From Earth to Enlightenment
Materiality, Technology and Cultural Transmission of Terracruda Sculpture Across Buddhist Asia
edited by Mònica López-Prat, Emma Cantisani, Susan S. Bean

Earth in Buddhist Modelled Sculpture
Material Diversity and Multi-Material Practices from Northwestern Pakistan to Central Asia

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Abstract This paper discusses the use of 'earth' in the creation of images at Buddhist temples from northwestern Pakistan to Central Asia. It brings together selected archaeological descriptions and recent analytical evidence regarding the use of earth in Buddhist sculptures, with particular attention to its relationship with architecture, to clarify its material characteristics and diversity, and consider potential interactions within the broader phenomenon of modelled sculptural production in the region; it concludes by outlining hypotheses to be tested in future research.

Keywords Modelling techniques. Buddhist sculptures. Architectural context. Material analysis. White plaster.

Summary 1 Introduction. – 2 Earth within Broader Modelled Sculpture Practices. – 3 Material Selection in Architectural Context. – 3.1 Architecture and 'Earth' Selection: A Working Hypothesis. – 3.2 Characteristics of Earth Use in Modelled Sculpture: A Comparison with Lime. – 4 Material Diversity within 'Earth'. – 4.1 Excavated Evidence. – 4.2 The Potential for Diversity in Earth-Based Sculpture: The Hirayama Ikuo Silk Road Museum Collection. – 5 Conclusion.

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1 Introduction

Sculptural production in Buddhist temples of northwestern Pakistan to Central Asia broadly encompasses stone carving and modelling plastic materials. This article uses 'modelled sculptures' for the latter, and sculptural production using earthen materials forms part of these modelling practices. Although its establishment remains incompletely understood, sculptural production through modelling is considered to have been a central image-making practice in Buddhist temples across the region.

One origin of Buddhist sculptural production can be traced to the stone-carving traditions of Gandharan art, which flourished primarily in Buddhist temples around the Peshawar Basin in present-day northwestern Pakistan. From the second to third centuries onward, however, stone carving within the region declined, while modelled sculpture, made primarily with a white material presumed to be lime and collectively known as 'stucco', is considered to have become prominent.[1] The use of modelling as a major method for creating images in Buddhist temples was not limited to this region but seen across Central Asia and continued for a longer period.

Sculptures made with earthen materials represent one facet of this broader phenomenon of modelled sculptural production within Buddhist temple contexts in northwestern Pakistan to Central Asia; however, their precise classification is not straightforward. Conventionally, coloured, soft, plastic materials that harden through moisture loss have been described in several ways, including clay, mud, or earth. The term 'clay' has frequently been used in archaeological literature as a broad descriptive label. In technical usage, however, 'clay' may refer to a particle-size fraction or to clay minerals. Its use as a general material label can therefore obscure differences among materials in technical discussion. Accordingly, this article uses 'earth' as an operational umbrella term for unfired mineral-based materials containing variable proportions of clay-, silt- and sand-sized particles, with or without organic matter. The term does not imply a uniform composition or a single preparation method.

While there are regional trends regarding the choice of earthen materials as a medium, the examples themselves are widely distributed across the regions considered here and span a broad chronological range. Furthermore, at some sites, these sculptures are found alongside works made from different materials, particularly lime- or gypsum-based plasters, which have traditionally been classified as 'stucco' in scholarship. These whitish, relatively fine-textured plasters typically acquire workability through the addition of water following thermal processing of their raw materials and subsequently set through chemical reactions.[2] In contrast, earth-based materials vary in colour, can become workable through the addition of water without requiring prior thermal processing, and acquire cohesion primarily through drying. This suggests that earthen materials could be used in combination with other materials and techniques within the broader framework of modelling practices.

1 Faccenna 1980-81; Naiki 2016; Olivieri, Filigenzi 2018; Behrendt 2018, etc.

2 Adhesive binders may also have contributed to cohesion, although this remains insufficiently demonstrated.

This article examines the material diversity of earth used in Buddhist sculpture, considering earth-based production both as a distinct technological practice and within broader modelling traditions with attention to its relationship with architecture. It focuses on Central Asia, with comparative evidence from northwestern Pakistan **[fig. 1]**.

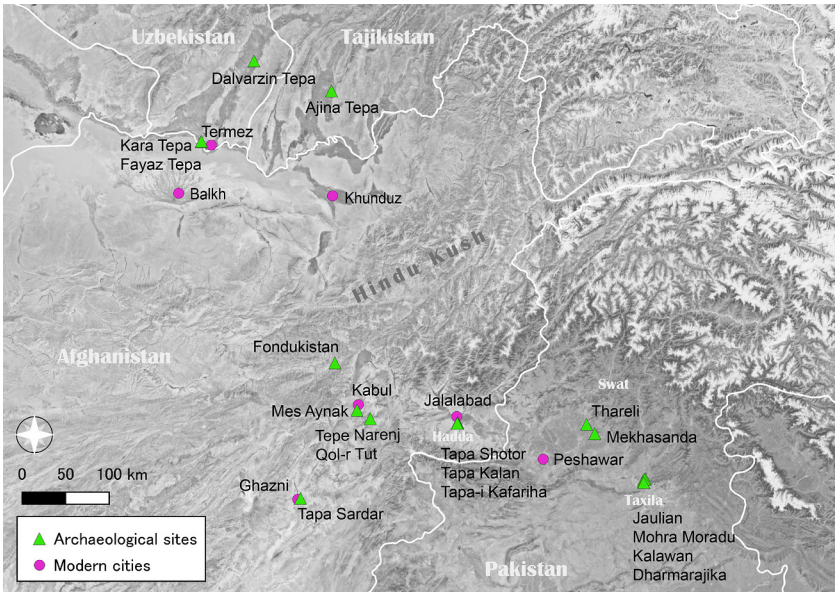


Figure 1 Distribution of archaeological sites discussed in this study. Site locations were plotted by the author through cross-referencing published excavation reports and maps with satellite imagery; coordinates were recorded from Google Maps where precise published coordinates were unavailable. Modern cities are shown for geographical reference. Base map: Google Earth.

