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Towards a diagnostic protocol for the study of modelling pastes in monumental *terracruda* sculpture

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ABSTRACT

This paper presents an emerging diagnostic protocol for the study of modelling pastes in monumental *terracruda* sculpture, a distinctive technological tradition of monumental sculpture in air-dried clay. The study combines some newly acquired analytical data from Uzbek case studies with previously published results, integrating them with textual and ethnographic evidence to establish a diagnostic framework for material characterization and conservation decision-making. The proposed approach builds on a circular process of comparison and feedback between different sources of knowledge (archaeometric analyses, historical textual evidence, and traditional practices) each informing and refining the others. This interdisciplinary synthesis allows the identification of functional and compositional variations within historical examples and provides the basis for interpreting regional and chronological patterns in the production of *terracruda* sculpture. By formalizing this integrative workflow, the paper aims to define a reproducible methodological framework for future studies and conservation strategies concerning monumental *terracruda* sculptures preserved in archaeological and historical contexts, as well as dispersed fragments held in museum collections worldwide.
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1. Introduction & research aim

1.1. Object of study

Monumental *terracruda* sculptures represent one of the most distinctive and technically sophisticated sculptural traditions in the cultural history of Asia. Previous literature has referred to these works inconsistently as "clay," [1–8] "clay-based," [9,10] "loess," [11] or "earthen sculptures," [12] often obscuring the unique technological logic behind them. In contrast, analytical evidence from archaeological case studies, combined with ethnographic documentation and historical sources including Sanskrit treatises, points to the existence of a coherent and long-standing technological tradition for making monumental sculptures in raw earth. Transmitted and adapted along the Silk Roads with the spread of Buddhism, this tradition appears to have been practiced from the turn of the Common Era to the present day.

The Italian term *terracruda* (literally "raw earth") is adopted to designate a specific technological tradition of monumental sculpture in air-dried clay, distinct from terracotta. Unlike terracotta sculptures, which are fired and often movable, Asian monumental *terracruda* sculptures are immovable, structurally integrated into architectural or natural-rock environments, and composed of complex, multi-material systems. These sculptures are typically supported by internal cores made of wood, masonry, or carved-stone, over which layered modelling pastes composed of clays, sands, and organic matter are applied to shape the volume and surface details, including polychromy [13].

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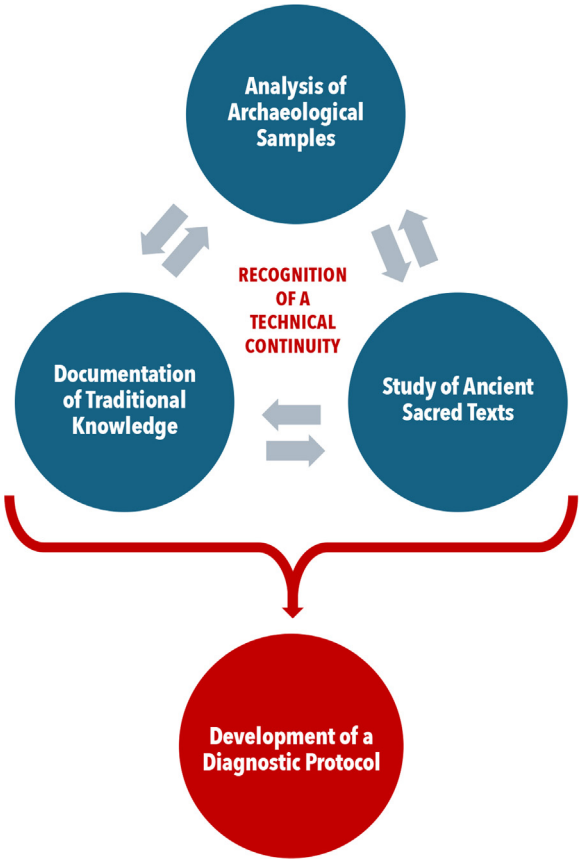


Fig. 1. Schematic representation of the iterative comparison and feedback among research strands leading to the development of the diagnostic protocol.

Within this framework, modelling pastes are not treated as homogeneous materials, but as stratigraphically differentiated mixtures whose composition, texture, and additives are intentionally modulated according to their function within the layered construction process.

The earliest known examples of this monumental sculptural tradition are attested in Central Asia around the 2nd century BCE in non-Buddhist contexts [4,14–17]. From the 2nd–3rd centuries CE onward, monumental *terracruda* sculpture was increasingly adopted and adapted within Buddhist artistic production, particularly in ancient regions of Gandhara and Bactria [5,18–20]. As Buddhism spread along the Silk Roads, this sculptural practice followed, proliferating in Central Asia and reaching the Tarim Basin [10,21], the Himalayas [2], East Asia [22], and beyond [3]. While the stylistic and iconographic aspects of these sculptures evolved across time and space, their materiality and technical characteristics point to the continuity of a specific knowledge system [13].

These sculptures often present significant conservation challenges [23]. Their air-dried nature makes them highly vulnerable to environmental degradation, salt contamination related to burial conditions, and mechanical stress during recovery. In many cases, internal structural elements have been lost, and the layered modelling pastes are disaggregated or fragmented. These issues have highlighted the urgent need to better understand the technical knowledge behind their making, with the final aim of informing targeted conservation strategies.

1.2. Research aim and diagnostic rationale

The aim of this research is to formalize a diagnostic protocol for the study of modelling pastes in monumental *terracruda* sculpture, integrating archaeological, analytical, textual, and ethnographic evidence, with particular attention to their stratigraphic differentiation and to the interpretation of their functional role within the sculptural system. Advances in the technological understanding of these sculptures stem from a progressively integrated and iterative research process that combined multiple sources of knowledge: analytical and archaeometric investigations of samples (including the review of previously published technological and compositional data on unfired clay sculpture), historical textual evidence (based on the study of translated ancient Sanskrit sources), and traditional practices.

