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Later Stone Ages at the Haua Fteah Cave, Cyrenaica, Libya

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ABSTRACT

Understanding the timing, conditions and characteristics of the Middle to Later Stone Age (MSA/LSA) transition in North Africa is critical for debates regarding the evolution and past population dynamics of *Homo sapiens*, especially their dispersals within, out of, and back into, Africa. As with many cultural transitions during the Palaeolithic, our understanding is based predominantly on archaeological and palaeoenvironmental records preserved within a small number of deep cave sediment sequences. To use such sequences as chronological cornerstones we must to develop a robust understanding of the formation processes that created them. This paper utilises geoarchaeological analyses (field observations, sediment micromorphology, bulk sedimentology) to examine site formation processes and stratigraphic integrity during the MSA/LSA at the Haua Fteah cave, Libya, one of North Africa's longest cultural sequences. The depositional processes identified vary in mode and energy, from aeolian deposition/reworking to mass colluvial mudflows. These changing processes impact greatly on the interpretation of the palaeoenvironmental and archaeological records, not least in identifying potential colluvial sediment deposition and reworking in layers identified as containing the MSA/LSA transition. This study highlights the importance of developing geoarchaeological analyses of cultural sequences to fully unravel the limitations and potential of their contained archaeological and palaeoenvironmental records.

KEY WORDS: Sediment Micromorphology; Geoarchaeology; Caves; North Africa; Site Formation Processes.

INTRODUCTION

The appearance of Later Stone Age (LSA) stone tool industries within Africa after ca. 50,000 years BP (ca. 50 ka) marked a major change in human behaviour, contrasting starkly with the behavioural practices of the Middle Stone Age (MSA, Barham & Mitchell 2008). The mechanisms, conditions and chronologies of the development of LSA industries from the MSA industries that preceded them are the subject of intense debate, as summarised by authors in Jones and Stewart (2016). Even polarising archaeological entities into neat conceptual 'blocks' — MSA or LSA — can be problematic, ignoring both variation in and the fluid nature of human behaviour (Mitchell, 2016: 409). The North African archaeological record is central to these debates. Given its location between Sub Saharan Africa and the Levant, North Africa is a region crucial to understanding the dispersals of *Homo sapiens* populations ('modern humans') out of as well as back into Africa (Foley and Lahr 1997; Garcea, 2012, 2016; Van Peer, 1998). Establishing the timing and palaeoenvironments of the MSA/LSA transition across this key region is critical if we are to reveal past population histories in North Africa, yet our understanding of this important transition still requires clarification (Barton et al., 2016). Although arguments concerning the MSA/LSA transition in North Africa have mostly centred on population dispersal scenarios, it currently remains unclear to what extent such a technological shift may reflect: 1) migrations into new regions of human populations using culturally and technologically distinct tool kits (Oliveri et al., 2006; Pereira et al., 2010); 2) *in situ* technological adaption to changing environmental conditions and resources (Garcea,

2010); 3) a change in population dynamics and enhanced opportunities for cultural transmission (Powell et al., 2009); 4) a biological change occurring in human populations (Klein, 1994); or 5) a combination of these scenarios, such as decreasing residential mobility, population growth and environmental change (Tryon & Faith, 2016).

Present understanding of the MSA/LSA transition in North Africa is, as in the case of most Palaeolithic regional chronologies, based largely on artefacts, palaeoenvironmental proxies and dating material preserved within cave sediment sequences. Yet each of these stratigraphies were formed through processes unique to their setting and history (Farrand, 2001; Woodward & Goldberg, 2001). Changing modes and rates of deposition have been long known to impact on the taphonomy of the archaeological record through sediment removal and reworking, or changing rates of sedimentation and hiatuses (e.g. Butzer, 1971; Harris, 1989; Stein, 1987, 2001). This can distort interpretation of these cultural and environmental chronologies, and create apparently abrupt changes in environmental proxies and/or technological artefact attributes, as well as 'inversions' of cultural material (Campy & Chaline, 1993; Hunt et al., 2015; Mallol et al., 2012). Therefore, if we are to use deep cave sequences as the cornerstones of regional cultural chronologies, we must understand the processes that created them, and consider the archaeological records they contain in light of this understanding.

