^{+1}/0-20	0-20	7+1	Red/ HUE 2.5 YR- 4/8	Vertical/ Horizontal	6	L38/B35	1.5	Cord Marked	Body part, big in size, course ware
5	M7/5^{-1}/40-50	40-50	5-1	Reddish brown/ HUE 5YR- 4/4	Vertical/ Horizontal	8	L60/B43	1	Cord Marked	Rim sherd, very big in size, course ware
6	M11/2^{-1}/0-20	0-20	2-1	Dark reddish gray/ HUE 5 YR- 4/2	Criss-Cross	9	L38/B27	1	Cord Marked	Body part, medium in size, semi course ware
7	M12/7^{+1}/20-30	20-30	7+1	Reddish brown/ HUE 5YR- 4/4	Vertical/ Horizontal	4	L32/B24	0.5	Cord Marked	Neck part, outward bending medium in size, course ware
8	M13/7^{+1}/20-30	20-30	7+1	Strong brown/ HUE 7.5YR- 4/4	Vertical/ Horizontal	5	L32/B28	1	Cord Marked	Body part, medium in size, course ware
9	M14/5^{-2}/30-40	30-40	5-2	Red/ HUE 2.5YR- 4/8	Criss-Cross	6	L32/B24	2.5	Cord Marked	Body part, medium in size, semi coarse ware
10	M17/5^{-1}/40-50	40-50	5-1	Red/ HUE 2.5YR- 4/6	Vertical/ Horizontal	8	L39/B36	1	Cord Marked	Body part, big in size, coarse ware

Results

Results of XRD Analysis

The mineralogical composition of clay-based ceramics plays an important role in determining their technological properties and firing behaviour. XRD analysis was carried out to investigate the mineralogical characteristics and possible provenance of the pottery samples recovered from the Neolithic site of Myrkhan. The XRD patterns of the analysed samples are presented in Figs. 4-6 (Table 3). The investigated potsherds exhibit heterogeneous mineralogical compositions. The identified mineral phases include quartz, kaolinite, microcline, goethite, anorthite, haematite, rutile, biotite, orthoclase, chrysotile, millisite, halloysite, amicite, ilmenite, variscite, muscovite, and hornblende occurring in varying proportions. Among these, quartz, kaolinite, goethite, haematite, and anorthite constitute the dominant mineral phases in most of the analysed samples. Quartz was identified as the most abundant mineral phase in almost all pottery samples as well as in the associated soil samples, except for sample M05, in which quartz was