Rather than following a strictly linear methodology, the diagnostic protocol emerged through an iterative process of comparison and feedback among distinct research strands, each validating, challenging, or reorienting the others over time. This approach grounded the protocol in converging lines of evidence, from material analyses, ethnographic observation, and sacred texts, that together demonstrate the existence of a shared technological knowledge (Fig. 1).

However, the novelty of the present paper lies not in the analytical data themselves, but in the establishment of a diagnostic framework applicable across sites and periods to the study and preservation of Buddhist monumental *terracruda* sculpture. This protocol enables the investigation of functional and compositional variations of modelling pastes across archaeological and historical examples, while informing the formulation of conservation-oriented strategies.

2. Sources of evidence

2.1. Archaeological record

In addition to the review of previously published technological data on Asian monumental clay sculpture, the analytical evidence consisted of archaeometric analysis of sculptural fragments found at three Buddhist sites located in the heart of the historical Silk Roads: Kara Tepe (Termez, Uzbekistan) and Tepe Narenj and Qol-e Tut (Kabul, Afghanistan). These sites span different chronological phases between the 2nd and 11th centuries CE and are representative of the monumental *terracruda* sculptural tradition of the region, artistically linked to Gandharan art [24].

The sculptural fragments of the Afghan sites (5th to 11th centuries CE) have already been studied and the results previously published [25–28]. In the present work, these data are complemented with some new analytical results obtained from material recovered at Kara Tepe (2nd–4th centuries CE). The selected fragments were chosen to represent the technological and compositional variability of the Kara Tepe corpus and to enable comparison with Tepe Narenj and Qol-e Tut.

The Uzbek samples originate from the Buddhist monastic complex of Kara Tepe [29–31], in southern Uzbekistan and were preserved in the reserves of the Institute of Archaeology of Samarkand. Sampling focused on fragments of sculpture where stratigraphy could be clearly identified, in order to capture examples preserving different finishes, shapes, or multiple layers. Each fragment corresponds to different parts of sculptural representations (such as fingers, hair, or clothing elements) and exhibits diverse materials and surface treatments, ranging from pure stucco to multi-layered clay compositions with coloured or white finishes (Fig. 2).

2.2. Sacred ancient texts

The second body of evidence was sourced from Sanskrit treatises that provide detailed instructions for making sacred clay images within the Āgama tradition, translated by K. M. Varma in

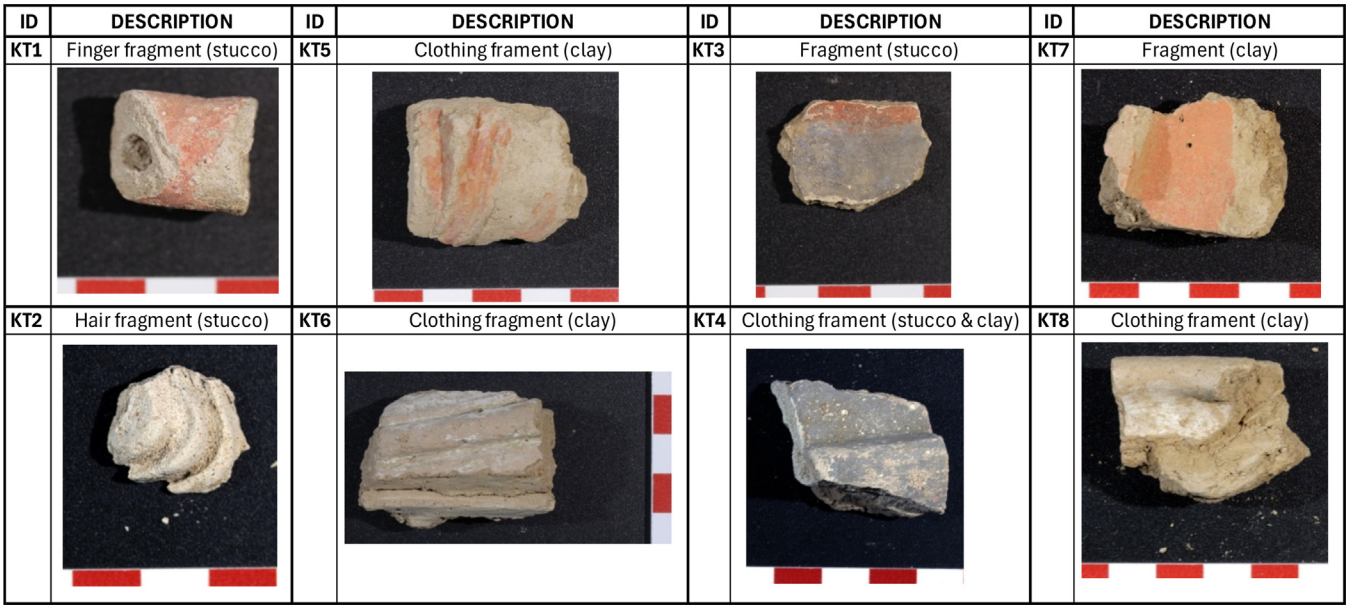


Fig. 2. Kara Tepe sculptural fragments with descriptions and material features.

his seminal book *The Indian Technique of Clay Modelling* (1970). The principal text is the *Kāśyapaśilpa*, belonging to the Śaiva sect, whose title means "the treatise on arts written by the sage Kāśyapa," also known as the *Amśumadbhedāgama*. According to Varma, it should be dated to the 12th century CE. Other texts include the *Vimānārcanākalpa* (or *Vaikhānasāgama*) of the Vaikhānasa sect, generally dated to the 8th century CE; the *Kāśyapajñānakānda* (or *Kāśyapasamhitā*), also of the Vaikhānasa sect dated no earlier than the 16th century CE; and the *Samūrtārcanādhikarana* (or *Atrisamhitā*), likewise of the Vaikhānasa sect, dated to the 16th–17th centuries CE.

