

Building on an oasis in Garamantian times: geoarchaeological investigation on mud architectural elements from the excavation of Fewet (Central Sahara, SW Libya)

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Abstract

The paper describes the micromorphological and mineralogical properties of earthen architectural elements from the excavation of the Garamantian compound of Fewet (Central Sahara, SW Libya), settled between the 2nd century BC and the 1st century AD, and compares this evidence with a set of samples from historical to modern context of Saharan and Sub-Saharan Africa. At Fewet, the production of mud bricks, plasters, and mortars employed in the building of the compound required raw materials available near the settlement. The earthen elements lack almost completely clay and organic temper, and their main components are quartz grains (sandy to silty) and a calcareous and slightly organic mud, available beside former springs. Only plaster and mortars show the addition (in limited quantity) of finely subdivided vegetal remains to the mixture. The

1 technology for earthen elements used in Garamantian times resembles those today applied at
2 many localities in Sub-Saharan Africa. Finally, our analyses showed that in the last millennia
3 archaeological sediments underwent limited postdepositional weathering, mostly related to solute
4 redistribution after occasional rainfalls. Today, the same process affects traditional mud brick
5 buildings.
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14 **Key-words**
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16 Earthen architectural structures; Late Holocene; Saharan oasis; Garamantian period; Technological
17 continuity.
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1. Introduction

Fewet is one of the three small oases clustered along the upper reaches of the Wadi Tanezzuft valley, in the Libyan Central Sahara (Bourbon del Monte Santa Maria, 1912). The oases of Fewet, Ghat, and Barkat (Fig. 1) represent the vestiges of a single, larger, Middle to Late Holocene palaeo-oasis running for tens of kilometres along the western flank of the Tadrart Acacus massif (Cremaschi and Zerboni, 2009, 2013).

The ancient oasis was settled by the beginning of the first millennium BC (e.g. Liverani, 2004), by a partly sedentary population (the Atarantes, according to Herodotus, contemporary to the Garamantes located in the region of the Wadi el-Ajal), which established a control of the territory of SW Libya, and exploited the natural resources sustained by local aquifers and residual rainfall. Today, modern buildings, often surrounding an ancient medina consisting of traditional houses made of mud bricks, occupy the three oases. The archaeological excavation carried out in the village of Fewet (Castelli et al., 2005; Mori, 2013) highlighted the existence, beneath the extant village, of an ancient settlement. It was composed of several compounds; the best preserved of them developed between the 2nd century BC and the 1st century AD (Mori, 2013). The compounds were built with mud-bearing architectural features, which are, in part, still preserved.

In this paper, we present a micromorphological and mineralogical description of earthen elements (mud bricks, plasters, and mortars) sampled during the excavation of Fewet in order to reconstruct the building technologies adopted in Garamantian times in SW Libya. Our approach includes the identification of the main sources of raw material adopted to produce earthen elements, and the interpretation the main technological and functional aspects of the sampled structures (*chaînes opératoires*). Moreover, we compared our results with building technologies described in modern African contexts in order to investigate if there is any technological analogy in the production of mud bricks and the preparation of plasters between the 2000 years old Garamantian village of Fewet and modern villages of the Central Sahara and Sahel. This

1
2 comparison also aimed to distinguish between the natural depositional and post-depositional
3 processes responsible for the preservation of the ancient earthen walls.
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6 7 **2. The study area: present and past settings** 8

9 The ancient village of Fewet (Fig. 1), dating to the Garamantian period, is located in southern
10 Libya, SW Fezzan region, in the upper reach of the Wadi Tanezzuft Valley (Latitude 24°56'57"N,
11 Longitude 10°04'46"E; elevation c. 600 m asl). The geological bedrock of the Wadi Tanezzuft
12 consists of a homocline composed, from the West to the East, of the following Palaeozoic rock
13 formations (El-Ghali, 2005): the Tassili sandstone (Silurian), the Tanezzuft shales (Upper Silurian),
14 and the Acacus and Tadrart sandstone (Upper Silurian to Devonian). Strata are gently tilted
15 toward the E-NE, in the form of a cuesta (Zerboni et al., 2015), and the valley of the Wadi
16 Tanezzuft runs in a consequent mode along the cuesta. The wadi bottom is cut into the almost
17 impermeable shales and thin-bedded sandstone of the Tanezzuft Formation. In the western side of
18 the valley, along the geological contact between the Tassili and Tanezzuft Formations, suitable
19 conditions exist for the aquifers to rise to the topographic surface; aquifers are trapped inside the
20 highly permeable Tassili sandstone Fm. (Cremaschi and Zerboni, 2009). Groundwater sustains the
21 palm groves and feeds the springs that are still active inside the oases of the region and up to few
22 years ago also a small, seasonal marsh at Fewet, suggesting a very shallow depth of the water table
23 (Cremaschi and Zerboni, 2013). The valley of Wadi Tanezzuft is filled by poorly weathered alluvial
24 silty-clayey sediments dating to the Holocene; in the region, soils are generally thin and affected
25 by several millennia of wind erosion (Zerboni et al., 2011; Zerboni et al., 2015).
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50 The present climate of the Libyan Central Sahara is hyperarid. Data from the
51 meteorological station located in Ghat indicate a mean annual temperature between 25° and 30°C
52 and a mean annual rainfall between 0 and 20 mm (Walther and Lieth, 1960). Precipitations are
53 mostly distributed in spring and summer, and regional average annual relative humidity is 17%; a
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1 strong wind activity is registered all the year, especially in spring, while occasional rainstorms are
2 recorded also in the winter season.
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4 During the Early and Middle Holocene, the region experienced a larger water availability,
5 thanks to the huge rainfall supplied by the northward migration of the ITCZ (Intertropical
6 Convergence Zone) and expansion northward of the SW African monsoon domain (e.g., Gasse,
7 2000; Gatto and Zerboni, 2015; Cremaschi et al., 2014). The water supply was considerable: it
8 saturated the immense hydrological reservoirs of the sandstone bedrock and caused a general rise
9 of the water table in all the physiographic units of the area (Cremaschi and Zerboni, 2009). Locally,
10 the interruption of the humid phase is dated at c. 3500 years BC, when the withdrawal of the
11 monsoon led to the progressive exhaustion of water reservoirs.
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24 After the interruption of the monsoon rain supply to the Central Sahara, the most fragile
25 ecosystems from the hydrological point of view (mountains, pediments, and interdune lakes)
26 dried quickly (Cremaschi and Zerboni, 2011). Conversely, thanks to the so-called oasis effect,
27 water availability persisted along the Wadi Tanezzuft, which survived aridification (Cremaschi
28 and Zerboni, 2009, 2013), allowing the formation of an oasis landscape and favouring the
29 establishing of permanent settlement and agricultural exploitation in Garamantian times. The first
30 traces of the existence of an oasis settlement along the valley of the Wadi Tanezzuft is dated to the
31 2nd millennium BC. The boundaries of the palaeo-oasis were stable in the 2nd and 1st millennia BC,
32 but during the 1st millennium AD the palaeo-oasis started contracting significantly and
33 progressively, reaching the extant configuration of three distinct oases hosting the settlements of
34 Ghat, Barkat, and Fewet (Cremaschi and Zerboni, 2013).
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53 **3. The Garamantes of the central Sahara and the settlement of Fewet**

54 During the 1st millennium BC the Garamantian culture spread in the Libyan region of Fezzan to
55 form a proper kingdom, which reached its peak during the first centuries AD. At that time, the
56 Fezzan oases became important centres, not only for permanent settlements, and irrigated
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1 agriculture, but also as crossroads in a network of the trans-Saharan caravan routes (Liverani,
2 2004; Mattingly, 2013). The Garamantian trade network spread along two major commercial
3 routes: the transverse route from Lower Egypt to Middle Niger (NE-SW), possibly opened already
4 from the 6th century BC (as described by Herodotus in *Historiae*) (Liverani, 2004), and the north-
5 south routes between Tripolitania and Fezzan and between Tunisia and the Hoggar, which seem
6 to have been opened slightly later (Mori and Gatto, 2012).
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14 Fewet was a small village located along the Wadi Tanezzuft (Fig. 1), in the south-
15 westernmost part of the region under the sphere of influence of the Garamantian Kingdom
16 (Castelli et al., 2005; Liverani, 2005; Mori, 2013). It was part of a larger system including the ancient
17 settlements of Ghat and Barkat, and was located along a NE-SW route leading from Ghat to the
18 Tassili massif. Inside the modern village of Tan Afella (Fig. 2), at the site of ancient Fewet, a
19 rounded compound defended by a perimeter wall made of mud bricks was excavated between
20 2001 and 2004 by the Italian-Libyan Mission in Acacus and Messak (University Sapienza, Rome).
21 The settlement consisted of a series of small dwelling units (Fig. 2), mostly rectangular in shape,
22 with walls in mud bricks that were arranged around a central courtyard with a communal well
23 (Castelli et al., 2005; Mori, 2013; Zerboni et al., 2013). The lifespan of the compound was
24 radiocarbon dated from the 2nd century BC to the middle of the 1st century AD (details in: Mori,
25 2013). Also, surveyed and partially excavated in the Fewet oasis is a large necropolis, composed of
26 1329 stone tumuli, mostly dating from the 6th century BC to the 4th century AD, and a surface site
27 located in the nearby village of Tan Ataram, which has been interpreted as a caravan staging post
28 (Mori, 2013).
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53 **4. Material and methods**

54 Besides the stratigraphic archaeological excavation of the compound (Mori, 2013), a
55 geoarchaeological investigation, mostly based on thin section analysis and mineralogical
56 determinations, was carried out (Zerboni et al., 2013, 2017). The micromorphological study of
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1 floors and mud bricks, mortars, and plasters contributes to understand the stratigraphy and the
2 architecture of an archaeological site, including the selection and availability of geological raw
3 materials, technological and functional aspects of selected features, and taphonomic processes
4 involved in the formation of the archaeological record (McIntosh, 1974; Goldberg, 1979; Courty et
5 al., 1989; Miller Rosen, 1986; Shahack-Gross et al., 2004 Goodman-Elgar, 2008; Macphail and
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Cammas, in press). For this purpose, a set of *in situ* and undisturbed blocks was collected from preserved earthen structures; the position of each sampling point is shown in the general plan of the excavation of Figure 3. Samples can be distinguished into three groups: (i) mud bricks, belonging to *in situ* and collapsed walls dating to the Garamantian period of the compound (four samples: MB1; MB2; MB3; MB4), (ii) wall plaster (three samples: PL1; PL2; PL3), and (iii) mortar (two samples: MT1; MT2). Moreover, six comparison samples were taken from contemporary settlements: a few hundred years old mud brick collected in the old town of Ghat (less than 10 km from Fewet); a modern mud brick from Mopti (a city in Mali); two modern mud bricks and a sample of plaster from Al Khiday (a village in the central Sudan; Usai and Salvatori, 2002); one mud brick from a historic building in Omdurman (Sudan); a mud brick from the Meroitic excavation at Dangeil that was provided by the Berber-Abidiya Archaeological Project (Sudan).

Thin sections (5x9 cm) were prepared at Servizi per la Geologia Lab. (Piombino, Italy) after consolidation with polyester resin according to the method described in Murphy (1986). Micromorphological studies of sediment thin sections employed an optical petrographic microscope (Olympus BX41, with a digital camera, Olympus E420) at various magnifications (16x, 20x, 40x, 100x, 200x, 400x, 1000x); thin sections were observed under plane-polarized light (PPL), cross-polarized light (XPL), and oblique incident light (OIL). In thin-section description, the terminology of Stoops (2003) was used. In the interpretation, we followed many of the concepts discussed in Courty et al. (1989), Stoops et al. (2010), and Nicosia and Stoops (2017). Results of thin

1 sections study are briefly presented in the Result section and reported in detail in Tab. 2; in the
2 same table some field properties of investigated features are reported.
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4 XRD (X-ray powder diffraction) analysis was performed on collected samples of mud
5 bricks, plasters, and mortars in order to clarify the mineralogical composition of specific features.
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7 A further sample was collected from the swamp deposit very rich in organic matter found near the
8 compound (sample Marsh). X-ray powder diffraction measurements were carried out using a
9 X'Pert Panalytical Diffractometer working in Bragg-Brentano geometry and equipped with an
10 X'Celerator Detector. Each sample was manually grinded in an agate mortar and then analyzed in
11 the 3-80° 2 θ range (Cu-wavelength, 40kV, 40mA) with a step size of 0.02° and a counting time of
12 20s. Qualitative mineralogical phase analysis was performed based on peak position (Klug and
13 Alexander, 1974), and indications about abundance of each mineral phase were obtained on the
14 basis of peaks intensities. We decided to create four different classes of abundance: +++++ if peaks
15 are dominant, +++ if peaks can be observed over the entire range, ++ if the main peak is well
16 visible but it is hard to distinguish the other peaks from the background, and + if the main peak
17 can be just distinguished from the background.
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38 **5. Results**

39 **5.1. Description of earthen architecture at Fewet**

40 The excavated compound was planned and built as a single structure, for the dwelling of an
41 enlarged family or small clan with an egalitarian socio-economic base (Liverani, 2005; Mori, 2013).
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43 The settlement had a defensive nature and was planned as an enlarged household, with a single
44 gate and a communal well, which ensured water availability (Fig. 4). The whole settlement was
45 built with mud bricks, using sandstone blocks for the wall's foundations. A central courtyard
46 allowed the inner circulation and provided a protected space for working activities, like the
47 threshing and grinding of cereals, and basketry and leather items production, which needed larger
48 spaces not provided by the relatively narrow roofed areas (Mori, 2013).
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1 The covered rooms were built along the compound wall's perimeter, and were generally
2 arranged in units composed of two rooms: a larger square room flanked by a smaller rectangular
3 one (Fig. 4). Remains of the original roofs were found only in three of the excavated rooms, which
4 burnt down and collapsed on the floors. Roofs were built in a similar way to the traditional local
5 architecture, with a frame of long beams of palm or tamarisk wood, covered by tree branches,
6 small wooden sticks, and mats stabilized with mud (Mercuri et al., 2013).
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14 Building techniques and materials are rather homogeneous: roughly dressed sandstone
15 slabs (or at least sandstone outcrops) were used almost exclusively for the mud brick wall
16 foundations and for the footing of the perimetral village wall (Fig. 4). Mud bricks were highly
17 standardized both in composition and size (50x35x8 cm), thus suggesting the use of moulds for
18 their production. The compound's wall was up to 4.5 m high, while inner rooms, according to the
19 excavated collapses, were at least 2.6 m high (Mori, 2013).
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31 **5.2. Thin sections' micromorphology of mud architectural elements**

