Archaeological and Anthropological Sciences (2025) 17:174
https://doi.org/10.1007/s12520-025-02283-7

RESEARCH

Resource use and plaster manufacture in the arid steppe: Micromorphological analysis of floor sequences at the final PPNB site of Qdeir (Syria)

Joaquim Sisa-López de Pablo[1,2] · Julia Wattez[3] · Rosa M. Poch[4] · Miquel Molist[1]

Received: 20 February 2025 / Accepted: 13 July 2025 / Published online: 28 July 2025

Abstract

The widespread use and production of plaster during the Neolithic transition in SW Asia represents a significant technological advancement and development in the material culture of early sedentary farming communities. The Final Pre-Pottery Neolithic case-study of Qdeir (7100−5720 cal BCE), located in the Syrian steppe, provides new evidence of resource management and technology in floor plaster manufacture. It also sheds light on the impact of the environment and activities on floor surfaces as indicators of continuity and change in space use and related socio-cultural implications within mobile pastoralist communities in a distinctive environment. Micromorphological analysis on archive samples reveals distinct floor plasters indicating different production processes and material sourcing, including carbonate sediments and gypsum, and the incorporation of animal dung as fuel to produce gypsum plaster. Dung was likely a major fuel source given the scarcity of wood and the community's reliance on pastoralism, underscoring the adaptive strategies employed by the community to overcome ecological constraints. Variability in floor sequences across occupation phases at Qdeir suggests differences in concepts of space and seasonal settlement strategies. The interplay between mud and gypsum plaster floors reflects changing technological and socio-cultural practices, possibly related to varying needs, sustainable management of fuel sources and material availability over time. This study highlights the importance of micromorphology in providing high-resolution contextual information on the nature, manufacturing processes, and post-depositional alterations of plasters and contributes to the broader understanding of the technological, ecological, and social dynamics that shaped Neolithic communities.

Keywords Neolithic · Plaster · Micromorphology · Animal Dung · Mobile pastoralism · Gypsum

Introduction

The widespread use and manufacture of plaster during the Pre-Pottery Neolithic B (PPNB hereafter) *c.*8.500–7000 cal. BCE reveals a crucial step in the material culture of early farming communities, embodying technological innovation and social and cultural change. Its function in daily life, as well as its ritual and symbolic significance, highlights the multifaceted role of plaster in the complex dynamics that characterised the transition to sedentary farming-herding

✉ Joaquim Sisa-López de Pablo
joaquim.sisalopezdepablo@reading.ac.uk;
joaquim.sisa@uab.cat

Julia Wattez
julia.wattez@inrap.fr

Rosa M. Poch
rosa.poch@udl.cat

Miquel Molist
miquel.molist@uab.cat

1 Departament de Prehistòria, Universitat Autònoma de Barcelona, Bellaterra, Spain

2 Department of Archaeology, School of Archaeology, Geography and Environmental Science, University of Reading, Reading, UK

3 Inrap Centre-Ile-de-France, Umr 5140 Archéologie des Sociétés Méditerranéennes, Equipe Sol-DMOS, AgroParisTech, Paris, France

4 Departament de Química, Física, i Ciències ambientals i del Sòl, Universitat de Lleida, Lleida, Spain

lifeways. Although early evidence of lime plaster production predates the PPNB, extending back to the Middle and Late Epipalaeolithic periods in the southern Levant (Bar-Yosef and Goring-Morris 1977; Kingery et al. 1988; Goring-Morris et al. 1997; Friesem et al. 2019; Grosman et al. 2020), it is during the PPNB, especially in the Levant and the Middle Euphrates regions, when there is a significant increase in the scale and specialisation of plaster production, becoming a further example of technological development and a wide cultural feature of early farming-herding communities (Kuijt and Goring-Morris 2002). The production of lime plaster, alongside other forms such as gypsum and mud plasters, became integral to the cultural, economic and symbolic practices of PPNB societies, with lime and gypsum plaster being used for a wide range of purposes, including building materials, burial practices and white-ware vessels (Gourdin and Kingery 1975; Contenson and Courtois 1979; Aurenche 1981; Garfinkel 1987; Kingery et al. 1988; Rehhof et al. 1990; Goren and Goldberg 1991; Moore et al. 2000; Goren et al. 2001; Kuijt and Goring-Morris 2002; Nilhamn et al. 2006; Goring-Morris and Horwitz 2007; Chu et al. 2008; Goren and Goring-Morris 2008; Regev et al. 2010; Clarke 2012; Toffolo et al. 2017; Molist et al. 2021; Dudgeon 2023; Herrick and Berna 2024; Nilhamn 2024).

The production of lime and gypsum plaster is both resource-intensive and time-consuming, and it likely necessitated some level of specialisation among the community on a large-scale production (Nilham et al. 2006), although this has been the subject of considerable debate (Garfinkel 1987; Kingery et al. 1988; Goren and Goldberg 1991). It is important to note that gypsum plaster manufacture is easier and requires less fuel compared to lime plaster (Gourdin and Kingery 1975; Garfinkel 1987; Kingery et al. 1988; Hauptmann and Yalcin 2000). Lime plaster is produced by heating limestone ($CaCO_3$) to temperatures typically ranging from *c*. 750 °C to 900 °C for a prolonged time in a process known as calcination. This process decomposes the limestone into calcium oxide (CaO), or quicklime, which is then slaked with water to form a paste consisting of calcium hydroxide ($Ca(OH)_2$). Upon drying, the paste hardens and reacts with atmospheric carbon dioxide, reverting to calcium carbonate (Kingery et al. 1988; Nilhamn et al. 2006; Friesem et al. 2019). Gypsum plaster, on the other hand, is obtained by heating gypsum rock ($CaSO_4 \cdot 2\,H_2O$) to a lower temperature, typically between *c*. 120 °C and 180 °C. This process removes about three-quarters of the water content from the gypsum, converting it into a hemihydrate form (bassanite, $CaSO_4 \cdot \frac{1}{2}H_2O$), known as plaster of Paris. When mixed with water, this hemihydrate reverts to its dihydrate form ($CaSO_4 \cdot 2\,H_2O$) and solidifies (Gourdin and Kingery 1975; Nilhamn et al. 2006). It is important to note that if the firing temperature exceeds 180 °C, the material changes into γ-anhydrite through a second dehydration process. As pointed out by Nilhamn and Kume (2024), γ-Anhydrite (γ-$CaSO_4$) is soluble and will still revert to hemihydrate upon mixing with water. However, if the temperature exceeds 260 °C, the anhydrite forms insoluble β-anhydrite (β-$CaSO_4$), which cannot easily return to its original form due to its poor capacity to absorb water, making it ineffective for use in plaster. Gypsum plaster is more easily made than lime plaster and requires less fuel for production, but it is more soluble and susceptible to water absorption, making it unsuitable for exterior use unless in very dry climates (Nilhamn et al. 2006). A more durable plaster can be achieved by heating the gypsum rock at a higher temperature, which slows setting time considerably, or by incorporating additives that slow the development of crystals (Gourdin and Kingery 1975).

Identifying the processes involved in gypsum and lime plaster production in the past can be challenging and pose some problems. Both gypsum rock and gypsum plaster share the same chemical composition, making it difficult to distinguish between them. Similarly, the calcium carbonate originated after the recarbonation process of slaked lime to obtain the finished lime plaster is mineralogically and chemically indistinguishable from raw sedimentary calcite (Gourdin and Kingery 1975; Barnett 1991; Goren and Goldberg 1991; Karkanas 2007). Additionally, problems are also originated from post-depositional alterations affecting dissolution and re-precipitation processes of carbonates (Leslie and Hughes 2002). Specialised techniques, such as scanning electron microscope-energy dispersive X-ray analysis (ESEM-EDX), Raman or Fourier transformed infrared spectroscopy (FTIR), are therefore required for analysing prehistoric plasters (Herrick and Berna 2024). However, these methods are not yet a routine procedure and are costly. Additionally, such techniques are bulk analysis methods, which cannot definitively determine whether burnt lime was accidentally incorporated as inclusions or whether it functioned as a true cementing binder (Barnett 1991; Leslie and Hughes 2002; Karkanas 2007). This distinction is key in the study of prehistoric plasters, as they typically contain very low and variable amounts of burnt lime or gypsum, and are often mixed with a range of materials, including earth, animal dung, plant fibres, unburnt limestone, or anthropogenic debris (Goren and Goldberg 1991; Matthews 1996; Karkanas 2007; Dudgeon 2023). On the other hand, micromorphological thin-section analysis appears to be an adequate analytical method for examining prehistoric plasters, as it enables the detailed study of both the mineralogical composition and the fabric of undisturbed samples, as well as the microscopic artefactual and bioarchaeological remains in their depositional and post-depositional contexts and the quantification of the proportion of the different constituents

(Barnett 1991; Leslie and Hughes 2002; Matthews 2005; Karkanas 2007; Herrick and Berna 2024).

Previous analyses revealed that plaster manufacturing practices and techniques in SW Asia during the Early Neolithic were highly diverse, even within relatively small geographical regions (Garfinkel 1987; Goren and Goldberg 1991). While the chemical transformation processes of both gypsum and lime are well known, it is necessary to examine the multiple steps involved in their production within specific case studies to better comprehend their role within particular communities and implications regarding social metabolism. Therefore, understanding plaster production at a local scale is key to gaining insights into technological developments, cultural innovations and their broader economic and social implications, such as craft specialisation and resource use and management within early settled communities.

The Final PPNB site of Qdeir dates back to 7100−5720 cal BCE (Stordeur 1993, 2000; Table 1) and is located in the modern-day Syrian desert steppe (Fig. 1). It is a unique case study due to the extensive use of gypsum plaster for building purposes and the manufacture of white-ware vessels (Maréchal 1982; Stordeur 1993; Abbès 2015) in an environmentally distinctive arid environment. In addition, while the widespread use of plasters is typically linked to more sedentary communities, this study explores its use and production within semi-nomadic groups. Building on previous geoarchaeological analysis (Stordeur and Wattez 1998), the current study aims to provide new insights into mud and gypsum plaster construction practices at Final PPNB Qdeir through the application of micromorphological approaches. This research will address material sourcing and manufacturing technologies, as well as concepts of space through the examination of floor sequences at high-resolution timescales. The aim is to approach floor plaster manufacture with regard to the community inhabiting Qdeir and to expand our knowledge of human-plant-animal-environment interactions and technological choices more widely during the Neolithic period.

Case study: Qdeir

Archaeological context

The site of Qdeir is located in the El Kowm oasis in the northern Syrian desert. Despite discovered by Olivier Aurenche in 1980, systematic excavations at the site were not carried out until the late 1980s and early 1990s, first directed by Danielle Stourdeur (1989, 1991 and 1993), under the framework of the 'Mission d'El Kowm-Mureybet' project lead by Jacques Cauvin, and later by Frédéric Abbès (in 1999, and 2001–2003).

Fieldwork at Qdeir revealed a sequence of well-preserved archaeological deposits ascribed to the Final PPNB (Stordeur 1993, 2000; Abbès 2015, 2019). Excavations were conducted on a surface of 200 m² from a total estimation of *c*. 2000 m² (Abbès 2015) (Fig. 2). A total of four occupation phases were established. The stratigraphic sequence comprised a succession of occupation deposits interrupted by periods of non-occupation where the site was rapidly buried by aeolian sediments, which contributed to its good preservation (Stordeur 2000; Stordeur and Wattez 1998).