Geoarchaeological analyses are well-placed to analyse site formation processes through a range of methods and analytical scales (e.g. Bailey and Woodward 1997; Frumkin et al., 2016;

Mallol et al., 2009). In particular, sediment micromorphology allows microscopic interrogation

of sediments, enhancing field observations and complementing quantitative sediment analysis

(Goldberg & Sherwood, 2006; Woodward & Goldberg, 2001), especially in studies of

sedimentation rates and stratigraphic integrity beyond the reach of radiocarbon dating (e.g.

Aldeias et al., 2014; Karkanas & Goldberg, 2010; Mallol et al., 2012).

   This paper utilises a range of geoarchaeological techniques to examine site formation

processes in the late MSA to early LSA layers at the Haua Fteah cave on the Cyrenaican coast

of northeast Libya (22°3'5"E, 32°53'70"N). The cultural sequence revealed by Charles

McBurney's excavations in the 1950s (McBurney, 1967) is unparalleled in North African

prehistory, with the earliest deposits dating to the end of MIS 6 (Douka et al., 2014; Jacobs et

al., 2017), and containing cultural material from the MSA to the present (McBurney, 1967).

Renewed investigations by a multi-disciplinary team, The Cyrenaican Prehistory Project

(CPP), between 2007 and 2015 have combined archaeological excavation with

palaeoenvironmental and chronological analyses (e.g. Barker et al., 2007, 2008, 2009, 2010,

2012; Farr et al., 2014; Rabett et al., 2013). The present study, part of that project, combines

sediment micromorphology, bulk sedimentology, and field observations to develop a

sedimentological and taphonomic framework for the sediments containing the late MSA and

early LSA artefacts. Within this framework, the existing and existing and emerging

archaeological and palaeoenvironmental records of this important cultural sequence can be situated and interpreted.

THE MSA AND LSA IN NORTH AFRICA

Reviews of the MSA and LSA of North Africa reveal a complexity of demographic scenarios that may underlie the equally complex cultural shifts that occurred both within the MSA and LSA and from the MSA to the LSA (Garcea, 2016; Van Peer, 2016). Population movements during this period have often been linked to periods of climate change and consequential ecological change (Timmerman & Friedrich, 2016). During humid episodes in MIS 5 (ca. 130–71 ka), for example, populations with MSA technologies exploited a network of rivers and lakes that traversed the Sahara (Drake & Breeze, 2016; Drake et al., 2013; Geyh & Thiedig, 2008; Osborne et al., 2008). In contrast, arid conditions from MIS 4 (ca. 71–57 ka) to MIS 2 (ca. 29–14 ka) — albeit with shorter humid periods during intervening MIS 3 (Hoffmann et al., 2016; Giraudi, 2005; Tjallingii et al., 2008) — are argued to have forced populations to contract to the edges of the continent (Ambrose, 1998, 2003; Garcea, 2012), or to small yet viable areas of the Nile valley (Van Peer et al., 2010: 241; Vermeersch & Van Neer, 2015).

At this time when these late Pleistocene climatic changes were profoundly shaping environments and landscapes in North Africa, LSA technologies appeared in various archaeological records at various times. It is currently unclear whether the LSA assemblages

preserved within North African sequences represent diverse local trajectories and responses to

local environments during the Late Pleistocene, or movements of populations themselves,

within, out of, or back into Africa (Barham & Mitchell, 2008; Barton et al., 2016; Garcea,

2016). Our understanding is hampered by a lack of archaeological sites with deposits dating to

MIS 3 (ca. 57–29ka) when the MSA/LSA transition occurred in certain areas of North Africa

(Barham & Mitchell 2008; Barton et al. 2016). The Central Sahara and Western Desert of

Egypt are argued to have been abandoned after MSA occupation, and remaining so until the

Holocene (Barham & Mitchell, 2008: 265; Garcea 2004, 2012; Garcea and Giraudi 2006; Jones

et al., 2016) although evidence from the Central Sahara suggests that the presence of

populations in the region with LSA technologies during MIS 3/2 cannot be excluded as a

possibility (Cancellieri et al., 2016: 142). The Nile Valley, an area that potentially preserved

localised refuges from Saharan aridity, reveals the presence of artefacts of the 'Khaterian'

complex at Nazlet Khater. These date from from 40–32ka (Vermeersch 2010) and suggest that

