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Thin Section Petrography of Neolithic Pottery from Northeast India

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Abstract

Twenty nine potsherds from nine Neolithic sites of Northeast India have been analysed using thin section petrography. The primary objectives of this article are to determine their provenance, to investigate the production techniques of Neolithic pottery and to understand the technical skills of the ancient potters of the studied region. Based on their mineralogical content and the composition of the matrices, the pottery samples have been classified into eleven fabric groups. The analysis of the fabrics showed dissimilarities in the processing and production of ceramics which were otherwise very similar at first sight. The dissimilarities provided indications of the clay sources and the occurrence of natural and artificial temper/inclusions, e.g., organic or inorganic substances used by the Neolithic potters of Northeast India during manufacturing processes. In all fabric groups, we found iron-bearing materials which show that the ancient potters used local clay to make pottery because the soil in this region contains a high amount of ferruginous substances. The results also confirmed that the analysed pottery was probably fired below 800 °C under an oxidizing atmosphere and also revealed the use of non-plastic inclusions, such as sand, quartz and organic materials during pottery production.

Introduction

Ceramic petrography is a powerful method to identify minerals and to conduct technological investigations of archaeological pottery. Petrographic techniques are also used to describe and classify rocks in geological sciences. These techniques helps investigators to gain an understanding of mineralogical composition as well as other textural properties of rock. In cases of sediments and sedimentary rocks, thin section petrography also helps to determine their provenance (MacKenzie/Adams 2005; Pichler et al. 1997; Quinn 2013; Riederer 2004). Pottery may be referred to as partially metamorphosed sediments: "The fabric of a potsherd consists principally of clastic grains held in a clay matrix, both partially altered during firing" (Rice 1987, 376–377; Williams 1983, 302; Shepard 1956, 139–140). The study of compositional groups or fabrics and their classification in relation to raw materials and technology is helpful for a determination of ceramic provenances. Petrographic fabrics usually reveal peculiarities in the processing and production of ceramics. These peculiarities can indicate their source through the examination of the clay content and the tempered materials. This presupposes that pottery manufacturing took place near localities where raw materials and natural deposits were available.

While thin section petrography was already first applied on a large scale in 1942 (Shepard 1942; Quinn 2013, 10), there are only few studies in India where thin section petrography has been used to examine archaeological pottery. In addition, most of the studies are done on Harappan Pottery. P. Biagi and his co-workers (2021) studied survey pottery and other cultural remains recovered from the archaeological site at Ras Muari-Sonari, Karachi, Pakistan. They analysed pottery using thin section petrography and their results revealed at least eleven fabric groups on the basis of the groundmass observed under the petrographic microscope. Krishnan and Hegde (1988) examined Harappan pottery using chemical and petrographic techniques. Krishnan and Coningham (1997) studied Rouletted ware and other pottery reported from Anuradhapur, Sri Lanka using petrographic techniques. Krishnan and Zulkernine (2012) investigated the pottery from Wari-Bateswar, Bangladesh, using typological and petrographic analysis. The pottery has been classified into several fabric groups on basis of their mineralogical composition. The results revealed that the raw clay, which has been used to produce these potsherds, came from two different regions. Other scholars, such as Dimri (1994), Kumar (1997) and Shah (1994), studied Harappan pottery using a petrographic approach. Pottery from Narayanakuppam (Sambhuvarayar, Tamil Nadu) was analysed by thin section petrography. The results demonstrated the presence of minerals such as quartz, hornblende, pyroxene, feldspars and iron in them. The pottery was made of fine-grained clayey materials (approx. 45 % of the total volume; Venkatachalapathy/Ramaswamy 1991).

The study of archaeological pottery from Northeast India with thin section petrography is lesser known. Most of the work is done on shape, size and design. The first pioneering work on Neolithic pottery reported from Northeast India was carried out by T.C. Sharma. T.C. Sharma (1967) explained a stratified cultural deposit from Daojali Hading in the Langting River Valley of the North Cachar Hills, today known as the Dima Hasao district. In a salvage operation, large quantities of potsherds and stone implements were reported. For the first time, potsherds were found in this area in association with polished adzes of ground stone, particularly double-shouldered adzes. Technologically, the potsherds can be divided into four groups of wares which are as follows: (i) cord-marked pottery (ii) incised pottery (iii) stamped pottery and (iv) plain fine red pottery (Sharma, T. C. 1966). Goswami and Sharma (1963) described the production process of Neolithic pottery from Daojali Hading. The paste of the pottery was very coarse and the shape was obtained by lining paste along a basket or bamboo vessels which was sun dried. The colour of the vessels is of varying shades of grey. O.K. Singh (1998–1999; 2008) discussed cord impressed pottery reported from Napachik and other sites and made a short note on pottery from Manipur. Thus, studies on ceramics have been based on design and colour so far.

The objective of the present study is to determine the provenance and to reconstruct the manufacturing techniques of pottery as well as to understand the technical skills of the Neolithic potters of Northeast India through thin section petrographic techniques. To this purpose, Neolithic pottery samples have been selected from various sites including Daojali Hading (DJL) – Assam; Nongpok Keithelmanbi (KM) and Napachik (NPC) – Manipur; Barapani (BRP), Sophet (SPT), Sawmer (SMR), Law Nongthroh (LNGH) and Gawak Abri (GWK) – Meghalaya and Ranyak Khen (RYK) – Nagaland (Fig. 1).