Phases I and III were characterised by the presence of circular/oval-shaped hut-like structures as evidenced by clearly delineated empty spaces in exterior areas. This interpretation is supported by the distribution of archaeological materials and the presence of stones, which were likely used to stabilise the wooden posts that surrounded these structures (Fig. 3), whereas Phases II and IV displayed multi-cellular quadrangular mudbrick structures. Consequently, the excavators were able to establish differences in the nature of the occupations (Abbès 2015). Phases I and III were interpreted as seasonal camps, as indicated by the presence of hut-like structures, sometimes reusing structural features such as mudbrick walls from previous occupations as in Phase III, with open areas where large knapping debris accumulated, leading to the identification of workshops for the manufacture of flint implements, sometimes associated with combustion structures. On the other hand, Phases II and IV were associated with multi-cellular earthen constructions, possibly related to both storage structures and dwellings, and

Table 1 Summary of sample location and contextual information

Sample	Stratigraphic unit	Phase	Sample location	Field context
QDR 92−17	D2/E1	I/II	DW91 - East profile	Occupation deposits and floors in hut-like structure / transition to Phase II
QDR 92−20	A2b/A3a	III	DW91 - East profile	Floor sequences in hut-like structure
QDR 92−21	D1b/D2b	II	DW91 - North profile	Floor deposits associated with an early phase of the mudbrick building and windblown sands
QDR 92−22	B2a/C1b	II	DW91 - North profile	Stratified sequence of gypsum floors and occupation residues in mudbrick building
QDR 92−23	B2a	II	DW91 - North profile	Floor sequences in mudbrick building
QDR 92−24	A1/B2	II/III	DW91 - North profile	Floors in hut-like structure suspectedly reusing a wall from the mudbrick building

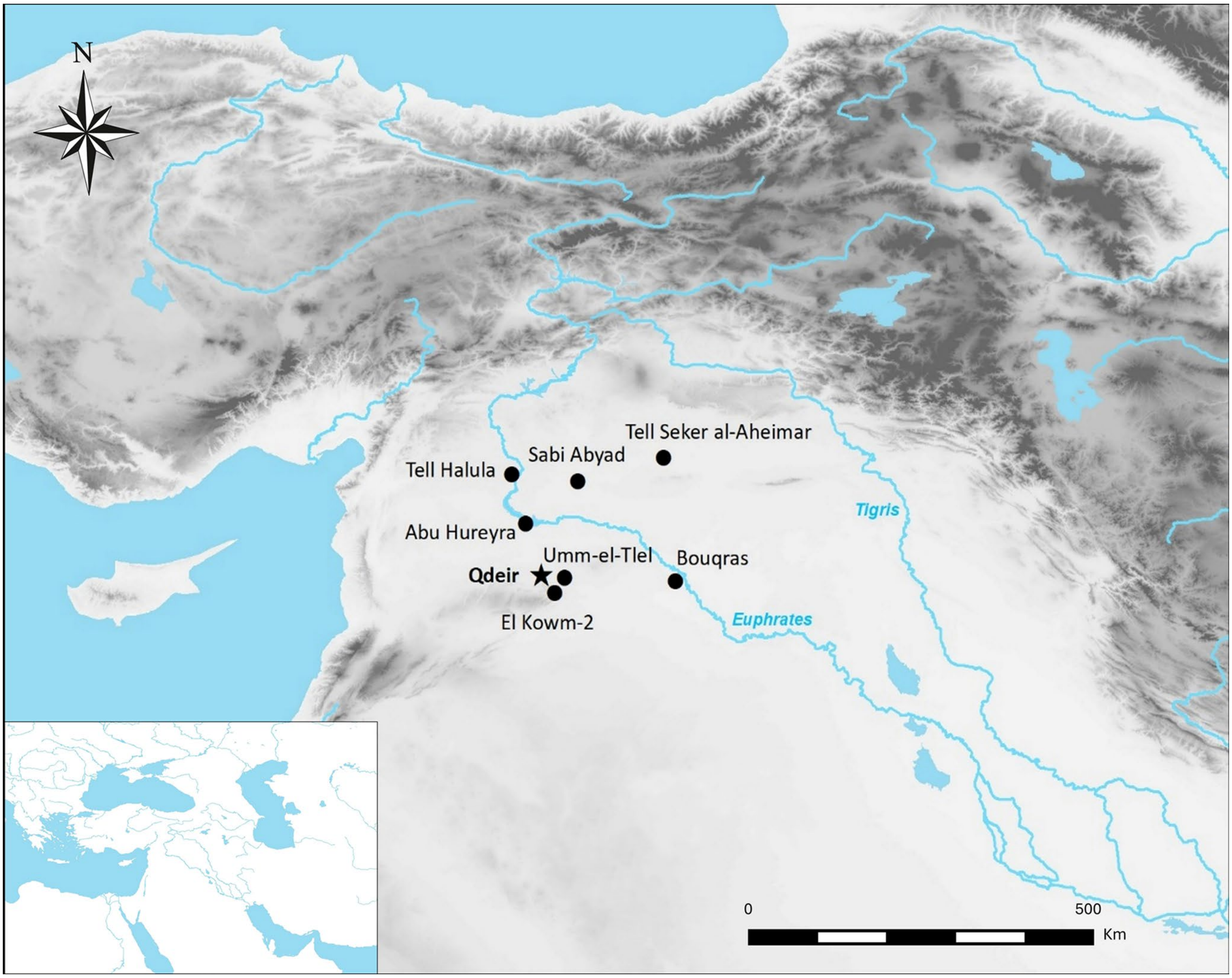


Fig. 1 Location of Qdeir and other sites mentioned in the text

therefore likely indicating more permanent occupations. Despite its contemporaneity and proximity to other sites in the area, such as El Kowm-2 (Stordeur et al. 1982; Stordeur 2000) or Umm-el-Tlel (Molist et al. 1992), Qdeir showed substantial differences, which led Cauvin (1994) to propose two different cultural facies known as *faciès* El Kowm, associated with more sedentary agricultural lifeways, and *faciès* Qdeir, attributed to mobile pastoralism.

The semi-nomadic character of the community inhabiting Qdeir is also supported by the important role of livestock herding, sustained by both direct archaeological evidence, including penning areas (Stordeur and Wattez 1998) and a zooarchaeological assemblage dominated by caprines complemented by gazelle remains (Gourichon 2004), and through ethnographic and environmental studies (Aurenche and Desfargues 1983; Chambrade 2012; Abbès 2019) which point to the suitable conditions of the area conducive to pastoralism due to the presence of watercourses and good pastures.

Geological and pedological background

The El Kowm cuvette extends 50 km east-west and 25 km north-south, surrounded by steppe desert vegetation. This depression, whose lowest point is 420 m above sea level, presents a series of particularities. Quaternary deposits are scarce due to wind erosion, leading to the formation of small hills, and small seasonal springs (*wadis*) are common. Wetlands are also present due to an underground water table forming the El Kowm oasis. The depression in which the oasis is located is excavated in limestone, marl and calcareous marl belonging to the Maastrichtian period with beds of gypsum that are occasionally covered by fine and irregular Quaternary deposits, which date back to the beginning of

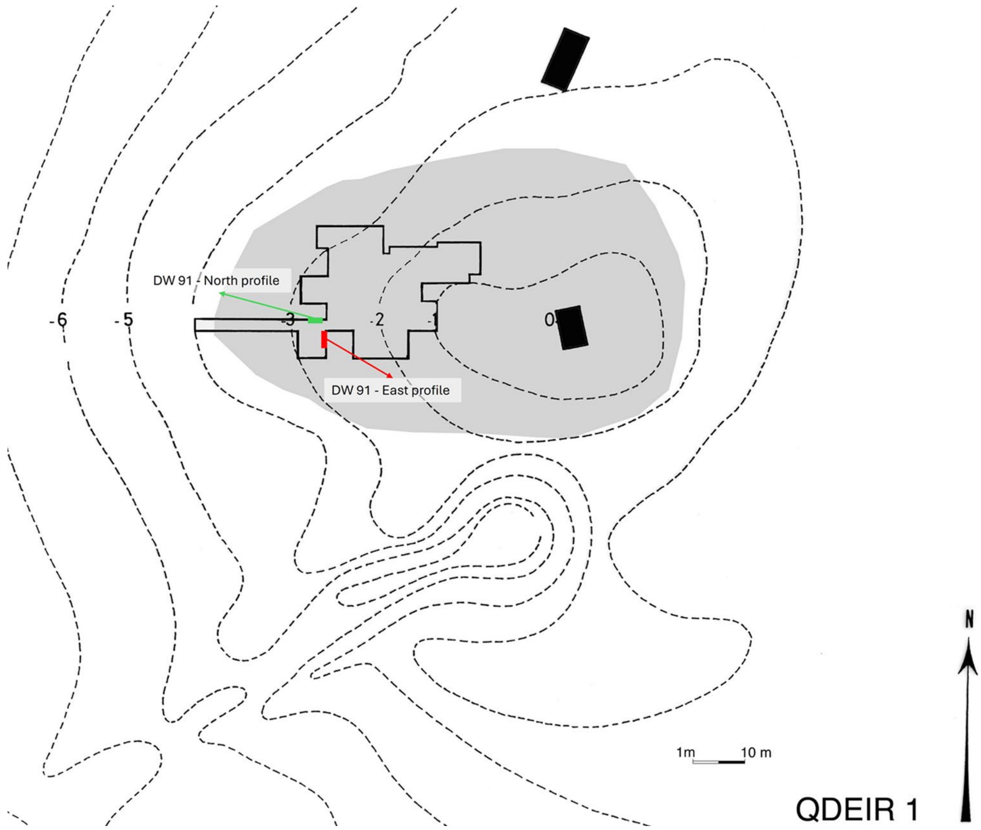


Fig. 2 Site topography, excavated surface and probable location of sampled profiles based on archives. The estimated area of the settlement is shown in grey, while black squares represent modern buildings. Image courtesy of F. Abbès

the Pleistocene (Fig. 4) (Ponikarov 1966; Besançon et al. 1982; Besançon and Sanlaville 1985; Chambrade 2012).

The topography of the oasis is quite irregular, with slight undulations given the presence of plateaus, such as that of Qdeir, surrounded by a series of small valleys formed by various *wadis* (Besançon et al. 1982; Chambrade 2012). In the El Kowm area, soils belong to the order of Aridisols[1], which are soils formed in arid or semi-arid climates characterised by high temperatures and low rainfall (Mohammed et al. 2020). At the suborder level, the most common soils are Gypsids, characterised by the accumulation of pedogenic gypsum in depth (Porta and Herrero 1990). The soil structure is usually subangular blocky, affected by carbonate and gypsum precipitation (Ilaiwi 1983, 1985). Soils in the region are extensively eroded by wind, which is the dominant erosive force, and occasional runoff from the *wadis*, which contribute to the overall soil erosion process.

[1] Soil types mentioned in the text follow Soil Taxonomy (Soil Survey Staff 2022 Keys to Soil Taxonomy, 13th ed.; U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA).

Materials and methods

Micromorphological analysis was conducted on six large-format (13,5 × 6,5 cm) thin-sections made from undisturbed sediment blocks collected in 1992 when extensive systematic and sequential sampling was performed to better understand the stratigraphy and occupation at the site and provide insights into its seasonality (Stordeur and Wattez 1998). Sediment blocks were dried for several days at room temperature and consolidated in the laboratory by impregnating them with polystyrene resin. Then, 30 µm thin sections were produced following the method described by Guilloré (1983) at the soil laboratory of AgroParis-Tech (Grignon, France). Samples analysed in this study concern all floor sequences obtained from roofed areas, that is, interior spaces from both perishable and mudbrick structures, as constructed floors in exterior areas were absent. These were collected from the north and western profiles of Trench DW91, comprising Phases I, II and III (Fig. 5). In total, three hut-like structures, one associated with Phase I and two with Phase III, and one mudbrick structure from Phase II comprising multiple occupations were sampled (Table 1). Unfortunately, due to political instability in the area, it was not possible to sample deposits and structures exposed during later seasons.

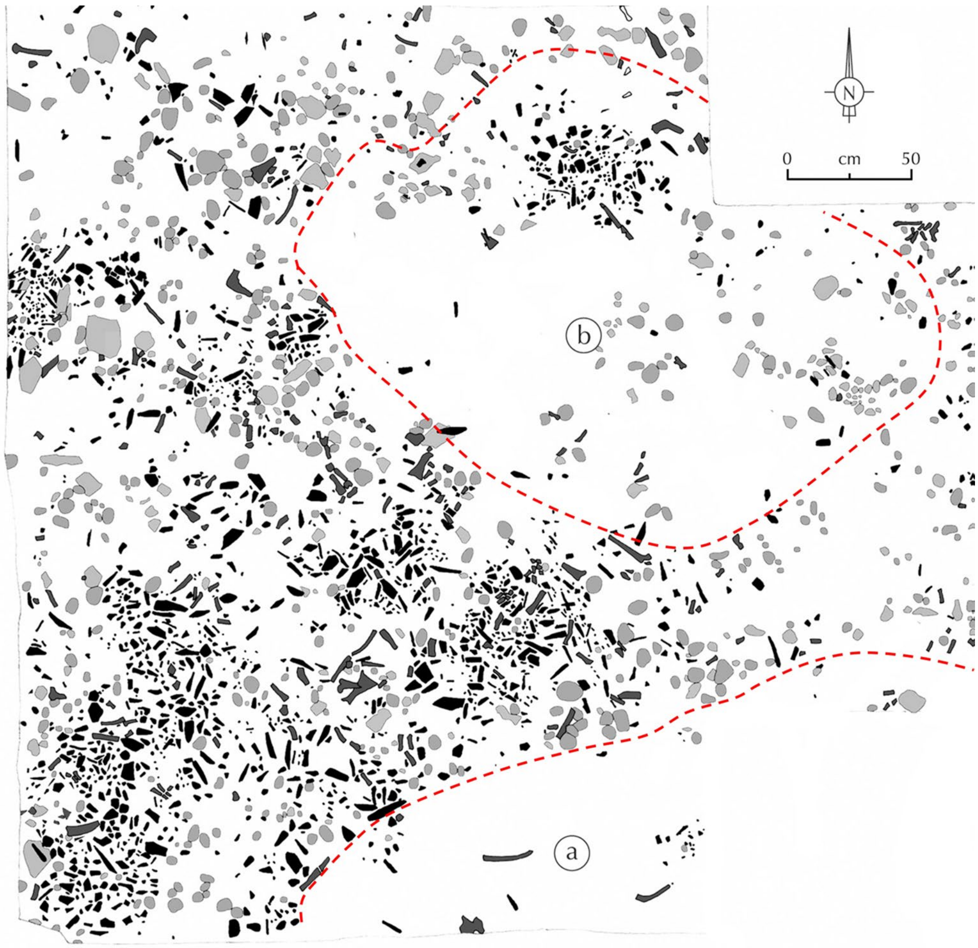


Fig. 3 Plan showing the probable locations of hut-like perishable structures (denoted as empty spaces A and B, outlined with dashed lines) surrounded by lithics (black). Image courtesy of F. Abbès

Micromorphological thin-sections were studied under a petrographic microscope (x25 to x400 magnifications) following standard published guidelines (Bullock et al. 1985; Courty et al. 1989; Stoops 2021). Further reference atlases were used to identify and analyse micromorphological features when necessary (MacKenzie et al. 2017; Nicosia and Stoops 2017; Stoops et al. 2018; Verrecchia and Trombino 2021).