LSA industries developed locally from the MSA, potentially driven by growing environmental

and population pressures (Van Peer & Vermeersch, 2007). Likewise, whilst sites in the

Maghreb may have been subject to sporadic abandonment, at Grotte des Pigeons (Taforalt), the

cultural sequence appears to contain a series of stepped, local changes in technology between

the MSA and LSA (Barton et al., 2016). The MSA/LSA transition is, however, later in the

Maghreb than the Nile Valley, with the earliest LSA Iberomaurusian dated to 25–23ka (Barton

et al., 2013). Situated between these two potential refuges, lies the MSA/LSA sequence at the

Haua Fteah, where the transition from the MSA to the LSA 'Early Dabban' industries has been

dated to 46–41 ka (Barton et al., 2015; Douka et al., 2014). This site occupies a central position

in understanding the potential cultural connections and local trajectories of this important

cultural shift.

THE HAUA FTEAH MSA/LSA SEQUENCE

The Haua Fteah cave is a semi-collapsed karstic phreatic cave on the northern escarpment of

the Gebel Akhdar ('Green Mountain') limestone massif in Northeast Libya. The Gebel Akhdar

(Figure 1) covers an area ~300 x 400 km and rises in series of three escarpments to over 800 m

(McBurney & Hey, 1955). Its topography and position in the path of Mediterranean Westerlies

cause it to receive more rainfall than the surrounding regions - ~800 mm per year compared to

~250 mm for the surrounding regions (Libyan National Meteorological Centre). The cave is ~1

km from the present shoreline and ~63 m asl, with a mouth ~80 m wide and ~20 m high. The

floor of the cave consists of bare, largely dry, silty sediment which is easily mobilised by the

wind and wetted in small areas by dripping from the cave roof. The floor remains largely dry

during rain, yet runoff from intense storms can transport significant volumes of sediment and

soil into the cave (Hunt et al., 2010).

The massif was connected to Saharan rivers and lakes during MIS 5 (Drake & Breeze, 2016;

Drake et al., 2013; Geyh & Thiedig, 2008; Osborne et al., 2008) and it probably acted as a

refuge during glacial periods (Klein & Scott, 1986; McBurney & Hey, 1955; Prendergast et al.,

2016; Reade et al., 2016). The Mediterranean coastline and the marine resources it contained

may have increased the area's attractiveness to hominin populations, as well as providing a

corridor for dispersal (Bailey & Flemming, 2008). The region's steep offshore topography

means that the position of the coastline in the immediate vicinity is unlikely to have receded

more than 3 km during peak glacial conditions (Lambeck & Purcell, 2005; GEBCO_14).

The location and long cultural sequence of the Haua Fteah make it pivotal to understanding

prehistoric cultural change in North Africa. The 1950s excavations revealed ~14 m of deposits

containing cultural materials from the MSA to the historic period (McBurney, 1967).

McBurney excavated in three stepped, inset trenches named by the present project, which

emptied the McBurney trench of the 1955 backfill: the Upper Trench (from the ground surface

to ~2 m depth), the Middle Trench (~2–7 m), and the Deep Sounding (~7–14 m). McBurney

excavated in spits that often cross-cut sediment layers, though the relationship of the spits to

stratigraphic layers was observed as the excavation proceeded downwards (McBurney, 1967).

The present project has excavated new areas alongside McBurney's trench in the Upper and

Middle Trenches, as well as the Deep Sounding where excavations extended a further ~1 m

below the base of McBurney's excavations. Of primary interest to the work presented here is

the ~2.0 x 1.0 m trench (Trench M) and a 0.3 x 0.3 m sample column alongside the Middle

Trench, as well as two 0.3 x 0.3 m sample columns excavated down the West- and North-

Facing Profiles (see below).