2 Earth within Broader Modelled Sculpture Practices

Based on records of archaeological finds from northwestern Pakistan, Afghanistan, southern Uzbekistan, and southeastern Tajikistan, sculptural production using earth includes both sculptures made entirely of earth and those with earthen layers finished with white plaster: lime and gypsum. As previously mentioned, while the term 'stucco' has traditionally been used as a collective term for these materials, its definition has lacked consistency among users; furthermore, given that the term derives from a Western architectural context distinct from that of the region considered here, this study instead employs 'white plaster' as a collective term for white materials that can be visually distinguished from earthen materials.

Excavated evidence and previous studies[3] indicate that modelled sculptures generally consisted of multiple layers. In a broader sense, their structure functionally comprised a 'core', which supports the multilayer structure (solid material in some cases); an 'inner layer', used to build up volume; and a 'shaping layer', which gave the sculpture its final form. The

3 E.g., Varma 1970; 1987; Tarzi 1986; Ohlídalová et al. 2016; López-Prat et al. 2024b.

workable materials used to form these sculptural layers are referred to here as 'modelling pastes'. The modelling paste in each layer is likely to have a different composition or technological function. In this system, the use of earth in sculptural production is not necessarily limited to earth alone; it's also combined with other materials, including white plaster.

Cases involving a white plaster finish fall into two categories: those where the white plaster itself creates the final shape over an earthen base, and those where the shape is first modelled in earth and the white plaster is applied as a thin finishing layer.[4] This article defines as 'earth-based sculptures' those in which earth constitutes the principal modelling material, as in the latter case, irrespective of thin ground, paint, or other surface-finishing layers.

Both techniques produce white surfaces and have sometimes been grouped under 'stucco' or a single technical category.[5] While it is impossible to discuss the precise relationship between these practices here, given the inability to directly examine and classify the excavated specimens, the two techniques were not necessarily mutually exclusive in a single sculpture, and could occur in combination to produce a white finished surface.

Composite earth and white plaster techniques are documented at several sites around the Hindu Kush (e.g., Tapa Shotor, Tepe Narenj, Kara Tepe, and Dalvarzin Tepa) where earthen architecture and earth-based sculptures were common. In northwestern Pakistan, where temples are predominantly coated with white plaster, contrasting with the former regions (this will be discussed later), comparable composite sculptures are less frequently documented in the published record. Some descriptions in Marshall's report on Taxila may refer to such examples, although the materials require further verification.[6]

At several sites around the Hindu Kush, similar technical features occur in these composite sculptures. Gypsum has been identified or proposed as the white plaster component,[7] and the use of cloth between earth and white plaster has been reported at several of these sites.[8]

Their chronological relationships are not uniform: Tarzi (1976) documented a transition from earth-based sculptural production to such combined practices at Tapa Shotor (near present-day Jalalabad) during the Kushano-Sasanian numismatic period, and excavated sculptures of Tepe Narenj (near present-day Kabul) and Tapa Sardar (near present-day Ghazni) suggest that this composite practice occurred during earlier phases at each site, before earth-based production became predominant (Forgione 2021; Verardi 1983). On the other hand, evidence from Kara Tepe suggests a different local sequence (Kovaleva 1996, 230, 235 etc.). Composite techniques may

4 The discussion here encompasses examples in which the coating is thick and homogeneous and completely conceals the underlying layer.

5 Tarzi (1976) reported examples of the latter method at Tapa Shotor. Kovaleva (1996) mentioned its thickness in sculptures from Kara Tepa.

6 For example, according to Marshall (1951), such sculptures were found at Jaulian A11, E1, S1, -3, and -4, and at Dharmarajika P1 and N18.

7 Gypsum is reported at Kara Tepa and Dalvarzin Tepa (e.g., Stavisky 1964; Pugachenkova, Rtveladze 1978) and supported by analyses from Tepe Narenj, Qol-e Tut (López-Prat et al. 2024a), and Fayaz Tepa (Hayakawa et al. 2013). However, lime-based outer modelling layers over earth are reported at Mes Aynak (Ohlídalová et al. 2016, nos 49, 51).

8 Verardi 1983: Tapa Sardar; Paiman, Alram 2013: Tepe Narenj; Tarzi 1986: Tapa Shotor, Kovaleva 1996: Kara Tepe etc.

have characterised an early stage in the broader development of modelled sculptural production in predominantly earthen temple contexts, although their chronological placement across the region remains uncertain.

3 Material Selection in Architectural Context

3.1 Architecture and 'Earth' Selection: A Working Hypothesis

In Buddhist temples of northwestern Pakistan and Central Asia, modelled sculptures were typically integrated with architectural settings, often adjoining architectural surfaces along vertical and/or horizontal planes. A comparison of *in situ* sculptures and their associated architecture also supports the hypothesis that the choice of materials for the sculptures may have been conditioned in part by architectural practices (Yamane 2026).

For heuristic comparison, two recurrent architectural practices may be distinguished: temples featuring extensive application of white plaster (presumed to be lime-based) and those constructed primarily of earth without such large-scale thick white plaster finishing.[9] The former type is characteristic of temples centred in northwestern Pakistan, whereas the latter is widely documented outside northwestern Pakistan. These practices were not mutually exclusive. Mixed architectural traditions occur around the Hindu Kush, while earthen construction is also documented at some sites in northwestern Pakistan,[10] and white finishes occur in earthen architectural contexts.[11] Likewise, earth-based, composite earth and white plaster, and white-plaster-based sculptural practices could coexist. The available evidence is therefore insufficient to posit a deterministic relationship between architectural and sculptural materials of these cases currently.

Correspondences between architecture and sculpture have so far been identified at the level of material description in many cases, but their precise relationship requires further examination, including the extent of material and structural continuity and the possibility of shared raw-material sources or preparation methods. As mentioned earlier, these sculptures consist of multiple layers that likely served different functions, while the nature and degree of their material and technical continuity with architecture may also have varied. It is worth noting that some studies have noted material and compositional similarities between the inner earth used for sculptures and earthen construction materials regarding earth-based sculptures (Tarzi 1986, 80, for Tapa Shotor; Kovaleva 1996, 231, for Kara Tepe). Architectural structures and possibly sculptures may also have undergone repairs in antiquity.

To address this question, while archaeological examination of these interventions is essential to understanding the relationship between

9 Cases where earth serves as the primary wall material with a white plaster surface finish should be seen as a variant of the latter.