32 **5.2.1. Mud bricks**

33 The five samples of mud bricks show a degree of homogeneity in visual, microscopic, and
34 mineralogical composition (see details in Tabs 1 and 2). In the field, mud bricks generally have a
35 prismatic structure, very pale brown to light yellowish brown in color (from 10YR 7/4 to 10YR
36 6/4), with a hard consistency, and made of sand, fine silt, and clay with interspersed coarser and
37 well rounded fragments of light yellow (2.5Y 7/4), calcium carbonate nodules.
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48 Under the microscope (Tab. 1), mud bricks display a massive structure (Fig. 5A), in few
49 cases they show a polyedric structure. Voids are scarce to common and consist of vesicles (the
50 most represented), channels, and vughs; sporadically, we notice the occurrence of pseudomorphic
51 voids (Fig. 5B,C), retaining the shape of chaff eventually added as temper (Courty et al., 1989; Gé
52 et al., 1993; Friesem et al., 2017). In most of the thin sections, two intermixed types of micritic
53 micromass can be distinguished: one (which generally dominates) is opaque, light yellowish
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1 brown in color (under PPL and XPL); whereas the other one is dusty, light gray to light brown,
2 and includes very small elongated to rounded dark minute organic particles (Fig. 5A). The mineral
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4 fraction consists of poorly rounded, silty to medium sandy quartz grains. The latter display an
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6 external thin layer of reddish iron oxides. Thin section analysis evidenced a generalized absence of
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8 organic components in mud bricks. Occasionally, we found small and angular charcoal fragments,
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10 cluster of phytoliths, unburned vegetal remains, and oxidized organic fragments. Moreover, the
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12 occurrence of vegetal fibres, phytoliths, and clusters of faecal spherulites (Fig. 5D-F) highlights the
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14 uncommon presence of fragmented coprolites, presumably ovicaprine pellets (Brochier, 1996;
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16 Canti, 1997, 1999). In the slides, sub-rounded to angular coarse carbonatic nodules were found;
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18 they are clearly distinguishable from the micromass due to a brown to gray-brownish (under PPL
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20 and XPL respectively), opaque color, and the lack of coarse mineral grains. Calcium carbonate
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22 nodules should be interpreted as pedorelicts (Fig. 6A, B). Few very small rounded soil aggregates,
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24 displaying evidence of modest heating, can be attributed to the same micropedological category.
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26 The larger CaCO_3 nodules are few millimetres in diameter; their microstructure comprises of
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28 layers of micro- and macro-calcite and some infillings, consisting of microcrystalline and palisades
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30 CaCO_3 crystals (Fig. 6). The general aspect of carbonate inclusions displays many analogies with
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32 stromatolite-like sedimentary features. Diatoms, sponge spicules, freshwater shell fragments, and
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34 microfossils of freshwater (possibly belonging to genus *Chara*; Premoli Silva, pers. comm.),
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36 indicates that carbonated formed in a freshwater sedimentary environment (Fig. 6). They can be
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38 attributed to palustrine/swamp carbonates or spring tufa, which largely formed in the region in
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40 the Early and Middle Holocene (Cremaschi et al., 2010; Zerboni et al., 2015). Other, less
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42 represented, pedofeatures are: Fe-bearing oxides impregnating the micromass, calcite
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44 neoformation along planar voids, and, in the case of sample MB4, cracks discontinuously filled by
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46 loose, randomly oriented lenticular gypsum crystals.
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60 **5.2.2. Plasters**

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1 Plasters were sampled in correspondence of earthen walls preserved *in situ* and not from the
2 collapsed ones, as in the latter case plaster generally underwent strong diagenesis or erosion.
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4 Plaster applied to walls has a silty to sandy, grey to light yellowish brown (from 10YR 5/1 to 10YR
5 6/4) groundmass, which includes small light yellow (2.5Y 7/4) angular aggregates.
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9 In thin section, plaster appears less massive than a mud brick. Voids (vughs, channels, and
10 vesicles) are common, but in some portions of the slides they are rare, probably due to higher
11 compaction of the groundmass (Fig. 7A). Locally, channels and vesicles are oriented along the
12 same direction and they may correspond to pseudomorphic voids (Fig. 7A). The groundmass is
13 rich in clay with interspersed common to abundant, subrounded to angular, silty to fine/medium
14 sandy quartz grains; it is yellow and slightly birefringent (under XPL). Within plasters,
15 constituents of organic origin are more common than within mud bricks. They consist of few
16 small, angular fragments of charcoal, unburned and well preserved vegetal remains, and very few
17 phytoliths concentrations (Fig. 7B). The groundmass includes sub-rounded to angular, mammilate
18 carbonatic nodules (like those described for mud bricks). The most common pedofeatures are
19 crystalline and are represented by randomly oriented, lenticular gypsum crystals (Fig. 7C). The
20 latters were found in the groundmass as growths of lenticular euhedral gypsum crystals (up to
21 some hundreds of microns long), and as dense infilling in vughs, chambers and channels and
22 dense-to-loose, almost continuous infilling along planes and cracks (Fig. 7D).
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45 **5.2.3. Mortars**

46 During the excavation, mortars were less evident than other mud elements; this fact is probably
47 due to their limited thickness. For that reason, only two, well-preserved samples of mortar were
48 collected for thin sections' analysis. Mortars displays a silty to sandy groundmass with a pale
49 brown–light yellowish brown to dark gray color (10YR 6/3–10YR 6/4 to 10YR 4/1), with
50 interspersed light yellow (2.5Y 7/4), small angular aggregates.
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1 In thin sections, mortars are highly compacted, with few voids. We distinguished two main
2 types of fabric: one is rich in brilliant yellow and birefringent clay (Fig. 8A), whereas the other is
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4 opaque and light grey to brownish. The latter shows a diffuse impregnation of calcite and
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6 amorphous organic particles (Fig. 8B). Sub-rounded to angular, Fe-stained silty to medium/coarse
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8 sandy quartz grains are interspersed in the groundmass; sometimes they display a preferential
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10 horizontal orientation (Fig. 8C, D). Very few angular, moderately preserved vegetal remains and
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12 clusters of phytoliths are present. Few large lenticular crystals of gypsum (single units or in
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14 cluster) are present in the groundmass.
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21 **5.2.4 Comparison samples**

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23 Mud brick comparison samples were selected among modern and ancient African contexts to
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25 compare the production technology and test its continuity through centuries. Ghat is one of the
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27 oldest Saharan cities (Bourbon del Monte Santa Maria, 1912) and the comparison mud brick comes
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29 (according to local informants) from a building in the oldest part of the city. Mopti was founded as
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31 a mud brick village in the XVIII century (Cailliè, 1830) and become a large city under the French
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33 occupation since the beginning of the last century (de Benoist, 1998). Comparison sample dates to
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35 the latter period. Mud brick samples from Sudan include: three recently produced mud bricks
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37 from the village of Al Khiday that was established few tens of years ago; a mud brick from an
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39 historic building in Omdurman (Kramer et al., 2013) that dates back (according to local
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41 informants) to the beginning of the last century; a mud brick from the Late Kushite (3rdcent. BC -
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43 4th cent. AD) city at Dangeil (Anderson et al., 2015, 2017).
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50 The thin section of a modern mud brick collected at Ghat shows many similarities with
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52 those from ancient Fewet. It shows a very massive structure with very scarce vughs and vesicular
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54 voids (Fig. 9A). It consists of a mixture of quartz grains in a clayey to calcitic micromass, and
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56 present very few vegetal inclusions. The mud brick from an historic building in Mopti is massive
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58 and hard, with very few vegetal inclusions and voids. Under the microscope, it largely consists of
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1 sand to silt quartz grains, with interspersed few elongated vegetal remains (possibly straw or
2 grass), common red, Fe-oxides-rich rounded pedorelicts, and common fragments of former clay
3 coatings and infillings (Fig. 9B, C).
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7 Mud bricks from the Meroitic buildings in Dangeil and those from the modern buildings in
8 Al Khiday are massive and hard, and vegetal inclusions are almost lacking. In thin section, these
9 samples display a sandy to silty groundmass, almost consisting of quartz grains (Fig. 10A-C); clay
10 is also represented. In the groundmass, several pedorelicts consisting of fragments of decantation
11 crust are present (Fig. 10A, C). Plaster from one of the buildings in Al Khiday display a typical
12 laminated structure, with millimetric compact laminae rich in quartz grains, it is richer in organics
13 (straw and coprolite fragments) than mud bricks (Fig. 10D, E). On the contrary, the mud brick
14 from a historic building in Omdurman shows a great abundance of vegetal remains added to a
15 mineral mixture, consisting mostly of sand, silt, and fragments of decantation crusts (Fig. 10E).
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31 **5.3. Mineralogical determinations**

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33 Results of X-ray diffractions are represented in the Tab. 2 and in the diagrams of Fig. 11; in the
34 latter, labels represent the mineralogical phase of the corresponding peaks. As evident, the
35 mineralogical composition of each analysed sample is almost homogeneous, with few differences
36 in the less represented mineralogical species. XRD on mud bricks evidenced that they are
37 dominated by quartz and calcite, while K-feldspar and plagioclase are occasionally present. X-ray
38 diffractions on plaster bulk samples rendered a mineralogical composition dominated by quartz,
39 while calcite, kaolinite, and gypsum, are less represented. K-feldspar is present in samples PL1 and
40 PL3; halite is in samples PL2 and PL3; and in one case (PL2) mica was detected. XRD on mortars
41 evidenced a large quantity of quartz and calcite, with K-feldspar and plagioclase less represented;
42 furthermore, in sample MT1 gypsum is present, whereas kaolinite was detected in sample MT2.
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1 Fewet (sample LK) was considered as a possible source. It highlighted a high content of quartz,
2 calcite, kaolinite, and gypsum, whereas halite, mica, and plagioclase are less represented.
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7 **6. Discussion: building technology of earth-based elements**

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9 Mud technology is widespread in arid environments because it offers two main advantages. In one
10 hand, mud bricks are easy to produce, as raw materials are largely available and low-cost, and
11 earthen-based houses are fast to build. Moreover, mud brick houses have good thermal insulation
12 to withstand extreme environmental conditions. During the warm season, mud walls gradually
13 warm up from the outside during the day, while at night they cool down again, thus helping the
14 interior of the rooms to stay cool all day long (Zerboni et al., 2013). Notwithstanding that, if we
15 compare the architectural elements preserved at Fewet with those described at other Garamantian
16 archaeological sites, we notice that in our case an earthen-based building technology was largely
17 employed, while elsewhere it was limited to marginal structures or features. At Aghram Nadharif,
18 a citadel few kilometres eastward Fewet, in hill-top sites such as Zinchecra, in the Wadi el-Ajal,
19 and in several castles/forts located along the main caravan routes of the Fezzan region. The
20 inhabitants made a large use of stones, especially in the building of foundations and outer
21 fortification walls, while earthen architectural elements were used for the inner rooms' walls or
22 smaller architectural elements such as small storage bins (Mattingly et al., 2003; Liverani, 2005;
23 Biagetti and di Lernia 2008). This difference could be related to defensive reasons, to a large
24 availability of stone slabs (the citadel was built on top of a sandstone outcrop), or to the limited
25 availability of water and other natural resources, thus making difficult the production of mud
26 bricks.
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52 **6.1. Raw material supply**

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54 The composition of mud elements from the compound of Fewet suggests a homogeneous choice of
55 primary mineral components to produce mud bricks, plasters, and mortars. Based on the
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2 comparison with the local geological context, we can suggest some considerations on the
3 procurement of the mineral components of the mixture used for earthen elements.

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5 Quartz grains are largely available in the Central Sahara, as well as along the Wadi
6 Tanezzuft. They originate after the dismantling of the local bedrock, which consists of almost pure
7 quartzarenite (El-Ghali, 2005). The exploitation of quartz grains from primary wind blown sand or
8 sediments shortly mobilized by fluvial activity is suggested by the shape and roundness of grains
9 and by the presence of grains stained by Fe-oxides, which is typical of local soils (Zerboni et al.,
10 2011; Zerboni et al., 2015; Knight and Zerboni, 2018). The clay evidenced in the micromass of mud
11 elements was probably found in correspondence with local soils, which display moderate clay
12 content, including kaolinite (Zerboni et al., 2011). Slides of plaster evidence a larger occurrence of
13 clay and they have many similarities with the fabric of the B horizons of the Pleistocene and Early
14 Holocene soils described in the region (Zerboni et al., 2011).

