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Gangopadhyay, Kaushik, Sanyal, Rajat, Chatterjee, Sharmistha, Singh, Pritam, Shaha, Chandrima, Naskar, Nabanita, Morgan, David and Sen, Kamalika 2024. Finding historical linkages between India and Myanmar through archaeological and physicochemical analysis of ceramics c. 1st century BCE to 13th century CE. *Journal of Archaeological Science: Reports* 60 , 104828. 10.1016/j.jasrep.2024.104828

Publishers page: <http://dx.doi.org/10.1016/j.jasrep.2024.104828>

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Finding Historical Linkages between India and Myanmar through Archaeological and Physicochemical Analysis of Ceramics c. 1st Century BCE to 13th Century CE

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Abstract:

Linkages of trade and culture between India and Myanmar, dating from the 1st millennium BCE, have been emphasized by several archaeologists. One of the significant set of artefacts that played a pivotal role in these processes of network is pottery. In this paper, the authors present the first ever comprehensive study of the physicochemical properties of potteries from important archaeological sites of India and Myanmar, chrono-culturally dated between 1st century BCE and 13th century CE. Results showed an interesting correlation among samples, underlining regular interactions between India and Myanmar. This possibly resulted not only in the transport of pottery but also in the sharing of its manufacturing techniques. A strong correlation in the composition of different elements, their interplay and the resultant structural details of the pottery obtained from the two regions play a key role in solving this ever-debated puzzle.

Keywords: India; Myanmar; Ayeyarwaddy; Pottery; Physicochemical Analysis

1. Introduction:

One of the serious gaps in research concerning early India and Myanmar is a lack of understanding linkages through archaeological ceramics, namely pottery. Unlike coins, art objects or religious architectural features, the provenance of pottery is difficult to ascertain through visual observation and requires detailed scientific studies. A recent survey conducted by the authors has made it possible to make certain preliminary conclusions regarding the nature of interaction between India and Myanmar by attempting to trace the provenance of visually similar groups of pottery after subjecting the samples to physicochemical analysis. The ceramic database from Myanmar and India reported here were recovered in course of recent explorations at sites in these regions by the authors.

1.1.Previous Researches:

Research on the history of interactions between South Asia and Southeast Asia has been multidimensional, spanning over nearly a century (Bentley 1986, Basa 1998, Basa 2018, Bellina 2017). In these papers the authors generally addressed the intellectual attitude whereby the theory of ‘Indianization’ was introduced in the colonial period primarily due to the availability of sources, which included inscriptions, coins, architecture and sculptures. These ideas were questioned by later scholars (Mabbet 1977, Smith 1999) and in recent years there has been several new publications on the archaeological evidence of interactions between South and Southeast Asia (Bellina and Glover 2004, Glover and Bellina 2011, Miksic and Goh 2017, Bellina 2017). These researches argue: firstly, that the Southeast Asian cultures were active agents in cultural interactions between South and Southeast Asia and secondly that the period for the onset of the contact can be pushed back to the late pre-classic stone-and glass-bead industry found at sites in Southeast Asia, which was a result of export of these items and also technical knowledge from South Asia (Miksic and Goh 2017). Recent excavations at Khao Sam Kaeo (KSK henceforth) in Thailand provides the necessary archaeological data to understand this problem (Bellina 2017). The importance of this excavation lies in the fact that it demonstrates that the portable items including beads of stone and glass and ceramics played not a passive but an active role in this larger canvas of varying linkages. The excavation at KSK successfully probed the issue of cultural matrix in Southeast Asia during the early period by exploring technological studies of industrial production system, which emerged along the maritime silk roads (Bellina 2017). Few researches have, however, addressed the problem of understanding interactions through pottery across Southeast Asia and scholars opine that the research on archaeological ceramics were

extremely limited (Miksic 1995). Research focusing on only pottery indicated trade networks on the basis of typological similarities. Published materials of so-called ‘Indian’ shapes and forming techniques were used to argue in favour of these connections. These pottery types were sprinklers in Black Polished and Red Polished Wares from both India and Thailand, recorded at the site of Chansen in Thailand and Dvaravati sites (Rispoli, Ciarla and Piggot 2013, Murphy 2016, Shoebridge 2017), moulded and stamped pottery found at different locations in Southeast Asia (Murphy 2016), Arikamedu Type 10, Karaikadu pottery and Rouletted Ware from Sembiran in Bali (Ardika 1995), decorative motifs of petals emerging radially from a central medallion found in Central Myanmar sites such as Biekthano and along coastal sites of Thailand and Vietnam and (Murphy 2016), further, paddle-impressed pottery found in the Ganga valley (Ray 1997). In recent literature certain critical attributes were assigned to the ceramic corpus from India and the Southeast Asian region, keeping in mind the congruencies of both archaeological stratigraphy and cultural chronology. For instance, the distribution of ceramics linking regions around the Bay of Bengal from the end of the 1st millennium BCE to the medieval period, recorded at key sites from Mahasthangarh in Bangladesh to Batujaya in Indonesia, has been critically studied (Lefranq, 2019). Although these researches are no doubt important, they provide a rather subjective view. As an example, Lefranq has largely identified those sherds from Southeast Asia, in the light of typological similarities with pottery from Mahasthangarh in Bangladesh. Phaedra Bouvet examined ceramics from Khao Sam Kaeo in Thailand and identified ‘Indian’ ceramics from the site (Bouvet, 2011). Bouvet classified the KSK fine wares into different groups (1-3a) as representing the Indian fine wares (Bouvet 2017). The research depended on techno-morpho-stylistic parameters of excavated pottery and less on geochemical signatures. There are techno-morpho-stylistic similarities between India and Myanmar ceramics and this could be another avenue of investigation in future but it will require access to more excavated ceramics from both regions.

Compared to the research on ceramic types between Thailand and India, or between India and the island regions of Southeast Asia, investigations on ceramic analysis between India and Myanmar have been limited. According to Pamela Gutman, pottery from Ayethma and Winka in Myanmar revealed a tradition drawn from Dvaravati sites in Thailand and eastern India. Although the excavator Mynit Aung (cited in Gutman) mentions that sprinkler-like vessels with flanged rim tops, found in the earlier context of ‘Pyu’ sites, could be placed in the early centuries of the CE originating in Andhra Pradesh (Gutman, 2001). The ‘Pyu’ period in Myanmar is dated approximately between 200 BCE and the 900 CE. The

appellation can be found in the Chinese texts as ‘Piao’ indicative of an ethnolinguistic group. This period coincides with the emergence of the first walled urban centres of Myanmar with urn burials (Aung Thwin and Aung-Thwin 2012). Dvaravati is a name assigned to a group of sites representing a cultural entity in central Thailand, with radio-carbon dates between and seventh and ninth centuries CE with similar artefactual remains (Miksic and Goh 2017). Recent researches have argued, however, that a closer scrutiny of published literature on material evidence from the region fairly suggests the genesis of the Dvaravati cultural idioms from an antecedent ‘proto- Dvaravati’ phase of development in the 4th-5th centuries CE or even earlier (Murphy 2016). Bulge-like spouts are found in both ‘Pyu’ and in pre-Dvaravati contexts, particularly at sites like U-Thong in Thailand. This could mean that ceramic technologies could have been shared between the ‘Pyu’ sites in Myanmar and pre-Dvaravati and Dvaravati sites in Thailand and both could have been influenced from an Indian pottery styles. Indian style in both early and late ‘Pyu’ culture of Myanmar can be identified as the ‘rouletted’ ware which was supposedly reported from the site of Beikthano (Nyunt Han, Maung and Moore 2002, Shoebridge 2017) . The influence of Indic pottery supposedly continued in the late ‘Pyu’ period. Excavations at the site of Yahanda in Sri Khestra, Myanmar provided evidence of ceramics, with stamps and rouletting, and could be relegated to the ‘Pyu’ period (Stargardt et al., 2015). Excavators of the site of Waddee reported that pottery from the protohistoric sites in the Samon valley closely parallels the pottery from eastern Indian Chalcolithic pottery (Ko, 2017). Given the subjective nature of these studies, the present research was oriented towards scientific analysis described in the next section.