10 For example, Jaulian E1 and S1–4 and the niches at Mohra Moradu belong to monastic courts; see also Kalawan B20 (Marshall 1951).

11 Reported examples are Kara Tepa (Stavisky 1964; 1996; etc.); the interior wall at B56 at Bagh Gai (at Hadda) (Barthoux 1933, 164-6); niche C of the Tapa Shotor interior walls (Mustamandi 1968, 64) etc.

architecture and sculpture, the evidence currently available limits the extent to which this relationship can be reconstructed broadly. Thus, the authors have been investigating these issues through detailed material and technological analyses, as discussed in the following sections.

Of course, the choice of materials, specifically the type of earth for sculptural production, cannot be attributed solely to architectural constraints or factors of convenience, cost-effectiveness, and rationality; the specific nature of material selection in image-making warrants further consideration. Earth-based sculpture occurs across a wide range of periods and regions, including in temples characterised primarily by lime plaster, indicating that its occurrence cannot be explained solely by broad regional or architectural tendencies.

3.2 Characteristics of Earth Use in Modelled Sculpture: A Comparison with Lime

As noted above, in the region considered here, sculptural production in architectural contexts characterised by extensive use of white plaster, often presumed to be lime-based, provides a useful contrast to sculptural production in predominantly earth-based architectural contexts. In northwestern Pakistan in particular, lime appears to have been used extensively.[12] Compared with earthen coating, lime plasters are generally more resistant to moisture and weathering and are therefore well suited to exposed architectural surfaces, particularly in environments receiving appreciable rainfall. A characteristic feature of image-making in this region is the repeated representation of figures such as Buddhas modelled in white plaster, often presumed to be lime-based, on exterior architectural elements, including stupas and chapel dadoes (Yamane 2026). By contrast, earth-based sculptures in the same region (cf. footnote 7) were more commonly installed within chapels or niches, where they appear to have functioned more prominently as objects of worship than as architectural decoration. These contrasting contexts suggest that lime-based image-making may have been more closely integrated with architecture, both functionally and in the production process.

To examine this relationship, scientific analyses were conducted by the authors on white plaster artefacts from Mekhasanda and Thareli, including sculptures, architectural decoration, and wall finishes. Both sites are situated on hilltops along the northeastern edge of the Peshawar Basin in present-day Pakistan. The archaeological evidence indicates that Thareli was active from the mid-second to mid-third century and continued into the mid-third to mid-fourth century (Mizuno, Higuchi 1978). Mekhasanda was established by at least the mid-second to mid-third century, flourished during the mid-third to mid-fourth century, and remained active from approximately the mid-fourth to mid-fifth century until the Kidarite period (Mizuno 1969). They were excavated by Kyoto University in the 1960s. Some of the excavated objects

12 Possible lime-preparation tanks occur at several sites (Mizuno, Higuchi 1978, 46; Nishikawa 1999, 69). Lime also occurs in architectural elements at Amluk-dara, Barikot, and Gumbat (Rosa et al. 2019).

were transferred to Japan after the excavations and are currently housed in the Institute for Research in Humanities, Kyoto University.

The analysis covered 19 sculptural fragments (18 from Mekhasanda and one from Thareli) and seven fragments of architectural decoration (four from Mekhasanda and three from Thareli) as well as remnants of the wall structures adhering to the latter's fragments **[fig. 2, tab. 1]**. All objects were examined microscopically and analysed non-invasively using portable X-ray fluorescence spectroscopy (pXRF), with measurement points selected based on microscopic observation. The samples consisted of detached fragments whose original positions within the objects could not be determined; nevertheless, they permitted comparison of the mineralogical and petrographic characteristics of the materials. X-ray diffraction (XRD), thin-section analysis, and cross-section observation by optical microscopy were conducted on selected samples. Details of the analysis settings are provided at the end of the article.

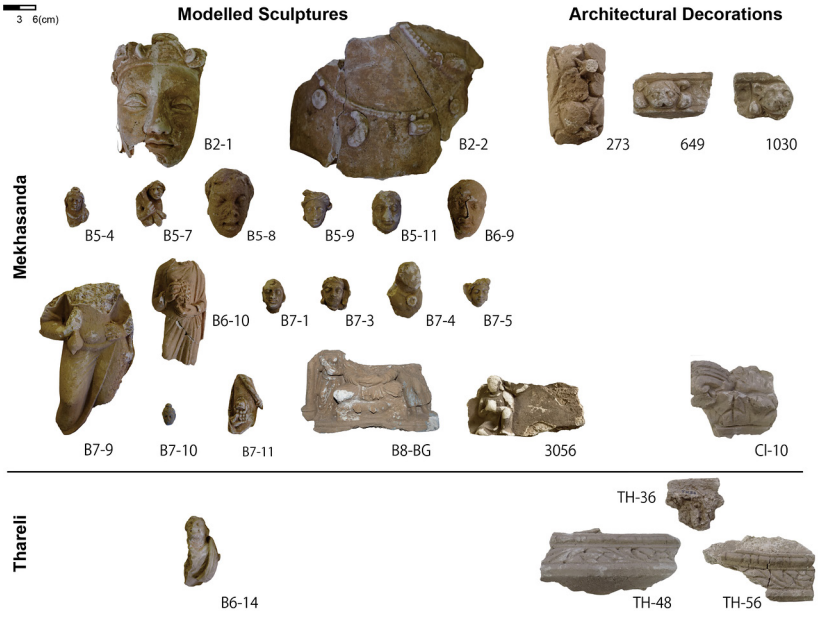


Figure 2 White plaster sculptural fragments and architectural elements from Mekhasanda and Thareli analysed in this study. Photographs by the authors, courtesy of the Institute for Research in Humanities, Kyoto University

These results were reported preliminarily in Yamane et al. (2026a; 2026b). Surface chemical composition analysis indicated that all products were primarily lime-based, with inclusions such as sand or mud-like material. Furthermore, analyses of relatively clean, smooth areas of the shaping layers (sculptures and architectural decorations) and the uppermost wall materials showed inherent variability within individual specimens. Although smaller figures tended to contain higher proportions of admixtures, no clear systematic differences were observed among sculptures, architectural decorations, and wall materials. Thin-section observations were conducted on samples from Thareli (architectural decorations) and Mekhasanda (sculptures and architectural decorations); however, rather than revealing significant

distinctions between modelled sculptures and architectural decorations, the analysis at this stage is highlighting marked differences in mineral composition between the two sites of Thareli and Mekhasanda.[13] Although definitive conclusions cannot be drawn at this stage, and further analysis of a broader range of examples is required, the findings from these two sites lend some support to the hypothesis that lime-based sculptural production was not a completely isolated activity but rather part of a continuous system involving other lime-related operations within the temple complex.