2.3. Traditional knowledge

The third category of evidence consists of ethnographic data collected through the observation and documentation of living *terracruda*-making traditions in India (West Bengal), Bhutan, and China. Fieldwork included direct observation of workshops and rituals, interviews with artists, and documentation of material preparation, layering techniques, and surface treatments for colouring. These living practices provided crucial insights into the logic behind material choices, the sequencing of modelling stages, and the functional use of organic matter [32].

3. Methodology

Each of the three sources of evidence (archaeological material, sacred texts, and traditional knowledge) was studied using methods appropriate to its nature, but with the shared aim of contributing to understand the technology behind the making of historical and archaeological examples of monumental *terracruda* sculpture. The selection of analytical techniques was not predefined but evolved in response to emerging questions from across the different research strands, resulting in a question-driven methodological design grounded in both material investigation and contextual interpretation. Within this framework, modelling pastes are considered as stratified materials, analysed according to their position and function within the sculptural system, rather than as a single homogeneous material category.

3.1. Archaeometric analyses

To characterise the composition and structure of the modelling pastes, a combination of petrographic, mineralogical, and molecular techniques was applied to the archaeological samples:

- *X-ray powder diffraction (XRPD)* was used to identify mineralogical phases and assess clay composition. To discriminate the clay minerals the XRPD analysis was also performed after saturating the samples with ethylene glycol at 60C for 24 h and after heating at 450 °C [28].
- *Polarised light microscopy (PLM)*, coupled with fluorescence observation enabled the petrographic characterisation of clay matrix and coarser particles in terms of composition, grain size, distribution, layering and the potential presence of biopolymers within the pastes [28].
- *X-ray micro-computed tomography (Micro-CT)* was used to non-invasively visualise internal layering, the distribution of inclusions, porosity and the presence of organic matter in selected fragments [26].
- *Phytolith analysis* and *fibre identification* were conducted to determine the nature and typology of the vegetal matter present [25].
- Epifluorescence microscopy provided preliminary evidence for the presence of organic compounds in samples lacking mineral fluorescence [28].
- *Fourier Transform Infrared Spectroscopy (FTIR)* and *Gas Chromatography–Mass Spectrometry (GC–MS)* were used to detect organic substances within the modelling pastes [27]. In addition to the previously published FTIR analyses, chemical imaging was performed using a Bruker LUMOS II FTIR microscope with a liquid nitrogen cooled 32 °C × 32 FPA detector. FPA-FTIR images were acquired within a 4000–750 °C cm^{-1} spectral region, each as a single FTIR image (1024 spectra) covering a sampling area of ca. 150 × 150 °C µm^2. In external reflection mode, a single spectrum in each FTIR image represents molecular information acquired from ca. 5 × 5 °C µm^2 area on the sample plane. All spectra were recorded with a spectral resolution of 4 °C cm^{-1} using 128 scans and expressed as pseudo-absorbance [A' = log(1/R); R = reflectance] spectra.



Fig. 3. From left to right: traditional artists from West Bengal (India, 2019), Shanxi (China, 2024), and Tashigang (Bhutan, 2025).

Background correction was accomplished by collecting the total reflectivity R from a gold mirror plate.

- *A mass spectrometry-based method combining enzymatic cleavage with MALDI-TOF analysis* was employed to identify saccharide fingerprints [27], to investigate the possible use of gums suggested by sacred texts and Bengali traditional sculptural practices.

Detailed analytical procedures, instrumental parameters, and data treatment protocols for these techniques are reported in the previously published studies from which part of the analytical dataset derives and are therefore not repeated here.

These analyses were conducted with particular attention to stratigraphic differentiation, allowing the identification of compositional differences between modelling pastes and preparation layers associated with polychromy.

3.2. Ethnographic documentation

Field documentation of traditional practices was undertaken through a combination of direct observation, semi-structured interviews, and audio–visual recording in different locations, primarily in West Bengal (India, September–October 2019) and Bhutan (November–December 2024). These regions were selected because they preserve living traditions of large-scale clay-based modelling associated with religious and ritual contexts, offering valuable analogies for understanding the operational logic of ancient *terracruda* sculpture.

A short field visit to Shanxi (China) was also conducted in June 2024, during which one traditional artist was interviewed about the continuity of clay modelling techniques in contemporary temple sculpture (Fig.3).

Documentation focused on workshops, community-based rituals, and the preparation of modelling materials, with full informed consent from all participants. Interviews with local masters explored aspects such as raw material selection, processing sequences, mixing ratios, use of organic additives, and criteria of material suitability according to ritual, symbolic, or practical considerations.

The resulting ethnographic records were analysed qualitatively and compared with both the archaeometric data obtained from the sampled sculptures and the technical prescriptions described in Sanskrit treatises. This triangulation of sources provided a dynamic interpretive framework to contextualize the technological choices observed in archaeological examples, highlighting continuities and transformations in knowledge transmission between past and present practices.

3.3. Textual interpretation

In his work, Varma [18] outlines a seven-stage modelling process symbolically associated with the human body: the *śūla* (armature) is correlated with *asthi* (bones); the *astabandha* (glue) with *medas* (fat); the *rajju* (ropes) with *śirā* (veins, arteries, tendons); *mṛt* (clay) with *māṃsa* (flesh, muscles); *śarkarākalka* (limestone paste) with *śonita* (blood); *paṭa* (fabric) with *tvak* (skin); and *varṇa* (colour) with *jīva* (life) (Fig. 4).