1.2. Scientific Studies:

Petrographic research on ceramics from the Dvaravati sites in Thailand by Aussavamas concluded that carinated pottery from the Dvaravati site was influenced by pottery from India, particularly the Deccan region, but clay was local (Aussavamas, 2011). A geochemical study of 13th-14th century pottery involving fine wares from India, Myanmar and Thailand concluded that fine wares from Tamil Nadu in India and Bagan had distinct geochemical signatures and therefore rules out importation of pottery from India to Southeast Asia in the medieval period (Sirisathitkul et al., 2018). Figure 1 represents a map showing the major archaeological sites of India and Myanmar. Considering all these diverse opinions on similarities of ‘ceramic styles’ between the early urban phase in Myanmar and Indian ceramic style, the following question can be addressed:

Whether the pottery found at different sites in Myanmar share common geochemical sources?

Or if the observed typological similarities appear due to the technological and ideological interactions between India and Myanmar?

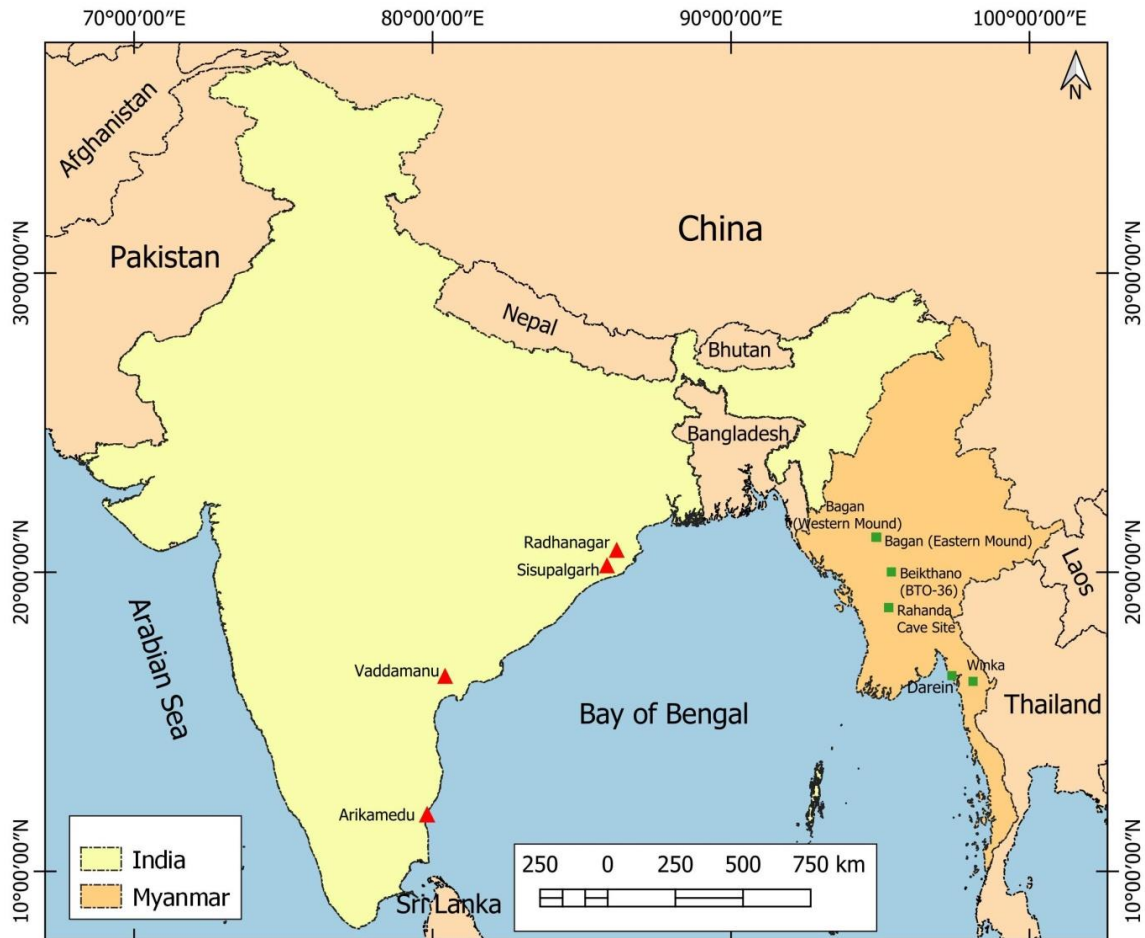


Fig. 1. Map of India and Myanmar showing distribution of sites discussed in the text

2. Region:

Myanmar: It is about twice as long north to south (2051 km) as it is east to west (936 km), having borders with Bangladesh, China, Thailand, India, and Laos. The geography of Myanmar is oriented north to south, with mountains paralleling the four main rivers namely; the Ayeyarwaddy (1130 km), Sittaung (420 km), Chindwin (644 km), and the Thanlwin (Salween, 241 km in the valley south of the Shan Plateau). The peninsula of Lower Myanmar faces the Bay of Bengal and the Indian Ocean, long facilitating interactions with Bangladesh, India, and Sri Lanka through both maritime and overland routes (Moore and Win, 2007). The sites from India discussed in this paper are on the east coast of India, viz., West Bengal, Odisha, Andhra Pradesh and Tamil Nadu. The east coastal plain comprises deltas of Mahanadi, Godavari, Krishna and Kaveri forming an emergent unintended coast.

3. Materials and Methods

Following is a summation of major pottery types based on published works (U Thaw Kaung, 2003), as well as the observation of the present authors.

- 1) Burial Jars.
- 2) Oil lamps.
- 3) Jars and vases in Red, Black and Grey Wares.

Pottery from Bagan, particularly from the Oten Taung mound 650 CE to 1410 CE (Hudson et al., 2001), shows the prevalence of surface decorations executed by using carved paddles. He also noted the presence of a clay tube for ‘stamping’ the pots with circular spokes of wheels as noted at sites like Beikthano in the 1st millennium CE context.