Compared with earthen materials, lime requires additional transformation steps, including calcination and slaking. Where lime was extensively used for architectural finishing and sculptural production, these activities may therefore have drawn on shared systems of material procurement and preparation. Earthen materials, by contrast, could potentially be obtained from a wider range of local deposits and often required less specialised, systematic processing before modelling, potentially reducing the need for coordinated systems of procurement and preparation. This distinction may have allowed greater variation in sourcing and preparation, although actual procurement practices must be assessed on a site-by-site basis. Consequently, the materials collectively referred to here as earth are likely to present a diverse and complex profile.

4 Material Diversity within 'Earth'

4.1 Excavated Evidence

Earlier excavation reports already document considerable variation in earthen modelling materials, typically differentiated by colour, which may reflect compositional differences but do not necessarily represent discrete material categories. At Tapa Shotor, 'greenish' or 'bluish' earth was primarily used for sculpting; although 'yellow' earth was sometimes employed for the core, it was rarely used in the sculptures themselves and was used mainly for components such as sun-dried bricks (Tarzi 1986). In contrast, 'yellow' earth has been reported as a primary material at sites such as Tepe Narenj and Tapa Sardar (Verardi 1983; Paiman, Alram 2013). At Kara Tepe, alongside the dominant 'yellow' earth, the use of 'reddish yellow' and 'bluish' earth has also been reported in some cases (Kovaleva 1996, 239), and at Ajina Tepe, 'brown' or 'green' earth specifically served for the surface sculpturing, whereas a distinct, 'finer and softer dark brown' earth was used for moulded components (Litvinsky, Zeimal 1971). Beyond these site-specific details, a 'red-clay' surface finish is documented at several sites along the southern foothills of the Hindu Kush from the later seventh to early eighth centuries onward (Forgione 2019, e.g., Fondukistan, Tepe Narenj, Tapa Sardar etc.).

These observations indicate that site-specific differentiation in earth selection had already been recognized in previous studies, although earlier reports recorded material differences using descriptive vocabularies appropriate to their respective research contexts. Because these

13 Mineral assemblages suggest local sediments from the foot of the site hills as potential sources (Yamane et al. 2026b).

vocabularies are not always directly equivalent, comparison between sites remains difficult. Thus, although red finishes are recognized as having become popular especially in the southern Hindu Kush in later periods, the temporal and regional trends in the use of earthen materials before that time remain poorly understood.

In recent years, visual inspection has increasingly been complemented by scientific methods, enabling more detailed characterisation of material properties. To date, studies have addressed the mineralogical characteristics and firing condition of earthen sculptural materials, their surface structures and polychromy at Mes Aynak and Kharwar, and sculptural structures at Tepe Narenj using CT (Ohlídalová et al. 2016); the surface polychromy of earth-based sculptures from Fondukistan (Pannuzi et al. 2019); and comprehensive analysis including the chemical and mineralogical characteristics as well as potential use of organic binders in sculptures from Tepe Narenj and Qol-e Tut (López-Prat et al. 2024a).

Although examples remain few and the research is still at a verification stage, establishing comparative criteria based on such detailed information may make it possible to compare analytical results from multiple archaeological sites and potentially integrate findings from different research groups into a systematic classification. Future research should apply similar methods to excavated sculptures to develop a broader understanding of their material and technical characteristics.

4.2 The Potential for Diversity in Earth-Based Sculpture: The Hirayama Ikuo Silk Road Museum Collection

To illustrate the material and, in part, technical diversity of earth-based sculptural practices, this section draws on the results of a comprehensive study of sculptures in the Hirayama Ikuo Silk Road Museum collection. Although the specific provenance of individual sculptures in the collection remains unconfirmed, the collection contains a large number of earth-based sculptures from the region considered here with varied styles and visible material characteristics. They are presented here to clarify the technical details and diversity of earth-based sculpture, aspects that remain largely unresolved for excavated examples.

The broader survey comprised 51 modelled sculptures, of which 19 were classified as earth-based. The present section focuses primarily on these 19 objects **[fig. 3, tab. 2]**. The surfaces were examined using a portable microscope and ultraviolet (UV) light. Subsequently, pXRF analysis was conducted on all the sculptures to investigate the elemental composition of the paint layers and modelling paste. To characterise the mineralogical composition in greater detail, samples were collected from modelling paste of four earth-based sculptures for XRD analysis and thin-section observation.

Based on visual observation of the modelling materials exposed at the surface, the earth-based sculptures in this collection were broadly classified into reddish and yellowish types as descriptive categories based on macroscopic observation. When the pXRF results were also considered, the reddish type exhibited three different surface-finishing techniques: a lead (Pb)-containing layer covering the surface; a white ground layer composed of lime or gypsum beneath the paint; and paint applied directly without a white ground layer **[figs 3-4]**. Among the yellowish type, examples

both with and without a white ground layer were identified. The ground layers included lime-based white layers. In addition, a relatively thick, pale reddish-pink layer was also identified and may have served as a ground.

Because clean, flat areas of exposed modelling paste are scarce, pXRF analysis was conducted on relatively well-preserved, suitable surface areas to assess compositional variation among the earth-based materials. The results indicate that ten reddish-type sculptures (100214, 101572, 102001, 102005, 102006, 102008, 102180, 102181, 102629, and 103719) show relatively similar surface elemental profiles, although two objects (102005 and 102180) are less closely associated with the main cluster because of their relatively low iron (Fe) content **[chart. 1]**, and this group includes examples of all three surface-finishing categories. Among the remaining objects, reddish-type sculptures 102956, 102958, and 102960 are characterised by relatively low silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3) and high calcium oxide (CaO) contents, while the yellowish-type sculpture 103476 shows a similar composition. Two further sculptures (105274 and 102161) are distinguished from the others by their high CaO contents.