Microstratigraphic units identified in thin-section were classified into distinctive deposit-types according to the matrix characteristics of the sediments, inclusions, and post-depositional alterations in order to reconstruct their pre-depositional, depositional and post-depositional histories. The procedures for interpreting deposit-types consisted of the qualitative and semiquantitative description of the microstratigraphic units (MSUs) within the sample group and their comparison considering their stratigraphic relationship. The basis for the interpretation of the functional and technological approaches relies on a set of indicators selected from previous micromorphological studies focusing on space use and plaster construction techniques (Gé et al. 1993; Cammas 2003, 2018; Wattez 2003; Friesem et al. 2017; Wattez et al. 2018; Mylona and Pomadère 2021) comprising the inclusion types, their abundance and spatial arrangement, microstructure and porosity, sorting, and pedofeatures.

Results

This section discusses the micromorphological characteristics of floor sequences that were analysed in the field and subsequently examined at high resolution, comprising the classification of microstratigraphic units into deposit-types followed by an evaluation of the taphonomic processes affecting archaeological deposits.

Characterisation of deposit types in sedimentary floor sequences

A total of 56 micro-stratigraphic units were identified in thin-section and subsequently classified into four distinctive deposit-types: mud plaster floors, gypsum plaster floors, occupation deposits, and natural deposits. Each deposit type's distinctive characteristics are discussed below (Table 2).

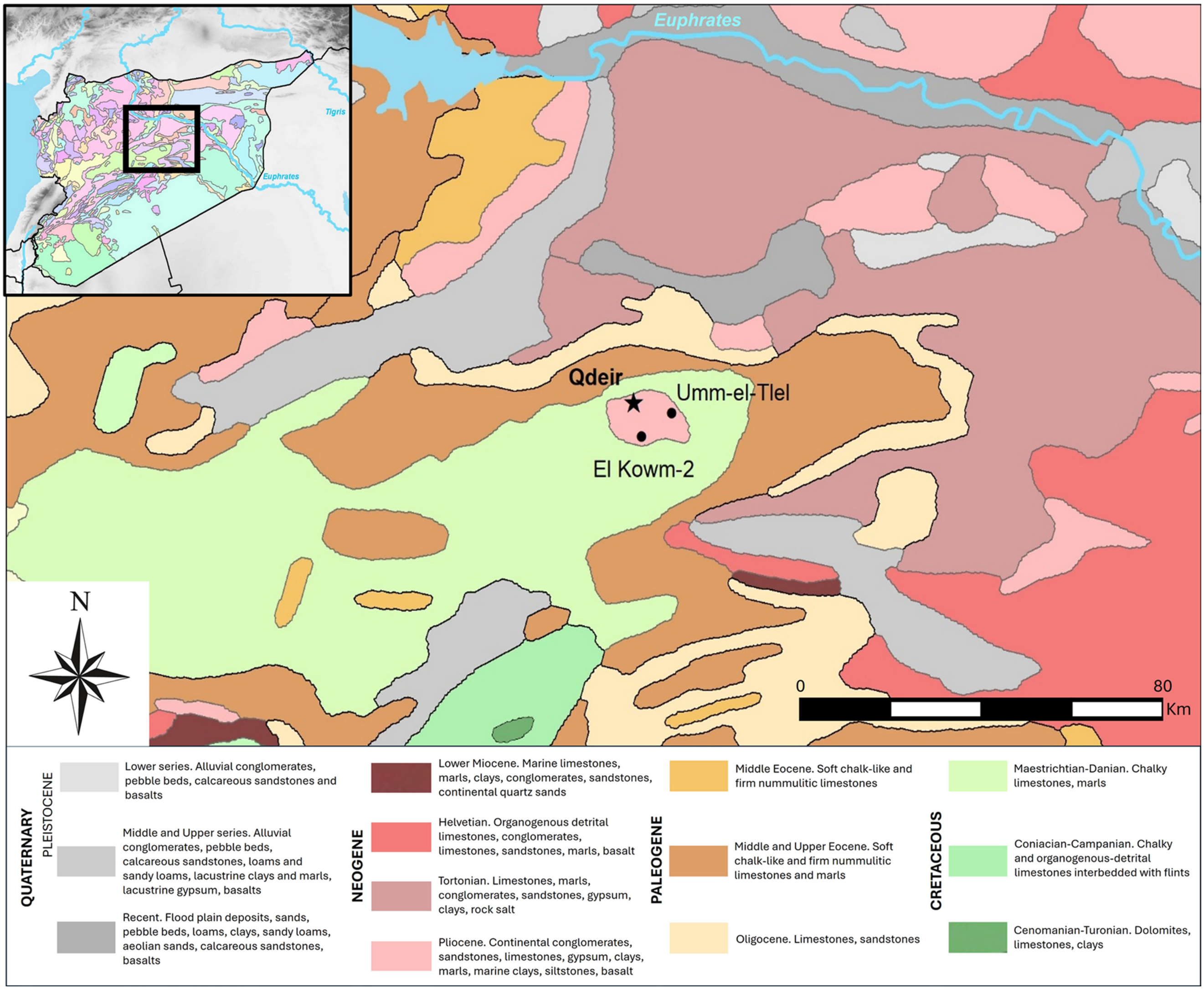


Fig. 4 Geological map of central Syria (adapted after Ponikarov 1966)

Mud plaster floors (deposit-type 1)

A total of twenty-eight mud plaster floors were identified in thin-section. Mud plaster floors are up to 2 cm thick deposits manufactured with local natural sediments comprising brownish grey carbonated silty clay and rounded calcareous aggregates (100–500 µm) along with sand-sized lenticular gypsum crystals, almost impossible to distinguish between inherited and post-depositional pedogenetic gypsum. These deposits display a massive microstructure with a porosity dominated by cracks, probably caused by shrinking and swelling processes. Two sub-types of mud plaster floors are distinguished based on the degree of sorting and homogeneity. Differences mainly concern the amount of gypsum sands and the presence of coarser elements such as calcareous gravel or gypsum rock fragments. Heterogeneous mud plaster floors (deposit-type 1.1) can also contain $<2\%$ of plant impressions and anthropogenic debris, including charred plant remains or bone fragments that are linearly distributed and poorly oriented. Conversely, homogeneous mud plaster floors (deposit-type 1.2) are almost exclusively made with carbonated silty clay and do not show anthropogenic residues (Fig. 6a-c).

Gypsum plaster floors (deposit-type 2)

Thin-section analysis revealed a total of seven gypsum plaster floors. These are formed by 1–2 cm thick layers of speckled, white microcrystalline gypsum (Fig. 6d), forming a massive microstructure with few vertical and subhorizontal cracks. Exceptionally these can reach up to 2.5 cm thickness. Despite its homogeneity, some inclusions were observed, including very few sediment and ashy aggregates as well as small fragments of dark brown fibrous aggregates

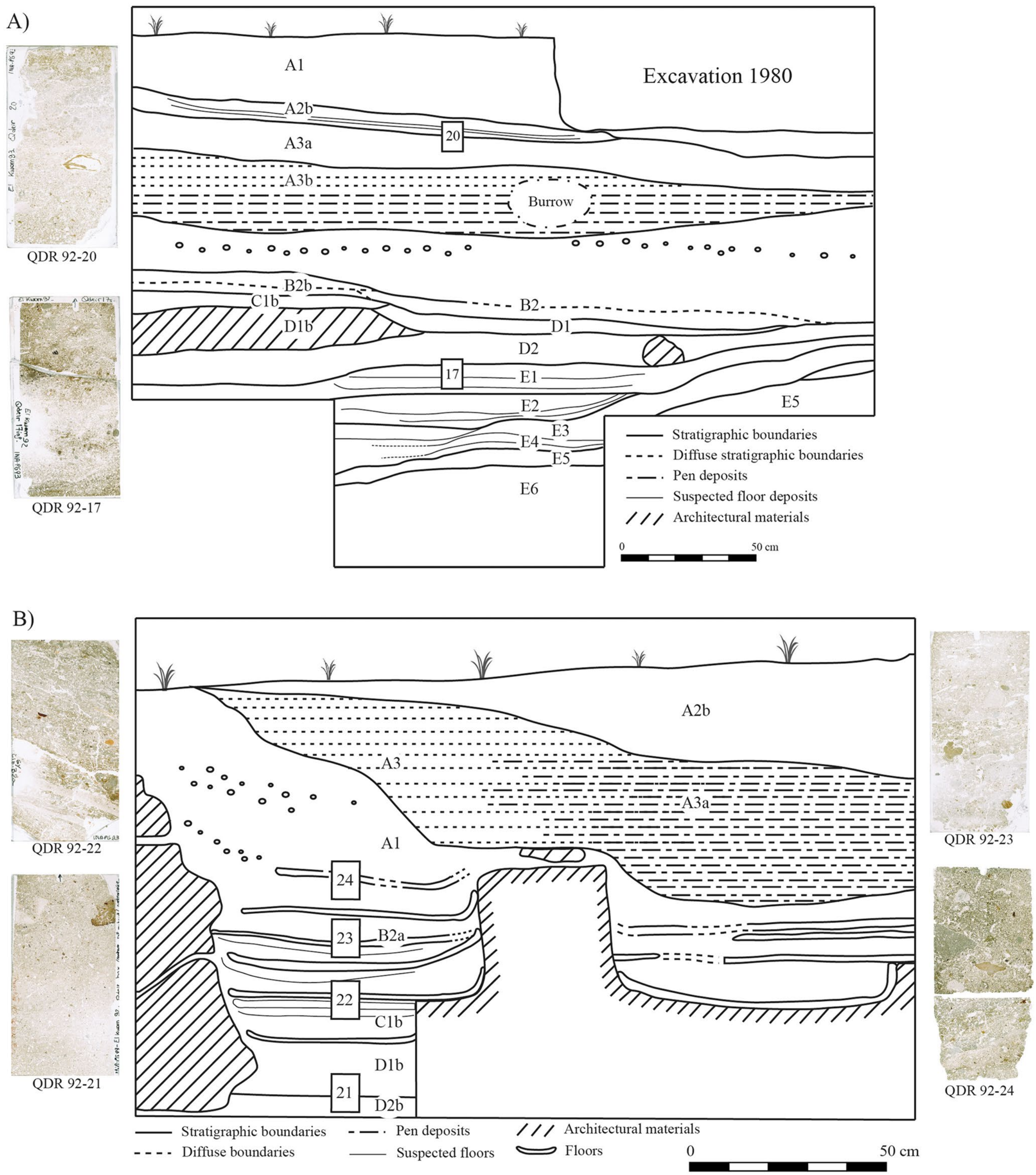


Fig. 5 Sampling areas and thin-section sampling location within trench DW91: **a**) East profile; **b**) North profile

associated with high concentrations of calcitic spherulites evidencing the presence of burnt herbivore dung (Canti 2003; Shahack-Gross 2011; Brönnimann et al. 2017) (Fig. 6e-f). Spherulite darkening and expansion, which occurs within a range between 500 and 700 °C with maximum production at 650 °C in reducing conditions (Canti and Nicosia 2018; Portillo et al. 2021) is rarely observed. Additionally, isolated bassanite crystals, a hemihydrated form of gypsum ($CaSO_4 \cdot 1/2H_2O$) (Mees and Tursina 2018), were also identified embedded in the gypsum mass (Fig. 6d). It is worth

Table 2 Summary of micromorphological attributes following deposit-type (DT). Classification of frequencies according to stoops 2021: ●≤1%, ●●2–5%, ●●●6–15%, ●●●●16–30%, ●●●●●31–50%, ●●●●●●>50%. Classification of the abundance of pedofeatures according to stoops 2021: + <2%, ++2–5%, +++6–10%, ++++11–20%, +++++>20%. C/f limit is 50 µm

Deposit-type	Deposit-subtype	Colour	Particle size	Micro-structure & Porosity	Groundmass	Mineral components	Anthropogenic inclusions	Pedofeatures
Mud plaster floors (DT-1)	Heterogeneous mud plasters (DT-1.1)	5Y 4/2	Silty clay, sand-sized gypsum, and calcareous and gypsum gravel	M: Vughy P: 15–20% vughs, channels, planes	c/f ratio: 1/1 c/f r.d.p: close porphyric b-fabric: undifferentiated	Limestone clasts ●● Gypsum ●●● Dolomite ● Quartz ●●	Bones ●● Charcoal ●● Plant impressions ●	Gypsum coatings in voids ++ Gypsum intergrowths + Gypsum dissolution +
	Homogeneous mud plasters (DT-1.2)	5Y 4/1	Silty clay and sand-sized gypsum and calcareous aggregates	M: Massive/Crack P: 10–15% planes, channels, vughs	c/f ratio: 1/2 c/f r.d.p: open porphyric b-fabric: undifferentiated	Limestone clasts ● Gypsum ●● Dolomite ● Quartz ●●	Bones ● Charcoal ●	Gypsum coatings in voids ++ Gypsum intergrowths + Gypsum dissolution +
Gypsum plaster floors (DT-2)		5Y 9/1	Micro-crystalline gypsum	M: Massive P: 2–5% planes, vughs	c/f ratio: 1/4 c/f r.d.p: open porphyric b-fabric: crystallitic	Gypsum ●●●●●● Bassanyte ●● Quartz ●	Ashes ● Burnt dung ●●	
Occupation deposits (DT-3)		5Y 4/2	Silty clay and sand-sized gypsum with coarse anthropogenic inclusions	M: Complex P: 20–25% channels, vughs, chambers	c/f ratio: 3/1 c/f r.d.p: close porphyric b-fabric: crystallitic	Limestone clasts ●●● Gypsum ●●●● Dolomite ● Quartz ●●	Ashes ● Bones ●● Charcoal ●● Phosphatic granules ●	Gypsum coatings in voids +++ Gypsum intergrowths + Gypsum dissolution +
Natural deposits (DT-4)		5Y 8/2	Silty clay and sand-sized gypsum and calcareous aggregates	M: Granular P: 35–40% Packing voids, channels	c/f ratio: 2/1 c/f r.d.p: enaulic b-fabric: calcitic crystallitic	Limestone clasts ●● Gypsum ●●●●● Dolomite ● Quartz ●●●	Bones ● Charcoal ●	Gypsum intergrowths ++ Gypsum dissolution ++

mentioning that bassanite can appear in thin-sections as an artefact, that is, as an alteration or defect during thin-section production. When samples containing gypsum are heated during the drying period prior to the impregnation, gypsum crystals can turn into bassanite (Mees and Tursina 2018). However, samples were dried at room temperature in this case, and bassanite crystals only appeared on gypsum plaster floors.