Geology and the Neolithic in Northeast India

Geologically, Northeast India is composed of a north-east/south-west trending "foreland spur" which is overthrust from the northwest by the

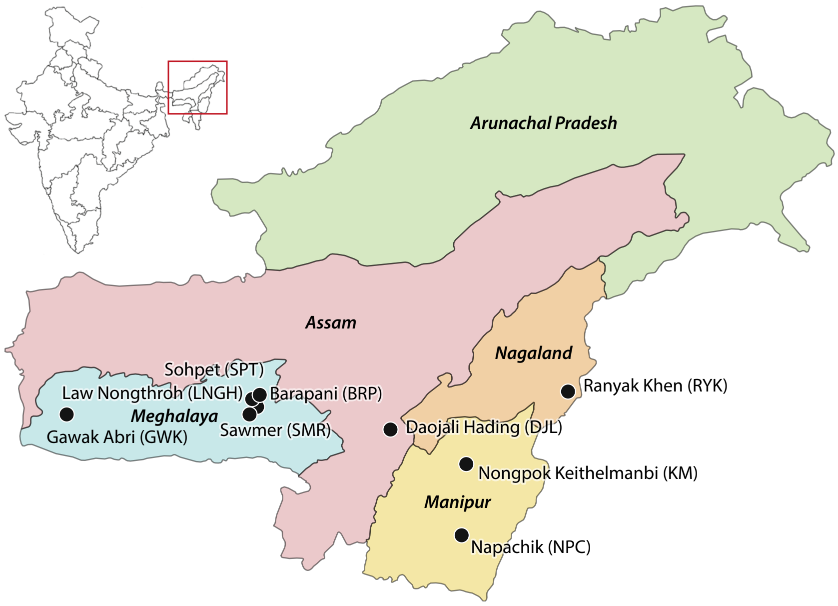

Fig. 1. Neolithic sites of Northeast India which are part of the present study (Graphics: S. Sabnis).

Arunachal Himalayas and from the southeast by the Naga Hills (Mathur/Evans 1964). The foreland spur forms a part of an autochthon together with the Shillong Plateau and the Karbi-Anglong Hills. Its subsurface trend approximately follows the Brahmaputra River and is composed of crystalline rocks which at present are covered by Tertiary and later sediments. The crystalline rocks are represented by hornblende-biotite schists, amphibolites, quartz-magnetite schists, garnet-mica schists, granites and granulites. The Arunachal Himalayas are composed of sedimentary rocks belonging to the Siwalik and Gondwana Groups in the lower reaches (i.e. up to the Main Boundary Thrust). Beyond the Main Boundary Thrust, the Arunachal Himalayas are composed of low to medium grade metasedimentary rocks and granite gneisses. The complete sequence of Tertiary sediments found in Northeast India is well-preserved in the Naga Hills. They are composed of a limited range of rock-types including alternations of sandstones, siltstones, clays, limestones and shales. Conglomerates, coal seams and carbonaceous shales have limited occurrence.

Geographically and culturally, Northeast India is a land bridge between India, Southeast Asia and China. There is a hypothesis that adze manufacturing techniques entered India through the Assam-Burma (Myanmar) corridor (Worman 1949, 199).

The Neolithic in Northeast India is considered to have lasted from 4500 BCE to 300 BCE. The oldest date is from Ranyak Khen 4450–4350 BCE (C14, Beta 260242) (Jamir et al. 2017), while the youngest date comes from Gawak Abari around 2.3 ± 0.2 Ka (OSL, Lab No. LD1727) (Sharma, S./Singh 2017). The distinctive cultural features of the Neolithic period in Northeast India are cord-marked pottery and double-shouldered adzes (Sharma, T.C. 1966; Mitri/Neog 2016), which were discovered first in 1961 in the region of Daojali Hading, Dima Hasao (North Cachar Hills) district, Assam. The first reported Neolithic implement from Northeast India is a ground and polished axe made of jadeite. It was found by E.H. Steel in 1867 and later, in 1870, he reported that some more similar tools were found from the villages of the Namsang Nagas (Sharma, T.C. 1966). The use of fossil wood as a raw material to make ground and polished axes and adzes is another feature of the Neolithic of Northeast India. Subsequently, stone implements, such as grinding stones, grooved hammers, notched pebbles, querns or milling troughs, muller, nut-crushers, and spindles, have also been reported from the various Neolithic sites of Northeast India.

Neolithic sites

The major findings from Daojali Hading (North Cachar Hills) include edged tools, grinding stones, querns, mullers, quartzite pebbles and fossil wood. The stone tools are made of shale, sandstone, quartzite and fossil wood which are locally available (Dikshit/Hazarika 2011–2012; Sharma, T.C. 1966). Along with these stone artifacts, various types of potsherds were also recovered. The major pottery types are represented by cord-marked pottery, incised pottery, stamped and fine red ware. According to T.C. Sharma (1966), only plain red ware is made of well levigated fine clay. Other types are made of coarse clay. In some cases, the clay is heavily tempered with quartz, sandstone grit and vegetative materials.

Different types of adzes and potsherds have been recovered from the Gawak Abri (West Garo Hills, Ganol Rongram Valley Meghalaya). The stone tools are mainly made of dolerite and are heavily patinated (Sharma, S. 2002). Potsherds are mainly handmade, coarse, and grey, grey-brown and dull brown in colour. Quartz may have been used as a tempering material.

At Law Nongthroh and Sohpet Bneng (Meghalaya), various types of finished and unfinished stones tools, several large stone fragments and small flakes have been found. Additionally, a large number of potsherds (approximately 643) with varied designs, patterns and impressions have been reported from Law Nongthroh. The soil study of the excavated site clearly indicates that these potsherds are made of locally available raw materials (Mitri et al. 2015). The AMS dates of four charcoal samples recovered with potsherds are either 1220–1020 cal BC or 770–415 cal BC. Similar artifacts have been reported from Barapani and Sawmer (Meghalaya).

Nongpok Keithelmanbi is situated on a flattened hill range towards the left bank of Thoubal River in Manipur. Major findings consist of adzes and unfinished pebble tools made of sandstone. Mainly corded ware was found in strata which were situated above a layer of the Hoabinhian techno-complex (Dikshit/Hazarika 2011–2012, 111–112). The potsherds are poorly-fired, heavily weathered and decorated with criss-cross patterns. They are made of fine clay. Moreover, sand and quartz particles were used as tempering materials, which are visible with the naked eye. One date of a charcoal sample from the corded ware stratum dates to 3512–2884 cal BC (BS-523: 4460 ± 120 bp, 95.4 %) (Singh, O.K. 2008; 1998/1999).

Napachik is located on the right bank of Manipur River at Wangu village, Bishnupur district, Manipur. The dominant cultural finds from Napachik are cord-marked potsherds and tripod legs. The potsherds are mainly handmade, fine-textured, and low-fired. Sand and vegetative matter have been used as tempering materials. In association, flakes, flake tools, pebble tools, cores, and ground stone adzes are also reported (Singh, O.K. 2008; 1998/1999).