The above studies show a continuity of pottery traditions from the ‘Pyu’ to the early medieval period of Bagan. Visual observations were conducted on excavated and explored ceramics from sites in Myanmar and compared to pottery from the Indian sites, primarily from the east coast. The collections were randomized, by analysing both excavated and explored pottery. The sites which provided us with representative samples included Beikthano, Halin, Sri Khestra and Bagan in central Myanmar and Thaton, Winka, Dare and Khaiketta in lower Myanmar. The measurements of bricks from Beikthano (50×25×7.5 cm) conform to the brick standards of the site of Pataliputra (Stargardt et al., 2015), which was the capital city under the Mauryan polity in India from the 3rd century BCE. The use of bricks for these measurements is also noted at the site of Sri-Khestra. These structures have been dated between mid-1st and 3rd centuries CE. It is also from Beikthano that the earliest evidence of contact with India has been claimed from the presence of rouletted ware (Kaung 2003). The sites are dated from about 2nd century BCE to 10th-11th centuries CE. These dates are ascertained on the basis of a few radiocarbon dates. The pottery types from the Upper and Lower Myanmar sites are tabulated below. During the survey, it was not possible to collect samples with precise chronology. The typology of the pottery renders important clue regarding temporal range of the ceramics from Myanmar on the basis of the internal chronology as reported in the published literature and after comparing with South Asian pottery typology of particularly early historic and early medieval period.

The pottery was observed at a laboratory of Beikthano and typology of wares is tabulated in Table 1. For comparison with the Indian samples excavation reports and articles were consulted (Subramaniam, R, 1964, Soundararajan et al 2006, Gangopadhyay 2012, Gangopadhyay and Chatterjee 2017, Kaung 2003) The excavated pottery from the Indian sites such as Nagarjunakonda and Rajbadidanga were also studied by the first author kept in the repositories of the Archaeological Survey of India and Calcutta University.

Table 1

Typology of pottery from Beikthano.

Ware	Characters	Shapes	Comparable sites in India	Decoration
Red Polished		Sprinklers	Several sites in Northern India and Deccan	
Bicolour	Grey body with a red slip on the outside	Bowls with internally beaked rim	Tamluk and Bahiri (West Bengal)	
Red Ware	Common red ware	Different shapes including bowls and dishes	Rajbadidanga in West Bengal and Salihundam in Andhra Pradesh	Twisted rope decoration and also paddle impressions
Red Ware	With polished surface	Squat pot	Andhra	Panel decorations
Red Ware	With Polished surface	Dish		Concentric patterns

The properties associated with pottery collected from Sri-Kshetra are tabulated in Table 2. (Stargardt et al 2015, Subramaniam, R, 1964, Sinha and Roy, 1969, Lal 1993, Kaung 2003)

Table 2

Characteristics of pottery collected from Sri-Kshetra.

Ware	Characters	Shapes	Comparable sites in India	Decoration
Red Ware	Common Red Ware	Sprinklers, convex sided bowls and Jars	Several sites in Northern India and Deccan and Southern India. Sringaverapura, Vaishali pd III and IV, and also from Nagarjunakonda	Stamped rosettes, <i>Sri Vatsa</i> symbol, applique twisted rope decoration, stamped panel diagram. Paddle impressions

The properties associated with pottery collected from Halin are tabulated in Table 3. (personal study by the first author and Kaung 2003).

Table 3

Characteristics of pottery collected from Halin.

Ware	Characters	Shapes	Comparable sites in India	Decoration
Red	Sandy texture, medium to coarse in fabric	Jars	Several sites in Northern India and Deccan	Paddle impressions, herring bone patterns
Bicolour	Sandy texture	Bowls	Unclear	
Rouletted Ware	Unclear	Possibly dish	Several sites in India	Small triangles

3.1. Bagan:

The site of Bagan represents the ‘Bagan’ period in the architectural history of Myanmar. The pottery from this site is difficult to assess because of the limited excavations in only a few areas within the city. The Bagan period pottery is plain Red Ware with a sandy texture and also formed with paddles and stamps (Hudson et al., 2001). The designs are simple with slanting lines and also ‘ladder’ like designs as noted at sites like Khalkatapattana in Odisha.

3.2. Lower Myanmar Sites:

Sites in Lower Myanmar are relatively later in date than the sites in central and upper Myanmar, the latter dating from the Neolithic period. The sites mostly lie between the Sittaung and Thanlwin rivers at the northern end of the coast. South of Tanintharyi Division is the border with Thailand, and Malaysia making up the southern part of the ~1800 km long peninsula. Sites of the Lower Myanmar region are generally attributed to the ‘Mon’ culture and several of them were found to have been moated (Moore and Win, 2007). The important sites in Lower Myanmar include Kyaikkatha, Thaton, and Winka. Excavations revealed occupation from the beginning of the 1st millennium CE with evidence of silver coins. Also, these sites bear finger-marked bricks and a large number of clay tablets similar to India (Moore and Win, 2007; Mu, 2018). The potteries collected from these sites have been tabulated in Table 4. These samples were visually observed by the first author and compared with sites in India such as Bahiri (Gangopadhyay and Chatterjee 2019).

Table 4

Characteristics of pottery collected from lower Myanmar sites.

Sites	Wares	Shapes	Decorations and any other special features	Comparable Sites in India
Winka	Red Ware	Bowls	Unclear	Similar to the site in West Bengal, Bahiri.
Zothoke	Red Ware	Bowls	Ochre washed pottery	Similar to types found in Bengal.
Thaton	Red unglazed Ware	Bowls and body sherds	Sandy and gritty texture. Paddle impressed and mould impressions.	Similar to pottery of the Bengal types.
Dare	Grey And Red unglazed Ware	Bowls and jars, mostly body sherds	Stamped motifs, combed designs	Tamluk, Bahiri in West Bengal, Manikpatana and Khalkatapatna in Odisha, also Ahichchatra IV in Uttar Pradesh

3.3. Chronology of the Pottery:

The pottery discussed in this paper can be placed under two phases: early historic to late historic (1st century BCE to 3rd century CE, 3rd to 6th century CE) and early medieval (7th to 10th/11th century CE). Red Ware from both Myanmar and India can be placed between the 1st and 6th centuries CE. Important shapes are spouted jars, often called sprinklers. Bicolour ware in the shape of bowl/dish with a beaked rim is the notable shape around 1st BCE-1st century CE. The external body decorations such as stamps within panels are found in Myanmar and also at Nagarjunkonda in India in the 4th century CE. Finally, the body-forming techniques using paddle and anvil, leaving a distinct ‘paddle’ mark, are found in India from the 3rd century BCE and also in Myanmar from the ‘Pyu’ period onwards. These visual similarities guided us in selecting the samples.

3.4. Pottery Descriptions:

Myanmar pottery samples (Fig. 2) are labelled A-G as described in Table 5. The time period of the pottery was difficult to assign given the limited stratigraphic data and radiometric dates from most sites.

Table 5

Details of pottery from Myanmar sites.