Although the number of sampled objects was limited, the analyses further revealed that, in addition to clay-dominated materials (102005 and 102181), some yellowish-type sculptures were made from silt-rich materials (102995 and 105274) **[fig. 5]**. The sample from the inner layer of sculpture 102995 consists of a silty matrix containing numerous fine mineral grains. Their relatively uniform grain size is consistent with the use of a naturally silty raw material, although deliberate processing cannot be excluded. The modelling layer of sculpture 105274 is also silt-rich. The material is also calcareous and contains calcite crystals, which may represent a naturally occurring component of the raw material, secondary formation, or deliberate addition; their origin cannot yet be determined.

Selected comparisons with lime- and gypsum-based objects in the collection further indicate that some surface-finishing practices were not exclusive to a single modelling material. Similar pigments and ground layers occurred across different modelling substrates. These observations suggest that the selection of modelling paste and the treatment of the visible surface were partly independent technological decisions. Comparable cases have been reported in excavated material, indicating shared surface-finishing practices across the regions in both earth- and white-plaster-based techniques (Yamane forthcoming).

The analytical results from the objects grouped here as 'earth-based sculpture' indicate material and technological heterogeneity. Because the pXRF surface measurements may reflect modelling paste, ground, and paint in combination, they cannot be interpreted as the composition of the earth alone. Nevertheless, surface elemental profiles did not necessarily correspond to either the descriptive colour categories or the surface-finishing categories. The recurrence of similar surface-finishing practices across objects with different modelling materials may further suggest that such treatments could be shared beyond a single material tradition. However, because the provenance of the museum objects remains uncertain, it is not possible to determine whether these similarities reflect regional, chronological, or workshop-related patterns. As further analytical data from securely excavated sculptures become available, comparative analysis may eventually allow such objects of uncertain provenance to be situated more securely within regional, chronological, and technological contexts.

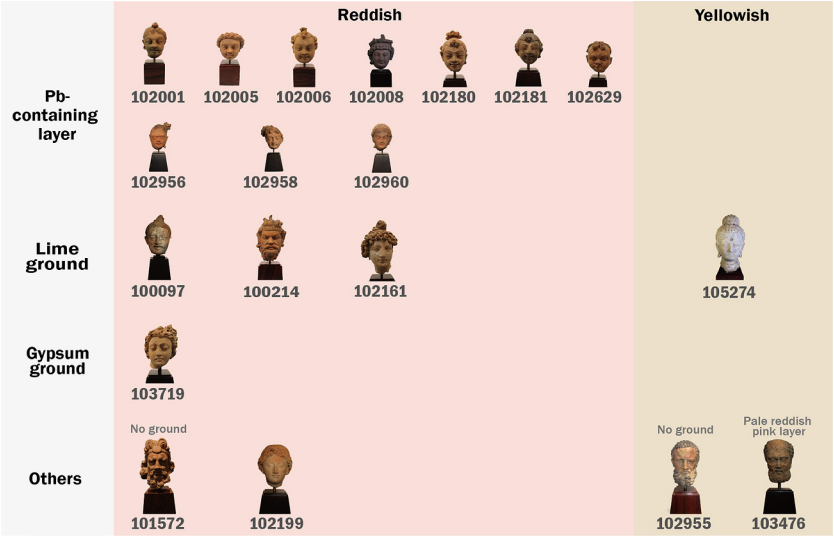


Figure 3 Overview of earth-based sculptures from the Hirayama Ikuo Silk Road Museum collection, classified according to the colour of the modelling paste and the ground layer. The scales are not standardised; for actual dimensions, see Table 2. Photographs by the authors, courtesy of the Hirayama Ikuo Silk Road Museum



Figure 4 Selected surface details illustrating different combinations of modelling paste and ground layers. Photographs by the authors, courtesy of the Hirayama Ikuo Silk Road Museum

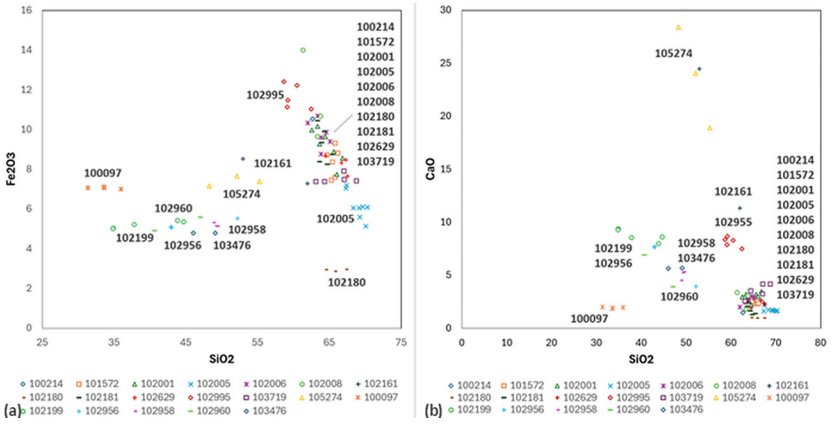


Chart 1 Bivariate plots of pXRF-derived elemental profiles in earth-based sculptures from the Hirayama Ikuo Silk Road Museum collection: (a) SiO_2 versus Fe_2O_3; (b) SiO_2 versus CaO

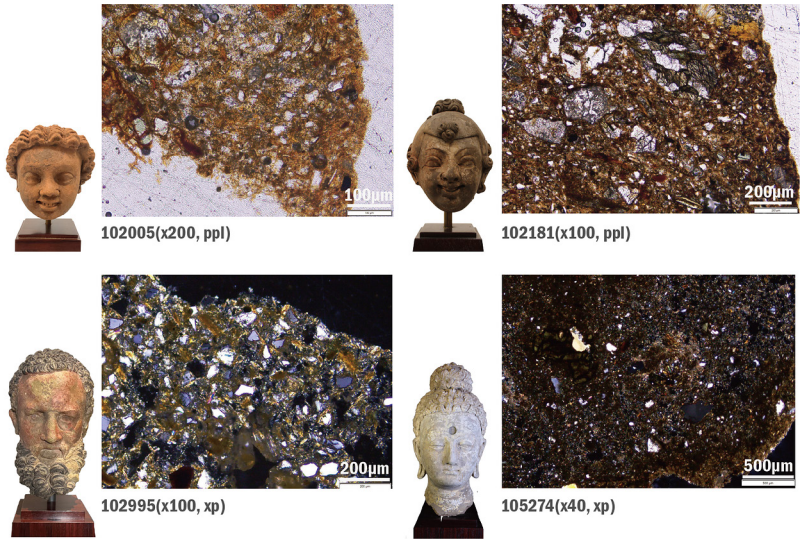


Figure 5 Thin-section images of the sampled earth-based sculptures. Observation under ppl: plane-polarized light; xp: crossed Nicols. Photographs and images by the authors