15
16 The carbonatic nodules and freshwater fossils found in earthen elements show a specific
17 sedimentary *facies*, suggesting they formed in shallow waters. Freshwater carbonates (spring tufa
18 and carbonatic limnites) are common in the region, and their depositional environments have been
19 described in several papers (e.g., Cremaschi et al., 2010; Zerboni et al., 2015). The
20 geomorphological survey of the area surrounding Fewet evidenced the occurrence of an active
21 spring near the compound (few tens of meters), located near a wide outcrop of organic matter-rich
22 deposits with a moderate to low carbonatic fraction (Tab. 2), which formed in a marsh
23 environment during the Middle Holocene (Cremaschi and Zerboni, 2013). The facies of some
24 calcite-bearing components observed in thin sections belongs to a different kind of lacustrine
25 sedimentary environment, like the whitish deposit identified at the foot of the easternmost fringe
26 of the Tassili Massif (Fig. 2). Carbonates were possibly provided from this place and the organic
27 mud from the spring deposit, thus explaining the occurrence of the differentiated groundmass of
28 mud bricks: one calcitic, the other richer in amorphous organic matter. The presence of few calcite
29 crystals (pseudomorphs after calcium oxalates, which originate from wood ash) in some slides

1 suggests that wood ash could be added to the mixture, as observed also at other sites (Miller
2 Rosen, 1986; Goren and Goldberg, 1991; Varanda, 2001).
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4 The identification of sources for raw material suggests the use of proximal resources for
5 building the compound of Fewet. Our interpretation is supported by descriptions of adobe and
6 plaster technology from several sites in the Sahel, West Africa, Morocco, and the Nile Valley,
7 which report the use of raw materials sources from earth pits close to the sites (Prussin, 1974;
8 McIntosh, 1974; French, 1984; LaViolette, 1994; Mattone, 2003; Pecquet, 2004; Macphail and
9 Goldberg, 2010; Nicolini et al., 2010).
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19 Mud elements from the Central Sahara lack of vegetal temper; for that reason they differ
20 from most of the archaeological contexts in the circum-Mediterranean, which are characterised by
21 abundant straw and dung added to the earthen blend (Carter and Pagliero, 1966; Goldberg, 1979;
22 Miller Rosen, 1986; Kemp, 2000; Stevanovic, 1997; Nodarou et al., 2008). A mixture for mud
23 elements poor in vegetal temper is recorded at protohistoric and historic archaeological sites in
24 Southern France (Cammass, 2003, 2015, in press). At Fewet, the general absence of preserved
25 organics in the groundmass and the very occasional occurrence of pseudomorphic voids (moldic
26 voids, Goldberg, 1979) retaining the shape of chaff after its decay, suggest that mud elements were
27 not intentionally plant-tempered. Organic remains are almost lacking in the mud brick from
28 ancient Ghat, and, in the region, Liverani (2005) reported that the few mud bricks found at
29 Aghram Nadharif are almost free of vegetal remains. We noticed that also the mud bricks from
30 Mopti, Dangeil, and Al Khiday have few vegetal fragments added to the mixture. The sporadic
31 occurrence in samples from Fewet of constituents that may result from the intentional cleaning of a
32 living floor such as fragments of ovicaprine coprolites, charcoal fragments, vegetal remains, and
33 heated pedorelicts (Courty et al., 1989; Macphail and Goldberg, 2010; Zerboni, 2011) suggests that
34 the production area was close to the settlement.
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57 Possibly, within the oasis dung, grass, straw, and cereal husks were scarce and represented
58 a precious resource in domestic economy; they were employed as fuel in domestic fireplaces
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1 (Zerboni et al., 2017), to feed domestic animals (Biagetti, 2014; Éguez et al., in press), or as inclusion
2 in pottery fabrics (Gatto, 2010). A building technology like the one described at Fewet is reported
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4 by several authors (Beck and Huard, 1969) for the Tebu people living in the Tibesti region (south-
5 eastern Fezzan), who used to produce mud bricks by mixing water, sand, and fluvial silt. At a
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7 continental scale, we found more technological correlations. At Kerma (Sudan) archaeological mud
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9 bricks exhibit a very low content of straw and charcoal as temper to prevent brick shrinkage
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11 (Nicolini et al., 2010). Moreover, in Sudan also Meroitic and modern buildings are made of silt-
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13 dominated mud bricks with few or at least with no organic temper. As stated before, the building
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15 technology adopted at Fewet in Garamantian times seems to be simple, but it is effective; in fact,
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17 almost the same method was widely adopted in a large part of the Sahel, from Burkina Faso to
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19 Mali, to build up religious edifices and houses (Prussin, 1974; McIntosh, 1974, 1977; Maas and
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21 Mommersteeg, 1992; LaViolette, 1994; Fiedermutz-Laun, 2005).

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29 Our results highlighted some other analogies between earthen architectural elements
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31 adopted in ancient Fewet and the one described for the Sahel and observed at Ghat, Al Khiday,
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33 Dangeil, and Mopti. In fact, the addiction of fine-textured and rolled nodules, pedorelicts, and
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35 surface crust fragments, which possibly represents the intentional addition as temper of former
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37 building debris (Miller Rosen, 1986; Nodarou et al., 2008; Macphail and Goldberg, 2010), is a
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39 practice reported from some contexts from the Sahel (Maas and Mommersteeg, 1992; LaViolette,
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41 1994). Moreover, if we compare mud brick architectures from Fewet with the sample from ancient
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43 Ghat, Mopti, and Al Khiday, we notice a similar occurrence of quartz grains. Some reports on
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45 modern adobe from the Sahel (LaViolette, 1994) and the Nile Valley (French, 1984) confirm they
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47 are enriched with local sand. This is expected, as quartz sand is the most common Quaternary
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49 sediment over continental North Africa.
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57 **6.2. Technological aspects of earthen buildings**

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1 The identification of the basal floor of the compound described in Zerboni et al. (2017), which lies
2 on the sandstone bedrock, suggests that at least part of the village was built directly on the
3 bedrock after levelling the rock surface and positioning mud bricks on it. Comparative
4 ethnographic and historical sources show that African mud brick buildings usually stand on none
5 or shallow foundations, excavated for few tens of centimetres (Prussin, 1974; LaViolette, 1994;
6 Mattone, 2003; Mori, 2013). The remnant part of the compound was built on a soft substrate. A
7 single row of sandstone slabs acted as foundations, as commonly observed at many modern and
8 ancient African sites. At the end of the excavation at Fewet (year 2004), the compound was
9 encircled by a mud brick wall, planned to protect the archaeological site. It was built according to
10 traditional techniques (Fig. 12): a single row of sandstone blocks, taken from an outcrop located
11 less than 100 m far from the site, was used as foundation. Mud bricks were made in wooden
12 moulds just few tens of meters far from the site (Fig. 12), where the sandy-silty sediments of a marsh
13 deposit were available.

14 The most significant difference in the technology of earthen elements between Fewet and
15 those described in the Levant (Miller Rosen, 1986) is the absence of straw and/or dung. This kind
16 of temper generally prevents bricks from cracking and increases their resistance to anthropic and
17 environmental stresses. But if we look at the technologies to produce earthen features reported
18 from historical and ethnographic (i.e., modern) contexts, those from contemporary Fewet and
19 Ghat, from many localities of northern and central Africa (Prussin, 1974; McIntosh, 1974, 1977;
20 Maas and Mommerste, 1992; LaViolette, 1994; Fiedermutz-Laun, 2005), and the examples from
21 Mopti, Dangeil, and Al Khiday we can find many analogies in the preparation of traditional adobe.

22 Prussin (1974) suggests that deposits rich in sand are rarely employed in manufacturing
23 traditional African adobe; in fact, the blends would not reach the cohesiveness required to build.
24 As confirmed by our observations on the mud brick from Mopti, soil/sediments richer in clay are
25 preferred, as much as in the sample from Al Khiday, where pedorelicts present high clay content.
26 Moreover, sometimes adhesive and hardening agents (dung and vegetal remains) making adobe

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lighter and more resistant to stress can be added. A limited availability of clay-rich raw material
near Fewet obliged the local population to find material suitable to produce mud elements. In fact,
in the area soils are generally discontinuous (due to strong erosion) and Bt horizons are very thin
(Zerboni et al., 2011; Cremaschi et al., in press). At Fewet, to solve the problem of cohesion of mud
bricks, a high quantity of calcium carbonate-rich sediments was added to the earthen mixture. In
this way, the final product was hardened by the recrystallization of calcite in the groundmass after
mixing to water and baking in the sun, which creates a semi-cemented final product (Miller Rosen,
1986; Macphail and Goldberg, 2010). This methods is also reported from several contexts in the
Near East and Mediterranean region (Miller Rosen, 1986; Goren and Goldberg, 1991; Pinińska and
Hemdan, 2008).

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At Fewet, we notice some differences in the mixtures used to produce mud bricks and the
one of the plaster for refining walls, being the latter richer in carbonate, sand, and organics. An
explanation is offered by comparing our case study with the production of *banco* (a specific blend
of clay, sand, cereal husks largely adopted as plaster; Pecquet, 2004) in modern Sahelian contexts.
The preparation of *banco* without cracks requires lower clay content and a higher percentage of
sand than mud bricks (Prussin, 1974; Maas and Mommersteeg, 1992; LaViolette, 1994). Moreover,
the occurrence of minute vegetal fragments in plasters from Fewet is comparable to the blend used
in Mali and Burkina Faso for *banco*, which is obtained mixing the mineral fraction with rice, millet,
or barley husks to improve wall rendering (LaViolette, 1994; Varanda, 2001). We observed the
addiction of few straws and cereal husks also in the Sudanese plaster.

50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 **6.3. Post-depositional processes and preservation of earthen archaeological structures**

At the archaeological site of Fewet, evidence of post-depositional processes is related to gypsum
redistribution, which occurred in most of the layers, and especially in those directly related to
firing activities (see Zerboni et al., 2017). Due to the high availability of gypsum within
archaeological layers, the process of its redistribution was strong enough to slightly affect also

1 earthen architectural elements. In fact, we noticed the occurrence of intergrowths of single or
2 sparse gypsum crystals and nodules infilling the voids in slides from plasters and mud bricks.
3

4 The main process promoting the redistribution of gypsum within earthen elements is an
5 enhanced evapotranspiration (Courty et al., 1989; Poch et al., 2010), triggered by increased aridity
6 during the last centuries (Cremaschi and Zerboni, 2009). Therefore, gypsic pedofeatures are related
7 to post-depositional processes of water movements within the upper part of the stratigraphic
8 record. Gypsum is more common in plaster, which is the outer and most porous earthen material.
9 On the contrary, mud bricks have a massive and less porous microstructure, possibly occluding
10 the circulation of water rich in solutes.
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21 The occurrence of gypsic pedofeatures in the voids of the most porous elements of earthen
22 structures may be responsible for the decay of the walls of the compound of Fewet (Fig. 13). The
23 main process of weathering of mud walls has been observed in recent and ancient earthen
24 buildings in the Sahel and the Levant (Carter and Pagliero, 1966; McIntosh, 1974; Miller Rosen,
25 1986; Goodman-Elgar, 2008; Pininska and Hemdan, 2008; Friesem et al., 2011). It consists of
26 capillary translocation of moisture and salts crystallization in interstitial pores, triggering the
27 superficial flaking of the wall. After that, under the influence of gravity and due to the
28 undercutting of basal lines of bricks (Fig. 14), the wall loses structural consistency and collapses
29 (McIntosh, 1974).
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43 From a general point of view, the climate and environmental settings of the Sahara largely
44 prevent the preservation of mud elements in an archaeological site (McIntosh, 1974; Friesem et al.,
45 2011), mostly due to i) strong wind erosion, which is the main natural factor promoting the
46 dismantling of the archaeological record, and ii) enhanced evapotranspiration, which contributes
47 to the physical and chemical alteration of sediments (e.g., McIntosh, 1974; Miller Rosen, 1986;
48 Goodman-Elgar, 2008; Pininska and Hemdan, 2008; Friesem et al., 2011). Moreover, the presence of
49 a growing village represented a great menace for the survival of the archaeological record. The
50 Garamantian compound of Fewet was endangered by both hazards: extremely severe arid climate
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1 negatively impacts on the stratigraphy, while later human disturbance seriously altered part of the
2 archaeological structures. Notwithstanding that, in our case study a rapid burying of
3 archaeological remains (Fig. 13) allowed a good state of preservation of the architectural structures
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5 (Carter and Pagliero, 1966).
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10 11 **7. Conclusions: the earthen architecture of southern Fezzan in Garamantian times and its** 12 13 **archaeological relevance** 14