Sample No.	Site	Ware	Shape	Decorations	Time period
A	Bagan	Red Ware	Body sherd	Paddle impression and parallel incised bands on the outer surface	Historic
B	Bagan	Red Ware	Body sherd	Paddle impression on the outer surface	Historic
C	Winka	Buff Ware	Body sherd	No decoration	Historic
D	Rahanda Cave	Red Ware	Body sherd	Paddle impression on the outer surface	Historic
E	Rahanda	Red Ware	Body sherd	Paddle impression on the outer surface	Historic
F	Beikthano	Red Ware	Body sherd	Embossed parallel bands and finger impression on the outer surface	Early historic
G	Darein	Grey Ware	Body sherd	Parallel incised bands and floral stamp motifs on the outer surface	Historic

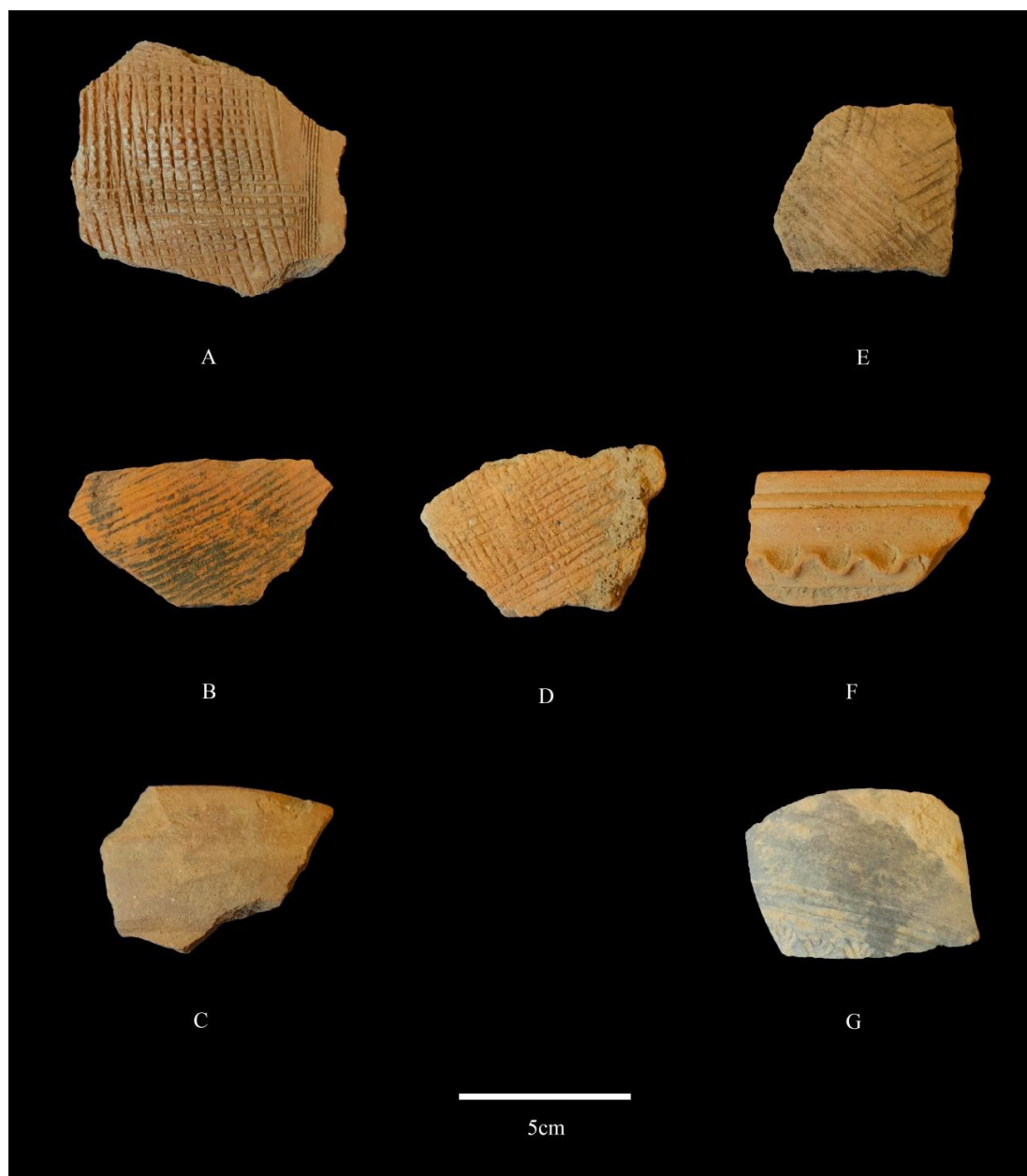


Fig. 2. Myanmar pottery plate.

3.5. Indian pottery samples:

Pottery samples for this study largely come from sites in the coastal regions of eastern and southern India. The sherds are derived from the excavated context from the site of Bahiri, West Bengal dated to the 1st century CE (Gangopadhyay and Chatterjee, 2019). Other samples are from surface context but typologically matching with the early historic types excavated from the same sites. The sites are Vaddamanu, a site in Andhra Pradesh, Sishupalgarh, an urban center in Odisha from the 3rd century BCE to 4th century CE, and the contemporary site of Radhanagar, also from Odisha. Arikamedu, which acted as a major port

site from the 2nd century BCE to 3rd/4th century CE, and continued to act prominently in the later the Indian Ocean trade network, provided three samples. Brief archaeological surveys had been conducted by the first author and the pottery collected from the surface were classified as early historic after comparative study (Gangopadhyay and Chatterjee 2013). The samples used in this study are tabulated in Table 6. It must be reiterated that a few samples used in the present study mark a preliminary step towards investigating the problem of interactions. The results of this study are encouraging to continue this research using more samples. Indian pottery samples (Fig. 3) are labelled A-D as described in Table 6. Photographs of sherds from Sishupalgarh and Radhanagar (Odisha) are not included in the plate.

Table 6

Details of pottery from the Indian sites.

Sample No.	Site	Ware	Shape	Decorations	Time period
A	Arikamedu	Light Grey Ware	Body sherd	Parallel incised bands on the outer surface	Early historic
B	Vaddamanu	Red Ware	Body sherd	Incised parallel bands on the outer surface	Early historic
C	Arikamedu	Black and Red Ware	Body sherd	No decoration	Early historic
D	Arikamedu	Red Ware	Body sherd	No decoration	Early historic

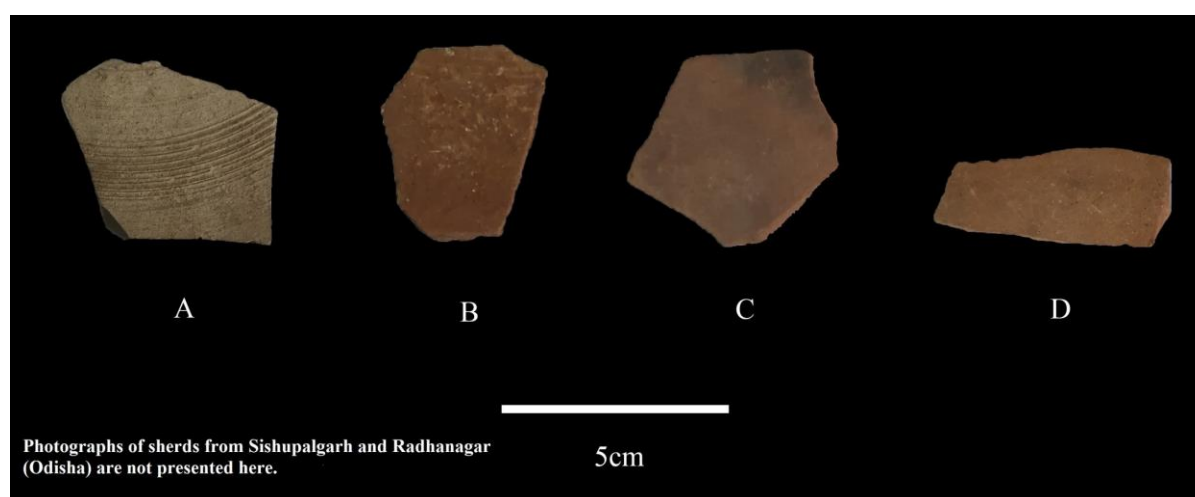


Fig. 3. Indian pottery plate.