Ranyak Khen is a cave situated in Kiphire district, Nagaland. The major cultural materials from there consist of grinding tools, hammer stones, disc-shaped scraper tools, bone tools and cord-marked pottery along with a human burial. The excavators of the site have declared that the cultural deposits are of pre-Neolithic origin (Dikshit/Hazarika 2011/2012, 119).

Materials and Methods

Pottery

Overall, 29 potsherds from the nine Neolithic settlements in Northeast India presented above have been investigated using thin section petrography. All selected potsherds are handmade and were part of a vessel body. Detailed descriptions of the sherds are summarised in Table 1.

Table 1. Morphological details of Neolithic potsherds from Northeast India.

	Sample Name	State	Trench	Layer	Depth (cm)	Texture	Colour	Remarks
Daojali Hading	DJL	Assam	Trench-B			Medium	Red	Plain
Gawak Abri	GWKF	Meghalaya	Trial			Fine	Red	Plain
	GWKC		Trial			Coarse	Red	Plain
Sohpet	SPT-01, SPT-02	Meghalaya				Very Coarse	Red	Plain
Barapani	BRP-01					Medium	Red	Plain
	BRP-02					Medium	Red	Groove pattern on outer surface
Sawmer	SMR-01					Coarse	Dark Brown	Groove pattern
	SMR-02					Coarse	Red	Plain
	SMR-03		Trial		44	Coarse	Pale Red	Recovered from outside of the excavated area
	SMR-04		1	2	52	Coarse	Red	Groove pattern
	SMR-05		10	1	44	Very Coarse	Red	Irregular grooves probably cord impressed
	SMR-06		73	1		Very Coarse	Red	Plain
	SMR-07					Medium	Light Brown	
	SMR-08			1		Medium	Light Brown	Coarse paddy ware; pattern-large/medium/small grooves
	SMR-09		74	1		Very Coarse	Red	Plain
Law Nongthrogh	LNGH-01				35	Very Coarse	Light Gray	
	LNGH-02				35	Very Coarse	Red	
	LNGH-03				35	Coarse	Pale Red	
Napachik	NPC-01	Manipur	4			Medium	Red	Grid pattern
	NPC-02		5			Medium	Dark Red	Grid pattern
	NPC-03		5		315–321	Medium	Pale Red	
	NPC-04		6		361	Fine	Pale Red	
	NPC-05		7			Fine	Pale Red	
Nongpok Kiethelmonbi	KM-01				26–30	Very Coarse	Red	Groove pattern on outer surface
	KM-02				35	Medium	Red	Groove pattern on outer surface
	KM-03				46	Very Coarse	Red	Groove pattern on outer surface
Ranyek Khen	RYK-01	Nagaland	1	3	82–90	Medium	Red	
	RYK-02		1	3	82–91	Medium	Red	
	RYK-03, RYK-04, RYK-05		1	3	82–94	Coarse	Red	

Method

A thin section is approximately a 30 µm thick sliver of pottery (or other artefacts) which is fixed on a glass slide. The prepared slide is then observed under a polarising light microscope. The 30 µm thickness of a workpiece provides the actual interference colours of individual minerals under the polarising microscope (Riederer 2004). The most important parts of a polarising microscope are a white light source from which the light beam passes through a filter, consisting of a lower polariser, a diaphragm and a condensing lens, before hitting the sample on the microscope stage. Above the microscope stage, an ocular lens magnifies and focuses the light. The upper polariser, a Bertrand lens and a conoscopic lens are removable and may be inserted when required (Perkins/Henke 2004;

Fig. 2. Representative Neolithic pottery samples from Northeast India (Photo: P. Singh).

MacKenzie/Adams 2005). Both polarisers enable the examination of minerals for their birefringence and refraction characteristics under plane-polarised light (ppl) and crossed nicols. The minerals are identified on the basis of their optical properties and inference colour under plane-polarised light (PPLA) and crossed nicols (Pichler et al. 1997).

The thin section petrographic investigations were carried out on a Leica DM2500P Petrological Microscope. The thin section slides were prepared at the Department of Geological Science, Gauhati University. All micrographs were captured under crossed Nicols (XPL). Only the micrographs of Fabric Group E were captured under plain polarised light (PPL).

Petrographic analysis

Based on their mineralogical content and the composition of their matrix, the thin sections of Neolithic potsherds are grouped as A, B, C D, E, F, G, H, I, J and K, with fabric group A including subgroup A1 and fabric group F including subgroups F1 and F2, respectively.

Fabric group A

The matrix of fabric group A (DJL and SMR-01) is characterized by a non-homogenous distribution of reddish ferruginous materials and irregular opaque (coaly?) materials. Mineralogically, larger fragments are composed of a mixture of quartz and clayey materials indicating that these particles are derived from metamorphic and metamorphosed sedimentary rock fragments (Fig. 3 A). A reddish colour indicates high iron concentration. Opaque inclusions are also observed in SMR-01 (Fig. 3 B). These black opaque inclusions may be carbon particles.

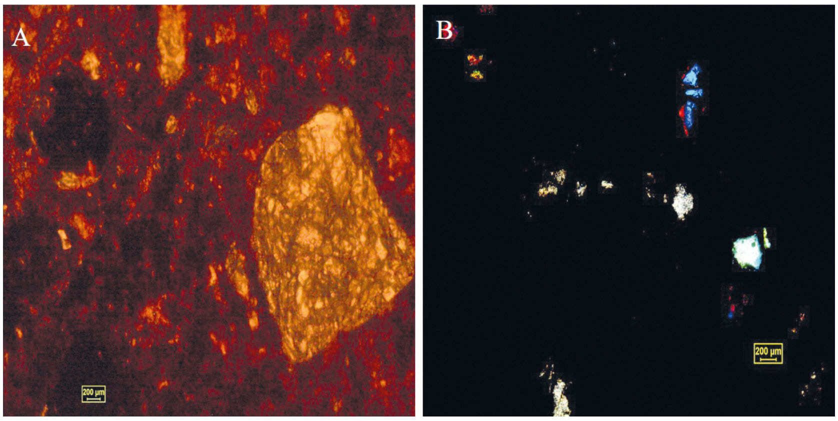

Fig. 3. Fabric group A: A) DJL is characterised by a few larger subrounded and fractured quartz grains floating in a red coloured matrix. The reddish colour may indicate a high iron concentration or staining of matrix constituents by ferruginous materials; B) SMR-01 has a matrix comprising of highly ferruginous materials (iron) and few angular grains of quartz floating in the matrix (Photomicrographs under XPL: J. J. Laskar/P. Singh).