Collectively, the texts provide detailed descriptions of the preparation and layering of pastes, including the incorporation of various organic and inorganic materials, the use of ropes, drying times, and the staging of the modelling process.

Particular attention was given to passages concerning the preparation of clays and the incorporation of organic additives, including bark decoctions, dairy products, flours, diterpenic resins, gums and spices. These references were revisited to explore their possible technical implications. They were systematically compared with archaeological evidence and living traditions, allowing a preliminary assessment of their practical validity and their alignment with observed material data.

While traditionally interpreted through a ritual or symbolic lens, these texts were re-examined here from a conservation-scientific perspective, with emphasis on the technological significance of the prescribed ingredients in relation to evidence from traditional earthen architecture.

4. Results & discussion

4.1. Functional stratification and soil processing

The combined analysis of archaeological, ethnographic, and textual data strongly suggests that monumental *terracruda* sculptures were produced through a complex stratified system, in which modelling pastes were deliberately prepared according to their functional role within the sculpture. These roles typically fall into three categories: inner modelling pastes (structural and volumetric build-up layers), surface modelling pastes (used to define and refine the form), and ground or preparatory layers associated with polychromy, each with distinctive compositions and technological treatments. The selection and processing of soils for monumental *terracruda* sculpture was therefore not a neutral or random act, but a technologically informed decision adapted to the requirements of each stage of construction.

Archaeometric analyses of samples from Kara Tepe, Tepe Narenj, and Qol-e Tut revealed comparable mineralogical compositions for

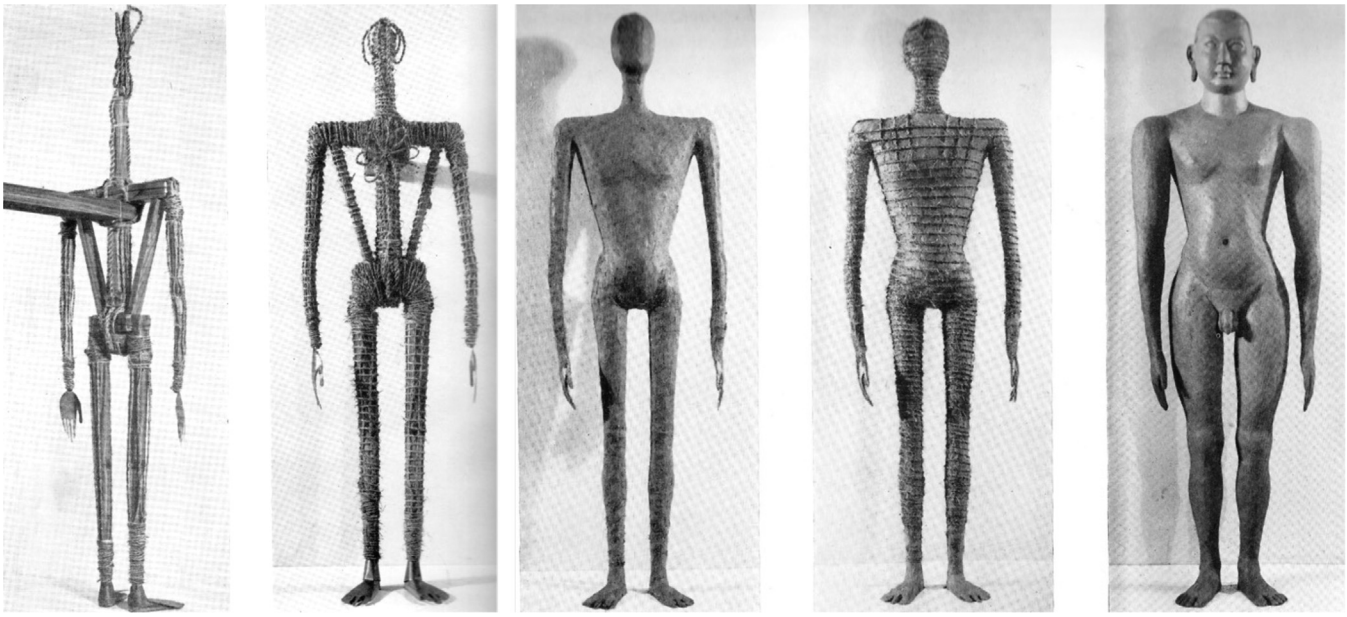


Fig. 4. Elaboration based on Varma's images documenting his experimental reconstruction of a sculpture modelled according to the method prescribed in the *Āgama* texts (adapted from Plate IV–V, Figs. 6–9, and 11, in [18]).

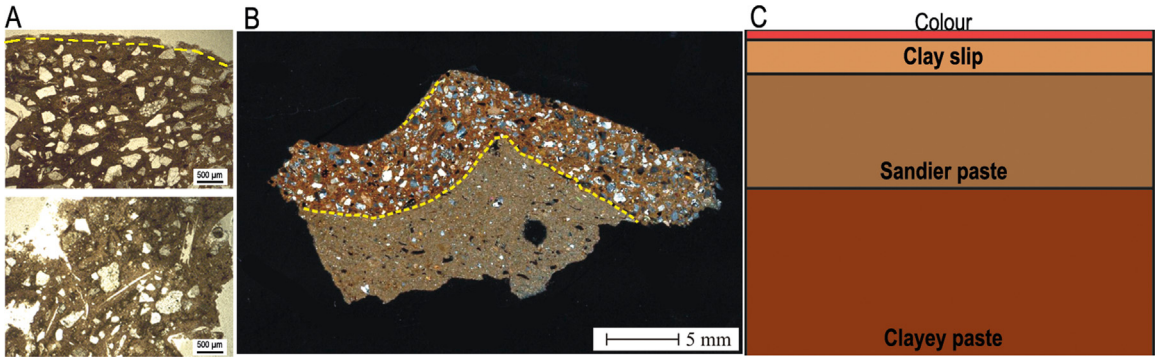


Fig. 5. Thin sections of fragments KT6 from Kara Tepe (Uzbekistan) (A) and TN2 from Tepe Narenj (Afghanistan) (B) showing the stratigraphy preserved within the analysed fragments. The images illustrate the characteristic use of a sandier and more homogeneous surface modelling paste, contrasted with a more clay rich, porous and heterogeneous inner modelling paste, resulting from a higher inclusion of fibrous organic matter. Both fragments exhibit a thin clay slip applied to seal the modelling surface prior to colouring. A schematic representation of the stratigraphy is shown in C.