4. Physicochemical Studies:

To correlate the similarities in origin of the materials used in pottery collected from the early historic sites of India and Myanmar, several physicochemical studies were performed with the pottery samples. Chemical and physical characterizations were performed to analyze the similar features of the pottery samples. Thermogravimetric (TG) and Differential Thermal Analysis (DTA) were performed to find out the thermal stability of the samples and assess the temperature as well as the technique used for the preparation of the pottery. Fourier Transform Infrared Spectroscopic analysis (FTIR) was done to find the similarities in the chemical composition of the samples. Powder X-ray diffraction (PXRD) patterns of the pottery samples were studied that helps to identify the crystalline nature of the samples that originates due to the temperature and techniques used during the making of the pottery. The elemental composition of the samples was analysed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICPOES) which helped to identify the trace elemental composition of the samples and thereby track the source of starting/base material (clay) for preparing the pottery. Factor analysis and cluster analysis of the results were done to find the inter-relations between the samples. Finally, the X-ray photoelectron spectroscopic (XPS) study was done to find the exact chemical forms of the elements. The sample identity with the location of each sample has been tabulated in Table 7.

Table 7
Sample Designation.

Sample ID	Sample Details	Location
AR 1	Red Ware pot sherd(body)	21° 10' 18" N, 94° 51' 30" E/Bagan (Western mound)/Myanmar
AR 2	Red Ware pot sherd (body)	21° 09' 39" N, 94° 53' 25" E/Bagan (Eastern mound)/Myanmar
AR 3	Buff Ware pot sherd (body)	16° 20' 46" N, 98° 6' 53" E/Winka/Myanmar
AR 4	Red Ware pot sherd (body)	18° 48' 49" N, 95° 17' 22" E/Rahanda/Myanmar
AR5	Red Ware pot sherd (rim)	20° 0' 19" N, 95° 22' 42" E/Beikthano (BTO-36)/Myanmar
AR 6	Grey Ware pot sherd (body)	16° 32' 15" N, 97° 24' 26" E/Darein/Myanmar
AR 7	Grey Ware pot sherd (body)	11° 54' 04" N, 79° 49' 12" E/Arikamedu/India
AR 8	Red Ware pot sherd (body)	16° 31' 53" N, 80° 25' 18" E/Vaddamanu/India
AR 9	Black and Red Ware pot sherd (body)	11° 54' 04" N, 79° 49' 12" E/Arikamedu/India
AR 10	Red Ware pot sherd (body)	11° 54' 04" N, 79° 49' 12" E/Arikamedu/India
AR 11	Pot sherd (body)	20° 13' 41" N, 85° 50' 53" E/Sisupalgarh/India
AR 12	Pot sherd (body)	20° 44' 45" N, 86° 10' 25" E/Radhanagar/India

The details of different apparatus used for physicochemical analysis and the methods of sample preparations are described in detail in the Supplementary information.

5. Results:

5.1. TG-DTA Analysis:

A gradual change in the mass loss with the increase in temperature was generally observed in the TGA for all the pottery samples. The TG graph shows a regular change in mass with the increase of temperature whereas, the DTA curve shows the temperature difference between the sample and the reference material with the increase of temperature and gives idea whether the sample loses (exothermic peak) or gains heat (endothermic peak) compared to the reference material respectively (Figure S1, Supplementary information) [Brown, 2002].

On an average, all the twelve samples showed similar TG-DTA curves with slight deviations. All the materials showed an initial mass loss due to desorption or evaporation of the adsorbed

moisture up to the temperature 100 °C. For most of the materials, this mass loss is very negligible (<2 to 4 %) and for AR 3, this mass loss is around 10 %. All these pottery samples are porous in nature and adhere minute to major amounts of water/moisture inside the pores. On heating, the adsorbed water gets evaporated causing the observed mass loss. Desorption of water was again confirmed by the endothermic peaks observed in the DTA curves in some of the samples.

Slight mass loss continued throughout the measurement which may be due to desorption of the adsorbed humic or organic substances. These pottery samples have been present in contact with soil for thousands of years and have become a part of the ecology of their immediate environment. Therefore, the accumulation of humic substances in the pores of the materials is quite natural. These organisms get decomposed and/or desorbed part by part in small amounts in the presence of high temperature. The weak or strong endothermic peak followed by a broad exothermic peak in the DTA curve of some of the samples may be due to a change in crystallinity or simultaneous change in chemical form of the metal ions present in the samples (as shown in ICP-OES section) or several breakdown reactions.

5.2. FTIR analysis:

The FTIR analysis of these samples (Figure S2, Supplementary information) reveals the identity of spectral patterns of the pottery samples.

For all of the samples, we get either a broad or sharp peak in the region of 3500 to 3600 cm^{-1} due to both the O-H (hydroxyl) and N-H bond vibrations [Vijayaragavan et al., 2013]. The broadness arises in the peak due to the H-bonding between the hydroxyl and the amine group. The source of the hydroxyl group is clear as the porous pottery samples may adsorb atmospheric moisture and give a clear impression on the FTIR analysis. The appearance of amine group can be accounted by the fact that all these pottery samples were in contact with decaying organisms in their immediate neighbourhood and developed an ecological relationship with them over thousands of years. The use of nitrogen (N) containing fertilizer or the development of several N-based micro-organisms may also get adhered on the surface or in the pores of the samples and show associated vibrational frequencies at the respective positions. The presence of peaks in the range of 1600 to 1700 cm^{-1} indicated the presence of conjugated carbonyl (C=O) group coming from functional groups like, amide containing substances (like, urea) or C=N group coming from several nitrogenous species, fertilizers, contaminations or reactions that took place in the immediate ecological system [Umesha et al., 2018]. Another intense peak which is common for almost all the samples is in the range

of ~ 1000 to 1100 cm^{-1} due to the C-N stretching vibration which again comes from N-containing substances present in the pores of the samples [Karimi et al., 2016].

FTIR analysis with their characteristic bond vibrations in the range of 1600 to 1650 cm^{-1} appear due to different alkenes which may be thought to have arrived from the pyrolysis of rice husk [Karimi et al., 2016 and Ismail et al., 2014]. This is in corroboration with the fact that ancient potters used to mix rice husk and ashes with clay for making pottery. For the same reason, the peaks in the region of <800 to 600 cm^{-1} were observed due to the bond vibration of the =C-H bond (present in alkene) [Karimi et al., 2016 and Trivedi et al., 2015]. As the soil contains different metals and during preparation of these pottery samples several external elements might also be used, therefore the presence of metal-oxygen bond vibration (<600 to 400 cm^{-1}) is quite obvious for these samples [Ismail et al., 2014 and Vijayaragavan et al., 2013]. The presence of organic or humic substances on the pores or inside of these pottery samples has already been observed from TG-DTA analysis and is further confirmed from FTIR analysis. The presence of different metals is also estimated using ICP-OES analysis. A detailed bond vibration data associated with their possible functionalities are tabulated in Table S1 (Supplementary information).