Fabric group A1

Fabric group A1 includes KM-02 (Fig. 4 A and B) and GWKF (Fig. 4 C) and is characterised by a ferruginous material matrix of reddish colour. Grains are angular, subangular to elongated and irregular in shape. Silt/mud stone particles, which are composed of fine quartz particles and irregular shaped opaque materials and pre-existing rock cemented together by ferruginous materials, are observed. Pores (or voids) have opaque lining and contain opaque and non-opaque materials.

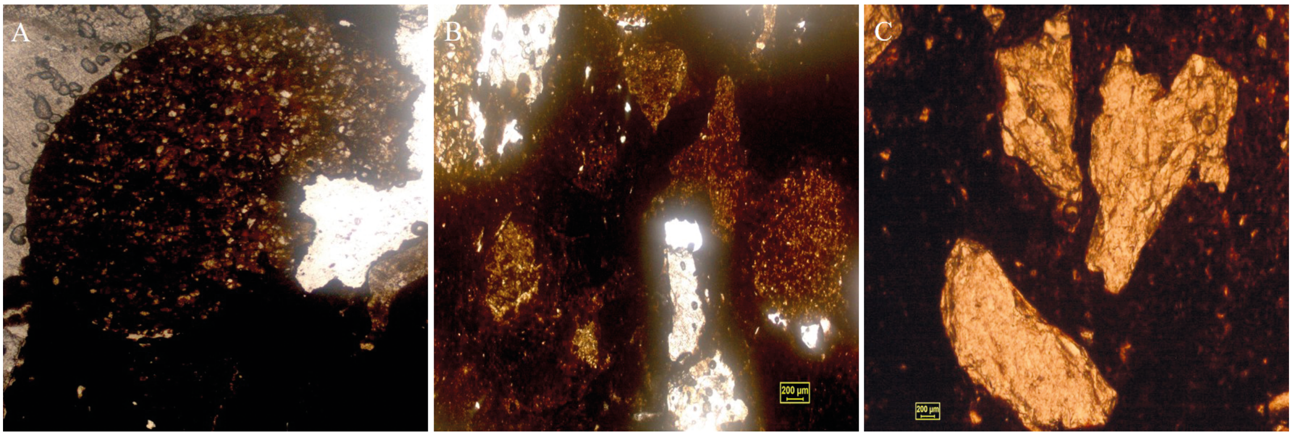

Fig. 4. Sub-Fabric Group A1: A) KM-02 displays a rounded grain consisting of siltstone/mud stone particles and composed of fine angular quartz particles and irregularly shaped opaque and reddish ferruginous materials; B) KM-02 includes sub-angular and elongated particles of pre-existing rocks, cemented together by ferruginous materials. Pore spaces can be observed; C) In GWKF, the matrix is composed of reddish ferruginous and highly angular quartz grains seated in it (Photomicrographs under XPL: J. J. Laskar/P. Singh).

Fabric group B

Thin sections of fabric group B (BRP-01, 02; NPC-05, RYK-01) (Fig. 5) are composed of fine microcrystalline and siliceous materials. Grains are elongated and irregular in shape. Particles of fibrous character are present in all potsherds in this fabric group, together with quartz, micaceous and siliceous materials.

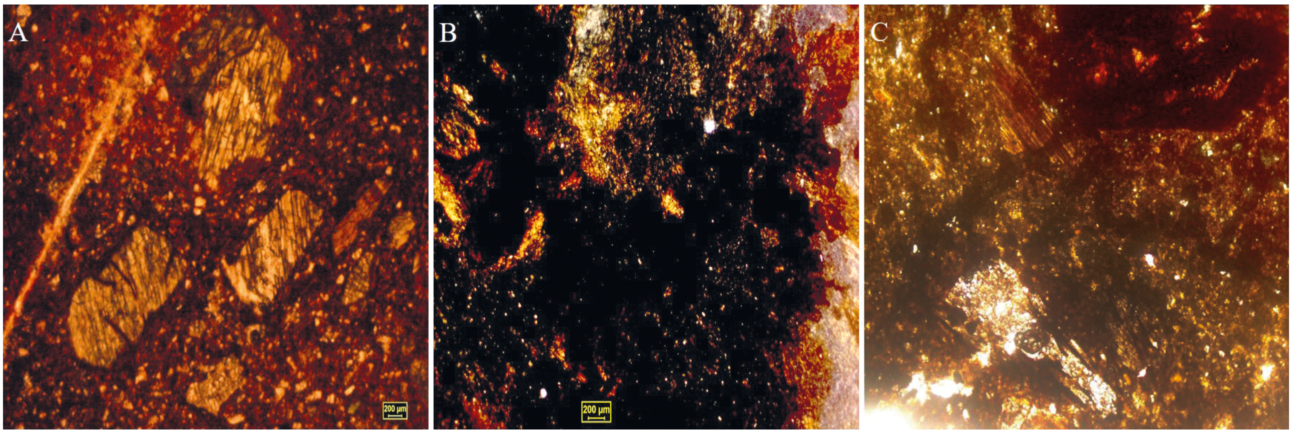

Fig. 5. Fabric Group B: A) BRP-01 exhibits irregular and fibrous woody materials with cracks. The spaces between the fibres and cracks are filled up by opaque materials. The grains show grey interference colours. The matrix is composed of ferruginous and siliceous materials; B) NPC-05 has a matrix composed of fine micaceous and siliceous materials. Irregular opaque materials and pore spaces are also present; C) RYK-01 exhibits a fibrous character (remnants of petrified wood particles). It is primarily composed of fine micaceous and siliceous materials. Irregular opaque materials and pore spaces are observed (Photomicrographs under XPL: J. J. Laskar/P. Singh).

Fabric group C

Fabric group C (SMR-02) (Fig. 6) has an interlocking framework composed of angular to subangular quartz grains which show the development of fractures. Reddish cementing materials fill up the inter-granular spaces.