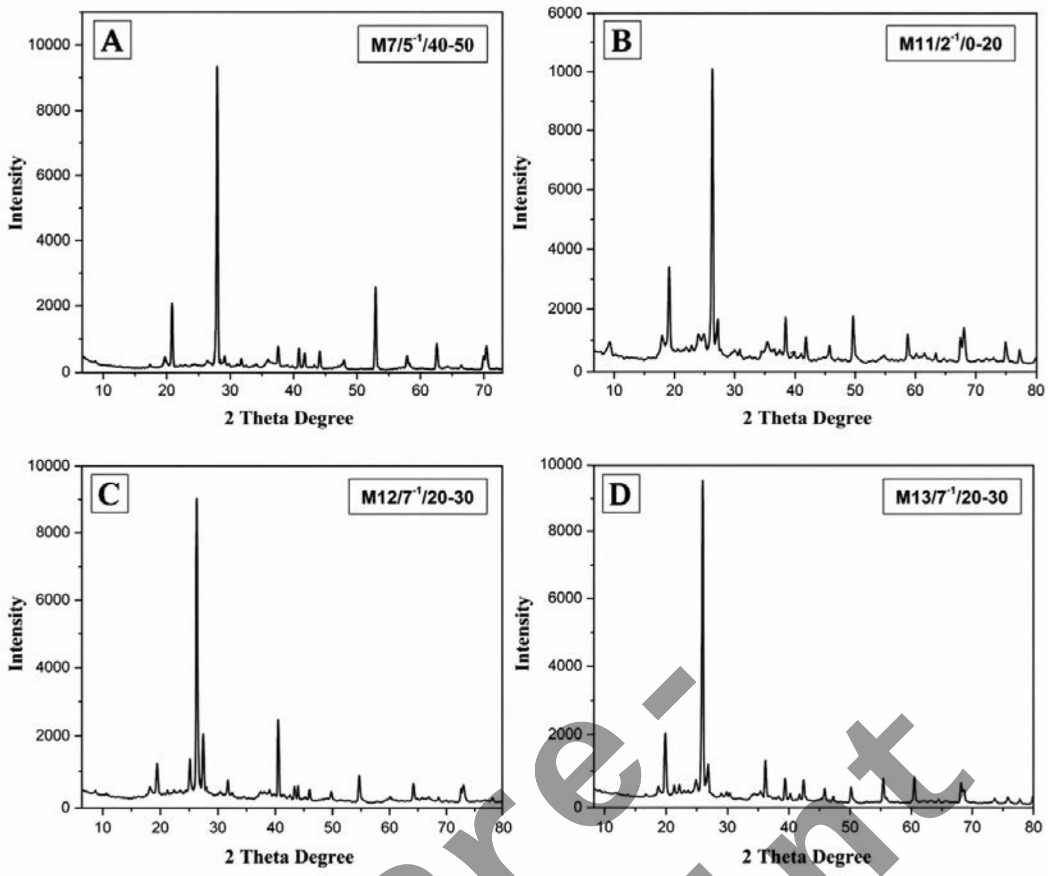

Fig. 5: XRD spectra of Neolithic ceramic samples M7, M11, M12, and M13 shown in A, B, C, and D, respectively illustrating the mineralogical phases present

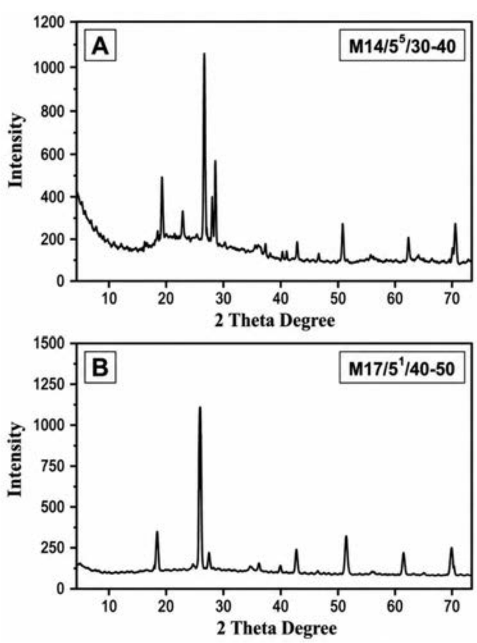

Fig. 6: XRD spectra of Neolithic ceramic samples M14 and M17 shown in A and B, respectively, illustrating the mineralogical phases present

Table 3: Major and minor mineral phases identified in pottery samples through XRD analysis

Mineral Group	Identified Minerals	Occurrence
Silicates	Quartz	Dominant (all samples)
Clay minerals	Kaolinite	Majority of samples
Feldspars	Microcline, Anorthite, Orthoclase	Frequent
Iron oxides	Hematite, Goethite	Common
Heavy minerals	Rutile, Ilmenite	Occasional
Amphiboles	Hornblende	Rare
Phosphates	Variscite	Limited samples

absent. Quartz commonly occurs as a natural inclusion in clay deposits, although it may also be intentionally added as temper material (Papachristodoulou *et al*. 2006). The high quartz content suggests the use of quartz-rich raw materials and may indicate procurement of clay from piedmont-derived sediments (Ravisankar *et al*. 2010). The persistence of quartz and feldspar minerals further suggests