Using the Middle Palaeolithic (MP) and Upper Palaeolithic (UP) terminologies of Europe

and the Near East, McBurney classified the earliest industry, a flake- and blade-based MSA

industry, as 'Libyan Pre-Aurignacian MP'. It occurred in three concentrations within the Deep

Sounding (McBurney, 1967), with occasional lithics and shell fragments recovered throughout

the Deep Sounding (Farr et al., 2014; McBurney, 1967; Rabett et al., 2013). These sediments

have been dated by Optically Stimulated Luminescence (OSL) to MIS 5, with the base of the

sequence lying below the MIS 5/6 boundary (Jacobs et al., 2017). Close to the base of the

Middle Trench, artefacts with 'Levalloiso-Mousterian MP' affinities were found by McBurney

in initially high numbers from sediments for which the present project, using new ^{14}C and OSL

determinations, has provided a modelled age of 75–70 ka (Douka et al., 2014). These levels

yielded two *Homo sapiens* mandibles at first regarded as 'Neanderthaloid' (McBurney, 1967;

McBurney et al., 1952, 1953; Tobias, 1967; Trevor and Wells, 1967) but since recognised as

fully modern human (Hublin, 1991, 2001). Artefact numbers then dropped significantly,

remaining low into McBurney's Layer XXV, which he identified as containing the first UP (i.e.

LSA) industry at the site, which he termed 'Dabban' because he had found similar material in

the nearby cave of Hagfet ed-Dabba a few years previously (McBurney, 1967; McBurney and

Hey 1955). Tephra shards identified as the Campanian Ignibrite/Y5 tephra, (dated to 39.28 ±

0.11 ka BP, De Vito et al., 2001) were found associated with the contact between Context 441

and 442 (Figure 4) in Early Dabban layers (Barton et al., 2015; Douka et al., 2014), and were

included in the Bayesian model which produced a modelled age of 46–41 ka for the deposition

of the Dabban layers (Douka et al., 2014), a date consistent with the earliest UP industries of

the Levant and Europe (Benazzi et al., 2011; Higham et al., 2011; Rebollo et al., 2011).

Genetic evidence suggests a migration of Levantine populations into North Africa at this time

(Olivieri et al., 2006), perhaps along the Mediterranean coastline.

The nature of the MSA/LSA transition at the Haua Fteah, as understood from the 1950s

excavations, is unclear. It is compounded by very low artefact densities in Layer XXV (as well

as in the immediately underlying and overlying layers) and is complicated by the fact that this

layer, which was subdivided into sub-units a–e, produced Levalloiso-Mousterian material in

XXVc overlying the appearance of potentially LSA Dabban material in XXVd (McBurney

1967: 138). Similar complexity is emerging from the initial analysis of the small number of

finds located at these depths by the new stratigraphic excavations (Farr et al., 2014; Rabett et

al., 2013). The potential interstratification of MSA and LSA technologies observed by

McBurney may mark the presence of residual MSA traits or groups in Cyrenaica after the

LSA, and/or erosion and reworking (McBurney, 1967: 138), and/or mixing of material by

McBurney's spit excavation method. The different scenarios have major implications for

understanding the MSA/LSA transition in the region, and highlight the need to situate the

emerging new archaeological data from the entire sequence within a solid model of formation

processes.

THE HAUA FTEAH SEDIMENT SEQUENCE

Basic sediment analysis and interpretation of the Haua Fteah sequence were undertaken

during the 1950s excavations, and a broad framework for understanding the modes of

sedimentation developed (McBurney 1967; Sampson, 1967). Layers of limestone gravel and

sand in the Haua Fteah sediments were interpreted as likely weathered from the cave roof

(Sampson, 1967), during periods of cooling and increased physical weathering (now correlated

with MIS 4, MIS 2; Douka et al., 2014). Deposition of fine material was attributed to wind and

water action (McBurney, 1967) in warmer phases such as the the Eemian (now correlated to

MIS 5, MIS 3; Douka et al., 2014). Moyer (2003) later posited that these fine sediments were

the result of inwash during pluvials. These interpretations were, however, based solely on field

observations and coarse material measurement, and in particular the deposition mechanisms of

fine material remained untested.

As part of the renewed excavations, the sediment sequence was divided into five facies

reflecting differences in the dominant site formation processes (Douka et al., 2014; Inglis,

2012) (Figures 3 and 4). Three fine-grained facies (Facies 1, 3 and 5) were separated by two

dominated by limestone gravel and sand (Facies 2 and 4). Field observations during the new

fieldwork, followed by bulk sedimentological studies, interpreted the silty layers within Facies

1 as deposited by inwash and mudflow events that were interleaved with heavily

anthropogenically-influenced sediments and debris-avalanche deposits from roof-collapse

(Hunt et al., 2010). Modelling of radiocarbon-dated shell fragments, and interpretation of

palynological analyses and field descriptions, extended this 'sump' model into the upper part of

Facies Two, where sediments were interpreted as predominantly debris flows (Hunt et al.,

2015).