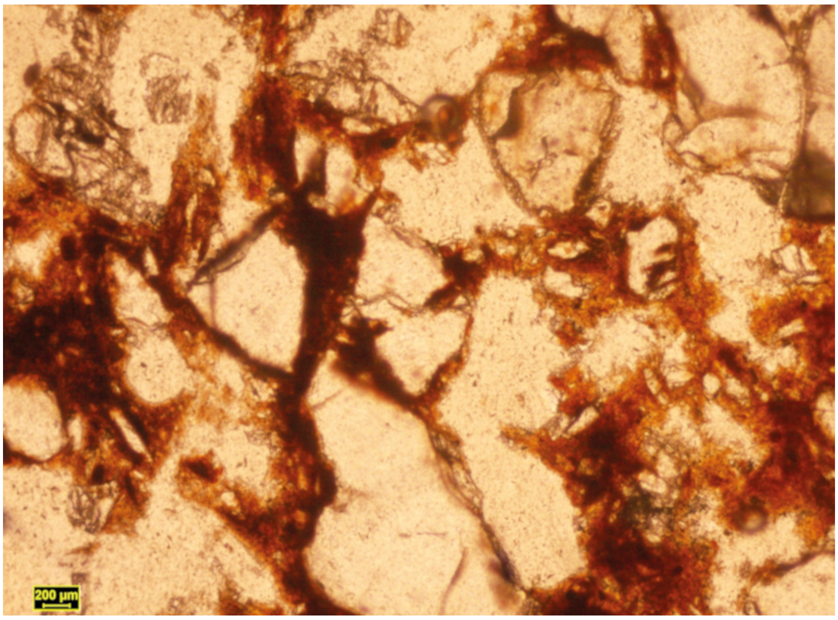

Fig. 6. Fabric group C: SMR-02 includes intermediate size quartz grains and exhibits corroded grain-boundaries due to inter-granular fluid movement. These spaces are filled with reddish cementing materials (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group D

The matrices of SPT-01 (Fig. 7) and SPT-02 are constituted of fine clayey and siliceous materials together with irregular opaque deposits. The mineralogical components include kyanite, mica and ferruginous materials. Concentrations of reddish opaque materials along the cleavage planes indicate leaching of ferruginous minerals, which might have occurred during the process of soil formation.

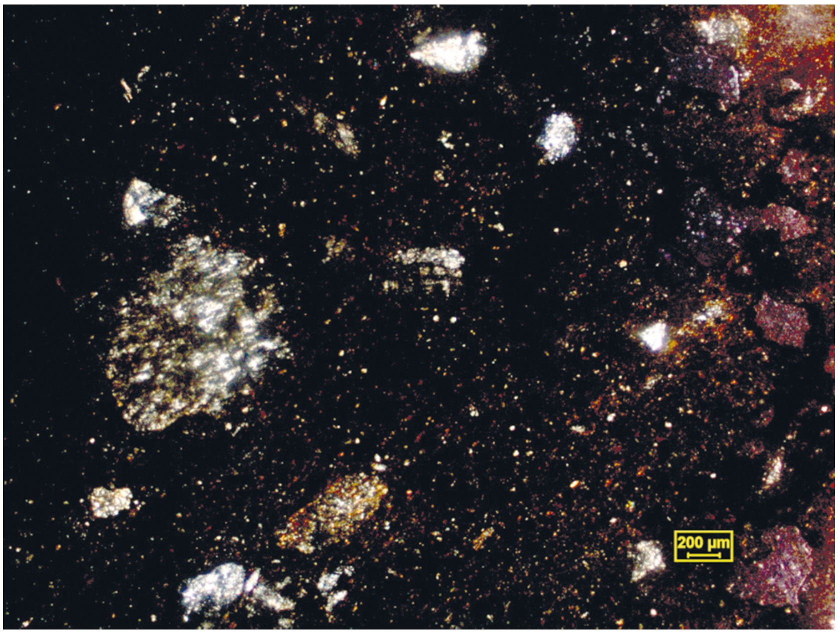

Fig. 7. Fabric group D: SPT-01 displays angular quartz particles and siliceous rock fragments floating in a silty/clayey matrix. Twinkling affects are observed which indicate the presence of slightly coarser quartz particles within the opaque fine-grained matrix (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group E

Thin sections belonging to fabric group E (KM-01 and KM-03) (Fig. 8) have a reddish to light brown matrix. Grains are sub-rounded to elongate in shape with varying sizes and do not show any specific orientations. There is some amount of preferred alignment of the grey-coloured grains. Voids are not observed. The mineralogical content includes quartz, siliceous materials, silt stone particles, aggregate quartz, and some unknown irregular aggregate materials.

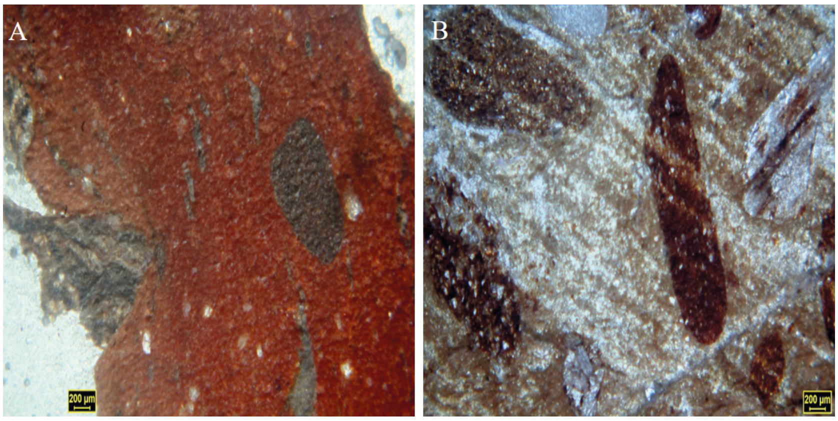

Fig. 8. Fabric group E: A) KM-01 features a very fine grained, reddish coloured matrix in which some small sub-rounded quartz particles together with some brownish elongated flakes of unknown materials show a parallel alignment. Some large irregular aggregates of unknown materials are also observed; B) KM-03 exhibits a very fine, light brown matrix which contains deep red coloured and elongated rounded siliceous materials (Photomicrographs under PPL: J. J. Laskar/P. Singh).

Fabric group F

The matrices of the potsherds (SMR-03, 04, 06, 08, 09; NPC-01, 03) (Fig. 9) assigned to fabric group F have fine grains, and include a brown coloured ferruginous element. Minerals such as quartz and hornblende are identified. Green-coloured hornblende shows one set of cleavage aligned parallel to the long axis of the crystal. The characteristics of individual matrix components are difficult to identify.