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16 The geoarchaeological study carried out at Fewet on earthen architectural elements allows to
17 elucidate the building technologies adopted by the local population of the region in Garamantian
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19 times.
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23 The rural compound of Fewet was partly built on the local geological bedrock, after a
24 rough levelling of the surface. Lacking rich plant or dung reserves, the people of Fewet started
25 producing mud bricks and muddy blends for plaster and mortar with local mineral resources. A
26 mixture basically composed of sand, clayey sediments, and carbonates improved the building
27 resistance to local environmental stress. In the Wadi Tanezzuft region, the Fewet compound was
28 the earliest residential structure built in mud bricks dating to the 3rd-2nd centuries BC. But the craft
29 and standardization of the mud bricks work implies an introduction and experimentation in the
30 area, prior to the 2nd century BC, for which we lack any archaeological evidence, yet (Mori, 2013).
31
32 Mud bricks technology was probably introduced in the Wadi Tanezzuft from the Wadi el-Ajal
33 region, where the earliest attested mud bricks were dated to the 4th century BC (Mattingly, 2013).
34
35 At the hilltop site of Zinkekra the earliest experiments with building materials new to the Fezzan
36 region (mud brick and dressed stones) and new building forms (multi-roomed complex
37 rectangular houses) took place in the latter centuries BC (the so-called Proto-Urban Garamantian
38 phase, see Mattingly et al., 2003). It has been suggested that the appearance of these new
39 techniques at ancient Jerma was related to the introduction of the foggara irrigations system and
40 introduced from the oases of the Egyptian Western Desert (Mattingly, 2013). The scanty available
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1 information apparently indicates that the introduction of mud bricks architecture in Sub-Saharan
2 West Africa occurred at the beginning of the 1st century AD (the site of Dia-Shoma, in the inner
3 Niger Delta; MacDonald, 2011). The Fewet evidence might represent a geographic and
4 chronological nexus in a theoretical north-east/south-west diffusion of earthen architecture. In
5 fact, the mud architectures at Fewet have few analogies with those described in the Near East, but
6 they are strictly related to those adopted in the Saharan and Sahelian belts of Africa.
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14 Our conclusions have to be supported by further systematic geoarchaeological and
15 micromorphological study of African contemporary architectural earth remains. In any case, we
16 suggest that in each case study here considered raw materials used to prepare mud bricks were
17 proximal to the production site. Moreover, we found evidence of technological continuity from the
18 early historical times till today, as confirmed by the traditional buildings in modern Fewet and
19 Ghat (Fig. 16). This continuity also represents an interconnection between Fewet and both the
20 northern region of the Wadi el-Ajal, and the southernmost fringes of the Sahara (Mori, 2013). The
21 hypothesis of a technological analogy mostly relies on micromorphological data and comparison
22 with contemporary ethnographic evidence from the Sahelian region (as in the case of Mopti and Al
23 Khiday) and with the historic case of Dangeil; the latter site is almost contemporaneous with the
24 compound of Fewet. Notwithstanding this, building technology over the region may have
25 changed across time, according to the local availability of certain resources such as vegetal matter,
26 animal dung, or water. In Garamantian times, the production of mud features was identical to that
27 employed for many centuries afterwards in the same region and in the whole Sub-Saharan Africa.
28 Even though micromorphological and mineralogical studies are not available for adobe and
29 plaster from contemporary and historical African contexts (a part from the samples here
30 discussed), the mixture of ingredients used in *banco* technology widely employed in Mali and
31 Burkina Faso resembles the one described in our study.
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57 The introduction of mud bricks in the Fezzan is apparently related to the use of a
58 rectangular module for dwelling units, which is well attested both in the Wadi el-Ajal and at Fewet
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1 (Mattingly et al., 2003; Mattingly, 2013; Mori 2013). Nevertheless, in our study region, the
2 rectangular plan of the houses is inserted in a circular or ovoidal plan of the compound, whereas
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4 in the Wadi el-Ajal an orthogonal arrangement is preferred (Mattingly and Sterry, 2013). This
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6 cultural trait points, once more, to older African models of dwelling (the Tichitt tradition for
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8 example), to which our region may have been related (Mori, 2013).
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4 very few <5%, few 5-15%; common 15-30%; frequent 30-50%; dominant 50-70%; very
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6 dominant >70%).
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9 Tab. 2. Results of qualitative mineralogical phase analysis. Key for peaks intensity (e.g., relative
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11 abundance of mineral in each sample): ++++ dominant peaks; +++ peaks observed over the
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13 entire range; ++ the main peak well visible, but hard to distinguish the other peaks from the
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57 room and the position of samples discussed in the paper.
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Fig. 4. (A) General view of the compound after excavation (the well is in the upper right corner) and (B, C) some details of the excavated rectangular rooms showing the earthen structures during the excavation. Note the stonewall supporting mud bricks all around the perimeter of the village.

Fig. 5. Photomicrographs of mud bricks from Fewet. (A) General view of the groundmass, note the large occurrence of sandy and silty-sized grains; the groundmass includes portions (on the right) largely impregnated by micrite (sample MB1, PPL); (B) portion of the slide of sample MB1 highly impregnated by calcium carbonate, which also displays sparitic recrystallization on voids (XPL); (C) elongate voids (indicated by the arrows) displaying a similar orientation that can be interpreted as pseudomorphic voids, which retain the shape of chaff eventually added as temper (sample MB2, XPL); (D) phosphate-rich nodules (indicated by the arrows) corresponding to a deformed and weathered coprolite englobed in the groundmass (sample MB2, PPL); (E) detail of (D) highlighting the occurrence of clusters of faecal spherulites (sample MB2, XPL); (F) faecal spherulites (sample MB2, XPL).

Fig. 6. Photomicrographs of calcium carbonate-rich features within the mud bricks from Fewet: (A, B) a large, rounded calcium carbonate pedorelict, possibly heated (sample MB3, XPL and PPL); (C) the arrow indicates a fragment of freshwater shell (sample MB2, XPL); (D) a fragment of freshwater algae (possibly genus *Chara*) in sample MB4 (PPL); (E) concentration of diatoms in a calcitic nodule (sample MB2, PPL); (F) a spicule of sponge (sample MB2, PPL).

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Fig. 8. Photomicrographs of mortars from Fewet: (A) clay-rich groundmass (sample MT1, PPL); (B) micrite-rich groundmass, note the occurrence of palisade CaCO_3 crystals along a planar void (sample MT1, XPL); (C) general view of the groundmass of sample MT2, note the preferential horizontal alignment of coarse grains due to compaction (PPL); (D) Fe-stained quartz grains (indicated by the arrows), note also the occurrence of few small gypsum crystals in the groundmass (sample MT1, XPL).

Fig. 9. Photomicrographs of modern example of mud bricks from Ghat and Mopti. (A) Massive structure of the mud brick from Ghat (PPL); (B) silt to sand quartz grains with interspersed few vegetal remains (indicated by the arrows) in the mud brick from Mopti (XPL); (C) fragments of clay coatings (indicated by the arrows) in the sample from Mopti (XPL).

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Fig. 11. X-ray powder diffraction pattern of analysed earthen features and marsh deposit close to Fewet in the $5-40^\circ 2\theta$ range. Mineralogical phases label are: Q for quartz, C for calcite, G for gypsum, A for anhydrite, P for plagioclase, K for K-feldspar, Ka for kaolinite, and M for mica.

Fig. 12. Pictures illustrating the building of the modern perimeter wall encircling the compound of Fewet (year 2004): (A) preparation of shallow foundation around the compound (on the right); (B) positioning of a single row of sandstone slabs and blocks; (C) area designated to the preparation of mud bricks with local resources with piles of sun-baked bricks.

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Fig. 13. (A) A collapsed mud bricks wall found during the excavation of the compound of Fewet and (B) a modern analogue in the village of Tan Ataram (picture taken in year 2003).

Fig. 14. An old wall in Fewet (Tan Afella) that suffered strong weathering (year 2004). Note the flanking of plaster at the basis of the wall (indicated by the arrows), which possibly is the result of the process described by McIntosh (1974) and identified at ancient Fewet.

Fig. 15. Modern earthen architectures in the Libyan Fezzan: (A) abandoned building in Fewet (year 2004); (B) panoramic view of the old city of Ghat (year 2003); (C) fresh plaster covering the walls of Tunin (Ghat) in 2004; (D) old house in Barkat (year 2009); (E) perimetral wall of an earthen house under construction at Jerma (notice on the left the occurrence of locally produced mud bricks backing in the sun (year 2010); (F) a detail of the mud bricks wall in Jerma, illustrating the texture of modern mud bricks and mortar (year 2010).

Highlights

- We investigated earthen architectural structures at ancient Fewet (Libya)
- XRD and thin section micromorphology reveal the composition of earthen features
- In the 2000 years old Fewet mud brick were prepared without adding vegetal
- The same mixture for earthen features have been observed today in the Sahara and Sahel
- We propose the possibility of a technological continuity from the late Antiquity up to today

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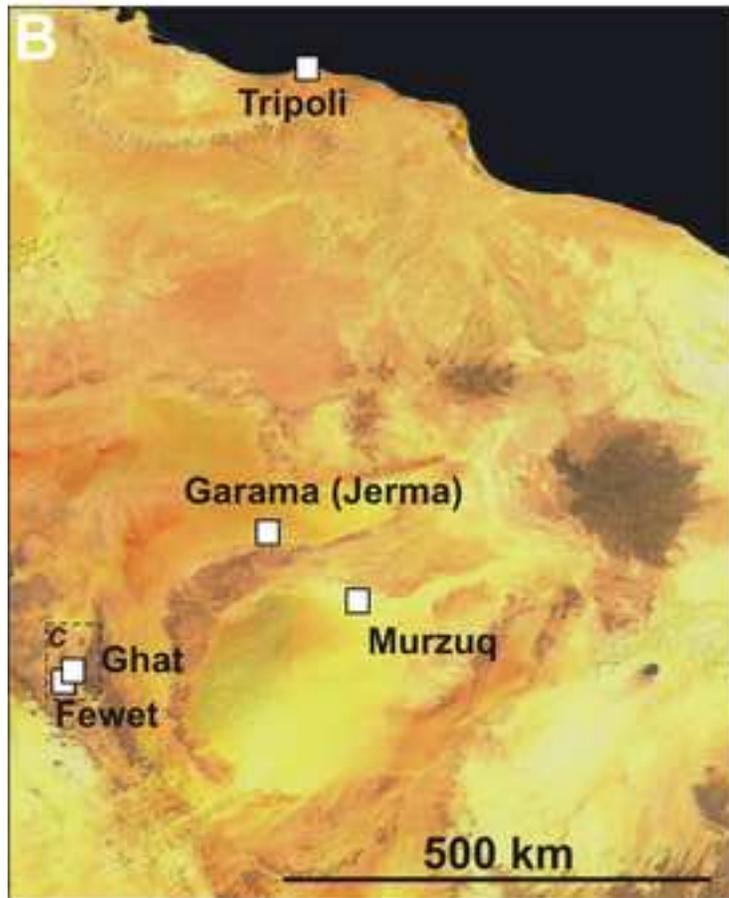
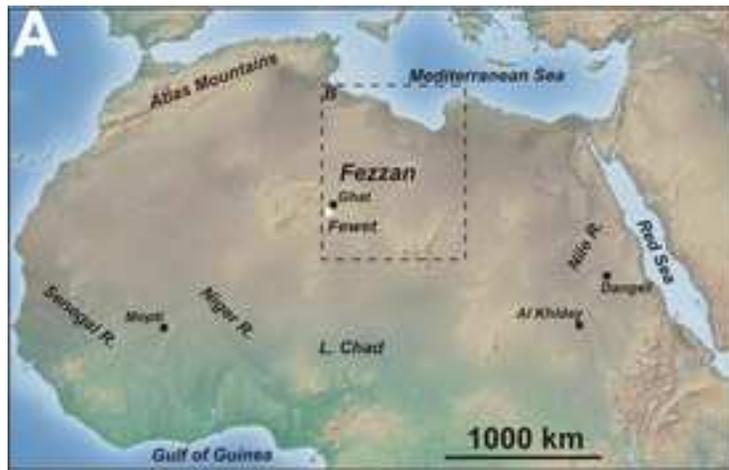


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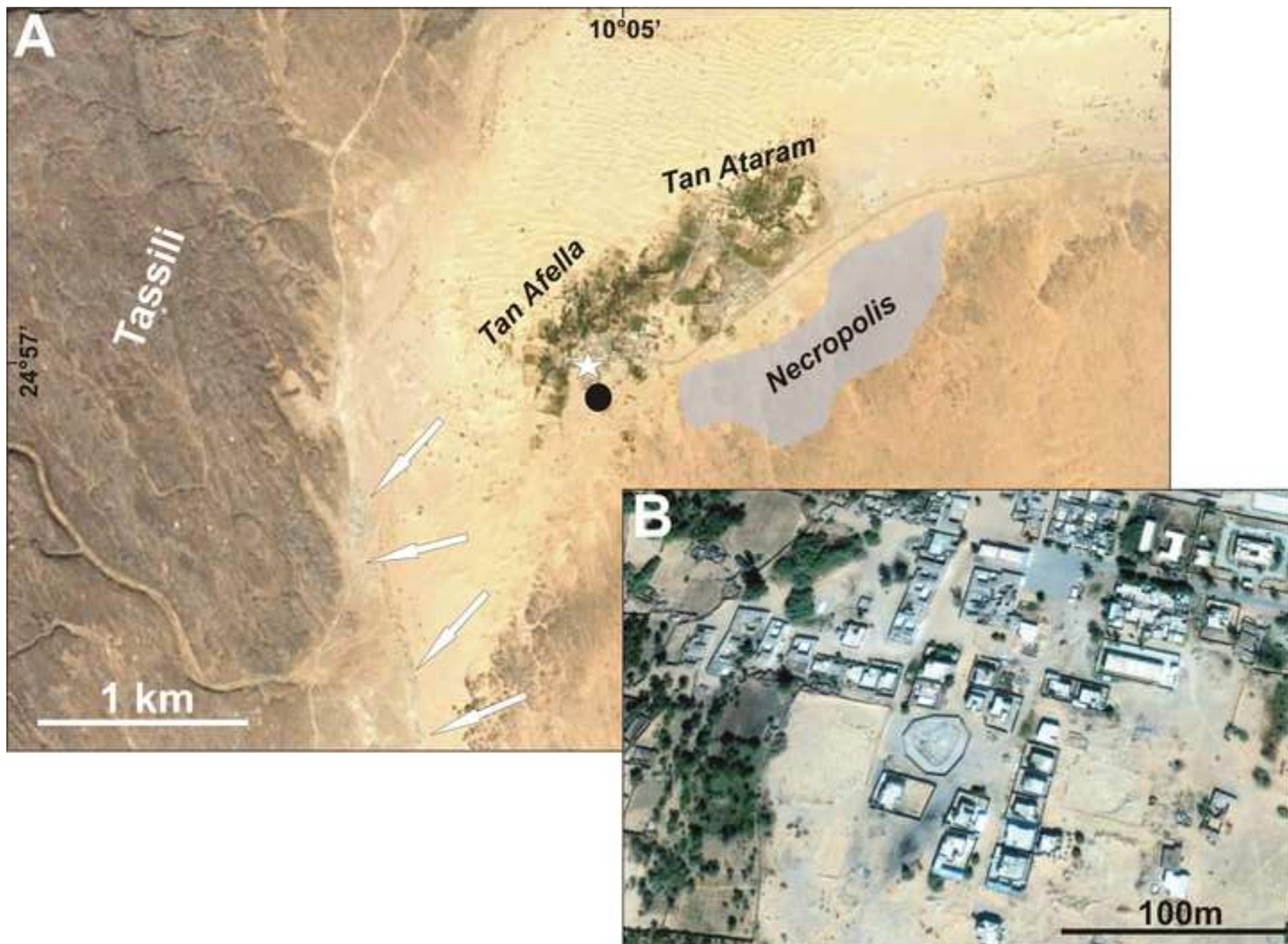