5 Conclusion

This study has shown that 'earth' encompasses materially and technologically diverse practices rather than a single homogeneous category in Buddhist sculptural contexts across Central Asia. Recent analyses have begun to reveal the internal diversity of the category previously classified as earth largely on the basis of visual inspection. In particular, the results from the Hirayama Ikuo Silk Road Museum collection suggest that 'earth' encompasses not only clay-dominated, but also silt-rich modelling pastes, some of which are also calcareous; consequently, characteristics previously identified by the naked eye are likely to be re-evaluated as distinct materials with specific

properties. While available evidence suggests that the selection of earth for Buddhist sculptures from northwestern Pakistan to Central Asia could be related to architectural practices in some contexts, material selection nevertheless also needs to be considered in relation to the requirements of modelling, desired visual effects, and access to raw materials.

Although this overview has focused primarily on material characteristics, future research should examine internal structure and architectural integration together, building on the technical classifications of Tarzi (1976), Verardi (1983), and Forgione (2021) for examples from the southern foothills of the Hindu Kush, as well as modelling materials. Following Varma (1970), comparisons between excavated and textual resources could clarify the range of technical choices by identifying agreements and divergences.

Earth-modelling practices should also be considered in relation to modelling with white plaster. The two material systems may be used separately or combined within the same sculptural construction, and their relative use may change through successive phases at individual sites. Notably, several documented examples of composite earth and white plaster occur in predominantly earthen architectural contexts during particular phases at some sites, and gypsum has frequently been identified or proposed as the white component at sites. These observations suggest possible relationships among modelling traditions, desired surface finishes, and architectural material practices, but the studies remain insufficient to establish any of these as a general regional pattern. They are therefore presented here as working hypotheses for future investigation.

Acknowledgements

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Analytical Settings

pXRF: Thermo Scientific Niton XL3t-950 portable XRF (output tube voltage: 50 kV; variable output current: maximum 200 μA; analysis mode: Mining Cu/Zn; measurement time: 60 s or 120 s).

Portable microscope: Three R Solutions Viewty autofocus microscope.

Optical microscopes: LEICA DMS (low-magnification observation: 0.75-6.0×); OLYMPUS BX53M (high-magnification observation: 20-400×).

XRD: Rigaku MiniFlex (output tube voltage: 40 kV; output current: 15 mA; goniometer scan speed: 1 deg/min; step: 0.02-0.06 deg; Kβ filter; divergence slit (DS): 0.65; divergence longitudinal limiting slit: 2 mm; receiving slit: open). The sample was crushed in an agate mortar and then packed into a fine-powder sample holder for measurement.

Bibliography

Barthoux, J. (1933). *Les Fouilles de Haḍḍa*, vol. 1. Paris: Éditions d'art et d'histoire. Mémoires de la Délégation archéologique française en Afghanistan 4.

Behrendt, K. (2018). "Architectural evidence for the Gandhāran tradition after the third century". Rienjang, W.; Stewart, P. (eds), *Problems of Chronology in Gandhāran Art*. Oxford: Archaeopress, 149-64.

Faccenna, D. (1980-81). *Butkara I (Swat, Pakistan) 1956-1962*. Rome: ISMEO.

Forgione, G. (2019). "Clays and colours: Tracking technologies and theories of vision in the ancient Buddhist art of Afghanistan". *Restauro Archeologico,* 27(1), 130-41. https://doi.org/10.13128/RA-25112.

Forgione, G. (2021). "Clay-based Sculptures: Analysis of Technical Aspects and Typologies". *Parthica: Incontri Di Culture Nel Mondo Antico*, 23, 145-76. https://doi.org/10.19272/202103501008.

Hayakawa, Y.; Furusho, H.; Aoki, S.; Aripdjanov, O. (2013). "Material Analysis of Objects Collected in The State Museum of History of Uzbekistan Using a Hand-held X-ray Fluorescence Spectrometer". *Science for Conservation*, 52, 59-70.

Kovaleva, N.A. (1996). "Monumental'nyi dekor Kara-Tepe (po materialam raskopok 1981-1989 gg.), ego polevaya konservatsiya i kameral'naya obrabotka (Monumental decoration of Kara-Tepe (based on the 1981-1989 excavations), its on-site conservation and post-excavation processing)". Stavisky, B.Y. (ed.), *Buddiiskie kompleksy Kara-Tepe v Starom Termeze*. Moscow: Vostochnaya Literatura, 224-67.

Litvinsky, B.A.; Zeimal, T.I. (1971). *Adzhina-Tepe. Arkhitektura, zhivopis', skul'ptura (Ajina-Tepe: Architecture, Painting, Sculpture)*. Moscow: Iskusstvo.

López-Prat, M.; De Luca, R.; Pecci, A.; Mileto, S.; Bandyopadhyay, S.R.; Bloise, A.; Guido, A.; Cipriani, M.; Lancelotti, C.; Carrascosa, B.; Noori, N.A.; Simón-Cortés, J. -M.; Miriello, D. (2024a). "The modeling pastes of the monumental *terracruda* sculpture of the Silk Roads: Archaeometric study of the Tepe Narenj and Qol-e-tut examples (Kabul, Afghanistan)". *Archaeometry,* 66(1), 76-99. https://doi.org/10.1111/arcm.12922.

López-Prat, M.; Pecci, A.; Lancelotti, C.; Miriello, D. (2024b) "Shaping the sacred along the Silk Roads: the millenary artistic tradition of making "monumental terracruda sculptures". Journal of Archaeological Science: Reports, 54, 104454. https://doi.org/10.1016/j.jasrep.2024.104454.