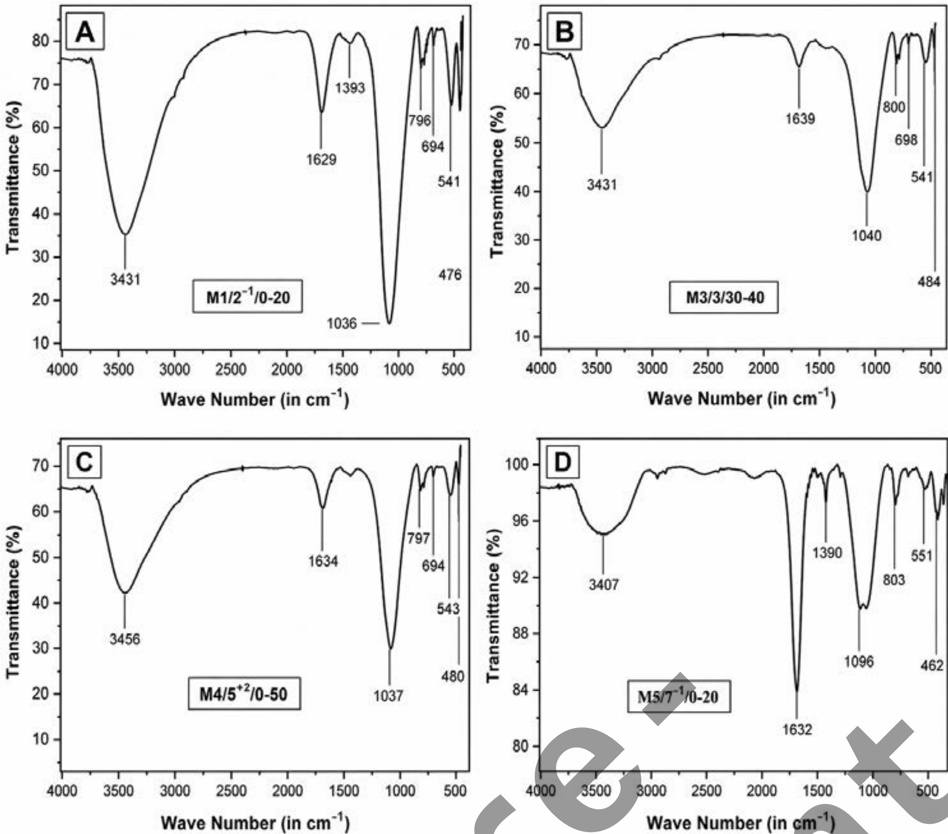

Fig. 7: FTIR spectra of Neolithic ceramic samples M1, M3, M4, and M5 shown in A, B, C, and D, respectively, indicating the presence of functional groups associated with clay minerals and firing processes

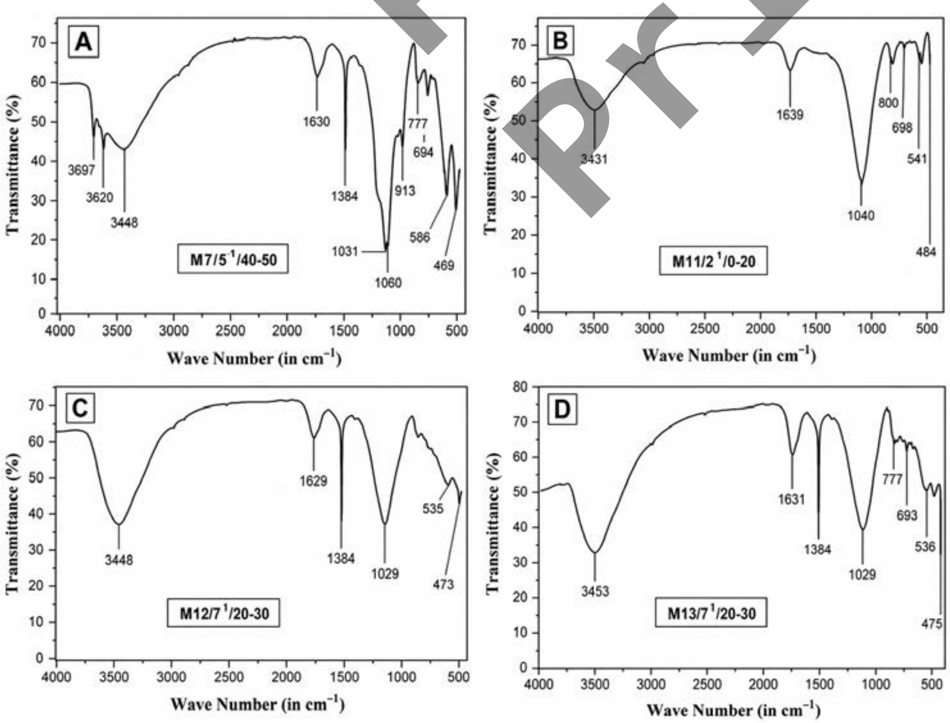

Fig. 8: FTIR spectra of Neolithic ceramic samples M7, M11, M12, and M13 shown in A, B, C, and D, respectively, indicating the presence of functional groups associated with clay minerals and firing processes

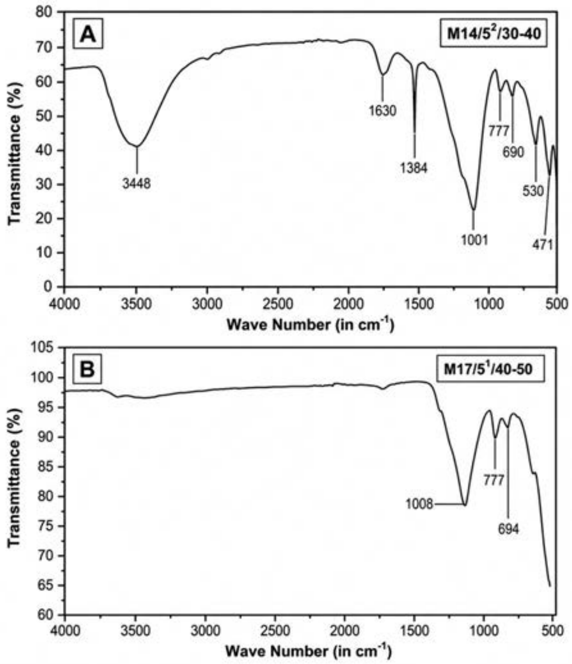

Fig. 9: FTIR spectra of Neolithic ceramic samples M14 and M17, respectively, indicating the presence of functional groups associated with clay minerals and firing processes

firing temperatures approaching or exceeding 900° C, as these minerals remain stable up to approximately 1000° C (Mirti and Davit 2001; Shimada *et al*. 2003).