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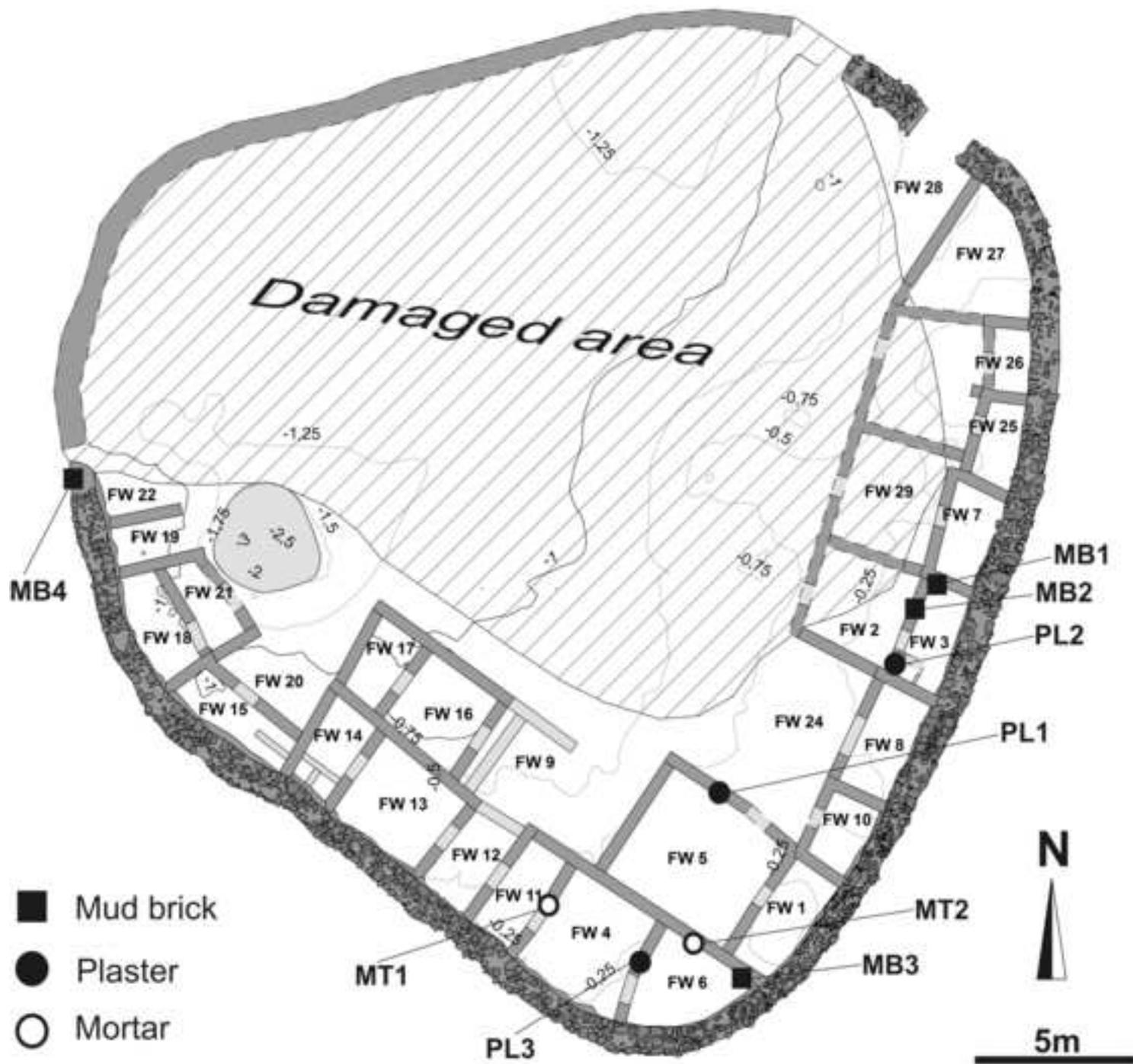


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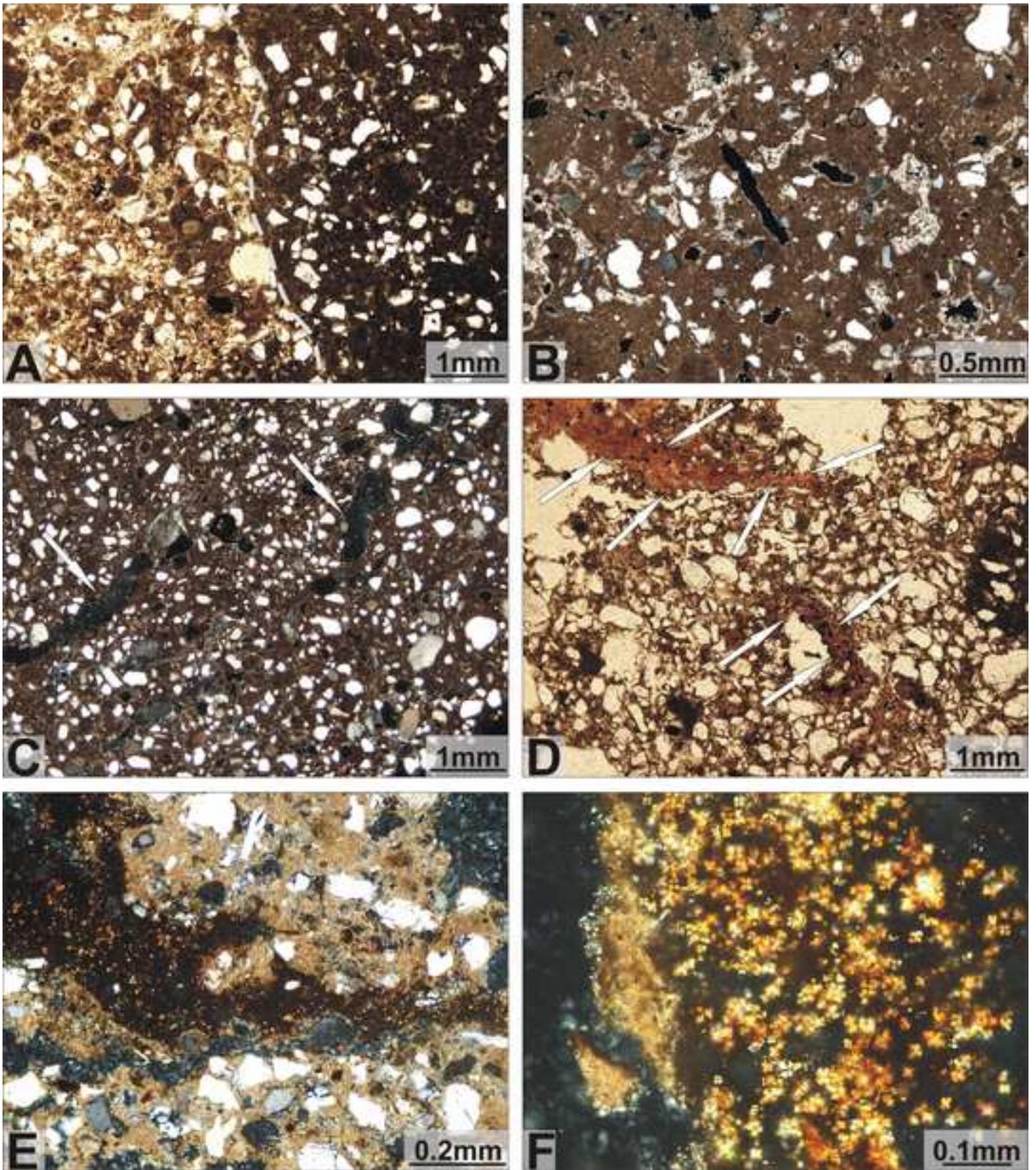


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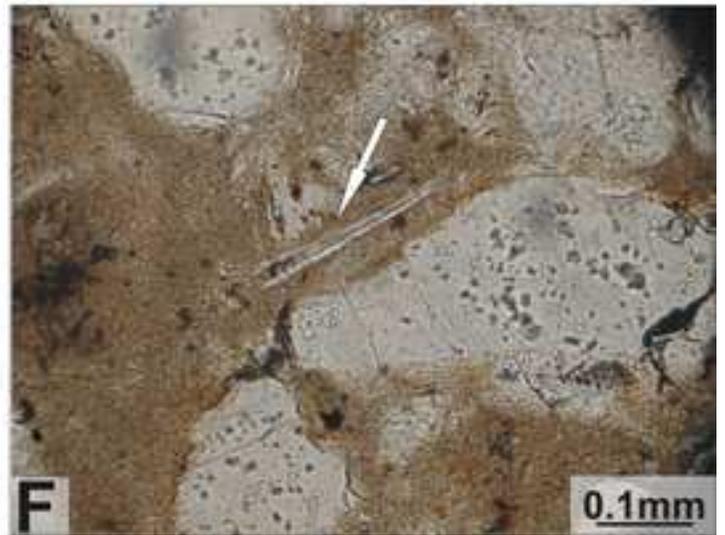
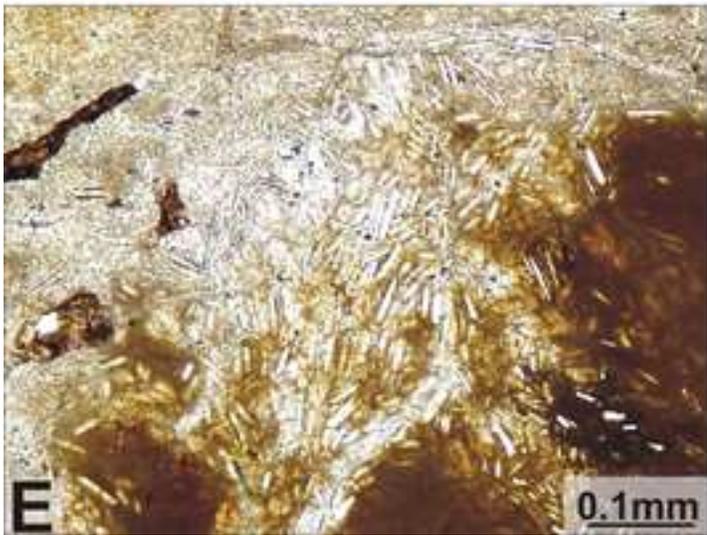
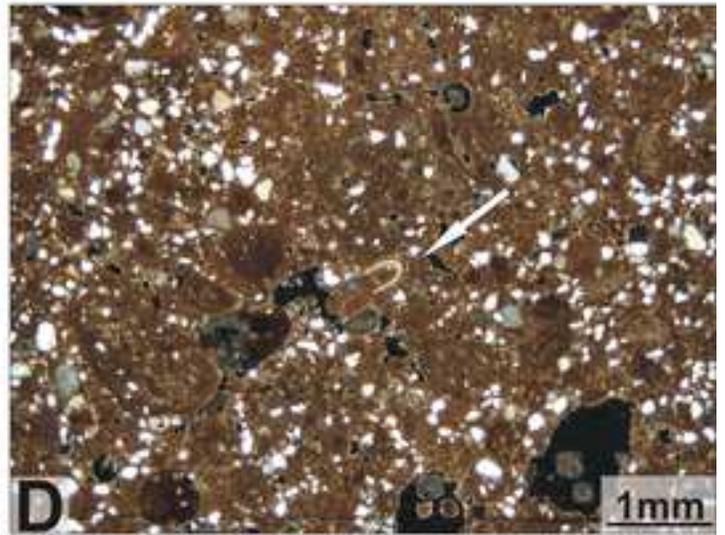
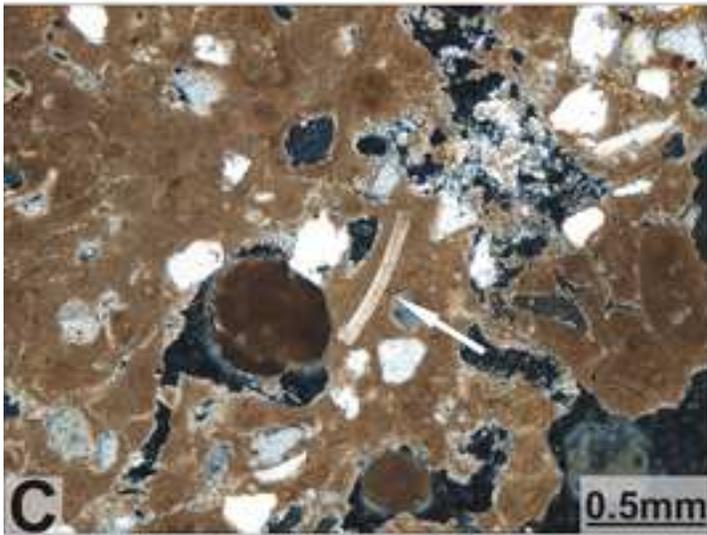
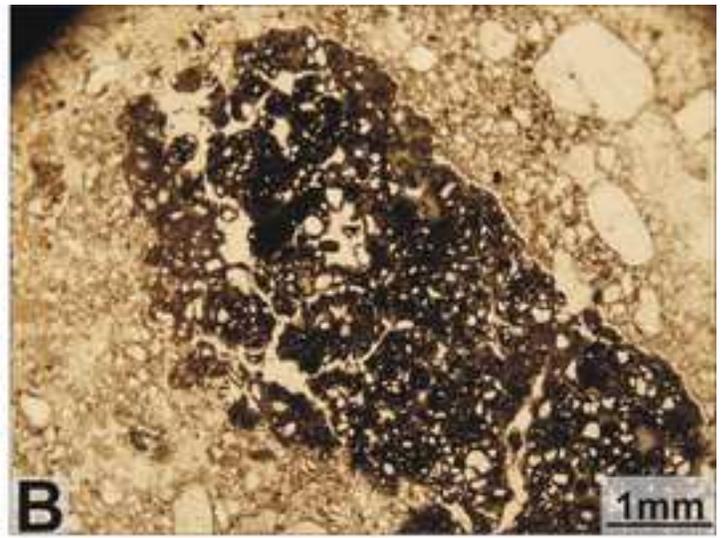
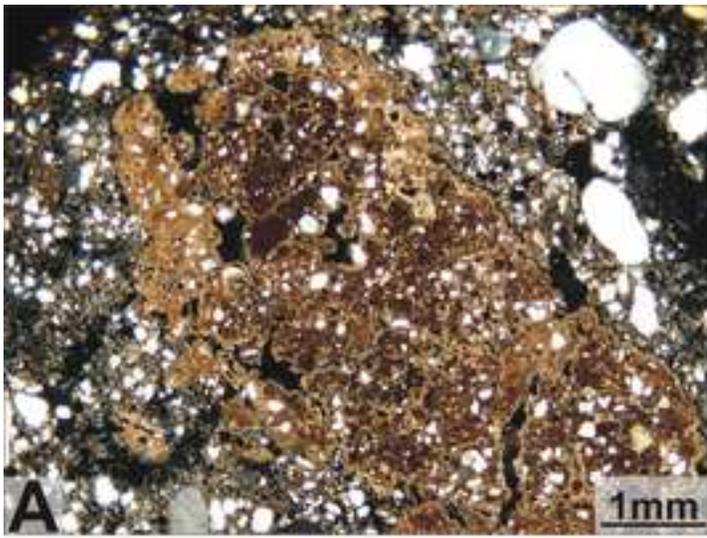