5.3. PXRD analysis:

The PXRD patterns of the samples are represented in Figures S3 (Supplementary information). The diffractions obtained were compared with the unique number of the Joint Committee of Powder Diffraction Standards (JCPDS) to get the probable (hkl) planes and possible systems as well as lattice of the samples tabulated in Table S2 (Supplementary information). According to the results, except AR 5, all other samples showed a similar crystalline nature with an end-centered lattice and monoclinic system [Rastsvetaeva and Chukanov, 1999, Demartin et al., 1996, Oberti et al., 1992]. The AR 5 sample was collected from the rim part of the pottery sample whereas the other samples were collected from their body parts. The rim part might have been prepared with untreated clay material and hence did not show any crystallinity. On the contrary, the treated body parts of the pottery showed crystallinity. This is because, upon heating at a very high temperature, the volatile components evaporate leaving only the strongly bonded highly organized molecular structure, which shows crystallinity. The major diffractions came from the 2θ values in the range 26 - 30° for all of the samples except AR 5. The majority of the samples showed another minute to highly intense peaks at four positions, viz., $\sim 21^\circ$, 42° , 50° and 60° .

5.4. ICP-OES analysis:

The result of the ICP-OES data is represented in Figure 4. A total of 14 metals (viz., Ca, Cr, Fe, K, Mg, Mn, Na, Pb, Zn, Ba, Cd, Cu, Sr and Ti) were estimated using this technique for the samples. Among them, only Fe, K, Ca, Na and Mg were found in major amounts and the remaining metals were present in trace and ultra-trace amounts. The associated figure also suggested that Fe is present in maximum amount (~20000 to 40000 ppm) among all the metals. This observation again suggests the prevalence of iron in the clay used for making pottery and in the nearby water bodies.

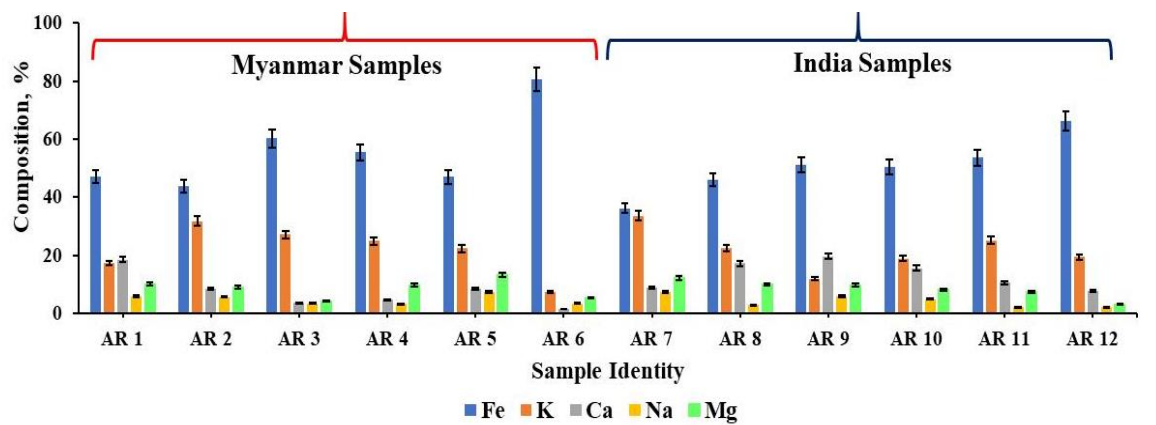


Fig. 4. ICP-OES data of all the samples.

5.5. Factor Analysis:

Factor analysis (FA) was performed for statistical analysis with the win STAT and SPSS software packages. The percentage of the elements Fe, K, Ca, Na and Mg as obtained from the ICP-OES analysis of the selected pot sherds were taken for this chemometric analysis. Al and Si as obtained from XPS analysis were not taken into consideration as signature elements as their presence in soil on any part of the earth is quite obvious. The data reduction technique FA was performed in two steps which included the extraction and rotation of factors. The FA can be expressed as (Zarei and Bilondi, 2013),

$$z_{ji} = a_{f1}f_{1i} + a_{f2}f_{2i} + \dots + a_{fm}f_{mi} + e_{fi}$$

where, 'z' represents the component score, 'a' the component loading, 'f' the factor score, 'e' the residual term accounting for errors/other sources of variation, *i* is the sample number and *m* represents the total number of variables. The rotated component matrix values of the 5 elements present in the chosen samples are shown in Table 8.

Table 8

Factor analysis of Archaeological Samples.

Variables	Factor 1	Factor 2	Factor 3
Fe	0.621	0.642	0.421
K	0.870	0.217	-0.158
Ca	0.606	-0.599	0.519
Na	0.870	-0.173	-0.384
Mg	0.969	-0.077	-0.107
% of Variance	64.12%	17.07%	12.60%

As shown in this table, factor 1 explains 64.12% of the total variance in the data set due to positive loadings of elements Fe, K, Ca, Na and Mg whereas factor 2 explains the positive loadings of elements Fe and K and the total variance is 17.07%. Finally, factor 3 explains the total variance is about 12.60% and the positive elements are Fe and Ca. There are three factors extracted from the data set and the total variance is 93.79%. Based on the distribution factor 1 alone explained 64.12 % of the variance. Sodium, potassium and magnesium have a high correlation with factor 1. According to this, the total variance is much higher than 50% which reveals that the principle component fit to the data set is considerable. From the FA analysis, three groups of samples were identified: group I consisting of elements K, Na and Mg, group II containing K and Fe and group III consisting of Ca and Fe. Figure 5 and 6 shows the bivariate plot of three principal component scores. This indicates an empirical relation between the factors chosen for each bivariate plot and therefore a coherence in the abundance of elements present in all the pottery samples which vary in correlation with each other.

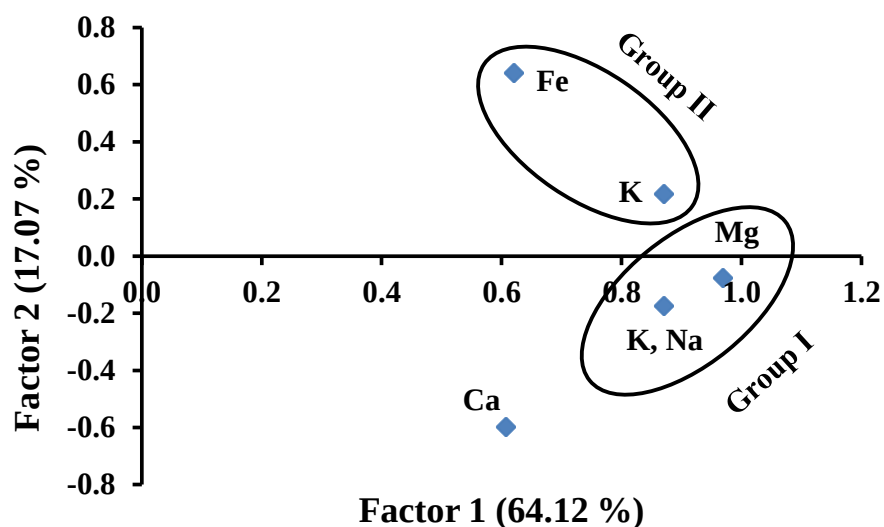


Fig. 5. Bivariate plot of Factor 1 and Factor 2 of Archaeological Samples.