Kaolinite was identified in limited quantities within the analysed pottery assemblage and was absent in the associated soil samples. Sample M06 exhibits a distinct mineralogical composition characterised by the occurrence of millisite, halloysite, and amicite, which were absent in the remaining samples, indicating possible variation in raw material selection or manufacturing practices.

Haematite was identified in several potsherds and likely contributed to the reddish colouration of the ceramics. The presence of haematite further suggests firing under oxidising conditions, as even small quantities of this mineral are sufficient to impart the red colouration to pottery (Palanivel and Kumar 2011).

Hornblende was identified in samples M03, M05, and M06. This mineral belongs to the amphibole group and is typically rich in calcium and magnesium (Barnes, 1930). Rutile was detected in samples M04, M06, M07, M09, and M12, whereas ilmenite occurred in samples M06, M07, and M11. The presence of ilmenite suggests that the raw materials used for these ceramics were enriched in iron and titanium-bearing minerals (Olivares *et al*. 2010). Variscite was identified in samples M12 and M13. The occurrence of non-clay minerals such as feldspars, biotite, and hornblende may indicate contributions from igneous or volcanogenic source materials (Grim 1953).

Table 4: Representative FTIR absorption bands and corresponding mineral assignments

Wavenumber (cm^{-1})	Assignment	Interpretation
3400-3450	O-H stretching	Absorbed water
1630-1640	H-O-H bending	Moisture
1030-1100	Si-O-Si stretching	Clay minerals (kaolinite)
700-800	Si-O bending	Quartz
~535	Fe-O	Hematite
460-480	Si-O-Si bending	Feldspar

Results of FTIR Analysis

The FTIR spectra of the analysed samples are presented in Figs. 7-9; Table 4. The spectra indicate the presence of quartz, feldspars (microcline and orthoclase), clay minerals (kaolinite and montmorillonite), iron oxides, and minor organic compounds. Quartz was identified in most samples through characteristic Si-O stretching and bending vibrations observed at approximately 467 cm^{-1}, 693 cm^{-1}, 777 cm^{-1}, and within the 900-1100 cm^{-1} region (Marel and Beutelspacher 1976; Kumar and Rajkumar 2014). The strong silicate-related absorption bands in the range of 1100–1000 cm^{-1} further confirm the dominance of silicate minerals within the ceramic matrix. Feldspar minerals, particularly microcline, were identified through absorption bands near 1011-1014 cm^{-1} (Bayazit *et al*. 2015).

Clay minerals, including kaolinite and montmorillonite, were identified through absorption bands near 1030 cm^{-1}, 1635 cm^{-1}, 3440 cm^{-1}, and hydroxyl-related bands at approximately 3696 cm^{-1} and 3620 cm^{-1} (Annamalai *et al*. 2014). These bands were particularly evident in samples M10, M11, M13, and M14. Weak absorption bands at 2926 cm^{-1} and 2853 cm^{-1} indicate the presence of organic compounds, possibly related to organic tempering materials or residual organic matter within the clay matrix (Ravisankar *et al*. 2013).

Iron oxide-related absorption bands near 535 cm^{-1} were observed in several samples, indicating the presence of haematite. The occurrence of haematite is consistent with the reddish colouration of the pottery and suggests firing under oxidising conditions (Palanivel and Kumar 2011). Haematite-related bands were particularly observed in samples M03, M05, M11, M12, and M13. Minor mineral phases such as gypsum and calcite were identified in samples M11 and M07, respectively.

Several spectral characteristics provide information regarding firing temperatures. The absence of hydroxyl absorption bands near 3630 cm^{-1} suggests that most pottery samples were fired at temperatures approaching or exceeding 800° C (Ross and Kerr 1931). Similarly, the disappearance of Al-OH vibration bands near 915 cm^{-1} indicates firing temperatures above 500° C (Elsass and Olivier 1978). However, the persistence of kaolinite-

Table 5: Average elemental composition of Myrkhan pottery samples (wt.%)

Element	Range (%)	Interpretation
O	42-56	Oxide matrix
Si	10-22	Silicate minerals
Al	4-10	Clay minerals
Fe	2-18	Iron oxides
K	0.6-2.4	Feldspar presence
Ca	Low	Non-calcareous clay
O	42-56	Oxide matrix
Si	10-22	Silicate minerals
Al	4-10	Clay minerals
Fe	2-18	Iron oxides
K	0.6-2.4	Feldspar presence
Ca	Low	Non-calcareous clay

related bands in some samples suggests incomplete thermal decomposition of kaolinite, indicating firing temperatures below approximately 650° C for those specimens (Ravisankar *et al*. 2013). The presence of metakaolinite-related bands near 1096 cm^{-1} in sample M05 further supports firing within the range of 450-650° C.