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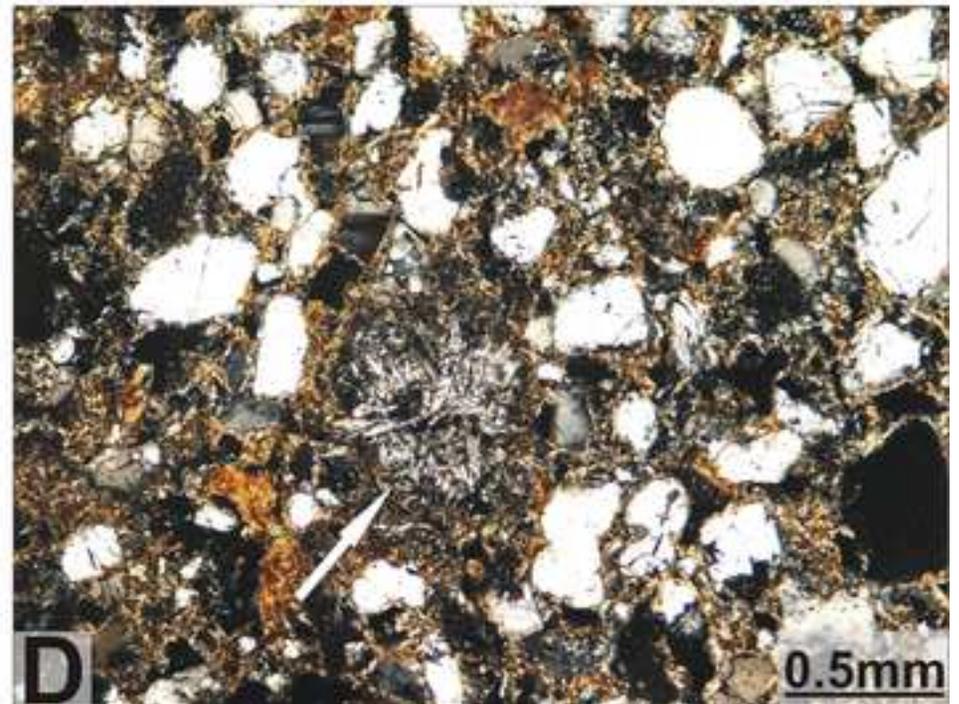
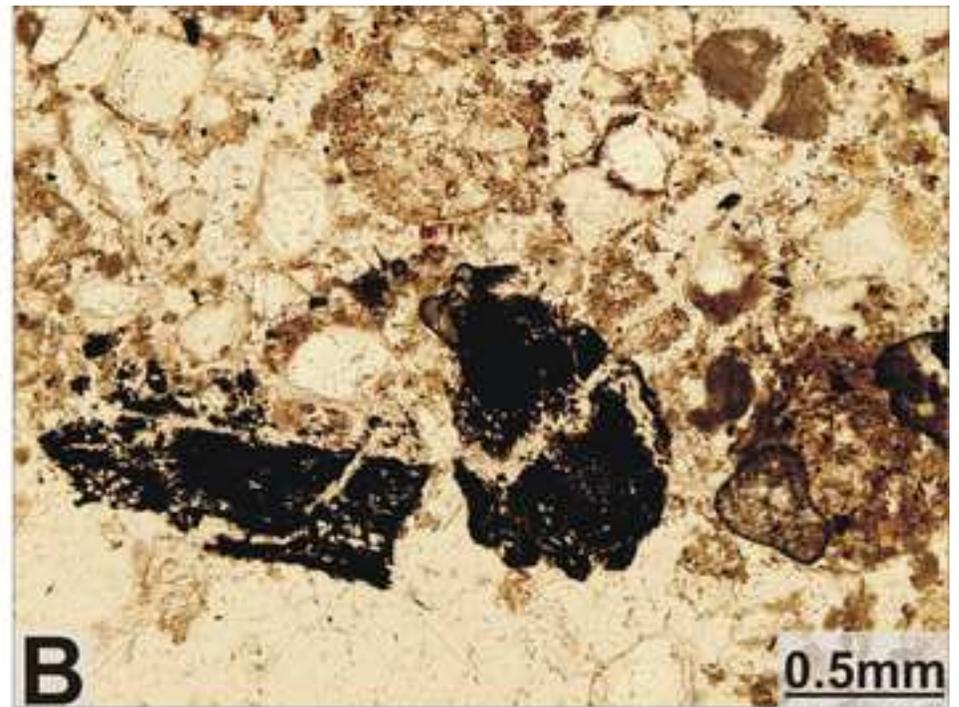
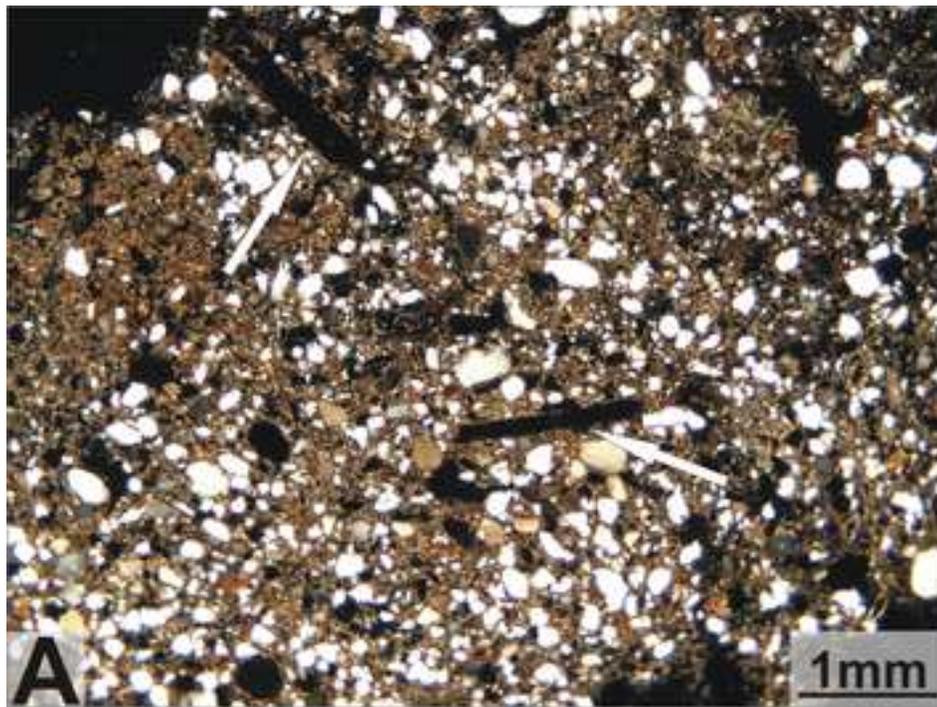


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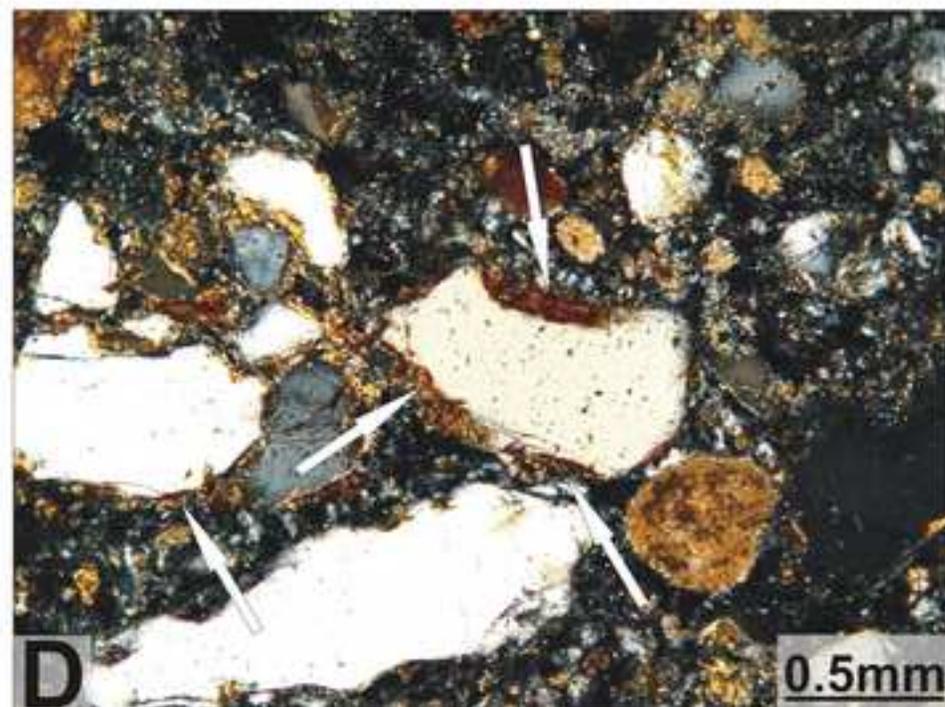
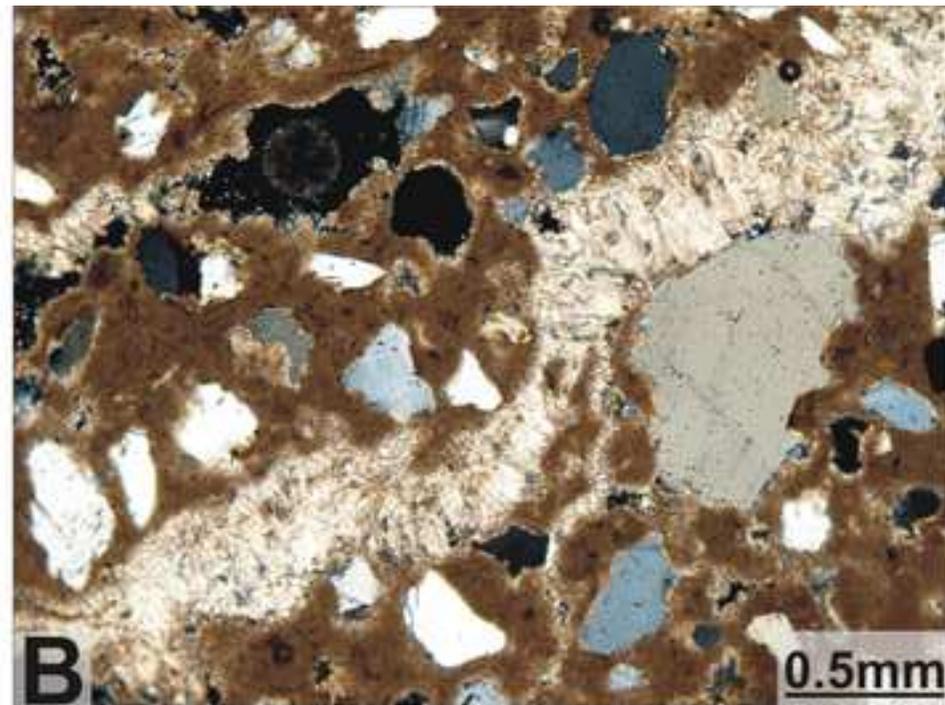
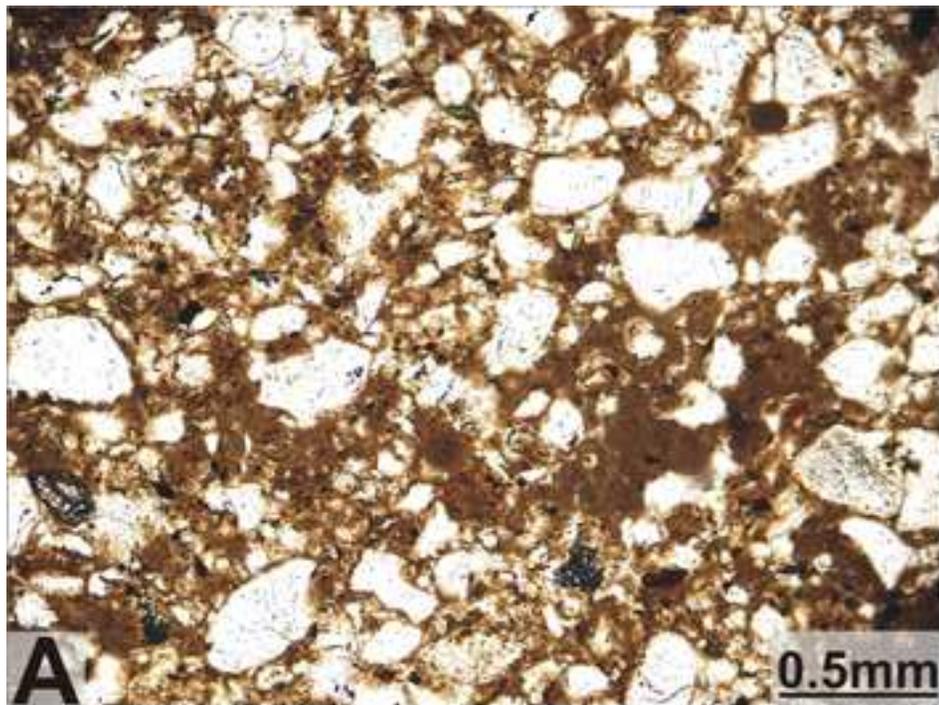