Occupation deposits (deposit-type 3) and impact of activities on floors

Only nine occupation deposits were identified within the floor sequences at Qdeir. These typically appear in thin section as layers 0.4–1 cm thick and are poorly preserved due to taphonomic processes. They tend to be slightly thicker when overlain by natural deposits, possibly as a result of abandonment episodes. Anthropogenic residues observed mainly comprise small fragments of bones and charred materials (Fig. 6g), all in very small quantities, probably due to the compact and firm surfaces of the floor plasters, which prevent the integration of residues and post-depositional processes (LaMotta and Schiffer 1999). Anthropogenic debris accumulated on floor surfaces is poorly to moderately oriented and distributed in bands parallel to the surface, partially affected by secondary gypsum that contributed substantially to modifying the original matrix. These observations contrast with the macroscopic evidence from deposits in exterior areas where abundant archaeological material was identified, consisting primarily of lithic tools, faunal remains, and combustion structures.

Trampling constitutes the primary activity affecting floor sequences documented at microscopic scale. Trampled occupation deposits are distinguished at Qdeir by slight compaction and the tendency to a subhorizontal orientation of the inclusions since sedimentary signatures associated with trampling (i.e. Gé et al. 1993; Rentzel et al. 2017) are masked by mechanical stress induced by gypsoturbation. Regarding floors, trampling effects appear as short horizontal and long vertical fissures, especially in mud plaster

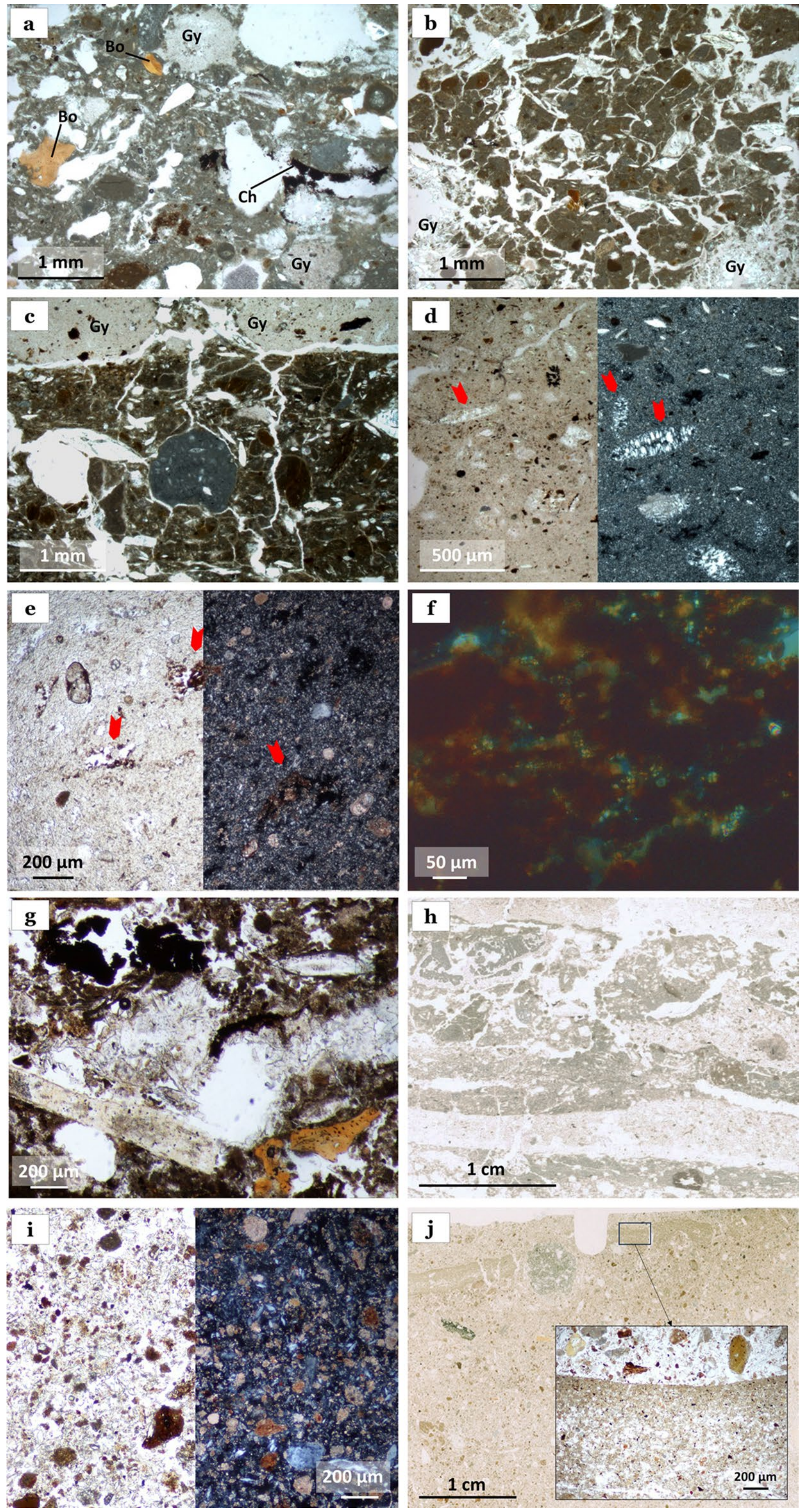


Fig. 6 Photomicrographs of deposit-types identified in thin-section: (**a**) Heterogeneous mud plaster floor, note the presence of coarse components including anthropogenic materials such as bones (Bo), charred plants (Ch) and microcrystalline gypsum (Gy) nodules, PPL; (**b**) Homogeneous mud plaster floor, note the absence of coarse inclusions and the crack structure due to shrinking and swelling processes and gypsum (Gy) precipitation, PPL; (**c**) Well-preserved homogeneous plaster floor coated by a gypsum plaster (Gy) with fissures caused by trampling, PPL; (**d**) Gypsum plaster floor, note the massive microcrystalline fabric containing few lenticular crystals of bassanite (arrows), left PPL, right XPL; (**e**) Gypsum plaster with embedded burnt animal dung aggregates (arrow), left PPL, right XPL; (**f**) Calcitic spherulites in faecal aggregates, XPL; (**g**) Anthropogenic residues, including burnt and unburnt bone fragments and charcoals in occupation deposit affected by bioturbation and pedogenic gypsum, PPL; (**h**) Multiple gypsum plasters showing lateral discontinuity and thickness variation, PPL; (**i**) Loose matrix formed by subrounded sediment aggregates and gypsum grains likely to be re-deposited by wind action, left PPL, right XPL; (**j**) Natural deposit with very sparse anthropogenic residues and without evidence of trampling. Note the presence of a water-laid crust on the surface as shown in detail, PPL

floors (Fig. 6c). On the other hand, gypsum floors display thickness variations, some pinching out laterally (Fig. 6h). Lateral discontinuity might result from abrasion by clearance practices or foot traffic (Gé et al. 1993; Mentzer 2018). Occasional phosphatic granules and phosphatic staining can be observed in occupation deposits as well as in floor surfaces, possibly related to the decay of organic matter or from the contamination of liquid waste (Macphail and Goldberg 2018). Other possibilities include the introduction of decayed herbivore dung from open areas and pen deposits by trampling.

Natural deposits related to periods of non-occupation (deposit-type 4)

A total of twelve microstratigraphic units were attributed to natural deposits. Five of these were observed between transitional phases of occupation, while the remaining eight were identified within the floor sequences. Within the floor sequences, natural deposits range from 1 to 2 cm in thickness, but between occupation phases they can exceed 5 cm in thin-section. These deposits are characterised by fine-grained, heterogeneous rounded sediment aggregates composed of brown and grey silty clay and subangular sand-sized gypsum crystals, displaying a granular microstructure (Fig. 6i). The moderately to well-sorted matrix and the shape of the components point to the accumulation of naturally re-deposited materials probably by wind action (Karkanas and Goldberg 2019) during periods of non-occupation. This is supported by the absence or low frequency of reworked anthropogenic materials and rarely observed undisturbed water-laid crusts (Fig. 6j).

Preservation conditions and taphonomy of floor sequences

Microstratigraphic analyses through micromorphological thin-sections at Qdeir constitute a unique example to assess preservation conditions and the impact of taphonomic agents on archaeological materials and deposits in the Syirian semi-arid steppe, where climatic and environmental conditions are characterised by water deficit and soil erosion (Chambrade 2012). These, along with the region's geological and pedological characteristics primarily represented by the sedimentary formation of limestones and marls, calcareous soils, and the presence of gypsum (Besançon and Sanlaville 1985; Ilaiwi 1985; Chambrade 2012) have directly influenced and altered the preservation of archaeological materials and deposits. The foremost taphonomic agent causing post-depositional alterations is pedogenic gypsum, frequently found in arid and semi-arid regions due to their aridic soil moisture regime where soil moisture rapidly evaporates and salts from the solution precipitate (Herrero and Porta 2000). Gypsum precipitation occurs when the amount of calcium and sulphate ions in the soil solution is high (Porta and Herrero 1990; Poch et al. 2018). These ions can emanate from the dissolution of calcium sulphates contained in rocks, the alteration of limestone, carbonates of biological origin, or sulphate-bearing formations (Poch et al. 2018), as is the most probable case considering the geological and environmental setting where the site is located.

Gypsum appears in all the microstratigraphic units observed and in multiple forms. Natural sediments at Qdeir derive from gypsiferous deposits (Pliocene formation, see Fig. 4) and contain high concentrations of sand-sized lenticular gypsum crystals. Even so, other gypsic pedofeatures are observed, which affect both gypsums from inherited natural sediments and secondary formations.

Pedogenic formations comprise microcrystalline xenotopic-lenticular aggregations found in biopores previously created by earthworms (Fig. 7a), which served as a passage for gypsum-saturated water to flow. Occasionally, lenticular gypsum forms have been observed coating pores. Lenticular crystals are also observed in the groundmass, likely to form in situ, although some may be incorporated into the groundmass after the disruption of pore infillings by biological activity (Poch et al. 2018). Sometimes lenticular gypsum contains impurities acquired from the surrounding groundmass as thin dusty lines corresponding to earlier growth stages that, along with the presence of swallow-tail twinning and calcite outlining previous gypsum growth phases, are indicative of seasonal changes in environmental conditions during gypsum growth (Poch et al. 2018) (Fig. 7b). Other gypsic pedofeatures comprise the dissolution of gypsum crystals evidenced by the presence of lenticular pseudomorphic voids that implies paleoclimatic changes from arid to more humid conditions (Poch et al. 2018 and references therein) (Fig. 7c).

Gypsum precipitation and associated pedogenic features contribute to the gypsoturbation of the archaeological deposits, which implies the pushing action and concomitant deformation produced by gypsum that, in turn, generates new voids where new gypsic features can occur (Herrero et al. 1992; Casby-Horton et al. 2015). Subsequently, these processes lead to the appearance of crack structures in architectural features, especially on mud plaster floors, favouring their collapse and breakdown and contributing to the deformation of vesicles, resulting in polyconcave vughs. Additionally, we should consider cracks and fissures caused by the aridity of the environment, enhancing shrink-swell action.

Among occupation deposits, gypsoturbation slightly affects the orientation and distribution of the inclusions and contributes to the attenuation of the boundaries between microstratigraphic units. Furthermore, fragile anthropogenic materials such as charred plant remains or bones will likely be more fragmented. Indeed, other post-depositional processes were identified amongst bones. In some cases, the internal structure of the bone has been mineralised and replaced by calcite. Likewise, on other occasions, bones appear weathered and show the initial stages of secondary mineral formation, presumed to be apatite (Fig. 7d).