The red colouration of the pottery is primarily attributed to oxidation of iron compounds during firing and cooling under oxidising atmospheric conditions, a process commonly associated with red ceramic fabrics (Shepard 1956; Rice 1987).

Results of EDX Analysis

EDX analysis was carried out on ten potsherd samples to determine their elemental composition and identify major and minor chemical constituents (Table 5; Figs. 10-14). The analysed samples contain major elements such as oxygen (O), carbon (C), silicon (Si), aluminium (Al), iron (Fe), potassium (K), magnesium (Mg), titanium (Ti), calcium (Ca), and sodium (Na) and minor elements including fluorine (F), copper (Cu), manganese (Mn), zink (Zn), bromine (Br), phosphorous (P), chlorine (Cl), sulphur (S), chromium (Cr), niobium (Nb), beryllium (Ba), and zirconium (Zr).

The EDX spectra indicate that Si, Al, Fe, and K are the dominant elements in most samples, although their relative abundances vary among the analysed potsherds. Following O and C, Si and Al constitute the major elemental components, reflecting the abundance of alumino-silicate minerals such as clay minerals and feldspars within the ceramic matrix (Vecstaudza *et al*. 2013). The relatively high iron content observed in several samples suggests the use of iron-rich raw materials during pottery manufacture.

Al occurs in comparatively high concentrations in most samples, except in sample M01. Similarly, iron concentrations are relatively lower in sample M01 compared to the remaining pottery samples. Ca was detected in all analysed samples, although generally in low

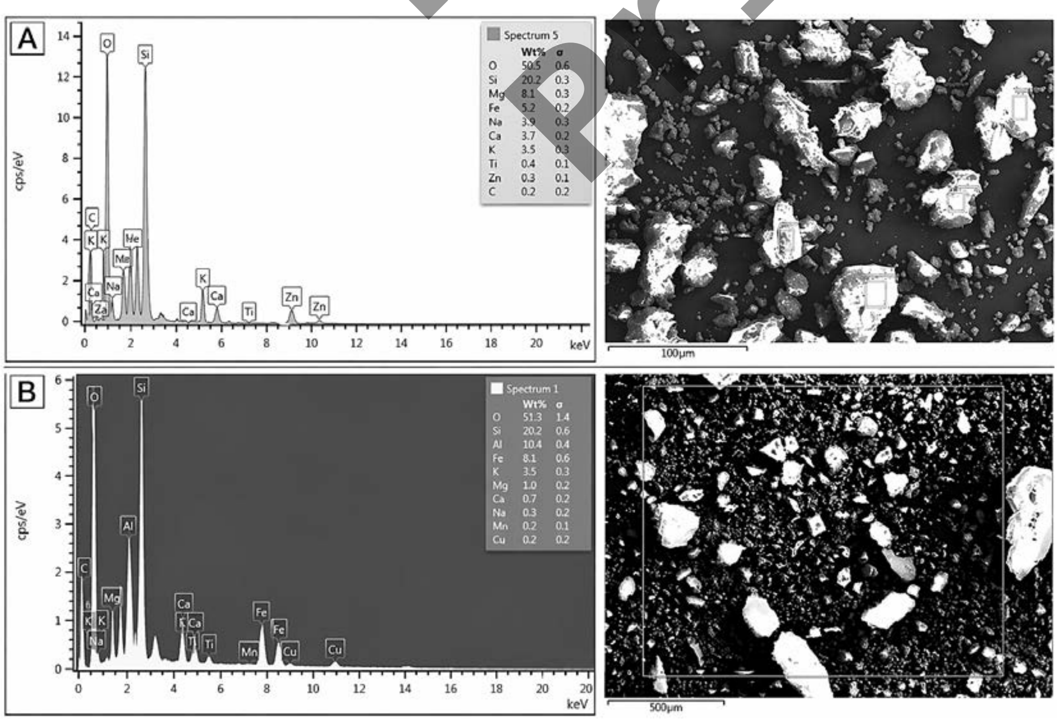

Fig. 10: EDX spectra and elemental composition charts of samples M1 and M3 shown in A and B, respectively, highlighting variations in elemental distribution