each group, indicating the use of similar clay sources (one characteristic of KT and another of TN and QT), as well as notable petrographic diversity within individual sculptural fragments. In fragments preserving multiple layers, clay-rich and more heterogeneous inner modelling layers were observed, whereas surface modelling layers showed greater homogeneity and a higher proportion of mineral aggregates, particularly metamorphic and carbonate rocks in the case of TN and QT [28]. Some samples also preserve a clay slip, as in the cases of KT6 and TN2 (Fig. 5). Moreover, some samples preserved traces of colour. In the case of KT6, the clay slip is further covered by a thin white layer, later identified as gypsum (see Fig. 8).

Today, clay sculptors clearly distinguish between inner and outer pastes, which are prepared differently and progressively applied in layers, the number of which depends on the size of the sculpture. Waiting times between applications, especially between the internal volume layers and the final modelling, allow for the construction of sculptures several meters high. In West Bengal, sculptural practices differentiate between *etel-mati*, a sticky, fine-grained clayey soil transported by boat from the Diamond Harbour region, where the Hooghly converges with the Bay of Bengal, and *bele-mati*, a sandy soil extracted from the Hooghly River, a distributary of the Ganges. The former is primarily employed for adhesion and the modelling of internal volumes, whereas the latter is preferred for external layers and the execution of finer details. In certain cases, both soils are combined in specific proportions to produce *domsa-mati* ("dual soil"), particularly suited for sculptural components such as fingers or other moulded features [32]. These practices resonate with Sanskrit Āgamic treatises, which describe three kinds of soil—*anupa* (damp), *jangala*(arid), and *miśra* (mixed)—and prescribe their mixing, application with ropes, and drying in successive phases [18].

4.2. The fibrous organic matter

Vegetal matter plays a fundamental role in the preparation of modelling pastes for monumental *terracruda* sculptures. Macroscopic imprints preserved in fragments from Kara Tepe, Tepe Narenj, and Qol-e Tut corroborate this (Fig. 6).

A first attempt to investigate their presence was carried out through phytolith analyses on samples from Tepe Narenj and Qol-e Tut [25]. These revealed a wide range of vegetal inclusions, including a strong presence of fibres not visible macroscopically or

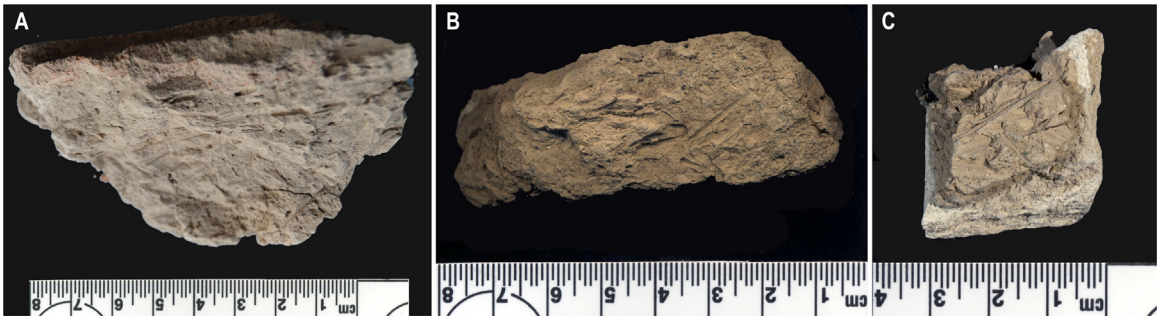


Fig. 6. Macroscopic images of the internal-layer surfaces of fragments: (A) TN2 (Tepe Narenj), (B) QT2 (Qol-e Tut), and (C) KT4 (Kara Tepe), showing imprints of vegetal matter.

in petrographic thin sections under optical microscopy. Archaeobotanical analysis also showed differences in the use of vegetal matter within the same sculptural fragment, across distinct layers. Phytoliths from cereal grasses suggested the use of various plant parts, including chopped straw and husk. Some fragments, such as a finger and a toe, contained higher concentrations of bast fibres (identified as belonging to the ramie or nettle family), preserved during phytolith extraction likely due to silicification [25]. The type, distribution and concentration of plant materials (whether straw, husk, or bast fibres) therefore appear to reflect a technological logic deliberately adapted to the role of each layer.

Micro-CT imaging confirmed these observations at a structural level. A finger fragment from Tepe Narenj revealed internal layering with higher concentrations of straw and fibres in the inner volume, while surface layers contained primarily finer or no fibrous components [26]. This distribution suggests a deliberate use of plant matter according to mechanical and functional requirements: greater reinforcement and lightness in the inner masses, and finer materials for modelling precision and surface finish. Fibres were also detected in stuccoes of powdered raw samples through SEM [28], though they remained invisible in thin sections and were only indirectly suggested in micro-computed tomography by patterns of porosity (voids) [26].