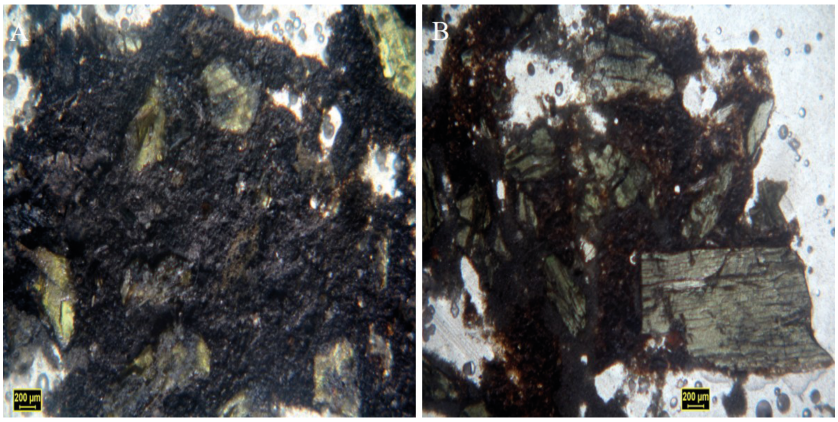

Fig. 9. Fabric Group F: A) SMR-03 and B) SMR-08 both show numerous green coloured hornblende grains seated in a brown ferruginous matrix. The characteristics of individual matrix elements are difficult to identify (Photomicrographs under XPL: J.J. Laskar/P. Singh).

Fabric Group F1

The matrices of fabric group F and fabric subgroup F1 (SMR-05) are very similar except that the matrix of F1 (Fig. 10) contains subhedral feldspar particles, which are highly weathered.

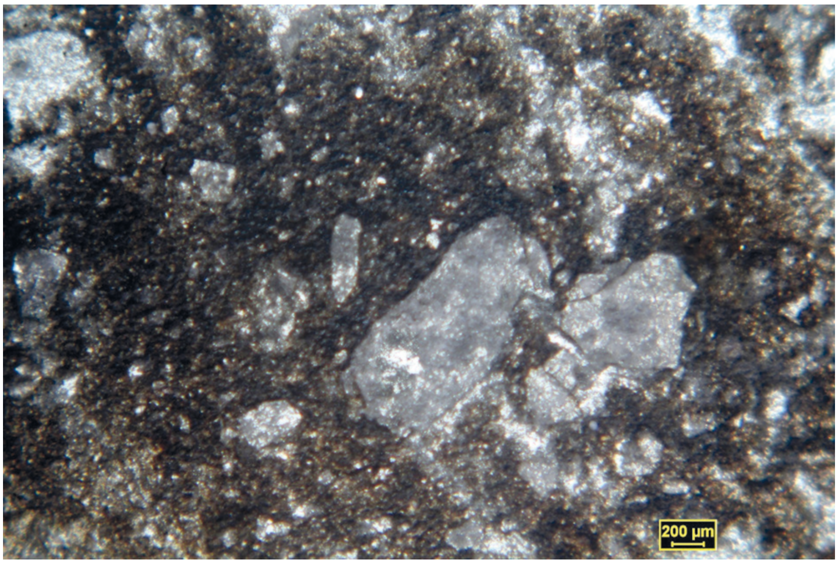

Fig. 10. Sub-Fabric Group F1: SMR-05 exhibits a matrix that is composed of subhedral feldspar laths distributed in a mixture of siliceous and fine-grained ferruginous matrix. Highly weathered feldspar grains are also observed (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group F2

The matrices of fabric group F, and subgroups F1 (SMR-05) and F2 (SMR-07) are very similar, the distinctive factor being the composition of the minerals. The matrix of fabric subgroup F2 (Fig. 11) shows poor sorting and alignment of muscovite flakes, hornblende and irregular distributions of opaque minerals within the matrix.

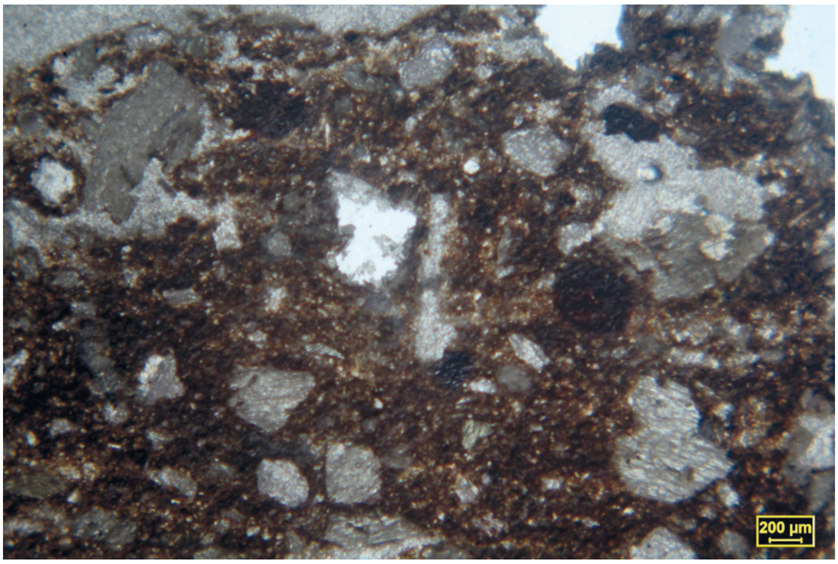

Fig. 11. Sub-Fabric Group F2: SMR-07 displays a matrix that is composed of fine-grained brown colour ferruginous and poorly aligned crystals of muscovite (mica). Hornblende and quartz as well as irregular distributions of opaque mineral within a fine grain matrix are observed (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group G

The thin section of NPC-02 comprises fabric group G. It has a greyish to brown colour and is composed of very fine materials. The optical character of individual grains cannot be identified. Irregular depositions of opaque materials have been observed at some locations of the matrix.

Fabric group H

The matrix of the thin section assigned to fabric group H (NPC-04) (Fig. 12) shows the occurrence of nummulites (foraminifera) and gastropod fossils, which indicate the use of limestone in clay preparation during the manufacture of the pottery.