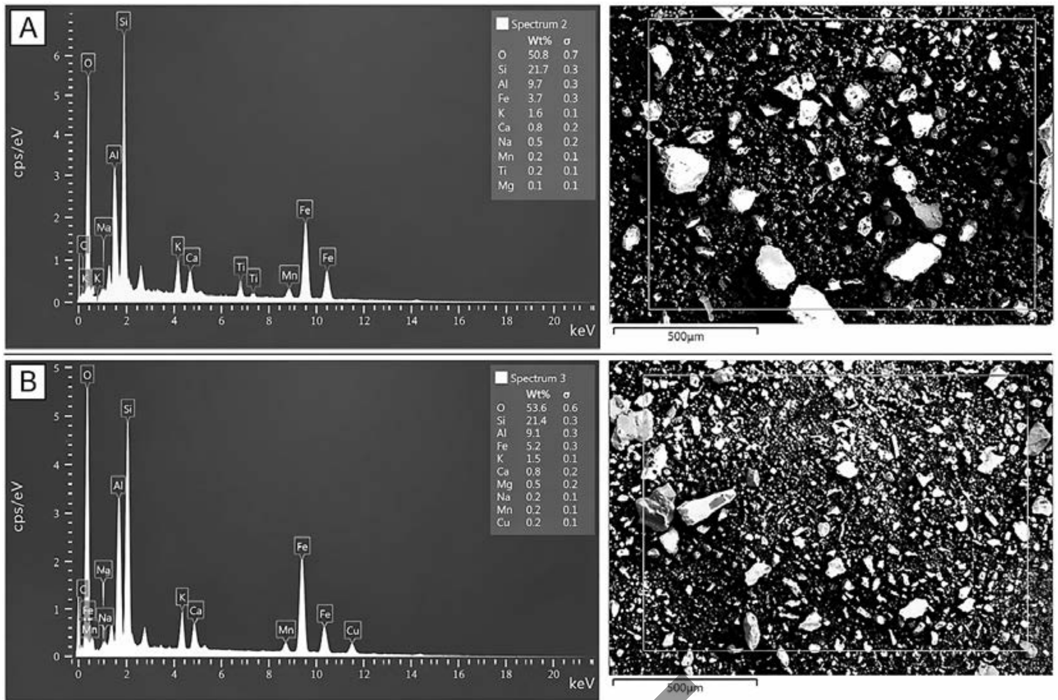

Fig. 11: EDX spectra and elemental composition chart of samples M4 and M5, shown in A and B, respectively, highlighting variations in elemental distribution

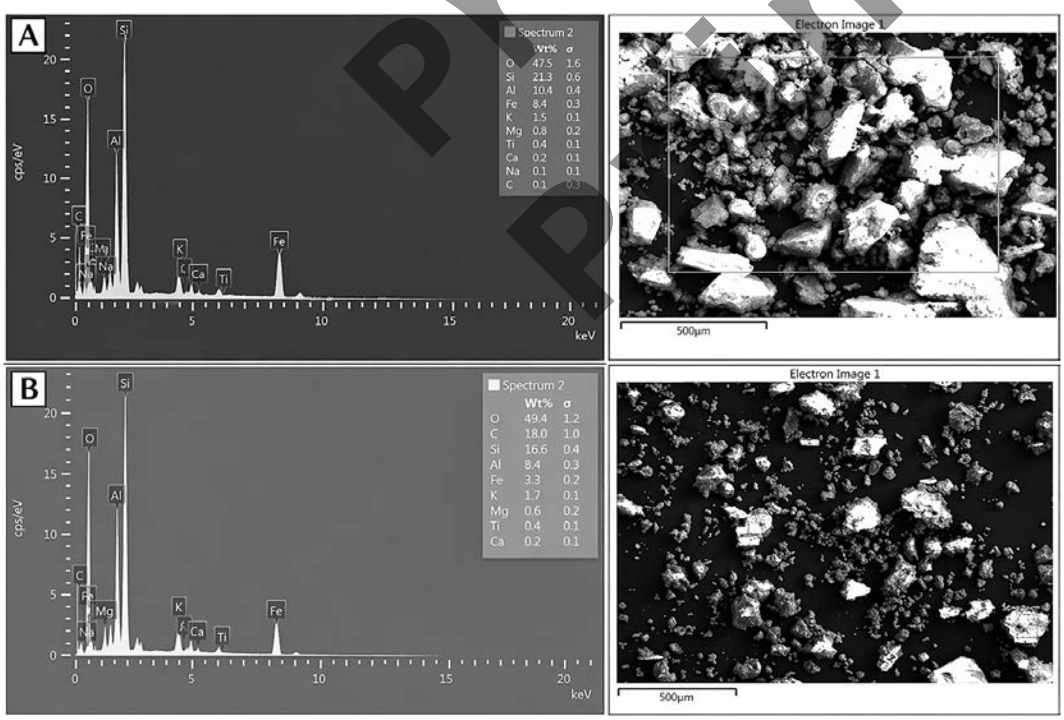

Fig. 12: EDX spectra and elemental composition chart of samples M7 and M11, shown in A and B, respectively, highlighting variations in elemental distribution