Ethnographic evidence from West Bengal supports the differentiated use of plant matter observed in archaeological samples. *Kumors* (the Bengali term for clay artists) consistently incorporate jute ropes wrapped around bundles of rice straw, add rice husk to inner pastes to provide bulk and lightness, use chopped straw in clay pastes to increase volume in larger sculptures, and mix jute fibres into finer layers or delicate parts requiring strength, such as fingers or crowns [32]. Sanskrit textual sources, translated by Varma [18], likewise prescribe the fabrication of coconut ropes to be added before and between modelling layers, the incorporation of coconut fibres into clay preparation in a 1:4 volumetric ratio, and the use of cotton fibres in preparing *sarkarakalka*, the colour-bearing paste.

These results highlight the importance of systematically investigating vegetal matter in historical and archaeological examples, which often remains undetectable macroscopically or even in thin sections under optical microscopy. Their presence, abundance, and state of preservation may be directly linked to the overall conservation of the sculpture and must therefore be taken into account when planning conservation treatments.

4.3. The biopolymers

The potential use of biopolymers in the modelling pastes of archaeological and historical examples of monumental *terracruda* sculpture mentioned in Sanskrit Āgama literature has long been overlooked. According to these texts, a variety of organic additives (including plant extracts, flours, oils, milk and resins) were prescribed for clay preparation in sacred image-making [18]. While these references have traditionally been interpreted as symbolic or ritual prescriptions [2,18], ethnographic parallels suggest a broader technological significance [33].

In West Bengal, for instance, sculptors apply a white finishing coat (*kore mati*) made of kaolinitic clay or chalk mixed with a tamarind gum preparation to prime surfaces before painting [32]. Although this gum is now restricted to polychromy stages, the initial hypothesis was that it may represent a remnant of earlier practices in which organic compounds were more widely integrated into modelling pastes, as suggested in ancient Sanskrit prescriptions and further supported by previous scientific evidence of gums detected in the pastes of other monumental Afghan *terracruda* sculptures [34–36].

Following this idea, initial screening with epifluorescence microscopy revealed biomolecular residues in several samples. The absence of inorganic fluorescence activators confirmed that the luminescence originated from organic matter, prompting further chemical investigation [28].

To specifically test for plant gums, we employed a targeted approach that combined enzymatic digestion (mannanase and galactanase) with MALDI-TOF mass spectrometry [27]. The resulting saccharide fingerprints confirmed the presence of polysaccharides in several fragments, consistent with the historical use of gums in sculptural practices [32].

Complementary FTIR spectroscopy confirmed the presence of multiple organic functional groups. Solvent-extracted samples showed signals associated not only with polysaccharides, but also with lipids, proteins, resins (e.g., diterpenoids), and oxalates [27]. For instance, in sample TN6, the analysis of the raw sample revealed the presence of calcium carbonate (calcite) (2515, 1795, 1436, 875 cm^{-1}) and clay minerals (3616, 1641, 1033 cm^{-1}). Subsequent extraction with different organic solvents uncovered additional bands diagnostic of lipids (2920, 2850, 1741 cm^{-1}) and proteins (3293, 3070,1653, 1544 cm^{-1}) (see Fig. 7).

To further explore the mix of biopolymers in modelling pastes of monumental terracruda sculpture and their spatial distribution, chemical imaging was performed on cross-sections from Kara Tepe using micro-FTIR with Focal Plane Detector (FPA-FTIR) in external reflection mode. These analyses followed the same approach described in other studies [37,38]. Preliminary analysis yielded positive results in fragment KT6 (Fig. 8). Infrared vibration bands suggesting the presence of a polysaccharide, with a spectral profile possibly associated with starch, were detected in the inner layer (yellow square, dark green spectrum; bands at 1250–1021 cm^{-1}). The chemical map of these bands showed spatial correspondence with an amorphous-looking agglomerate. The outermost layer exhibited bands indicative of gypsum (red square, pink spectrum; bands at 3545, 3400, and 1130 cm^{-1}). Other silicates and quartz were also detected (light green and red spectra, respectively).

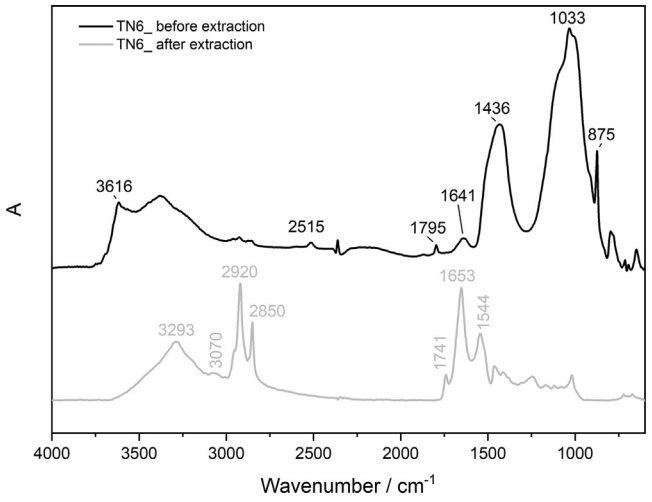


Fig. 7. Transmission FTIR spectra collected on sample TN6 before (black line) and after (grey line) extraction with organic solvents.

GC–MS analyses of samples from Tepe Narenj and Qol-e Tut further revealed fatty acid profiles consistent with plant-derived products, although additional analyses are still required [27].

These findings expand the expected range of organic additives beyond the initial hypothesis of plant gums, pointing to a broader historical use of organic materials that resonates with Sanskrit textual descriptions. The detection of organic binders in fragments from KT, TN and QT raises the possibility that such materials served systematic technological functions. Comparable evidence from traditional earthen architecture supports this view, as biopolymers are known to improve workability, cohesion, durability, and surface properties [33]. The preservation of organic substances in archaeological examples of monumental *terracruda* sculpture, in amounts sufficient for detection, therefore, suggests a deliberate and layer-specific use of binders to modify the technological behaviour of the modelling pastes. This challenges the long-standing assumption that their mention in Āgama literature was purely ritual, instead pointing to a complex and intentional technological practice that warrants further study. The analytical protocol developed demonstrates the feasibility of identifying such organic compounds, but it requires further refinement to distinguish among the complex admixtures described in the texts, an essential step if we are to test the hypothesis that these prescriptions reflect a traditional alchemy of clay: a body of empirical knowledge aimed at transforming and improving raw earth for sculptural purposes.