Marshall, J. (1951). *Taxila: an illustrated account of archaeological excavations carried out at Taxila under the orders of the Government of India between the years 1913 and 1934*. 3 vols. London: The Syndics of the Cambridge University.

Mizuno, S. (ed.) (1969). *Mekhasanda: Buddhist monastery in Pakistan surveyed in 1962-1967*. Kyoto: Kyoto University Press.

Mizuno, S.; Higuchi, T. (eds) (1978). *Thareli: Buddhist site in Pakistan surveyed in 1963-1967*. Kyoto: Dohosha.

Mustamandi, S. (1968). "A Preliminary Reports on the Excavation of Tapa-I Shotur in Hadda". *Afghanistan: historical and Cultural Quarterly*, 21(1), 58-69.

Naiki, S. (2016). *Gandharan sculptures and Buddhism*. Kyoto: Kyoto University Press.

Nishikawa, K. (ed.) (1999). *Ranigat: a Buddhist site in Gandhara, Pakistan surveyed 1983-1992: report of the Kyoto University scientific expedition to Gandhara*. Kyoto: Kyoto University Press.

Ohlídalová, M.; Kozáková, R.; Šulcová, V.; Šefců, R.; Šreinová, B.; Malíková, R.; Fort, M. (2016). "Technical Analysis, 6. Material and technology of earth-based figural sculptures and wall-paintings". Tisucká, M.; Stančo, L.(eds), *Afghanistan Rescued Treasure of Buddhism*. Prague: National Museum, 126-39.

Olivieri, L.; Filigenzi, A. (2018). "On Gandharan Sculptural Production from Swat: Recent Archaeological and Chronological Data". Rienjang, W.; Stewart, P. (eds), *Problems of Chronology in Gandhāran Art*. Oxford: Archaeopress, 71-92.

Paiman, Z.; Alram, M. (2013). "Tepe Narenj À Caboul, ou l'art bouddhique à Caboul au temps des incursions musulmanes". Paris: Publications de l'Institut de Civilisation Indienne du Collège de France.

Pannuzi, S.; Talarico, F.; Guida, G.; Rosa, C. (2019). "Polychromy and gilding in the Gandharan sculptures from Pakistan and Afghanistan: samplings from Museum Guimet in Paris,

Civic Archaeological Museum of Milan and Museum of Oriental Art of Turin". *Restauro Archeologico*, 27(1), 40-81. https://doi.org/10.13128/RA-25128.

Pugachenkova, G.; Rtveladze, E. (1978). *Dal'verzintepe - kushanskii gorod na ûge Uzbekistana* (Dalverzintepe—a Kushan city in southern Uzbekistan). Tashkent: Fan.

Rosa, C.; Theye, T.; Pannuzi, S. (2019). "Geological overview of Gandharan sites and petrographical analysis on Gandharan stucco and clay artefacts". *Restauro Archeologico*, 27(1), 12-39. https://doi.org/10.13128/RA-25095.

Stavisky, B.Y. (ed.) (1964). *Kara-Tepe – buddiiskii peshchernyi monastyr' v Starom Termeze* (Kara-Tepe: A Buddhist Cave Monastery in Old Termez). Moscow: Nauka.

Stavisky, B.Y. (ed.) (1996). *Buddiiskie kompleksy Kara-Tepe v Starom Termeze* (Buddhist Complexes Kara-Tepe in Old Termez). Moscow: Vostochnaya Literatura.

Tarzi, Z. (1976). "Hadda à la lumière des trois dernières campagnes de fouilles de Tapa-è-Shotor (1974-1976)". *Comptes rendus des séances de l'Académie des Inscriptions et Belles-Lettres*, 120(3), 381-410. https://doi.org/10.3406/crai.1976.13266.

Tarzi, Z. (1986). "La technique du modelage en argile en Asie Centrale et au Nord-Ouest de l'Inde sous les Kouchans: La continuité malgré les ruptures". *Ktèma*, 11, 57-94. https://doi.org/10.3406/ktema.1986.2635.

Varma, K.M. (1970). *The Indian Technique of Clay Modelling.* Santiniketan: Proddu.

Varma, K.M. (1987). *Technique of Gandharan and Indo-Afghan Stucco Images – Including images of gypsum compound*. Santiniketan: Proddu.

Verardi, G. (1983). "Osservazioni sulla coroplastica di epoca kuṣāṇa nel nord-ovest e in Afghanistan in relazione al materiale di Tapa Sardār, seguite da una precisazione sulla natura e la data delle sculture di Ushkur". *Annali: rivista del Seminario di studi asiatici e del Seminario di studi africani,* 43, 479-504.

Yamane, M. (2026). "Modelled Sculptures in Buddhist Temples Across Central Asia". *Silk Roads Archaeology and Heritage*, 3(1), 1-20. https://doi.org/10.5334/srah.23.

Yamane, M.; Zhu, R.; Mukai, Y.; Taniguchi, Y. (2026b). "Reevaluating the Production of 'Stucco' Sculptures at Mekhasanda, Northwest Pakistan: Material and Technical Characteristics of Objects Excavated by Kyoto University". *Book of Abstracts 27th International Conference of the European Association for South Asian Archaeology and Art,* 106-7.

Yamane, M.; Kurosawa, M.; Taniguchi, Y.; Mukai, Y. (2026c). "Materials of Lime-based Objects from Gandharan Buddhist Temples in Northwestern Pakistan Housed in the Institute for Research in Humanities, Kyoto University". *The 43rd Annual Meeting of the Japan Society for Scientific Studies on Cultural Properties Abstracts*, 158-59.

Yamane, M. (forthcoming). "An Attempt to Reconstruct the Practice of Buddhist Sculpture in Central Asia: Technological Approaches Through Scientific Analysis". Forgione, G.; Mancini, S.; Moscatelli, C. (eds) *Proceedings of the International Conference "Re-materialising the ephemeral: The clay and stucco artistry of Ancient Asia", held at "L'Orientale" University of Naples, 16-17 September 2025*. Rome: ISMEO.