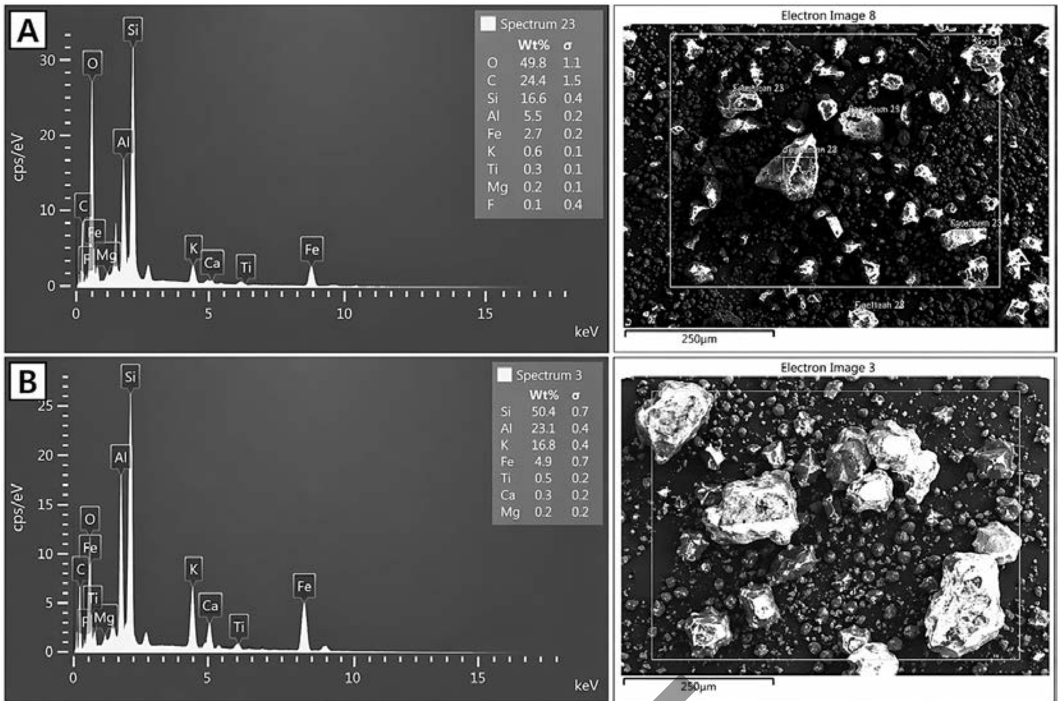

Fig. 13: EDX spectra and elemental composition chart of samples M12 and M13, shown in A and B, respectively, highlighting variations in elemental distribution

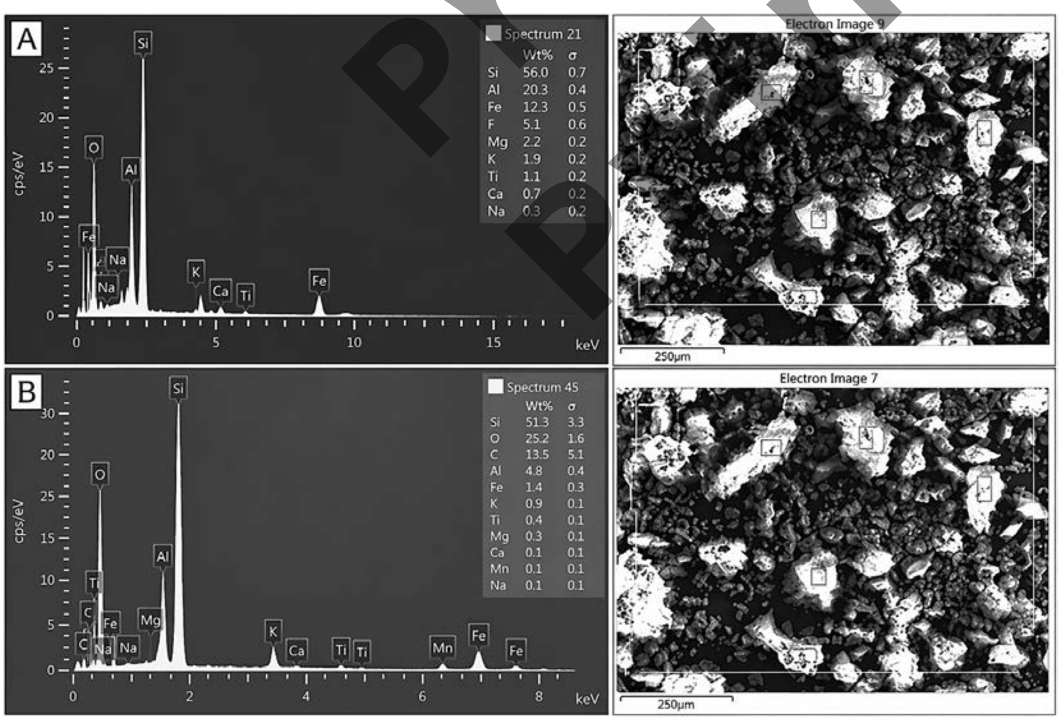

Fig. 14: EDX spectra and elemental composition chart of samples M14 and M17, shown in A and B, respectively, highlighting variations in elemental distribution

concentrations except for sample M12. The dominance of Si and comparatively lower Ca contents suggest the use of non-calcareous clay sources for pottery production (Damjanovic *et al.* 2011).