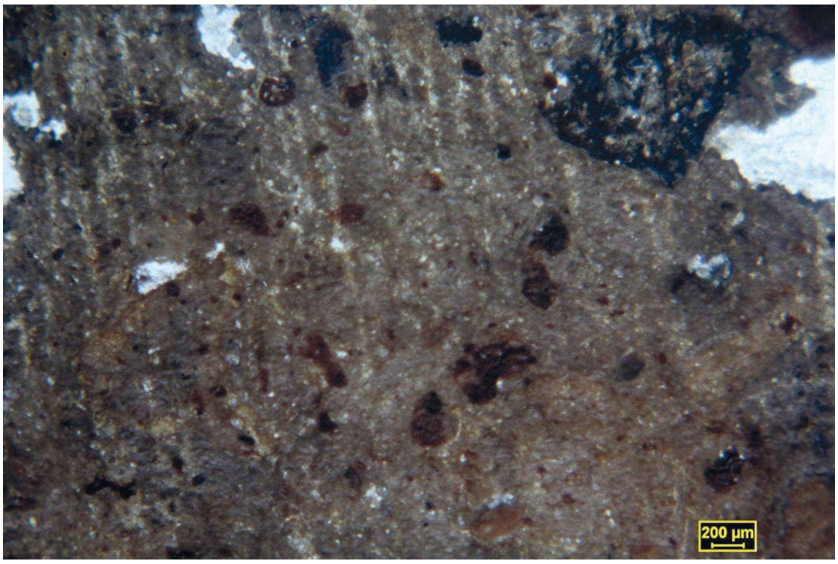

Fig. 12. Fabric Group H: NPC-04 features the occurrence of nummulites (foraminifera) and gastropod fossils (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group I

The thin sections of RYK-02 to 05 (Fig. 13) are characterised as fabric group I which is of deep brown colour and has a granular matrix. Grains are subangular to subrounded in shape. Non-plastic inclusions are comprised of quartz, sandstone, siltstone, quartzite and weathered siltstone.

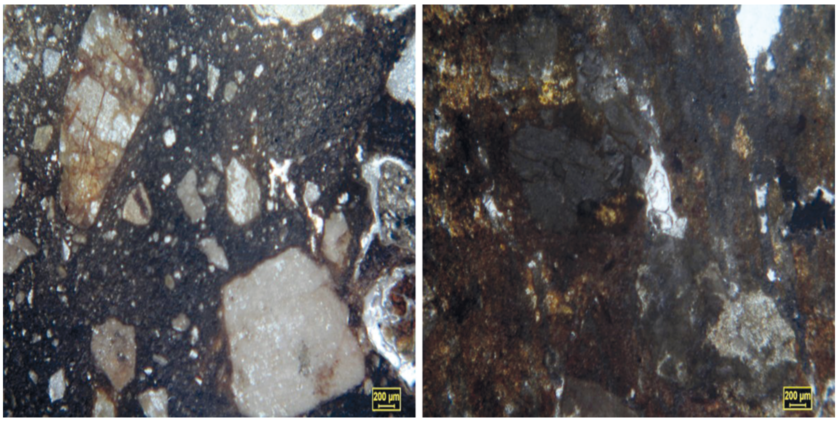

Fig. 13. Fabric Group I: A) RYK-02 and B) RYK-05 both show a deep brown granular matrix with the presence of numerous subangular to sub-rounded fragments of fine-grained sandstone, siltstone, quartzite and weathered feldspar fragments (Photomicrographs under XPL: J. J. Laskar/P. Singh).

Fabric group J

The thin section of LNGH-01 (Fig. 14) was assigned to fabric group J and has a micaceous matrix. Mineralogically, plagioclase feldspars and quartz grains are observed. Grains are irregular in shape. Carbonaceous substances are also present in the matrix.

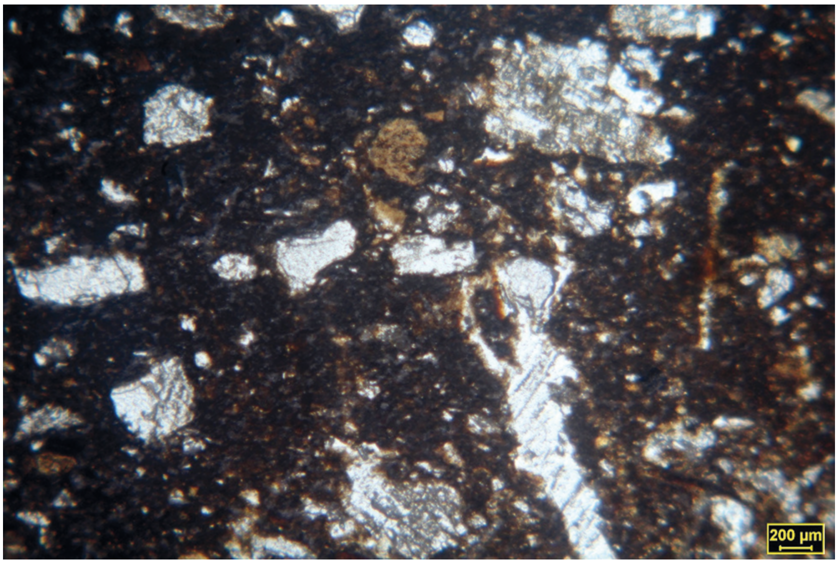

Fig. 14. Fabric Group J: LNGH-01 contains numerous irregular plagioclase feldspar particles. Opaque particles may represent carbonaceous matter and show a typical polysynthetic twin. Some irregular quartz grains are also observed (Photomicrograph under XPL: J. J. Laskar/P. Singh).

Fabric group K

The thin sections of LNGH-02 and LNGH-03 (Fig. 15) comprise fabric group K. The matrix is composed of dark brown micaceous materials and extensive occurrences of angular quartz. Voids are observed in the matrix. Carbonaceous matters are also present. Burnt spaces, mud fragments and woody materials are observed in LNGH-03.