METHODS

This paper presents the analysis of the sediments, and the interpretation of the processes that

deposited them, in the 'Levalloiso-Mousterian' MSA and 'Early Dabban' LSA layers in the

Middle Trench: Facies 3, 4 and the top part of Facies 5, which were the subject of RHI's PhD

(Inglis, 2012). A multi-scalar geoarchaeological approach was employed: field descriptions

were combined with high-resolution soil micromorphological analysis of each context, while

bulk sedimentological analyses on the <2 mm fraction provided measurement of the fine

sediment properties. In addition, two soil pits in the local *terra rossa* were dug and sampled to

provide modern analogues, Pit R directly upslope of the cave opening and 5 m from the lip of

the roof (two small bulk samples collected), and Pit T, located on the slopes below the cave, ~

200 m to the NNW of the Haua Fteah (three small bulk).

Field Observations After removal of the backfill and cleaning the 1950s sections, the

excavators used the single context system (MOLAS, 1994) to record discrete sediment layers

defined by several key field characteristics, e.g., colour, texture of fine and coarse material,

shape, and clast orientation. Use of context divisions in sampling for sedimentological,

micromorphological and palaeoenvironmental analyses ensured that data could be correlated

with archaeological assemblages from each context as excavations progressed.

Sediment Micromorphology Sediment micromorphological sampling was undertaken of

the majority of contexts on the West-Facing Profile in Facies 5–3, as well as corresponding

North-Facing Profile contexts in areas of variable stratigraphy and at the depth of McBurney's

Layer XXV (Figure 4). Sampling focused on upper and lower contacts of each context to

characterise the mode of deposition, material within each deposit and the transitions between

them. Intact sediment blocks were removed from profiles using Kubiena tins or foil food

containers, and secured with tissue paper and parcel tape to allow drying in the field before

wrapping in clingfilm for transport. Blocks were air-, then oven-dried for 48 hours prior to

impregnation with crystallitic polymer resin under vacuum, following capillary rise. Thirteen ×

7 cm or 7 × 5 cm slices were cut from cured blocks and ground to 30μm using a Brot

multiplate grinding machine. Thin-sections were examined by eye and using a Leica Wild M40

wide-view microscope (×4 to ×35 magnification), and a Leitz Laborlux 12 Pol microscope

(×40 to ×400 magnification), under plane polarized (PPL), crossed polarized (XPL), and

oblique incident light (OIL). Description followed Bullock et al. (1985), Courty et al. (1989),

and Stoops (2003). Micro-fabrics within each slide were defined on the basis of changes in

micromorphological characteristics within a sample, and numbered in stratigraphic order from

the top of the slide. For example, Micro-Fabric 2521:1 overlies 2521:2 and is the uppermost

unit in the slide made from Sample 2521 (the sample number was assigned in the Haua Fteah

environmental sample register).

Bulk Sediment Analyses Sample columns (30 × 30 cm) were excavated through Facies 3–5

sediments on the North- and West-Facing Profiles (Figure 4). Samples at 5 cm intervals

respecting context boundaries were collected for bulk sedimentological analyses, as well as

palynology, phytolith analysis and tephrochronology (e.g. Barton et al., 2015; Douka et al.,

2014; Simpson, 2014). The <2 mm fraction was analysed for: particle size distributions,

percent loss on ignition organics (%LOI organics), percent carbonate (%CaCO$_3$), and magnetic

susceptibility. For the particle size analysis alone, carbonates were removed from the sample

prior to analysis (see next section); all other bulk sedimentological analyses were carried out

on the complete <2mm fraction.