Fluorine was detected in samples M03 and M05 with concentrations of 4.8 wt.% and 3.6 wt.%, respectively. Minor quantities of Zn, Br, Cr, Nb, Ba, and Zr were also identified in several samples. Zirconium was primarily detected in the associated soil samples, although its concentration remained relatively low.

The occurrence of broadly similar elemental compositions among the pottery samples suggests similarities in raw material selection and manufacturing practices. Such compositional similarities may also indicate shared technological traditions and possible exchange or movement of pottery materials among Neolithic communities (Karapukaityte *et al.* 2006).

Discussion and Conclusions

The integrated archaeometric analyses of the Myrkhan cord-marked pottery assemblage provide important insights into raw material selection, ceramic technology, firing conditions, and cultural interactions associated with the Neolithic communities of Northeast India. The combined results of XRD, FTIR, and EDX analyses indicate that the pottery assemblage is mineralogically and chemically heterogeneous, suggesting variability in clay procurement and ceramic preparation practices. However, the recurrence of similar elemental and mineralogical patterns across multiple samples also reflects a broadly shared technological tradition within the pottery-producing community.

The dominance of quartz, feldspars, kaolinite, haematite, and other iron-bearing minerals suggests the utilisation of locally available alumino-silicate clays rich in naturally occurring mineral inclusions. The high quartz content observed in most samples indicates that the ceramic paste was either naturally self-tempered or intentionally mixed with siliceous inclusions to improve thermal resistance and mechanical stability during firing (Papachristodoulou *et al*. 2006). The occurrence of feldspars, hornblende, biotite, and ilmenite further reflects the incorporation of igneous-derived sediments, likely originating from nearby piedmont or weathered granitic formations associated with the Khasi Hills region (Grim 1953). These observations strongly support the inference that the pottery was produced using locally available raw materials rather than imported resources.

The FTIR and XRD analyses together provide important evidence regarding firing technology. The persistence of quartz and feldspar phases, together with the disappearance of specific hydroxyl bands, suggests firing temperatures generally ranging between approximately 500° C and 800° C. Samples containing kaolinite indicate comparatively lower firing temperatures, likely below 650° C, since kaolinite decomposes into metakaolinite at higher temperatures (Ravisankar *et al.* 2013). The occurrence of haematite and the reddish coloration of the pottery indicate firing under oxidising conditions, probably achieved through open firing or simple kiln structures with controlled oxygen circulation during cooling (Shepard 1956; Rice 1987). Such firing conditions are characteristic of Neolithic ceramic traditions employing relatively simple pyro-technological practices.

The detection of organic compounds and hydrocarbon residues in the FTIR spectra may indicate either naturally occurring organic matter within the clay matrix or the intentional addition of organic tempering materials during paste preparation. Such organic additives are commonly associated with improved plasticity and workability of ceramic paste (Ravisankar *et al.* 2013). The presence of hydrated minerals and absorbed moisture bands additionally suggests post-depositional alteration processes affecting the buried ceramics.

EDX analysis further confirms the alumino-silicate nature of the pottery through the predominance of silicon, aluminium, iron, and potassium, while the generally low calcium content indicates the use of non-calcareous clay sources (Damjanovic *et al.* 2011). Variations in elemental composition among the samples imply differences in clay preparation or raw material procurement, although the overall compositional similarities suggest technological continuity within the ceramic tradition.

From a cultural perspective, the cord-marked pottery of Myrkhan exhibits stylistic and technological parallels with Neolithic assemblages reported from other parts of Northeast India and regions of East and Southeast Asia. However, the clear evidence for local raw material procurement and indigenous manufacturing practices suggests that these ceramics were locally produced. The observed similarities therefore likely reflect processes of cultural interaction, technological diffusion, and knowledge exchange rather than large-scale population movement. Overall, the cord-marked pottery of the Myrkhan pottery assemblage represents a locally produced Neolithic ceramic tradition characterised by moderate firing technology, selective use of regional raw materials, and technological adaptability. The present study demonstrates the value of integrating archaeometric techniques with archaeological interpretation for reconstructing prehistoric ceramic production systems and contributes significantly to the understanding of Neolithic cultural dynamics in Northeast India.

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