Another leading cause of post-depositional alteration is bioturbation by faunal activity. It is well attested in thin-section by the appearance of channels and chambers in the deposits, sometimes containing earthworm pellets, which

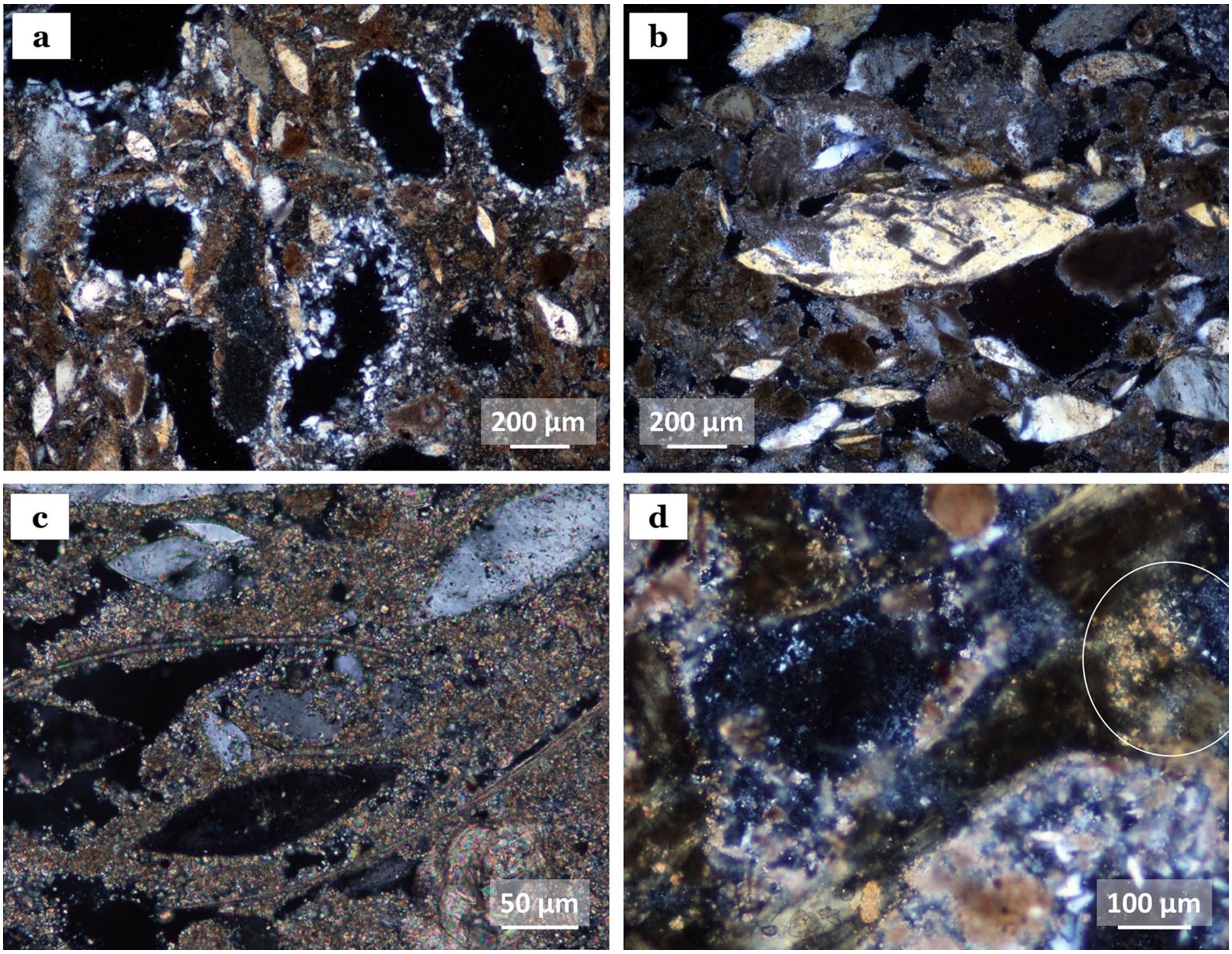


Fig. 7 Photomicrographs of taphonomical processes identified in thin-section: **a**) Secondary gypsum coating biopores, XPL; **b**) Lenticular gypsum crystal containing impurities of earlier growth stages, XPL; **c**) Lenticular pseudomorphic voids after gypsum dissolution, XPL; **d**) Poorly preserved bone fragment showing initial replacement stages by secondary mineral formation, XPL

are responsible for the increase of porosity and formation of new aggregates (Babel 1975). This phenomenon mainly affects occupation deposits as they are easy to break through and contain higher amounts of organic matter and, therefore, are more attractive to micro-organisms. Certainly, soil mesofauna may have contributed to the poor preservation of archaeobotanical remains (Stein 1983; van Vliet et al. 1993; van Vliet and Hendrix 2007), especially in arid environments.

Discussion

This section further explores different aspects of floor plaster manufacture at Qdeir, focusing first on the materials, resource management strategies and techniques, then on the comparison between floor sequences according to contextual and temporal variation, and finally examining gypsum plasters from Qdeir within a broader regional context, comparing them to other practices at neighbouring sites to provide a deeper understanding on resource use and human-environment interactions more widely.

Resource management and technology in floor-plaster manufacture

The archaeological site of Qdeir is located on a gypsum bed and a few hundred metres from the *wadi* Qdeir. All the raw materials employed in the site were available on the site itself or nearby, except obsidian (Orange et al. 2019) and wood, which would require to be collected from the steppe or from the upper levels of the remaining hills (Chambrade 2012), as vegetation was affected by wind erosion and gypsum in soil. The analysis conducted at Qdeir indicates that the geology and soils of the el Kowm oasis were advantageously used in the manufacture of floor plasters. Micromorphological observations show that local carbonate sediments and gypsum were selected and manipulated to produce diverse floor-plaster types.

Mud plaster floors

The sediments used to manufacture mud plaster floors were probably collected from alluvial deposits, as indicated by the fine matrix and absence of pedogenic gypsum or aeolian sands, which align with the location of the site near *wadis*. However, mud plaster floors vary according to the presence/absence of coarse materials, such as gypsum rock fragments and anthropogenic debris, which could suggest two different sourcing strategies. Where present, anthropogenic microresidues and coarse elements are randomly distributed and only slightly oriented within the floor matrix. The fact that these inclusions do not tend to accumulate near the upper boundary challenges their interpretation as trampled materials. Their occurrence, therefore, suggests that sediments used to manufacture heterogeneous mud plasters could have been collected close to the surface and / or mixed near occupied areas. The extraction of materials from pits dug directly on site is a well-documented form of resource exploitation in both archaeological and ethnoarchaeological contexts, often referred to as sedimentary recycling (Berna 2017; Lorenzon 2023). On the other hand, sediments to produce homogeneous mud plasters could have been obtained closer to water courses or extracted after surface removal. Using materials readily available near a construction site may reflect strategies to achieve efficient solutions in terms of labour and time. Alternatively, we cannot rule out the hypothesis that sediments were sieved. The sparse quantity of plant impressions suggests these may not have been intentionally added as stabiliser, and therefore could have been incorporated from the source or mixing area.

Both types of mud plaster floors are present in similar numbers (16 heterogeneous and 12 homogeneous). These were likely manufactured following the same process known as direct shaping (Friesem et al. 2017), consisting of the application of layers that were smoothed flat to cover the whole surface until the desired thickness and density were achieved. The absence of vesicles or polyconcave vughs indicates that the sediments were mixed and applied under slightly wet, plastic conditions (Cammas 2003, 2018; Wattez 2003). The nature of the silty clay sediments, along with the fluctuating moisture conditions in this region, contributed to the development of shrink-swell processes that affected these deposits causing several fractures and fissures.

Gypsum plaster floors

Gypsum was also a frequently used material at the site and was locally available. The ways in which gypsum appears and accumulates are highly varied, including small crystals, cemented gypsum sands, large crystals forming low permeability horizons, and gypsum crusts (Furley and Zouzou 1989). The widespread use of gypsum for architectural purposes and the manufacture of gypsum vessels (Maréchal 1982) suggests that gypsum was a crucial resource for the communities inhabiting Qdeir. In order to produce gypsum plaster floors, gypsum rocks, widely available around the site, should have been burnt. Once the materials had cooled down, they required water to be transformed into gypsum to get a suitable paste (Kingery et al. 1988; Nilhamn et al. 2006). After mixing, the plaster needed to be applied shortly after. This process of reverting hemihydrate gypsum with water was easy if burning temperatures were low, not exceeding 260ºC, otherwise the material forms insoluble β-anhydrite (β- $CaSO_4$) that cannot readily revert to its original state and no longer binds (Nilhamn and Kume 2024). Interestingly, micromorphological results of gypsum plasters from Qdeir revealed the presence of bassanite ($CaSO_4 \cdot 1/2H_2O$) embedded in the gypsum mass, which indicates that once gypsum rocks were heated and dehydrated and then mixed with water, some fragments were not completely transformed. This is an interesting fact as a greater or lesser presence of these elements could indicate different degrees of specialization and control over firing temperatures in carrying out the transformation of gypsum.

Microscopic examination of gypsum plasters also enabled the identification of burnt herbivore dung. Its exclusive and recurrent presence within the gypsum floors, alongside the existence of areas specifically designated for animal stabling at the site (Stordeur and Wattez 1998), indicates that its inclusion was not coincidental. Ruminant excrement is commonly used in vernacular architecture (Doat et al. 1991; Reddy 1998; Boivin 2000; Berna 2017; Vissac et al. 2017) and has been attested in few archaeological gypsum plasters (Goren and Goldberg 1991; Dudgeon 2023). Its presence in architectural materials is due to the many partially decomposed cellulose fibres, which are easy to mix with other elements and contribute to the building materials' cohesion and resistance, making plaster more tensile, improving water resistance and reducing cracking (Norton 1986; Houben and Guillaud 2001; Vissac et al. 2017). Moreover, when mixed with the gypsum paste, dung additives may have retarded crystal development to reduce the plaster setting time (Kingery et al. 1988). However, in the case of Qdeir, animal dung appears burnt, therefore changing the properties of excrement as an additive and pointing to its use as fuel.

The extensive use of gypsum at the site would have required a substantial fuel supply. In this regard, the microscopic identification of burnt herbivore dung in gypsum floors provides direct evidence of the use of animal dung as fuel. Dung fuel can reach high temperatures of around 800–1000ºC (Matthews 2010; Vergès et al. 2016), enough to produce gypsum plaster and burns more evenly and slowly than wood (Sillar 2000), despite creating unhealthier environments, especially indoors (Shillito et al. 2022).

The sporadic appearance of darkened and expanded spherulites associated with burnt herbivore dung could indicate that burning temperatures to obtain gypsum plaster occasionally reached about 500–700ºC. The use of animal dung as fuel is particularly significant considering the scarcity of other materials in the area, such as wood, and the prominence of pastoralism as an economic activity in the region. Penning deposits were identified within the site through thin-section micromorphology displaying compressed layers of animal dung containing calcitic spherulites along with herbaceous phytoliths, possibly related to sheep/goat according to the zooarchaeological analyses (Gourichon 2004). Therefore, herbivore dung was probably collected when animals were penned on or near the site.

Interestingly, the ethnographic study by Maréchal and Aurenche (1985) reveals that animal dung was still used mixed with chaff in the early 80s by the community of the modern village of Qdeir as fuel to obtain gypsum plaster. The dung used was collected from cleaning penning areas. The process, carried out by women, involved digging shallow pits on the outskirts of the village to minimize air pollution. Crushed gypsum fragments were placed in these pits, covered with mixed animal dung and chaff, and burned for 24 to 36 h. Afterwards, the material was left to cool for several days before being collected. Despite thorough cleaning, ash residues inevitably mixed with the calcined gypsum during collection, which could help explain the presence of microscopic fragments of burnt dung and ash aggregates observed in the archaeological gypsum plasters. Compared to other methods to obtain gypsum plaster, such as kiln firing, open fires are less time-consuming but enable less control of fire conditions, therefore the dehydrated gypsum obtained is less pure (Kume 2013), which could explain the presence of bassanite in Qdeir's gypsum plasters.

Altogether, this suggests that herbivore dung at Qdeir was probably selected due to a combination of factors. These factors include: the scarcity of alternative fuel sources, likely indicating the scarcity of woody plants in the region also in the past; the properties of animal dung as fuel; and the benefits regarding waste management in case dung was collected from animal pens, as penning deposits can be a significant route for the transmission of infectious diseases. As a result, herbivore dung provided a sustainable solution that was not only well-suited to the local ecology but also aligned with the technological needs for gypsum transformation.