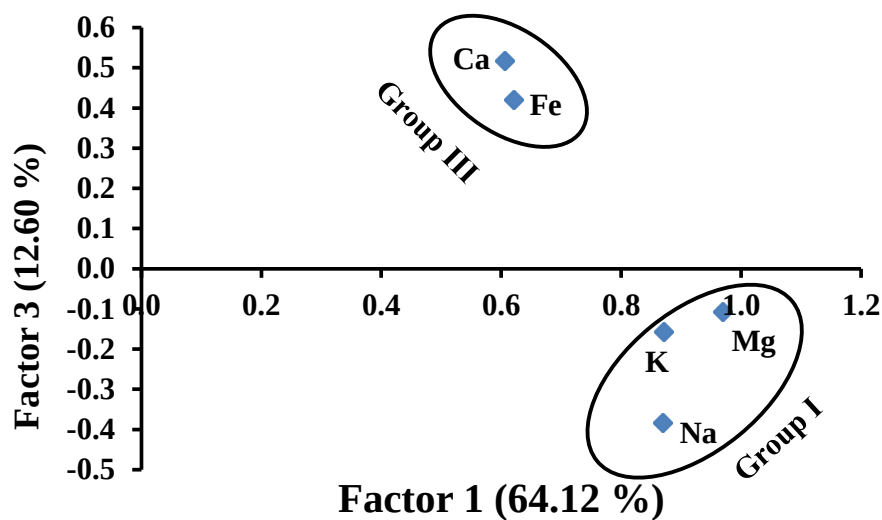


Fig. 6. Bivariate plot of Factor 1 and Factor 3 of Archaeological Samples.

5.6. Cluster Analysis:

In the cluster analysis, simple linkage methods and Euclidean distance were used and three cluster memberships were obtained (Table 9). The dendrogram of the potsherds, shown in Figure 7, shows that cluster 1 is comprised of only AR 7 sample that stands alone with a distinct trace element composition type. Cluster 2 is comprised of AR 2, AR 3, AR 4, AR 5, AR 8, AR 10, AR 11, AR 12 with closely related trace element compositions. Finally, cluster 3 is comprised of samples AR 1, AR 6 and AR 9. The results indicate that the samples from

each cluster closely resemble each other in composition and in each cluster there are samples from both the countries. Each cluster identifies the exact locations of Myanmar and India that were found to have trace elements combined in similar manner.

Table 9
Cluster Membership

Case Number	Sample ID	Cluster	Distance
1	AR 1	3	6677.671
2	AR 2	2	9337.458
3	AR 3	2	8333.328
4	AR 4	2	5993.229
5	AR 5	2	11403.562
6	AR 6	3	10467.032
7	AR 7	1	.000
8	AR 8	2	12538.792
9	AR 9	3	6645.424
10	AR 10	2	6159.948
11	AR 11	2	1901.599
12	AR 12	2	9473.726

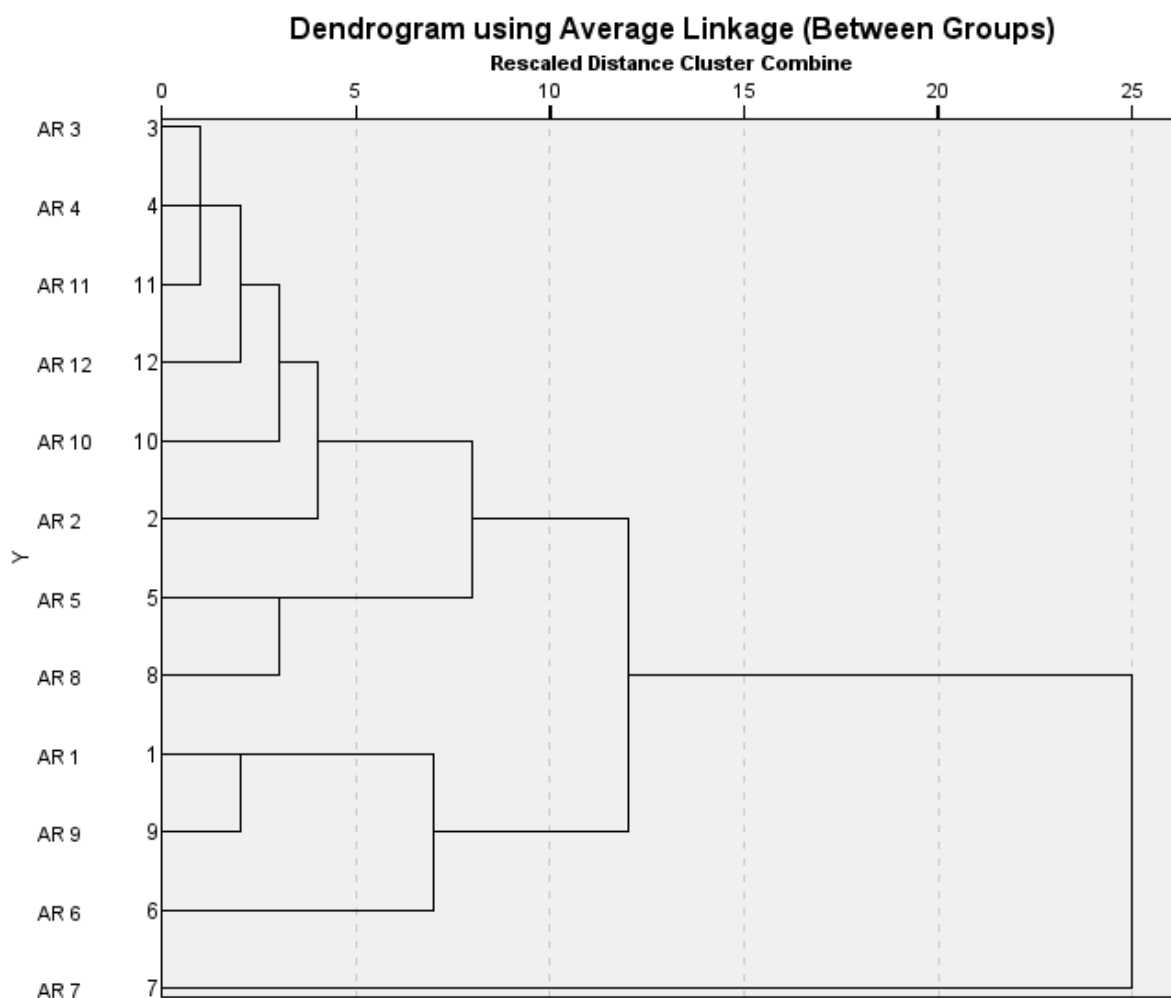


Fig. 7. Cluster analysis dendrogram for pottery samples.

5.6. XPS analysis:

XPS provides information on the surface and near-surface region, which is approximately at a depth of 10 nm. The XPS spectra shown in Figure S4 indicates the presence of majority elements present in the samples (all of which are tabulated in Table 10 with their percentage compositions). If we compare the results with that of ICPOES, we get a similar trend. The contents of O, Si and Al could not be analysed using the latter due to technical restrictions. Therefore, the resultant percentage of Na, Mg, Ca, K and Fe are relatively lesser in XPS results due to obvious reasons. The excess amounts of Si and Al in the sample are justified as the samples were prepared from topsoil of earth surface rich in these elements (SiAl). O content is very high indicating that majority elements are present as oxides. Discussion about binding energy of Fe, O, Si and Al can be found in the supplementary file in the XPS analysis section.

Table 10

Elemental composition of the pottery shards obtained from XPS analysis.