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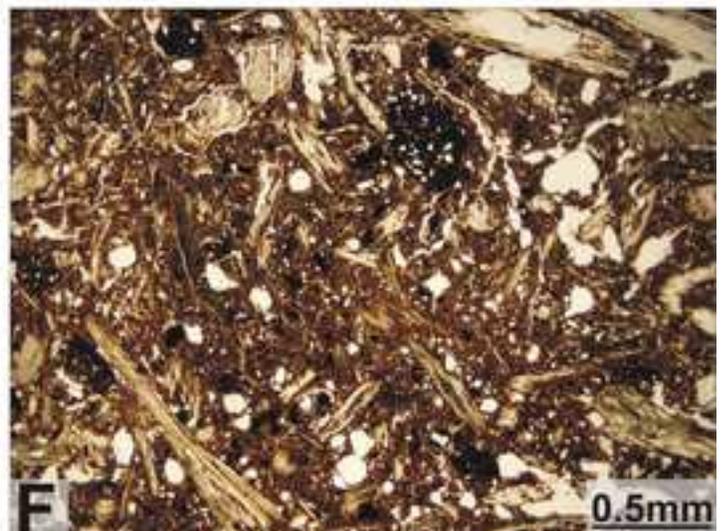
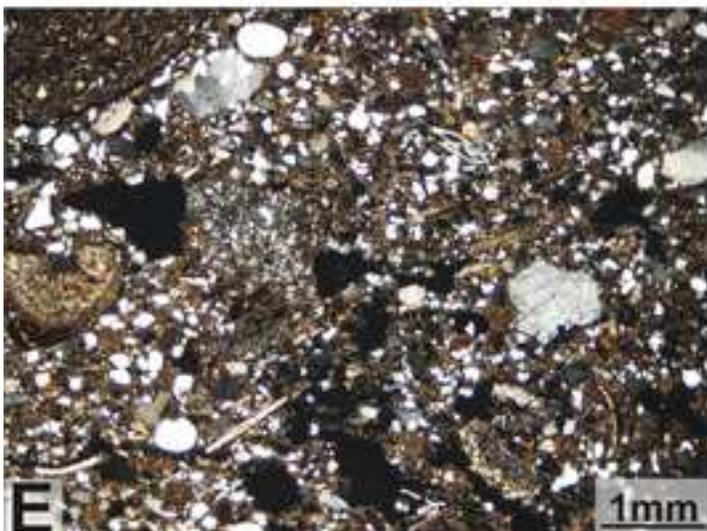
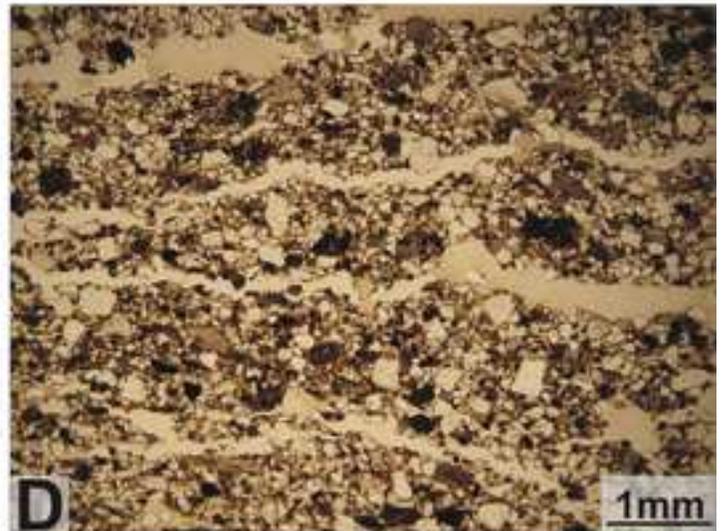
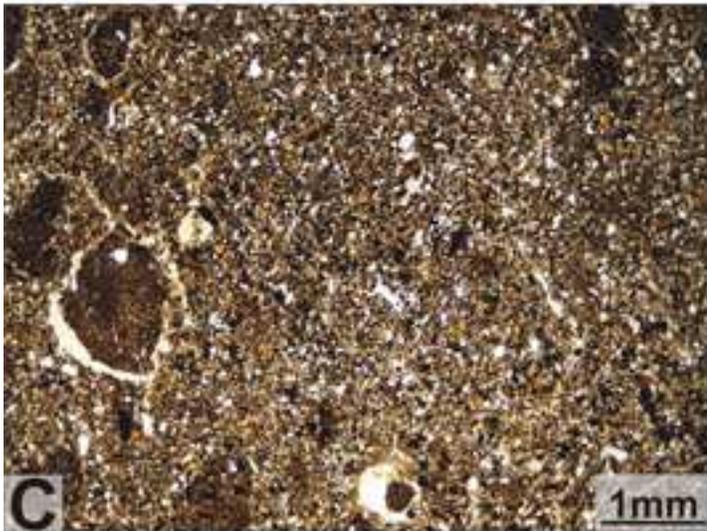
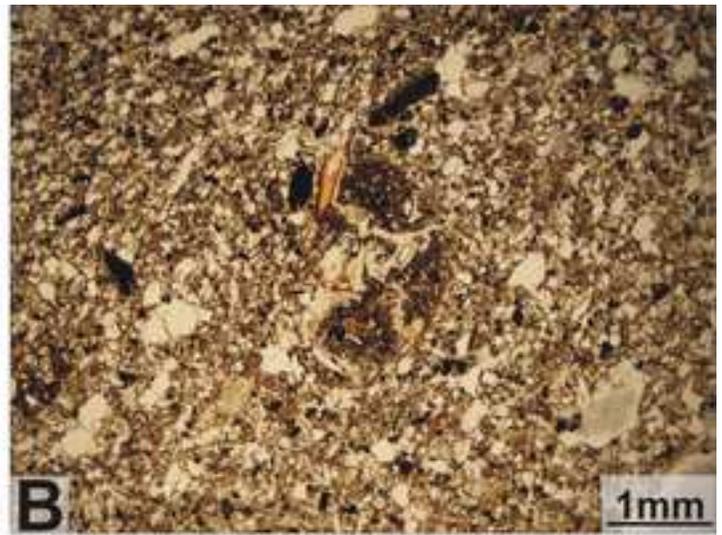
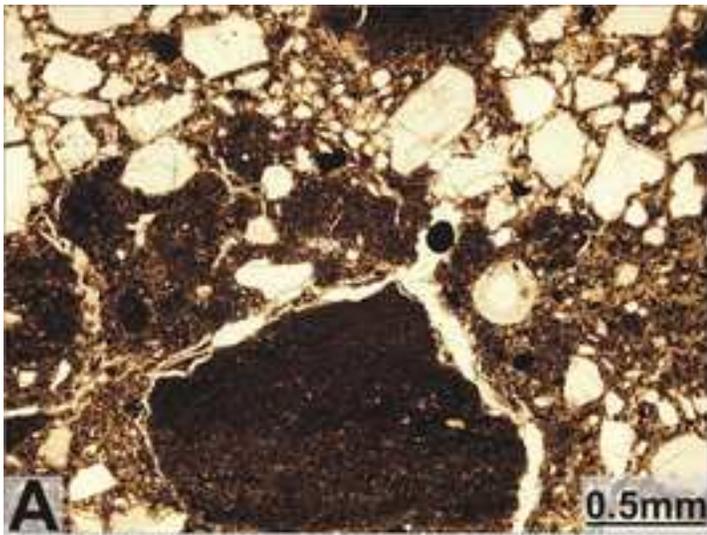


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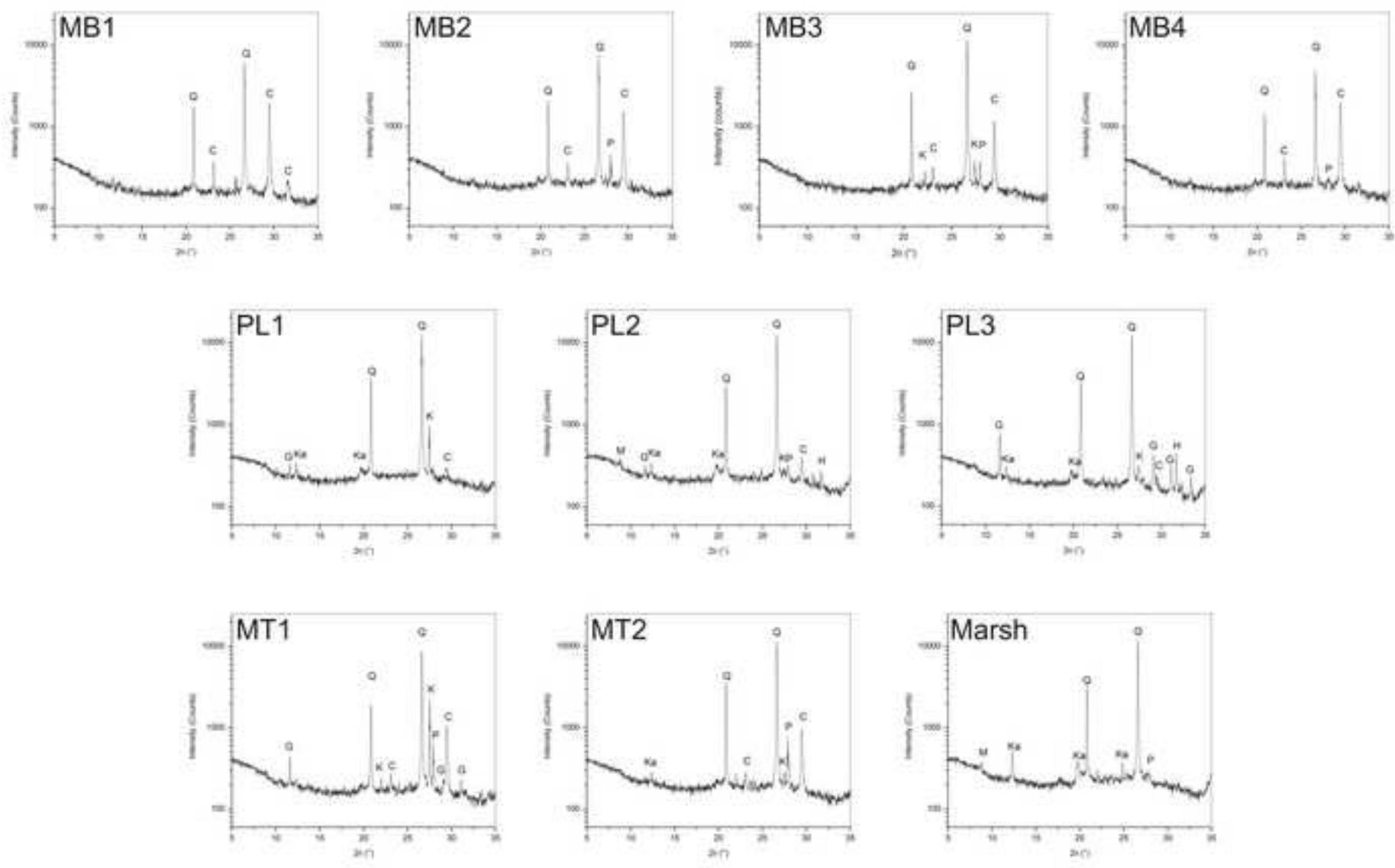


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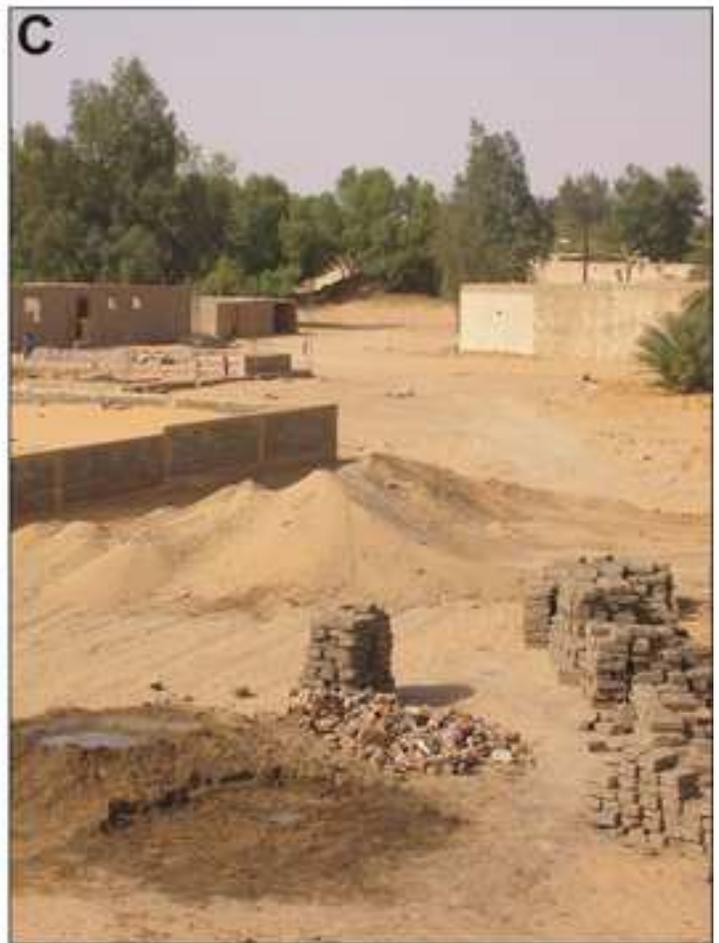