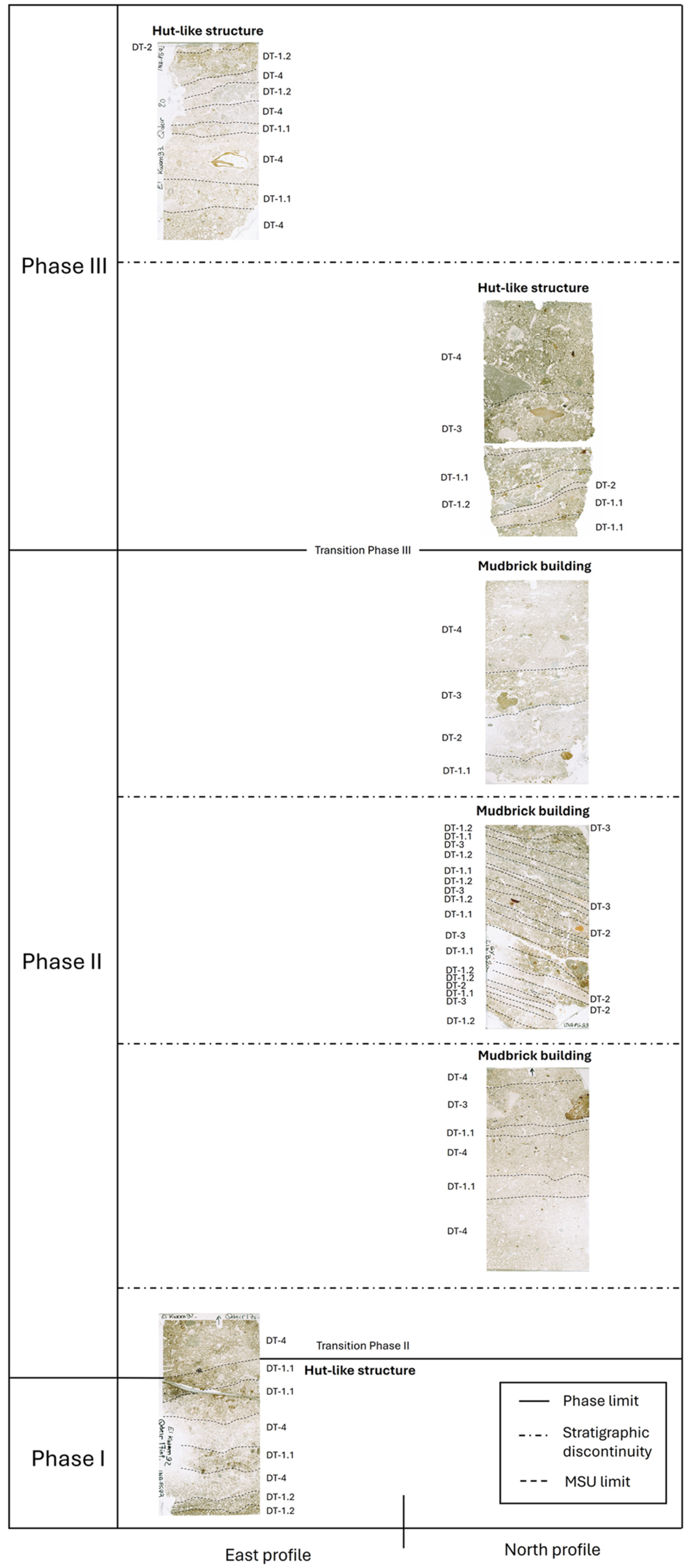
Floor sequences and contextual variation

The samples analysed in this study show certain variability among floor sequences according to contextual information and temporal variation in the patterning of floor types and the presence/absence of occupation and natural deposits following the different phases established at the site (Fig. 8). Floor sequences recorded in thin-section attributed to Phase I display a series of mud plaster floors alternated with deposits rich in sediment aggregates induced by wind action. The absence of occupation deposits suggests that activities carried out on top of constructed floors did not leave any traces on the surface or were regularly cleaned. This is a common feature observed in various micromorphological studies with a particular focus on floors, regardless of their geographical setting or chronology (Karkanas and Van de Moortel 2014; Mateu et al. 2019; Sisa-López de Pablo et al. 2024; Tomé et al. 2024). Additionally, this would indicate a period of brief abandonment before the construction of a new floor, possibly indicating certain seasonality in the use of the structures. Indeed, this would be further supported by the low preservation of the floors during this phase due to post-depositional processes.

Samples studied from Phase II show greater variability despite that both heterogeneous and homogeneous mud plaster floors are present in similar quantities. In contrast to Phase I and III, gypsum plasters are notably more common in Phase II. Also of note is the absence of natural deposits, which are only observed at the beginning and at the end of the sequence, possibly indicating a period of non-occupation or general abandonment, and the presence of occupation deposits between constructed floors, which are only present during this phase. Sequences analysed from Phase III are similar to Phase I in that they usually alternate constructed floors with naturally-laid deposits or poorly preserved floors, likely indicating the semi-permanent character of the occupation, although greater continuity is apparent during the earlier occupation of this phase, as demonstrated by the succession of mud plaster floors, one of which coated with gypsum.

The semi-permanent character of the occupations observed in floor sequences at Qdeir is consistent with faunal data (Gourichon 2004), which point to alternating periods of site use reflected in gazelle hunting, caprine mortality profiles, and the presence of migratory birds. These observations indicate that human populations inhabited Qdeir primarily during spring and autumn, possibly on a regular basis, with some occupations extending from autumn through to spring. The faunal assemblage also suggests that

Fig. 8 Diagram showing the micromorphological thin-sections analysed with MSU identified and related DT



the site was not occupied during the summer months. These interpretations could explain certain observations in thin-section, such as the presence of natural deposits between floors and sequences of resurfaced floors, which may reflect varying intensities and durations of occupation.

Taken together, the variation in building materials across phases suggests different concepts of space or spatial conventions through time, as gypsum plasters mainly appear during Phase II in contrast to Phase I, when they are absent, or Phase III, when they are very sparse. Differences also concern the homogeneity of mud plaster floors and the intensity of the occupations between phases I and III. Interestingly, no levelling floors were identified, indicating that floor plasters were laid directly on top of the surface, except for gypsum plasters, which were only laid on previously constructed surfaces.

Differences regarding occupation deposits are also of note, as they are exclusively associated with Phase II, although exhibiting very thin thicknesses and still considerably fewer in number compared to constructed floors, suggesting that interior spaces during Phase II were actively maintained through cleaning practices. This phase is interpreted as representing a more intensive period of occupation, evidenced by the repeated resurfacing events and the absence of naturally laid deposits. The absence of comparable occupation residues in phases I and III is therefore particularly striking, raising further questions about the nature and duration of site use across the different occupational phases. Microstratigraphic sequences recorded in phases I and III point to more ephemeral occupations, as suggested by the excavators according to the architectural features observed in the field. While maintenance of floors is typically associated with high-intensity, long-term habitation, its presence in this context raises questions about the nature of occupation among semi-mobile groups. The evidence of constructed floors with clean surfaces suggests that even within non-permanent occupations, investment in built space may reflect recurring or seasonally patterned re-use, and/or increased associations with place. It also implies a degree of foresight and organisation. Indeed, if these spaces were revisited regularly, maintenance could represent a shared communal investment or even a symbolic anchoring of social memory. Finally, the sporadic presence of gypsum floors in Phase III challenges the assumption of gypsum plasters occurring in permanent occupations linked to mudbrick architecture, which is suggestive of the complex relation between building materials and space use and management within the context of mobile communities. Altogether, these observations suggest that the dichotomy between mobile and sedentary lifeways among early farming communities may be overly simplistic and show a nuanced occupation strategy that contributes to broader discussions about the emergence of sedentism.

Gypsum plasters at Qdeir in a regional context

Plaster floors and objects are widely distributed throughout SW Asia. However, when distinguishing between lime plaster and gypsum plaster based on their differing technologies, some scholars have argued for the distinction of different technocomplex areas (Kingery et al. 1988). Indeed, previous studies have emphasized variations in both gypsum and lime plaster production practices both between sites and within individual sites.

Gypsum plasters were commonly found at the sites of El Kowm-2 (Maréchal 1982) and Umm-el-Tlel (Molist et al. 1992), both of which are contemporaneous with Qdeir and located in the same region. However, unlike Qdeir, these are settlements characterised by sedentary farming lifeways. The semi-nomadic character of Qdeir is not a compelling reason to dismiss the production of gypsum plaster, usually associated with more permanent settlements, which was likely well-known in the region. Consequently, the use of gypsum plaster in those sites indicates a deep understanding of local material properties and suggests a potentially established engagement with the natural environment, as well as an interconnectedness among the communities inhabiting the El Kowm area and nearby.

Evidence from sites along the Middle Euphrates and in wider Northern Syria indicates that both gypsum and lime plasters were employed. In the southernmost zone, gypsum predominates at sites such as Bouqras (Van Zeist and Waterbolk-Van-Rooijen 1985) and Abu Hureyra (Kingery et al. 1988; Le Mière 2000). In contrast, the northernmost region shows a predominance of lime, particularly in architectural elements, at sites like Tell Halula (Molist et al. 2021; Sisa-López de Pablo et al. 2024). Further east, in the Balikh and Khabour valleys, gypsum was the primary material used for plaster production during the Neolithic (Kirkbride 1973; Kingery et al. 1988; Rehhof et al. 1990; Nishiaki and Le Mière 2005), although both materials are sometimes documented simultaneously as in Sabi Abyad (Nilhamn and Koek 2013). As some authors have noted, the choice between gypsum and lime plaster likely depended on several factors, including the local geology, the availability of fuel sources, economic considerations, technological expertise, and the intended function of the plaster (Nilhamn et al. 2006).

The application of microarchaeological techniques, such as soil micromorphology, enabling the simultaneous analysis of the fabric and inclusions in plasters in their precise context is relatively limited compared to the research focused on the chemical composition of plasters. New approaches applying microscopic multi-proxy techniques including phytolith and calcitic spherulite analyses have also provided valuable information on gypsum plaster production, despite lacking micro-contextual in situ information. For example, the study by Dudgeon (2023) identified the presence of animal dung in gypsum plasters from Abu Hureyra, proposing its use as an additive. In contrast, the micromorphological analysis of plasters from Qdeir reveals the use of animal dung as fuel. This distinction highlights how these techniques reveal different applications of other materials apart from gypsum, such as herbivore dung, in gypsum plaster production. Such findings are significant as they provide insights into human-animal-environment interactions, shedding light on local innovations and adaptations in different ecoregions, as well as on cultural and technological practices. Whether dung was similarly incorporated into plasters at other sites remains unknown, underscoring the need for microscopic analyses on undisturbed samples on a broader scale to clarify shared practices or site-specific choices among settlements in nearby regions.

Conclusions

This study has demonstrated the potential of the application of soil micromorphology to analyse plaster floors and, more specifically, gypsum plasters. Micromorphological analyses are key as they provide high-resolution contextual information on the nature, structure and post-depositional alterations of plasters in greater detail, and therefore, on floor plaster making, including the selection of raw materials and technology applied. The case study presented in this paper allowed the examination of resource management, plaster manufacture and taphonomy of floors in a specific environmental setting characterised by its aridity.

The process of selection and modification of natural materials at Qdeir demonstrates a profound knowledge of local material properties. The identification of herbivore dung burnt within the gypsum matrices of gypsum floors indicates its use as fuel to dehydrate gypsum rocks to manufacture gypsum plaster. Dung was, hence, likely a major fuel source due to its burning properties, the absence of woody plants in the area and the focus on animal husbandry. The incorporation of herbivore dung as fuel to produce gypsum, rather than as an additive, emphasises the ability of the community to manage available materials and reveals sustainable practices, particularly in the context of limited fuel sources. The use of locally sourced gypsum, alongside innovative techniques for its transformation into plaster, further supported by ethnographic studies in the region, reflects a deep understanding of local material properties and adaptation to the region's ecological constraints. Analysis of wider sets from other sites, including thin-sections from other gypsum-based craft materials, such as white-ware vessels, will provide further information on resource use, management, and technology.

The variability in floor sequences across different phases identified at Qdeir provides valuable insights into the dynamics of space use and occupation patterns, potentially linked to seasonal or semi-permanent settlement strategies. In this regard, plaster manufacture was probably not uniform across the site and could have varied between households or over generations, as reflected in the number and appearance of mud and gypsum plasters. Another reason that could potentially explain differences in frequencies between mud and gypsum plasters could hypothetically be related to the sustainable management of fuel sources. A larger sampling is needed to enable a more reliable interpretation of changes in building practices between different spaces over time.

The comparison of gypsum plaster at Qdeir with other regional sites reveals both shared practices and distinctive choices, underlining the complexity of material culture and technological practices in SW Asia during the Neolithic transition. Overall, these findings contribute to a broader understanding of human-environment interactions, technological innovation, and possible site-specific traditions more widely, as lime and gypsum plasters became widespread during the Early Neolithic in SW Asia.

Acknowledgements This work was supported by a Doctoral Training Studentship Grant of the Ministerio de Ciencia, Innovación y Universidades, Gobierno de España, under the project "Procesos de transferencia e interacción social en el Neolítico del Próximo Oriente: estudio de los ámbitos del Valle del Éufrates y altiplanos del Zagros" (project reference HAR2016-78416-P) led by Miquel Molist (GRAMPO-SAPPO) at the Universitat Autònoma de Barcelona. We are very grateful to Dr Fredderic Abbès for providing contextual information and graphic material notwithstanding the fact that the site's final monographic volume is still unpublished. We also wish to thank the anonymous reviewers for their constructive comments and valuable suggestions, which contributed to improving the quality and clarity of this manuscript.

Author contributions Conceptualization, JSLdP; writing—original draft preparation, JSLdP; writing—review and editing, JSLdP, JW, RP, MM. All authors have reviewed and agreed to the published version of the manuscript.