Table 1 List of analysed objects from Kyoto University

Object no.	No. in this study	Report	Find spot	Microscopy	pXRF painting	pXRF Modelling paste	Sample analysis
—	B2-1	Mizuno ed. (1969) Pl52-6	Behind Chapel 48	Yes	Yes	Yes	XRD Thin section
3274	B2-2	Mizuno ed. (1969) Pl52-8	Behind Chapel 48	Yes	Yes	Yes	No
402	B5-4	Mizuno ed. (1969) Pl57-19	—	Yes	No	Yes	No
545	B5-7	Mizuno ed. (1969) Pl57-31	West of Stupa11	No	No	Yes	No
1191	B5-8	Mizuno ed. (1969) Pl56-4	—	Yes	No	Yes	No
1252	B5-9	Mizuno ed. (1969) Pl56-5	—	No	No	Yes	No
2674	B5-11	Mizuno ed. (1969) Pl56-12	—	No	No	Yes	No
859	B6-9	Mizuno ed. (1969) Pl56-13	—	Yes	No	Yes	No
905	B6-10	—	—	Yes	Yes	Yes	No
TH31	B6-14	—	—	No	Yes	Yes	No
203	B7-1	—	—	Yes	No	Yes	No
313 (S?)25	B7-3	—	—	Yes	No	Yes	No
517	B7-4	—	—	Yes	No	Yes	No
S.15 432	B7-5	—	—	Yes	Yes	Yes	No
2026	B7-9	Mizuno ed. (1969) Pl59-17	—	Yes	Yes	Yes	No
242	B7-10	Mizuno ed. (1969) Pl57-12?	—	Yes	Yes	Yes	No
—	B7-11	Mizuno ed. (1969) Pl59-16	—	Yes	Yes	Yes	No

Object no.	No. in this study	Report	Find spot	Microscopy	pXRF painting	pXRF Modelling paste	Sample analysis
—	B8-BG	Mizuno ed. (1969) Pl59-13	—	Yes	Yes	Yes	No
273	273	Mizuno ed. (1969) Pl63 63	—	No	—	Yes	No
694	694	Mizuno ed. (1969) Pl60-2	—	Yes	—	Yes	No
1030	1030	Mizuno ed. (1969) Pl60-3	—	Yes	—	Yes	XRD Thin section
3059	3059	Mizuno ed. (1969) Pl57 34	—	Yes	—	Yes	XRD Thin section
Cl10	Cl10	—	—	Yes	—	Yes	XRD Thin section
TH36	TH36	—	—	No	—	Yes	Thin section
TH48	TH48	—	—	Yes	—	Yes	XRD Thin section
TH56	TH56	—	—	Yes	—	Yes	XRD Thin section

Table 2 List of earth-based sculptures from the Hirayama Ikuo Silk Road Museum collection

Inventory no.	Object	Height (cm)	Attributed provenance (unverified)	Modelling paste	Ground layer	Tentative interpretation of polychromy and surface finish based on elemental composition	Sample analysis
100097	Head of worshipper	20.0	Pakistan or Afghanistan	Reddish	A Ca-rich white ground, lime-based ground layer	Arsenic was detected across much of the surface, presumably indicating orpiment, while a red pigment (ochre?) was used for linear details	—
100214	Head of worshipper or royalty	22.8	Pakistan or Afghanistan	Reddish	A Ca-rich white ground, lime-based ground layer	The original polychromy is difficult to reconstruct	—
101572	Head of worshipper or royalty	24.5	Pakistan or Afghanistan	Reddish	No ground layer	Red lead paint on the facial flesh areas, whereas the other areas appear to have been painted with earth pigments, possibly iron-containing ochres	—
102001	Head of worshipper (vidūṣaka)	14.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	—

Inventory no.	Object	Height (cm)	Attributed provenance (unverified)	Modelling paste	Ground layer	Tentative interpretation of polychromy and surface finish based on elemental composition	Sample analysis
102005	Head of worshipper	12.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	XRD Thin section
102006	Head of worshipper (vidūṣaka)	13.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	—
102008	Head of worshipper	11.2	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	—
102161	Head of worshipper	31.0	Pakistan or Afghanistan	Reddish	A Ca-rich white ground, lime-based ground layer	Yellow flesh paint, probably orpiment-based, with unidentified orange linear details	—
102180	Head of worshipper (vidūṣaka)	21.5	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	—

Inventory no.	Object	Height (cm)	Attributed provenance (unverified)	Modelling paste	Ground layer	Tentative interpretation of polychromy and surface finish based on elemental composition	Sample analysis
102181	Head of worshipper (vidūṣaka)	18.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	XRD Thin section
102199	Head of worshipper	20.0	Pakistan or Afghanistan	Reddish	No ground layer	Painted predominantly with orpiment, with red lead used for the lips?	—
102629	Head of worshipper (vidūṣaka)	12.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	The surface appears to have been exposed to fire	—
102956	Head of worshipper	11.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	Cinnabar paint on the lips and eyes; lapis lazuli on the eyes? An As-containing pigment was also detected	—
102958	Head of worshipper	10.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	Lapis lazuli on the eye? Small remnants of gold leaf remain on the head	—

Inventory no.	Object	Height (cm)	Attributed provenance (unverified)	Modelling paste	Ground layer	Tentative interpretation of polychromy and surface finish based on elemental composition	Sample analysis
102960	Head of worshipper	10.0	Pakistan or Afghanistan	Reddish	A Pb-containing layer covering the surface	Cinnabar paint on the lips; an As-containing pigment on the ornament and skin? Lapis lazuli on the eyes?	—
102995	Vajrapāṇi or Heracles	31.0	Afghanistan	Yellowish	No ground layer	Red ochre was applied directly to the surface for the flesh, and black pigment, presumably carbon black, for the hair	XRD Thin section
103476	Head of worshipper	22.0	Pakistan or Afghanistan	Yellowish	A pale reddish-pink ground layer	No additional paint was identified on the flesh areas, whereas the hair was painted black. Traces suggest that the sculpture may originally have been entirely covered with gold leaf.	—
103719	Head of worshipper	21.0	Pakistan or Afghanistan	Reddish	A Ca- and S-rich ground, consistent with a gypsum-based material	Orpiment, realgar, and red lead appear to have been used	—
105274	Head of Buddha	21.0	Pakistan or Afghanistan	Yellowish	A Ca-rich white ground, lime-based ground layer	Covered with gold leaf	XRD Thin section