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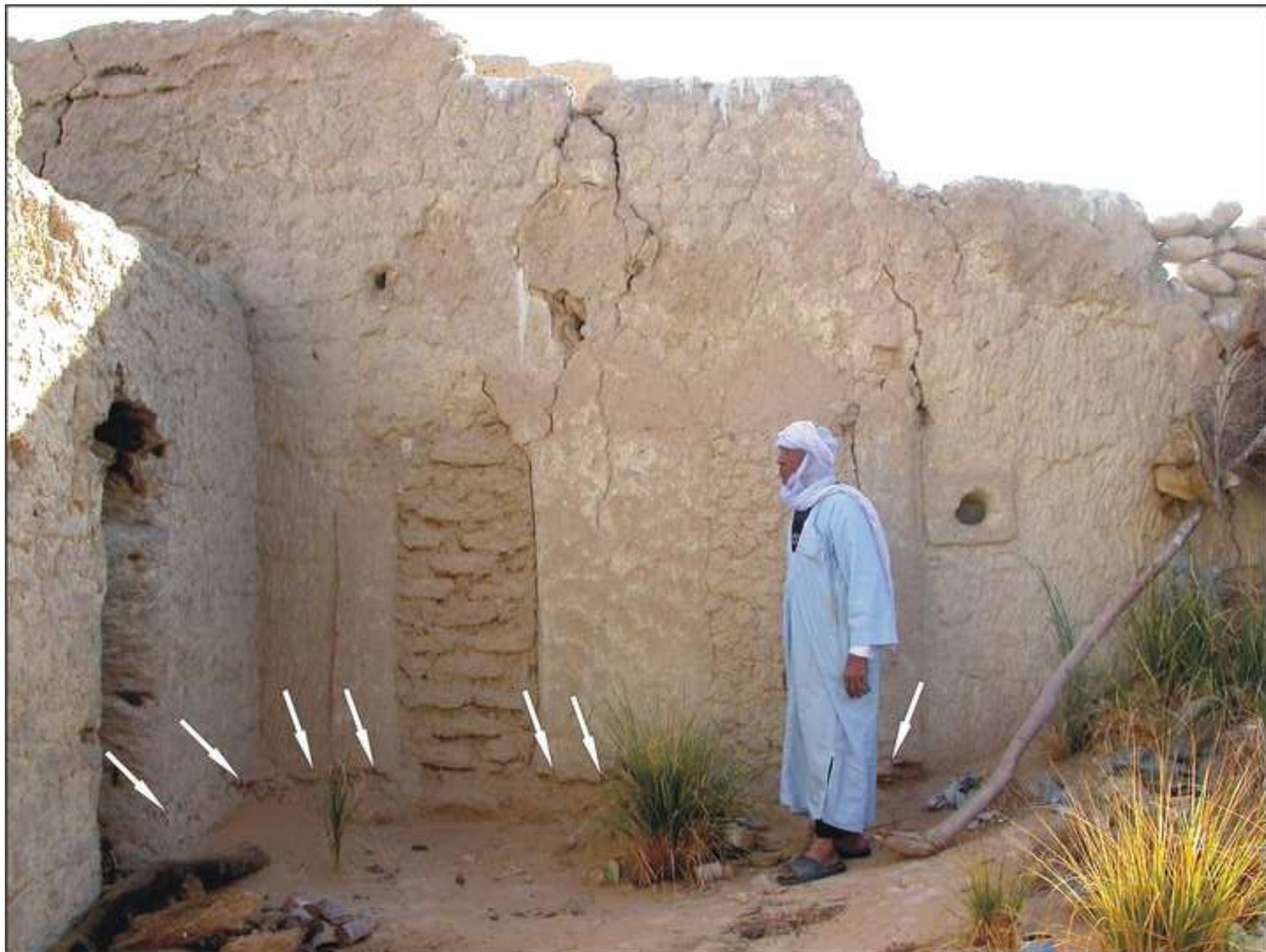


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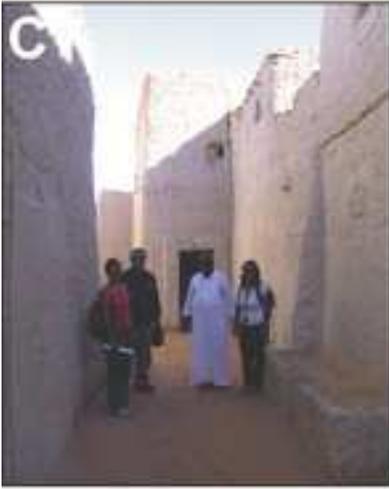


Table 1

Table 1. Summary of field and micromorphological properties of each sample (Classes of frequency: very few <5%; few 5-15%; common 15-30%; frequent 30-50%; dominant 50-70%; very dominant >70%).

Sample	Field properties				Micromorphological properties								
	Origin	Archaeological Layer	Type	Color	Structure	Coarse mineral components	Biogenic constituents	Voids	Micromass	Microstructure	b-fabric	c/f related distribution	Pedofeatures
MB1	Fewet excavation	FW3.W5	Mud brick	10YR 7/4	Massive	Silty to sandy quartz grains; very few white mica grains	Amorphous particles in the groundmass	Few to common chambers, vughs, vesicles; very few planes and channels	Micritic, yellowish brown to gray	Complex (massive to spongy)	Crystallitic	Single spaced porphyric	Very few lithorelicts (sandstone); common to frequent CaCO ₃ nodules; few CaCO ₃ coatings and infilling
MB2	Fewet excavation	FW3.W9	Mud brick	10YR 6/4	Massive	Silty to sandy quartz grains; very few white mica grains	Amorphous particles in the groundmass; very few charcoal fragments; small fragment of ovicaprine coprolite; very few phytoliths	Few to common vughs, vesicles, chambers; very few channels	Micritic, yellowish brown to gray	Complex (massive to spongy)	Crystallitic	Single spaced porphyric	Very few lithorelicts (sandstone); frequent CaCO ₃ nodules; very few CaCO ₃ coatings and infilling
MB3	Fewet excavation	FW6.W6	Mud brick	10YR 7/4	Massive	Silty to sandy quartz grains	Amorphous particles in the groundmass; very few small fragments of ovicaprine coprolite; very few phytoliths	Few to common vughs, vesicles, chambers	Micritic, yellowish brown to gray	Massive	Crystallitic	Single spaced porphyric	Very few lithorelicts (sandstone); frequent CaCO ₃ nodules; very few CaCO ₃ coatings and infilling
MB4	Fewet excavation	FW.W1	Mud brick	10YR 7/4 to 10YR 7/4	Massive	Silty to sandy quartz grains	Amorphous particles in the groundmass; in carbonatic pedorelicts: fragments of <i>Chara</i> , diatoms, fragments of molluscs.	Few to common vughs, vesicles, chambers	Micritic, yellowish brown to gray	Massive	Crystallitic	Single spaced porphyric	Very few lithorelicts (sandstone); common to frequent CaCO ₃ nodules; few dense to loose gypsum infillings
PL1	Fewet excavation	FW5.W11	Plaster	10YR 5/1	Massive to slightly laminated	Sandy to silty quartz grains	Very few finely subdivided vegetal fragments (straw or grass); few phytoliths	few vughs and vesicles	Micritic, yellowish brown to gray and less common birefringent yellowish clay	Massive	Crystallitic to granostriated	Close to single spaced porphyric	very few lithorelicts (sandstone); few coarse to fine CaCO ₃ nodules; few dense to loose gypsum infillings
PL2	Fewet excavation	FW3.b1	Plaster	10YR 6/4	Massive	Sandy to silty quartz grains	Very few finely subdivided vegetal fragments (straw or grass); few fragments of charcoal; few phytoliths	few to common vughs and vesicles, few channels	Micritic, yellowish brown to gray and birefringent yellowish clay	Massive	Crystallitic to granostriated	Single spaced porphyric	Very few lithorelicts (sandstone); few to common coarse to fine CaCO ₃ nodules; few dense to loose gypsum; infillings very few isolated gypsum phenocrysts in the micromass
PL3	Fewet excavation	FW6.W6	Plaster	10YR 5/1	Massive	Sandy to silty quartz grains	Very few finely subdivided vegetal fragments (straw or grass); very few fragments of charcoal; few phytoliths	Few vughs, vesicles, and channels	Micritic, yellowish brown to gray and birefringent yellowish clay	Massive	Crystallitic to granostriated	Single spaced porphyric	Very few lithorelicts (sandstone); few to common coarse to fine CaCO ₃ nodules; very few dense to loose gypsum infillings; few isolated gypsum phenocrysts in the micromass
MT1	Fewet excavation	FW4.W17	Mortar	10YR 4/1	Platy	Sandy to silty quartz grains	Very few fragments of charcoal; few phytoliths	Few to common vughs, vesicles, and channels; few planes	Birefringent yellowish clay and micritic, yellowish brown to gray	Massive (locally spongy)	Granostriated to crystallitic	Single spaced porphyric	Very few lithorelicts (sandstone); few CaCO ₃ nodules; very few dense to loose gypsum infillings
MT2	Fewet excavation	FW6.W6	Mortar	10YR 6/3	Massive	Sandy to silty quartz grains	Very few finely subdivided vegetal fragments; very few fragments of charcoal; few phytoliths	Few vughs, vesicles, and channels; few planes	Birefringent yellowish clay and micritic, yellowish brown to gray	Massive	Granostriated to crystallitic	Close to single spaced porphyric	Very few lithorelicts (sandstone); few fine CaCO ₃ nodules; very few dense to loose gypsum infillings
Ghat	Ancient building	-	Mud brick	10YR 6/4	Massive	Silty to sandy quartz grains; very few white mica grains	Very few charcoal and grass fragments; small fragment of ovicaprine coprolite; very few phytoliths	Few vughs and vesicles	Yellowish brown to gray	Massive	Crystallitic to undifferentiated	Close porphyric	Very few lithorelicts (sandstone); few CaCO ₃ coatings and infilling
Mopti	Historic building	-	Mud brick	10YR 7/4	Massive	Sandy to silty quartz grains	Few elongated vegetal remains (grass); very few clusters of phytoliths; a weathered fragment of bone	Few vughs and vesicles; very few channels and cracks	Brownish gray	Massive	Undifferentiated	Monic to close porphyric	Common pedorelicts (rounded red soil fragments); common fragments of former clay coatings and infillings; very few CaCO ₃ coatings
Al Khiday 1	Modern building	-	Mud brick	10YR 7/4	Massive	Silty to sandy quartz grains	Very few grass fragments	Few vughs and vesicles	Yellowish brown to gray	Massive	Undifferentiated	Close porphyric	Few to common pedorelicts (fragments of decantation crust)
Al Khiday 2	Modern building	-	Mud brick	10YR 7/4	Massive	Silty to sandy quartz grains	Very few grass fragments	Few vughs and vesicles	Yellowish brown to gray	Massive	Undifferentiated	Close porphyric	Few to common pedorelicts (fragments of decantation crust)
Al Khiday 3	Modern building	-	Plaster	10YR 7/4	Laminated	Sandy to silty quartz grains	Scarce grass and coprolite fragments;	Common planar voids and few vughs and	Brownish to gray	Massive	Undifferentiated	Single spaced	Very few pedorelicts (fragments of decantation crust)
Omduman	Historic building	-	Mud brick	10YR 6/4	Massive	Silty to sandy quartz grains	Very common grass and coprolite fragments	Scarce vughs and vesicles	Yellowish brown to gray	Massive	Undifferentiated	Close porphyric	Very few pedorelicts (fragments of decantation crust)
Dangeli	Meroitic building	-	Mud brick	10YR 6/4	Massive	Silty to sandy quartz grains	Very few grass fragments	Few vughs and vesicles	Yellowish brown to gray	Massive	Undifferentiated	Close porphyric	Few to common pedorelicts (fragments of decantation crust)

Table 2

Table 2. Results of qualitative mineralogical phase analysis. Key for peaks intensity (e.g., relative abundance of mineral in each sample): +++++ dominant peaks; +++ peaks observed over the entire range; ++ the main peak well visible, but hard to distinguish the other peaks from the background, + the main peak can be just distinguished from the background.

Sample	Quartz	Calcite	K-feld	Plagioclase	Gypsum	Kaolinite	Halite	Mica
MB1	+++++	+++	-	-	-	-	-	-
MB2	+++++	+++	-	++	-	-	-	-
MB3	+++++	+++	++	++	-	-	-	-
MB4	+++++	+++	-	+	-	-	-	-
PL1	+++++	+	+++	-	+	+	-	-
PL2	+++++	++	-	+	+	++	+	+
PL3	+++++	++	+	-	++	+	+	-
MT1	+++++	+++	+++	++	++	-	-	-
MT2	+++++	+++	+	++	-	+	-	-
Marsh	+++	+++	-	+	+++++	+++	++	+