Funding Open Access Funding provided by Universitat Autonoma de Barcelona.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

References

Abbès F (2015) La steppe syrienne lieu de parcours et d'échanges Durant Le néolithique précéramique. In: Naudinot N, Meignen L, Binder D, Querré G (eds) Les systèmes de mobilité de La préhistoire. Actes des XXXVe recontres internationales d'archéologie et d'histoire d'antibes Au Moyen âge. APDCA, Antibes, pp 261–272

Abbès F (2019) Vivre la Steppe. Qdeir un campament neolithique en Syrie. Éditions de la Sorbonne, París

Aurenche O (1981) La Maison orientale: l'architecture du proche orient ancien des origines Au milieu du quatrieme millenaire. P. Geuthner, París

Aurenche O, Desfargues P (1983) Travaux d'ethnoarchéologie En syrie et En Jordanie. Rapports Préliminaires Syria 60(1/2):147–185

Babel U (1975) Micromorphology of soil organic matter. In: Gieseking JE (ed) Soil components, 1: organic components. Springer, New York, pp 369–473

Bar-Yosef O, Goring-Morris A (1977) Geometric Kebaran a occurrences. In: Bar-Yosef O (ed) Prehistoric investigations in Gebel maghara, Northern Sinai. Qedem, Jerusalem, pp 331–368

Barnett WK (1991) Optical petrography as a tool for examining gypsum and lime plaster pyrotechnology. J Field Archaeol 18(2):253–255. https://doi.org/10.1179/009346991792208290

Berna F (2017) Geo-ethnoarchaeology study of the traditional Tswana Dung floor from the Moffat mission church, kuruman, North cape province, South Africa. Archaeol Anthropol Sci 9(6):1115–1123. https://doi.org/10.1007/s12520-017-0470-0

Besançon J, Sanlaville P (1985) Le Milieu Geographique. In: Sanlaville P (ed) Holocene Settlement in North Syria: Resultats de Deux Prospections Archéologiques Effectuées Dans la Région Du Nahr Sajour Et Sur Le Haut Euphrate Syrien. BAR International Series 238 Archaeopress, Oxford, pp 7–22. https://doi.org/10.30861/9780860543077

Besançon J, Copeland L, Hours F, Muhesen S, Sanlaville P (1982) Prospection géographique et préhistorique Dans Le Bassin d'el Kowm (Syrie). Rapport préliminaire. Cahiers De l'Euphrate 3:9–26

Boivin N (2000) Life rhythms and floor sequences: excavating time in rural Rajasthan and neolithic Catalhoyuk. World Archaeol 31(3):367–388. https://doi.org/10.1080/00438240009696927

Brönnimann D, Ismail-Meyer K, Rentzel P, Pümpin C, Lisá L (2017) Excrements of herbivores. In: Nicosia C, Stoops G (eds) Archaeological soil and sediment micromorphology. Wiley, Hoboken, pp 55–65. https://doi.org/10.1002/9781118941065.ch7

Bullock P, Fedoroff N, Jonguerius A, Stoops G, Tursina T, Babel U (1985) Handbook for soil thin section description. Waine Research, Albrighton

Cammas C (2003) L'architecture En Terre crue à l'âge du fer et à l'époque romaine: apports de La discrimination micromorphologique des modes de mise En oeuvre. In: Chazelles CA, Klein A (eds) Échanges transdisciplinaires Sur les constructions En Terre crue, 1, Terre modelée, Découpée Ou coffrée: matériaux et modes de mise En oeuvre, actes de La table Ronde de Montpellier (17–18 novembre 2001). Editions de l'Espérou, Montpellier, pp 33–53

Cammas C (2018) Micromorphology of Earth Building materials: toward the reconstruction of former technological processes (Protohistoric and historic Periods). Quat Int 483:160–179. https://doi.org/10.1016/j.quaint.2018.01.031

Canti MG (2003) Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. CATENA 54(3):339–361. https://doi.org/10.1016/S0341-8162(03)00127-9

Canti MG, Nicosia C (2018) Formation, morphology and interpretation of darkened faecal spherulites. J Archaeol Sci 89:32–45. https://doi.org/10.1016/j.jas.2017.11.004

Casby-Horton S, Herrero J, Rolong NA (2015) Gypsum soils-Their morphology, classification, function, and landscapes. Adv Agron 130:231–290. https://doi.org/10.1016/bs.agron.2014.10.002

Cauvin J (1994) Naissance des divinités, naissance de l'agriculture: La révolution des Symboles Au néolithique. CNRS éditions, París

Chambrade ML (2012) Dynamique spatio-temporelle et environnement des sites néolithiques précéramiques de Syrie intérieure. Dissertation, Université de Franche-Comt&#233

Chu V, Regev L, Weiner S, Boaretto E (2008) Differentiating between anthropogenic calcite in plaster, Ash and natural calcite using infrared spectroscopy: implications in archaeology. J Archaeol Sci 35(4):905–911. https://doi.org/10.1016/j.jas.2007.06.024

Clarke J (2012) Decorating the neolithic: an evaluation of the use of plaster in the enhancement of daily life in the middle pre-pottery neolithic b of the Southern levant. Camb Archaeol J 22:177–186. https://doi.org/10.1017/S0959774312000224

Courty MA, Goldberg P, Macphail RI (1989) Soils and micromorphology in archaeology. Cambridge University Press, Cambridge

De Contenson H, Courtois L (1979) A Propos des vases En Chaux recherches Sur leur fabrication et leur origine. Paléorient 5:177–182

Doat P, Hays A, Houben H, Matuk S, Vitoux F (1991) Building with Earth. The Mud Village Society, New Delhi

Dudgeon K (2023) Insights into resource management and technological development through microbotanical and Geoarchaeological characterisation of floor plasters from neolithic Abu hureyra, syria, 8600– 6000 cal. BC Quat Int 655:55–68. https://doi.org/10.1016/j.quaint.2023.02.007

Friesem D, Wattez J, Onfray M (2017) Earth construction materials. In: Nicosia C, Stoops G (eds) Archaeological soil and sediment micromorphology. Wiley, Chichester, pp 99–110. https://doi.org/10.1002/9781118941065.ch10

Friesem D, Abadi I, Shaham D, Grosman L (2019) Lime plaster cover of the dead 12,000 years ago–new evidence for the origins of lime plaster technology. Evol Hum Sci 1(e9):1–23. https://doi.org/10.1017/ehs.2019.9

Furley PA, Zouzou R (1989) The origin and nature of gypsiferous soils in the Syrian mid-Euphrates. Scott Geogr Mag 105(1):30–37

Garfinkel Y (1987) Burnt lime products and social implications in the Pre-Pottery neolithic B villages of the near East. Paléorient 13(1):69–76

Gé T, Courty MA, Matthews W, Wattez J (1993) Sedimentary formation processes of occupation surfaces. In: Goldberg P, Nash DT, Petraglia MD (eds) Formation processes in archaeological context. Monographs in world archaeology. Prehistoric, Madison, pp 149–164

Goren Y, Goldberg P (1991) Special studies: petrographic thin sections and the development of neolithic plaster production in Northern Israel. J Field Archaeol 18(1):131–140. https://doi.org/10.1179/009346991791548735

Goren Y, Goring-Morris AN (2008) Early pyrotechnology in the near east: experimental lime-plaster production at the Pre-Pottery neolithic B site of Kfar hahoresh, Israel. Geoarchaeology– Int J 23(6):779–798. https://doi.org/10.1002/gea.20241

Goren Y, Goring-Morris AN, Segal I (2001) The technology of skull modelling in the Pre-Pottery neolithic B (PPNB): regional variability, the relation of technology and iconography and their archaeological implications. J Archaeol Sci 28:671–690. https://doi.org/10.1006/jasc.1999.0573

Goring-Morris N, Horwitz LK (2007) Funerals and feasts during the Pre-Pottery neolithic B of the near East. Antiquity 81(314):902–919. https://doi.org/10.1017/S0003598X00095995

Goring-Morris AN, Goldberg P, Goren Y, Baruch U, Bar-Yosef DE (1997) Saflulim: a late Natufian base camp in the central Negev highlands, Israel. Palestine Explor Q 131(1):36–64. https://doi.org/10.1179/peq.1999.131.1.36

Gourdin WH, Kingery WD (1975) The beginnings of pyrotechnology: neolithic and Egyptian lime plaster. J Field Archaeol 2(1–2):133–150. https://doi.org/10.1179/009346975791491277

Gourichon L (2004) Faune et saisonnalité: l'organisation temporelle des activités de subsistance dans l'Épipaléolithique et le Néolithique précéramique du Levant nord (Syrie). Dissertation, Université Lumière-Lyon II

Grosman L, Raz T, Friesem DE (2020) Tomorrow's mundane is today's extraordinary: A case study of a plastered installation during neolithization. Humanit Soc Sci 7(1):1–13. https://doi.org/10.1057/s41599-020-00579-8

Guilloré P (1983) Méthode de fabrication mécanique et En séries des lames minces. Département des sols. INA-PG J Soil Sci 29:585–587

Hauptmann A, Yalcin Ü (2000) Lime plaster, cement and the first puzzolanic reaction. Paléorient 26(2):61–68. https://doi.org/10.3406/paleo.2000.4710

Herrero J, Porta J (2000) The terminology and the concepts of gypsum-rich soils. Geoderma 96(1–2):47–61. https://doi.org/10.1016/S0016-7061(00)00003-3

Herrero J, Porta J, Fedoroff N (1992) Hypergypsic soil micromorphology and landscape relationships in Northeastern Spain. Soil Sci Soc Am J 56(4):1188–1194. https://doi.org/10.2136/sssaj1992.03615995005600040031x

Herrick HM, Berna F (2024) A review of methods to analyze archaeological lime production: investigating Raw materials selection and firing conditions. J Archaeol Method Theory 31:1668–1694. https://doi.org/10.1007/s10816-024-09652-x

Houben H, Guillaud H (2001) Earth construction. A comprehensive guide. Intermediate Technology, London

Ilaiwi M (1983) Contribution to the knowledge of the soils of Syria. Dissertation, University of Ghent

Ilaiwi M (1985) Soil map of Arab countries, soil map of Syria and Lebanon. The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Damascus

Karkanas P (2007) Identification of lime plaster in prehistory using petrographic methods: a review and reconsideration of the data on the basis of experimental and case studies. Geoarchaeology–Int J 22(7):775–796. https://doi.org/10.1002/gea.20186

Karkanas P, Goldberg P (2019) Reconstructing archaeological sites: Understanding the Geoarchaeological matrix. Wiley-Blackwell, Oxford. https://doi.org/10.1002/9781119016427

Kingery WD, Vandiver PB, Prickett M (1988) The beginnings of pyrotechnology, part II: production and use of lime and gypsum plaster in the Pre-Pottery neolithic near East. J Field Archaeol 15(2):219–243. https://doi.org/10.1179/009346988791974501

Kirkbride D (1973) Umm Dabaghiyah 1973: A third preliminary report. Iraq 35(2):205–209. https://doi.org/10.2307/4199965

Kuijt I, Goring-Morris N (2002) Foraging, farming, and social complexity in the Pre-Pottery neolithic of the Southern levant: a review and synthesis. J World Prehist 16(4):361–440. https://doi.org/10.1023/A:1022973114090

Kume S (2013) Gypsum plaster manufacturing in Northeast syria: an ethnographic case study. In: Nishiaki Y, Kashima K, Verhoeven M (eds) Neolithic archaeology in the Khabur valley, upper Mesopotamia and beyond. SENEPSE 15. Ex oriente, Berlin, pp 80–95

LaMotta VM, Schiffer MB (1999) Formation processes of house floor assemblages. In: Allison P (ed) The archaeology of household activities. Routledge, London, pp 19–29

Leslie AB, Hughes JJ (2002) Binder microstructure in lime mortars: implications for the interpretation of analysis results. Q J Eng Geol Hydrogeol 35(3):257–263. https://doi.org/10.1144/1470-923601-2

Lorenzon M (2023) Earthen architecture as a community of practice: A case study of neolithic earthen production in the Eastern mediterranean. Camb Archaeol J 33(4):601–618. https://doi.org/10.1017/S0959774323000033

MacKenzie WS, Adams AE, Brodie KH (2017) Rocks and minerals in thin section. CRC, London. https://doi.org/10.1201/9781315116365

MacPhail RI, Goldberg P (2018) Applied soils and micromorphology in archaeology. Cambridge University Press, Cambridge. https://doi.org/10.1017/9780511895562

Maréchal C (1982) Vaisselles blanches du Proche-Orient: El Kowm (Syrie) et l'usage du plâtre au Néolithique in Travaux de laboratoire. Cahiers de l'Euphrate St-André-de-Cruzières 3:217–251

Maréchal C, Aurenche O (1985) Note Sur La fabrication actuelle du plâtre à Qdeir (Syrie). MOM Éditions 47(1):405–412

Mateu M, Bergadà MM, Armada X-L, Rafel N (2019) Micromorphology of the early Iron age semi-cemented floors: El calvari Del molar (Tarragona, NE Spain) as case study. J Archaeol Science: Rep 23:746–762. https://doi.org/10.1016/j.jasrep.2018.11.028

Matthews W (1996) Microstratigraphy, micromorphology and sampling report. Qatalhoytik Archive Report. Website address: http://www.catalhoyuk.com/archive_reports/1996/ar96_07.html