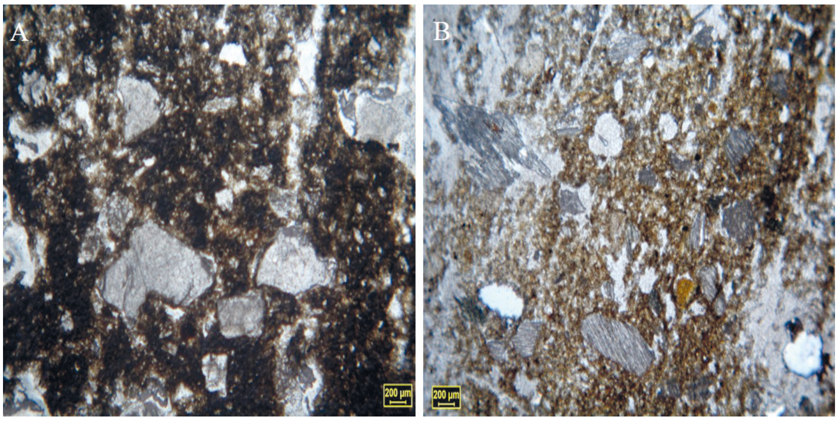

Fig. 15. Fabric Group K: A) LNGH-02 shows a matrix composed of dark brownish micaceous materials with extensive occurrences of angular quartz grains. Void spaces are observed. Carbonaceous materials are also identified; B) LNGH-03 has a matrix with an extensive amount of voids spaces, some of which have been formed due to removal of vegetative materials from the mineralogical framework. Partially burnt spaces also occur extensively. Mud fragments and woody materials can be identified (Photomicrographs under XPL: J. J. Laskar/P. Singh).

Discussion

In the present work, Neolithic potsherds have been analysed and characterised by using thin section petrography. This characterisation is based on microstructure and the mineralogical composition of the groundmass. The matrices of the fabric and sub-fabric groups A, C, D and F as well as A1, F1, F2 show an appreciable amount of ferruginous composition while fabric groups B, J and K contain micaceous concentrations. The analysis indicates a certain homogeneity in the fabric and secondary materials, such as organic matter and tempering materials. The colour of the groundmasses varies from red, green, light brown to brown under plane polarised light.

Provenance Analysis

Primary or secondary clay deposits and their mineralogical framework can be identified on the basis of numerous and distinctive characteristics in thin sections. For examples, residual clay deposits show coarse textural characteristics and ill-sorted silt in thin sections, whereby grains are normally of angular shape.

The petrographic results show that quartz is the principal component in most of the samples. Plagioclase feldspars are also observed in fabric group J and sub-fabric group F1. All fabric groups have organic substances in their composition, but the reason for this is difficult to ascertain. It is not known whether the organic substances were original constituents of the raw clay or were added later on during the manufacturing process. In fabric group H, foraminifera and gastropod fossils are identified, which indicate the use of lime from limestone.

The mineral compositions of the analysed pottery sherds are formed due to mechanical and chemical weathering of pre-existing crystalline and sedimentary rocks occurring in the region, and this process is greatly facilitated by the prevailing climatic conditions. The red coloured matrix and the presence of cementing materials indicate the oxidation of ferruginous minerals such as hornblende and biotite. Most feldspar grains are weathered to sericite and kaolin. This also indicates the prevalence of a humid climatic condition during their formation.

Grains are mostly coarse in size and angular to subangular and subelongated to rounded in shape. They are poorly sorted. The angularity of grains indicates that the clay used to make the pottery was derived from nearby places and did not travel over long distances from its place of formation. Otherwise, it would have resulted in a complete rounding of the constituent grains. Rounded and sub-rounded shaped grains occur only rarely in all fabric groups. This indicates that primary clay was used to make the

Neolithic pottery of Northeast India. In all fabric groups, iron-bearing materials are found which indicates the use of locally occurring iron-rich clay in the manufacture of pottery.

Chemical analyses of Neolithic pottery (see Singh, P. et al. 2018, 71–82) using Laser-induced breakdown spectroscopy (LIBS) and Energy Dispersive Spectroscopy (EDX) demonstrated that SiO2, Al2O3 and FeO are present as major elements, while other compounds such as Na2O, MgO, P2O5, K2O, CaO, TiO3 and Cl only make up a small part of the matrix. This also attests the usage of iron-rich clay.

Technological investigation

Temperature and atmosphere are two key factors of the firing process of pottery. Depending on the specifics of these two factors, clay and inclusions, such as rocks or minerals which had been added during ceramic production, change their optical and physical properties. Such changes due to firing can be detected in thin section petrographic analysis and thus help to reconstruct the firing technology in the production of archaeological pottery.

All fabric groups of Neolithic potsherds show a light red to reddish and brown coloured matrix in the thin sections. This as well as the presence of organic matter in fabric groups G and H indicate that these potsherds might have been fired above or around 600 °C under an oxidizing environment. A previous study showed similar results as the firing temperature was also confirmed by SEM-EDX (Singh, P. et al. 2018). The SEM micrographs revealed that for all analysed potsherds no vitrification stage occurred during firing. Furthermore, the presence of fluxes was also confirmed. Both observations suggest that the analysed potsherds were all fired below 800 ˚C.

The analyses show that a wide variety of natural and artificial, e.g. inorganic and organic materials, were employed as temper. The use of organic substances, quartz grit and sand as tempering materials are also confirmed by past studies on Neolithic pottery (Sharma, T. C. 1967).

Conclusion

The thin section petrographic investigations of the potsherds from several Neolithic sites in Northeast India have revealed that the pottery was made up of a wide variety of clay together with other inorganic and organic materials. Mineralogically, quartz, feldspars, silt stone, clayey and siliceous materials, ferruginous materials and organic substances have been identified. The present study has shown that the materials used for making pottery during the Neolithic in Northeast India were affected by weathering due to the prevalence of highly humid climatic conditions. The angular nature of quartz fragments indicates that the materials used to make pottery were derived locally, since all localities are situated in regions composed of sedimentary and meta-sedimentary rocks which provide a high yield of minerals such as angular quartz, feldspars, mica and clay minerals.

The frequently observed organic particles could be part of the original clay or also the materials used for tempering. The present analysis also confirmed that all characterised fabric groups of Neolithic potsherds show a light red to reddish and brown coloured matrix and the presence of organic matter. This indicates that these potsherds might have been fired above or around 600 °C under an oxidizing environment. Moreover, an oxidizing atmosphere also indicates the usage of an open firing (open hearth) or bonfire technique. The thin sections of all analysed pottery showed ill-sorted as well as angular and coarse grains which indicate that less sieved or less levigated clay might have been used during the manufacturing process.

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