Sample	Calculated atomic % concentration										
	Na 1s	Fe 2p	O 1s	Ca 2p	C 1s	K 2p	Cl 2p	P 2p	Si 2p	Al 2p	Mg 2p
AR 1	0.34	1.89	53.97	1.16	20.31	1.37	0	0	14.3	6.1	0.56
AR 2	0.18	1.02	56.18	0.66	18.47	1.17	0	0.53	13.82	7.65	0.32
AR 3	0.14	1.47	54.99	0	22.83	0.22	0	0.64	7.99	11.72	0
AR 4	0.42	1.42	52.82	0.48	23.37	0.8	0	1.06	12.42	6.7	0.51
AR 5	1.3	2.37	52.62	0.81	20.84	0.49	0	0.11	13.59	7.15	0.72
AR 6	0.39	0.82	42.75	0.39	34.32	0.55	0	0.22	12.78	7.59	0.19
AR 7	1.95	1.5	53.83	0.5	17.15	1.32	0.33	0.39	14.97	7.12	0.94
AR 8	0.23	2.32	56.32	1.27	17.73	0.89	0	0	13.56	7.13	0.55
AR 9	0.61	1.23	50.74	0.72	24.38	0.69	0	0.44	15.54	5.19	0.46
AR 10	0.36	1.77	53.71	0.73	22.03	0.61	0	1.13	12.88	6.32	0.46
AR 11	0.14	1.41	50.14	0.52	27.91	0.32	0	0.99	10.93	7.21	0.43
AR 12	0.19	2.06	49.05	0.27	31.16	0.19	0	0.58	9.2	7.13	0.17

6. Discussion:

The results of physicochemical analyses revealed essential factors to find the key features of identity amongst the pottery samples collected from the two countries: India and Myanmar. The results of TG-DTA for most of the pottery samples show that the mass loss continued up to 800 °C and after that a saturation point attained with respect to mass loss. These observations specify the temperature of production of these pottery samples. As after this high temperature, there was no change in the mass of the pottery samples, these samples might have been prepared at this high temperature. Hence, no further mass loss is observed at such high temperature. The samples obtained from Myanmar and India share these common features suggesting that they all were prepared in a similar fashion. The FTIR spectral patterns of all the pottery samples appeared similar, although they were collected from different parts of India and Myanmar. Therefore, we can make a general remark that the synthetic architecture, methodology and raw materials—have many similar features. As the pottery samples are prepared by heating at around 800-900 °C, it is expected that any non-metal should not be present after preparation at such a high temperature. However, during the FTIR analysis, we found several peaks in the spectrum arising out of different non-metal species possibly due to the adsorption on the porous surface of the pottery during their prolonged stay under the soil. X-ray diffraction patterns of all the pottery samples collected from both the countries showed similar pattern of crystallinity and this originated due to similarity in their method of production. Results of elemental analyses by ICP-OES technique suggested that iron was prevalent in the clay that was used for making the pottery

and in the nearby water bodies. The elemental analyses data obtained from ICP-OES were further validated using the statistical techniques of factor and cluster analyses. The factor analysis classified the elements into three groups. Bivariate plots of group I (K, Na and Mg) and group II (K and Fe) elements as well as that of group III (Ca and Fe) and group I elements show logical dependence on each other. Accordingly, the cluster analysis helped to identify the precise locations of India and Myanmar where the pottery samples showed close resemblances in elemental compositions. Lastly, XPS analysis helped to quantify O, Si and Al that were found in excess in the pottery samples, since they could not be analysed by ICP-OES. This clearly indicated the use of soil from the top layer of earth present as (SiAl) and formation of oxides during their production. All physicochemical experimental data strongly buttress the argument in favour of an intense exchange amongst the population between the two countries.

The pottery samples collected for this study originated from different sites across India and Myanmar. Previous assessment of pottery from these regions have depended mostly on visual characterization and it is in this context that the present research becomes important. Previous scientific analysis had been conducted on sites from the east coast of India, such as the site of Arikamedu (Gogte 1997, Ford et al 2005, Das et al 2017), as also from sites in regions such as Odisha (Gogte 2000) and West Bengal (Das et al 2017). These earlier researches have also probed into the problem of provenance between firstly archaeological sites along the east coast of India. However, a detailed comparative study including various techniques accompanied by statistical analysis as reported in this work has never been attempted before. Finally, through this present survey the broader range of interactions and contact can be visualized. Recent excavations at sites in South-East Asia (Bellina et al 2017) have established that in all possibility Indian craftsmen such as bead makers were operating at the site of Khaeo-Sam-Kao and also the presence of Indian style pottery. Myanmar, therefore could have acted as a corridor for this interaction along the Northern Bay of Bengal region. The study not only establishes connectivity but also throws light on its nature, as discussed in the foregoing.

7. Conclusions:

The visual observations lend support to the hypothesis that there is a possibility of the pottery originating from the same source. This conclusion is strongly supported by the observations of the physicochemical experiments that reveal some salient features common to samples collected from both India and Myanmar: (i) the elemental composition of both the groups

bears substantial semblance including the trace elements (as seen from ICPOES and XPS data) (ii) the physiochemical studies show that the potteries were fired at very high temperature and the synthetic architecture are similar considering the oxide content (TG-DTA and XPS data) (iii) PXRD shows similar micro-crystallinity in both the groups of samples indicating identical technique of sample preparation. (iv) FTIR spectra also support this fact in showing similar vibrational frequencies of bonding (v) factor analysis indicates a strong coherence in abundance of trace elements present in pottery samples of both the countries (vi) cluster analysis brings about an idea about the compositional similarity of potsherds from exact locations of both the countries. Similarity in typology is therefore indicated to be most preferable due to transport of pottery as well as sharing of common technology between the two connected regions. These conclusions indicate the methodological validity of using these proxies in arguing in favour of cultural interactions. Thus, the present paper marks a new methodological beginning towards the presumption that ceramics were regularly transported from India to Myanmar over a long period of time. Also, there is a possibility that pottery tradition in Myanmar successfully adopted facets of Indian ceramic tradition, as fairly reflected in the scientific analysis demonstrated in this paper.

CRedit authorship contribution statement:

Kaushik Gangopadhyay: Conceptualization, Exploration, Methodology, Investigation, Data curation, Writing (original draft), Supervision; **Rajat Sanyal:** Exploration, Investigation and Data curation; **Sharmistha Chatterjee:** Exploration, Methodology, Writing; **Pritam Singh:** Experiment, Data curation, Writing; **Chandrima Shaha:** Investigation, Data curation; **Nabanita Naskar:** Experiment, Data curation; **David Morgan:** Experiment, Data curation, **Kamalika Sen:** Exploration, Data curation, Writing (original draft), Methodology, Editing, Review.

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements: The authors express sincere thanks to University of Calcutta for funding (UGC UPE II program, 12/09/2018). We are beholden to the Ministry of Religious Affairs and Cultures, Government of Myanmar for making this trip possible and also to Ye

Myat Lwin for accompanying us to the field. The ministry is also thanked for allowing us to carry the pottery samples to India. Snehadip Saha is acknowledged for making the map. Prof Elizabeth Moore is acknowledged for the discussions in Myanmar with our group. We express our sincere gratitude to Dr. Aparna Datta, UGC-DAE Consortium for Scientific Research, Kolkata, India, for obtaining FTIR data. We thank DST FIST (SR/FST/CS-II/2017/27(C) dated 29.09.2018) for funding the PXRD instrument.

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