Matthews W (2005) Micromorphological and microstratigraphic traces of uses and concepts of space. In: Hodder I (ed) Inhabiting çatalhöyük: reports from the 1995-99 seasons. McDonald Institute for Archaeological Research and British Institute of Archaeology at Ankara, Cambridge, pp 355–398

Matthews W (2010) Geoarchaeology and taphonomy of plant remains and Microarchaeological residues in early urban environments in the ancient near East. Quat Int 214(1–2):98–113. https://doi.org/10.1016/j.quaint.2009.10.019

Mees F, Tursina TV (2018) Salt minerals in saline soils and salt crusts. In: Stoops G, Marcelino V, Mees F (eds) Interpretation of micromorphological features of soils and regoliths. 2nd Edition, Elsevier, Amsterdam, pp 289–321. https://doi.org/10.1016/B978-0-444-63522-8.00011-5

Mentzer SM (2018) Micromorphological analyses of anthropogenic materials and insights into tell formation processes at Aşıklı höyük, 2008–2012 field seasons. In: Ozbasaran M, Duru G, Stiner M (eds) The early settlement of Aşıklı höyük: essays in honor of Ufuk Esin. Yayinlari, Estambul, pp 105–128

Mière M Le (2000) Pottery and plaster analysis. In: Moore AMT, Hillman GC, Legge AJ (eds) Village on the euphrates: from foraging to farming at Abu Hureyra. Oxford University Press, Oxford, pp 532–533

Mohammed S, Khallouf A, Kiwan S, Alhenawi S, Ali H, Harsányo E, Kátai J, Habib H (2020) Characterization of major soil orders in Syria. Eurasian Soil Sci 53:420–429

Molist M, Stordeur D, Alcalde G, Anfruns J (1992) Umm El Tlel i Qdeir (Siria): noves aportacions a l'estudi de La prehistòria de les zones desèrtiques Del pròxim orient. Tribuna D'arqueologia 1989–90:41–52

Molist M, Gómez-Bach A, Faura J, Gangonells M, López C, Breu A, Sisa J (2021) White ware or Vaiselle Blanche in the Chrono-Cultural and technological context of the first ceramic productions at tell Halula (Euphrates Valley). In: Özbal R, Erdalkiran M, Tonoike Y (eds) Neolithic pottery from the near east. Production, distribution and use. Koç University, Istanbul, pp 13–24

Moore AMT, Hillman GC, Legge AJ (2000) Village on the euphrates: from foraging to farming at Abu Hureyra. Oxford University Press, Oxford

Mylona P, Pomadère M (2021) The contribution of soil micromorphology in Understanding the use of space in area Pi at Malia (Crete). J Archaeol Sci: Rep 36:102785. https://doi.org/10.1016/j.jasrep.2020.102785

Nicosia C, Stoops G (2017) Archaeological soil and sediment micromorphology. Wiley, Hoboken, NJ. https://doi.org/10.1002/9781118941065

Nilhamn B (2024) The beaded rim: an assessment of functionality of neolithic plaster ware and pottery. Paléorient 50. https://doi.org/10.4000/12uv6

Nilhamn B, Koek E (2013) Early pottery neolithic white ware from tell Sabi abyad. In: Nieuwenhuyse O, Bernbeck R, Akkermans PMMG, Rogasch J (eds) Interpreting the late neolithic of upper Mesopotamia, vol 9. PALMA, Brepols, Turnhout, pp 289–296

Nilhamn B, Kume S (2024) Experiencing gypsum plaster. In: Düring BS, Plug JH (eds) The archaeology of the 'margins'. Studies on ancient West Asia in honour of Peter M.M.G. Akkermans. Analecta praehistorica leidensia 53. Sidestone, Leiden, pp 283–296. https://doi.org/10.59641/h66998kt.

Nilhamn B, Astruc L, Gaulon A (2006) White ware - near Eastern plaster container. In: Astruc L, Gaulon A, Salanova L (eds) Méthodes d'approche des premières productions céramiques: étude de Cas Dans les Balkans et Au levant Table-Ronde de La Maison de l'archéologie et de l'ethnologie. Verlag Marie Leidorf GmbH, Nanterre, France, pp 63–72

Nishiaki Y, Mière ML (2005) The oldest pottery neolithic of upper mesopotamia: new evidence from tell Seker al-Aheimar, the khabur, Northeast Syria. Paléorient 31(2):55–68. https://doi.org/10.3406/paleo.2005.5125

Norton J (1986) Building with earth: A handbook. Intermediate Technology Development Group Limited, United Kingdom

Orange M, Carter T, Le Bourdonnec FX (2019) Obsidian consumption at Qdeir 1, a final Pre-Pottery neolithic site in syria: an integrated characterisation study. CR Palevol 18(2):268–282. https://doi.org/10.1016/j.crpv.2018.08.002

Poch RM, Artieda O, Lebedeva M (2018) Gypsic features. In: Stoops G, Marcelino V, Mees F (eds) Interpretation of Micromorphological Features of Soils and Regoliths. Elsevier 2nd Edition, Amsterdam, pp 259–287. https://doi.org/10.1016/B978-0-444-53156-8.00010-6

Ponikarov VP (ed) (1966) The geological map of syria. Explanatory notes on the geological map of syria. scale 1:2000 000. Ministry of Industry, Syrian Arab Republic

Porta J, Herrero J (1990) Micromorphology and genesis of soils enriched with gypsum. In: Douglas LA (ed) Soil Micromorphology: A Basic and Applied Science. Developments in Soil Science, 19. Elsevier, Amsterdam, pp 321–339. https://doi.org/10.1016/S0166-2481(08)70344-1

Portillo M, Dudgeon K, Allistone G, Raeuf Aziz K, Matthews W (2021) The taphonomy of plant and livestock Dung microfossils: an ethnoarchaeological and experimental approach. Env Archaeol 26:439–454. https://doi.org/10.1080/14614103.2020.1800344

Reddy SN (1998) Fueling the hearths in India: the role of Dung in paleoethnobotanical interpretation. Paleorient 24:61–69. https://doi.org/10.3406/paleo.1998.4677

Regev L, Poduska KM, Addadi L, Weiner S, Boaretto E (2010) Distinguishing between calcites formed by different mechanisms using infrared spectrometry: archaeological applications. J Archaeol Sci 37(12):3022–3029. https://doi.org/10.1016/j.jas.2010.06.027

Rehhof L, Akkermans P, Leonardsen E, Thuesen I (1990) Plasters: gypsum or calcite?? A preliminary case study of Syrian plasters. Paléorient 16(2):79–87. https://doi.org/10.3406/paleo.1990.4534

Rentzel P, Nicosia C, Gebhardt A, Brönnimann D, Pümpin C, Ismail-Meyer K (2017) Trampling, poaching and the effect of traffic. In: Nicosia C, Stoops G (eds) Archaeological soil and sediment micromorphology. Wiley, Hoboken NJ, pp 281–297. https://doi.org/10.1002/9781118941065.ch30.

Shahack-Gross R (2011) Herbivorous livestock dung: formation, taphonomy, methods for identification, and archaeological significance. J Archaeol Sci 38(2):205–218. https://doi.org/10.1016/j.jas.2010.09.019

Shillito LM, Namdeo A, Bapat AV, Mackay H, Haddow SD (2022) Analysis of fine particulates from fuel burning in a reconstructed Building at Çatalhöyük world heritage site, turkey: assessing air pollution in prehistoric settled communities. Environ Geochem Health 44(3):1033–1048. https://doi.org/10.1007/s10653-021-01000-2

Sillar B (2000) Dung by preference: the choice of fuel as an example of how Andean pottery production is embedded within wider technical, social and economic practices. Archaeometry 42(1):43–60. https://doi.org/10.1111/j.1475-4754.2000.tb00865.x

Sisa-López de Pablo J, Bach-Gómez A, Wattez J, Molist M (2024) Rethinking the life-cycle of the house atMPPNB tell Halula. In: Sisa-López de Pablo J, Bach-Gómez A, Molist M (eds) Households and collectivebuildings in Western Asia Neolithic societies. LEMA IV, Brepols, Turnhout, pp 171–183. https://doi.org/10.1484/M.LEMA-EB.5136714

Soil Survey Staff (2022) Keys to soil taxonomy, 13th edn. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA

Stein JK (1983) Earthworm activity: a source of potential disturbance of archaeological sediments. Am Antiq 48(2):277–289. https://doi.org/10.2307/280451

Stoops G (2021) Guidelines for analysis and description of soil and regolith thin sections. 2nd Edition, Soil Science Society of America / John Wiley and Sons, Madison. https://doi.org/10.2136/guidelinesforanalysis2

Stoops G, Marcelino V, Mees F (2018) Interpretation of Micromorphological Features of Soils and Regoliths. 2nd Edition, Elsevier, Amsterdam. https://doi.org/10.1016/B978-0-444-53156-8.00028-3

Stordeur D (1993) Sédentaires et nomades du PPNB final Dans Le désert de Palmyre (Syrie). Paléorient 19(1):187–204. https://doi.org/10.3406/paleo.1993.4590

Stordeur D (2000) El Kowm 2. Une Île Dans Le désert. La fin du néolithique précéramique Dans La steppe syrienne. CNRS Éditions, Paris

Stordeur D, Wattez J (1998) À La recherche de nouvelles clés. Étude géoarchéologique de Qdeir 1, PPNB final, désert Syrien. Cahiers De l'Euphrate 8:115–138

Stordeur D, Maréchal C, Molist M (1982) El Kowm 2 caracol. Campagnes 1978, 1979, 1980. Stratigraphie et architectures. Cahiers De l'Euphrate St-André-de-Cruzières 3:33–49

Toffolo MB, Ullman M, Caracuta V, Weiner S, Boaretto E (2017) A 10,400-year-old sunken lime kiln from the early Pre-Pottery neolithic B at the Nesher–Ramla quarry (el-Khirbe), Israel. J Archaeol Sci: Rep 14:353–364. https://doi.org/10.1016/J.JASREP.2017.06.014

Tomé L, Iriarte E, Blanco-González A, Jambrina-Enríquez M, Égüez N, Herrera-Herrera AV, Mallol C (2024) Searching for traces of human activity in earthen floor sequences: high-resolution Geoarchaeological analyses at an early Iron age village in central Iberia.

J Archaeol Sci 161:105897. https://doi.org/10.1016/j.jas.2023.105897
Van de Karkanas P (2014) Micromorphological analysis of sediments at the bronze age site of mitrou, central greece: patterns of floor construction and maintenance. J Archaeol Sci 43:198–213. https://doi.org/10.1016/j.jas.2014.01.007
van Vliet PC, Hendrix PF (2007) Role of fauna in soil physical processes. In: Abbott LK, Murphy DV (eds) Soil biological fertility. A key to sustainable land use in agriculture. Springer, Dordrecht, pp 61–80. https://doi.org/10.1007/978-1-4020-6619-1_4
van Vliet PC, West LT, Hendrix PF, Coleman DC (1993) The influence of Enchytraeidae (Oligochaeta) on the soil porosity of small microcosms. In: Brussard L, Kooistra MJ (eds) Soil structure/soil biota interrelationships. Elsevier, Netherlands, pp 287–299. https://doi.org/10.1016/B978-0-444-81490-6.50028-5
Vergès JM, Burguet-Coca A, Allué E, Expósito I, Guardiola M, Martín P, Morales JI, Burjachs F, Cabanes D, Carrancho A, Vallverdú J (2016) The Mas Del Pepet experimental programme for the study of prehistoric livestock practices: preliminary data from Dung burning. Quat Int 414:304–315. https://doi.org/10.1016/j.quaint.2016.01.032
Verrecchia EP, Trombino L (2021) A visual atlas for soil micromorphologists. Springer Nature, Switzerland. https://doi.org/10.1007/978-3-030-67806-7
Vissac A, Bourgès A, Gandreau D, Anger R, Fontaine L (2017) Argiles & biopolymères-les stabilisants naturels pour La construction En Terre. CRAterre éditions, Villefontaine
Wattez J (2003) Caractérisation micromorphologique des matériaux façonnés en terre crue dans les habitats néolithiques du Sud de la France: exemple des sites de Jacques Coeur (Montpellier, Hérault), du Jas del Biau (Miliau, Aveyron), la Capoulière (Mauguoi, Hérault). In: de Chazelles CA, Klein A (eds) Échanges transdisciplinaires sur les constructions en terre crue, 1, Terre modelée, découpée ou coffrée: matériaux et modes de mise en oeuvre, actes de la table ronde (Montpellier, novembre 2001), Éditions l'Espérou, Montpellier, pp 21–31
Wattez J, Peinetti A, Onfray M, Mylona P, Eddargach W (2018) Le second oeuvre Dans les habitats pré-néolithiques, néolithiques et du début de l'âge du bronze En contextes méditerranéen et tempéré: première synthèse géoarchéologique Sur les sols construits. In: de Chazelles CA, Léal E, Klein A (eds) Construire En terre. Torchis, techniques de garnissage et de finition. Architecture et mobilier. Éditions l'Espérou, Montpellier, pp 279–292
Zeist WVan, Waterbolk-Van-Rooijen W (1985) The palaeobotany of tell bouqras, Eastern Syria. Paléorient 11:131–147. https://doi.org/10.3406/paleo.1985.4371