4.4. Characterization of MTS modelling pastes: key diagnostic questions and analytical workflow

Taken together, the observations presented above integrate previously published analytical evidence from Tepe Narenj and Qol-e-Tut with new observations obtained from the Kara Tepe fragments, allowing a comparative assessment of technological features across

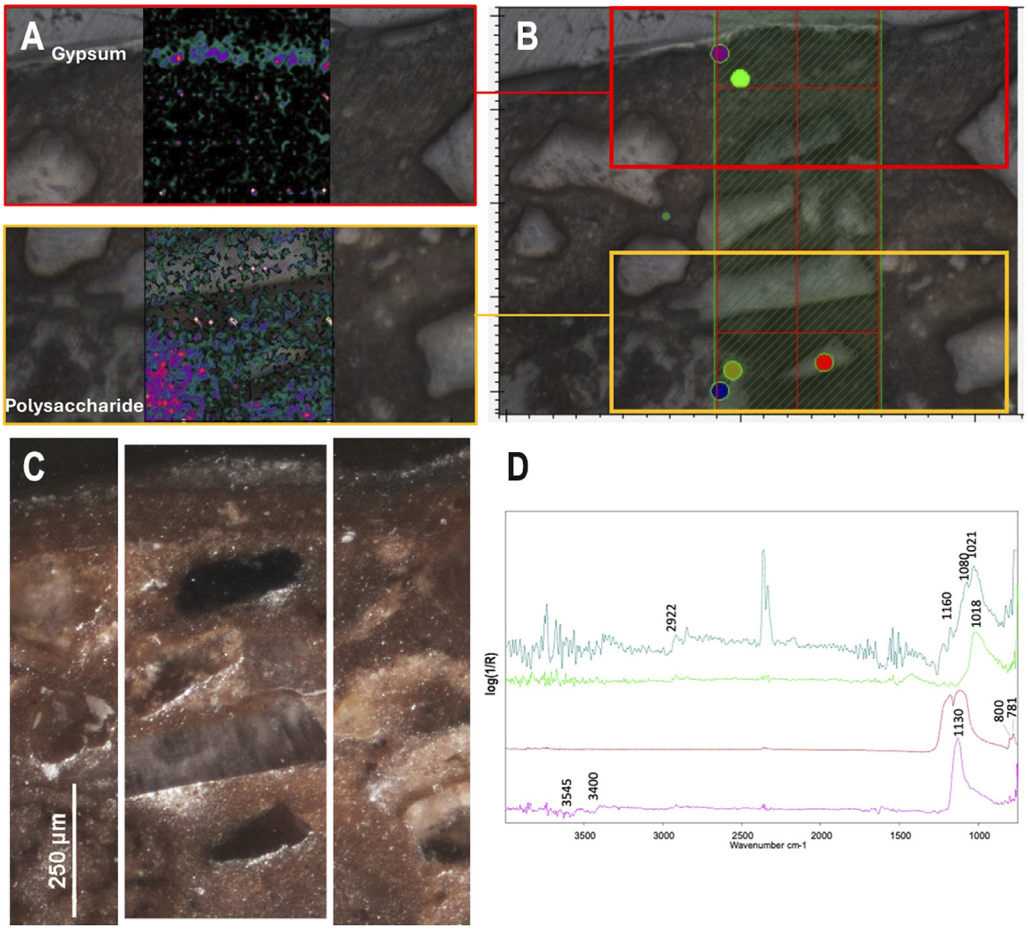


Fig. 8. FPA-FTIR chemical imaging of sample KT6. (A) Spatial distribution maps showing gypsum at the surface of the fragment and organic material associated with polysaccharides in the underlying layer. (B) Optical image of the analysed area with the corresponding locations of the extracted spectra indicated. (C) Optical microscope images of the cross-section in the visible range, highlighting the same analysed area. (D) Representative FTIR spectra of the detected compounds. Spectra are shown as raw reflectance data, without Kramers–Kronig transformation.

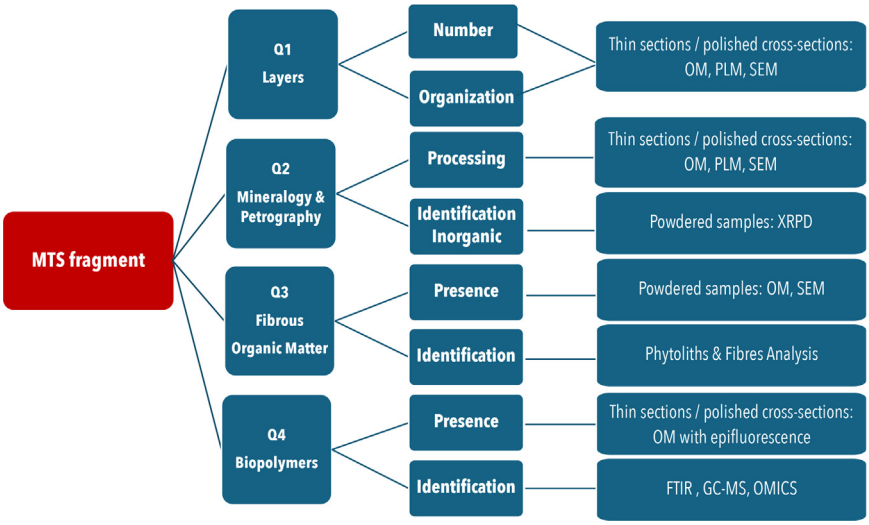


Fig. 9. Schematic representation of the key diagnostic questions and corresponding analytical workflow.

different case studies. Despite their different chronological and geographical contexts, these case studies reveal recurring technological patterns, including the functional differentiation of modelling pastes, the systematic incorporation of vegetal fibres, and the presence of organic additives. When interpreted in dialogue with historical textual sources and ethnographic observations, these results allow the identification of key technological variables that must be addressed in the study of modelling pastes of monumental terracruda sculptures. On this basis, a set of diagnostic questions and corresponding analytical approaches can be formulated, forming the methodological framework proposed below.

The analytical workflow for the characterization of modelling pastes has been therefore conceived as a sequence of diagnostic questions derived from archaeological, historical, and ethnographic sources, aimed at reconstructing the technological processes underlying their production. Each question is addressed through specific analytical and interpretive tools (Fig. 9).

The proposed workflow includes a set of core diagnostic techniques that provide a solid and replicable basis for the systematic study of modelling pastes of MTS samples. Depending on the specific research objectives, the protocol can be further refined or complemented by advanced or non-destructive approaches—such as micro-computed tomography (μ-CT) or chemical imaging (e.g., FPA-FTIR mapping)—to achieve higher spatial resolution and explore the spatial distribution of compounds across layers.

This question-based design ensures that every step of the investigation contributes directly to understanding material composition, stratigraphic organization, and manufacturing technology, offering an optimized and structured framework for future diagnostic and conservation-oriented studies of monumental *terracruda* sculpture modelling pastes.

Q1 – How many layers compose the modelling system and how are they organized?

Diagnostic Techniques: Thin sections and polished cross-sections examined using Optical microscopy (OM) and Scanning Electron Microscopy (SEM).

Rationale: Layer stratigraphy was investigated to determine the number and organization of the modelling layers. In some cases, OM alone is insufficient, as layers applied at different stages may share identical petrographic and mineralogical compositions and can only be distinguished at higher magnification using SEM or μ-CT.

Q2 - What are the mineralogical and petrographic characteristics of the pastes?

Diagnostic Techniques: Thin sections and polished cross-sections examined using Optical Microscopy (OM), Polarized Light Microscopy (PLM) and Scanning Electron Microscopy (SEM). X-Ray Powder Diffraction (XRPD) was used to identify mineralogical phases and assess clay composition.

Rationale: These observations enabled identification of the different processing of the modelling pastes according to their position (inner and surface) and determination of mineral phases in terms of clay mineral composition, aggregate type, distribution, and grain-size. The results allow differentiation between paste types and provide insights into raw-material selection, soil preparation, and the technological logic underlying stratigraphic differentiation.

Q3 - What types of fibrous organic matter were added, in what form and proportion, and what is their state of preservation?

Diagnostic Techniques: Powder samples observed under OM and SEM; phytoliths and fibres identification.

Rationale: These methods allowed recognition and characterization of plant-derived fibrous materials (straw, husk, bast fibres) and assessment of their preservation. Although plant matter imprints are commonly visible in macroscopic observation, this does not necessarily indicate preservation of the organic material itself. Individual fibres are rarely visible in sections, as they may be lost during sample preparation or transformed into voids due to decomposition.

Q4 - Were organic binders or biopolymers intentionally incorporated, and of what nature?

Diagnostic Techniques: Optical Microscopy (OM) coupled with epifluorescence observation, Fourier-transform infrared spectroscopy (FTIR), gas chromatography–mass spectrometry (GC–MS), and mass spectrometry-based multi-OMICS analyses.

Rationale: Optical Microscopy (OM) coupled with epifluorescence observation of thin sections or polished cross-sections serves as a preliminary tool to assess whether biopolymers are present in sufficient amounts to warrant further molecular analysis. When positive indicators are observed, Fourier-transform infrared (FTIR) spectroscopy has been employed as a prescreening method to identify the functional groups of organic components. Subsequently, GC–MS analysis and OMICS characterization could be used to characterise the addition of organic substances such as lipids, proteins, resins, and gums, providing insights into their specific functions and preservation.

When preservation conditions and sample size permit, micro-computed tomography (μ-CT) offers an exceptional non-destructive

complement to this workflow. It enables three-dimensional visualization of internal stratigraphy, inclusion distribution, and fibre networks, thereby contributing valuable information to Q1 (layer organization), Q2 (mineral and textural heterogeneity), and Q3 (fibre orientation and porosity) without the need of sampling.

5. Conclusions

The diagnostic protocol based on targeted techniques proposed here did not emerge from a linear sequence of hypothesis, sampling, and confirmation. Rather, it developed through an iterative and integrative process in which different lines of investigation (archaeometric, ethnographic and textual) were progressively cross compared. Taken together, the evidence drawn from both ancient and living practices highlights the existence of a shared technological knowledge. This study also reinforces the need to consider modelling pastes not as homogeneous materials, but as functionally and stratigraphically differentiated components within a complex sculptural system.

This practice did not arise incidentally, in regional isolation, or merely as a response to material scarcity or expedience, as has often been suggested in academic discourse. Instead, it reflects a complex empirical knowledge that appears to have been transmitted and adapted across centuries and geographies. Recognizing this consistent technical organization is essential both for interpreting historical examples and for designing conservation–restoration treatments, as well as for re-evaluating the intangible knowledge preserved in this singular Asian sculptural tradition.

More broadly, this research demonstrates the value of interdisciplinary approaches in heritage science. Future work will focus on refining the molecular identification of organic additives, replicating organic–inorganic recipes to evaluate their performance, and applying the diagnostic protocol within the context of conservation decision-making.

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