Laser particle size analysis of the 0.02–2000 μm sediment fraction can distinguish a

sediment's transport method or source (Folk, 1966; Pye & Blott, 2004), potentially useful at the

Haua Fteah for distinguishing between colluvially- and aeolian-transported sediments. Given

that the limestone from the cave left <1% residue after dissolution (Inglis, 2012), the volume of

limestone required to produce this would be far greater than that dissolved in the formation of

the cave. The non-carbonate fraction in the Haua Fteah sediments was therefore considered to

be predominantly allochonthous. Removal of carbonates was therefore undertaken to avoid

concretion of sediment particles by carbonate precipitated in the cave, and to examine the allochonthous, non-carbonate source of the material. It is noted, however, that this would also remove purely allochonthous carbonate material (if present), although it would be expected that such variation in lithology, if of a sufficient magnitude, would be visible in the micromorphological observations. The processes may also remove phytoliths from the sample, altering the silt fraction in the non-carbonate PSD. Samples were treated overnight with 10% HCl, and dispersed in 4.4% sodium pyrophosphate and distilled water. Analysis was carried out using a Malvern Mastersizer 2000, and the ultrasonic probe used throughout measurement to ensure clay deflocculation. Samples were measured three times for 30 s, and the average distribution taken. Measurement was repeated until the curve stabilised.

%LOI organics. Raised organic content of sediments may indicate anthropogenic activity (e.g. Macphail et al., 2004; Sànchez Vizcaíno & Cañabate, 1999; Stein, 1992) or palaeosol formation (Ellis & Mellor, 1995). %LOI organics was determined by heating pre-weighed, dried samples to 425°C for 24 hours and, on cooling, noting the mass lost.

%CaCO$_3$ in limestone cave sediments originates from multiple sources: limestone roof-spall from physical weathering (Laville, 1976), carbonate-rich source material (e.g. aeolian sources, Coudé-Gaussen & Rognon, 1993), precipitation from carbonate-rich water (White, 2007) or ash (Canti 2003). These different depositional processes highlight the need for bulk %CaCO$_3$

to be interpreted in the context of field and micromorphological observations. %CaCO₃

contents were determined through calcimetry following Gale and Hoare (1991).

Magnetic Susceptibility serves as a measure of ferro- or ferrimagnetic materials within a

sample (Thompson & Oldfield, 1986), the concentration of which can be raised or lowered

through changes in redox conditions through burning, waterlogging, wetting and drying cycles,

or biological activity (Sternberg, 2001). Variation in magnetic susceptibility may also mark

variation in source material, and magnetic susceptibility variability of re-deposited soils has

been used in caves as a proxy for external environmental conditions (e.g. Ellwood et al., 2004),

although this latter intepretation did not take into account the multiple mechanisms that may

raise magnetic susceptibility, including burning (Tite & Mullins, 1971). The low frequency

magnetic susceptibility of the samples was measured using a Bartington MS2B Meter.

RESULTS

Micromorphological and Field Observations

The three MSA and LSA facies are described from the base of the Middle Trench upwards.

Interpreted site formation processes and bulk sedimentological variables are summarised by

context in Figure 5. For summary micromorphological descriptions, refer to Supplementary

Tables 1–5, and Inglis (2012) for full descriptions. All facies dates are modelled Bayesian age

ranges for deposition following Douka et al. (2014), and thus some overlap with adjacent

facies.

Facies 5 (Middle Trench): ~ 75–65 ka

Facies 5 (Contexts 528–520, West-Facing Profile; 538–521, North-Facing) in the Middle

Trench consists of red and orange silt layers, some of which crossed both profiles, interspersed

with combustion features and rare organic lenses. Some redder, more clayey layers lens out on

the West-Facing Profile towards the back wall of the cave (e.g. Context 520), indicating their

origin outside the cave mouth. Between Contexts 523 and 521 a series of small combustion

features were spaced across the South-, East- and West-Facing Profiles. Micromorphological

sampling covered Contexts 523–520 (West-Facing Profile) and 528–521 (North-Facing).

Micromorphological observations (Supplementary Table 1) showed a largely consistent fine

material composition of sandy silt/silt loams with micritic crystallitic to stipple-speckled b-

fabrics. Micro-fabrics throughout Facies 5 shifted between those that contained lenses of

material (fine sand, silt, or dung), and rarer micro-fabrics with more chaotic arrangements and

sharp lower boundaries. These variations occurred within, and between, contexts (e.g. Context

563). Occasional crust fragments were observed on both profiles, and calcite precipitation on

the West-Facing Profile (Context 521). Lenses of charcoal, ash and other charred and humified

material were observed throughout. Facies 5 was capped on the West-Facing Profile by a dark

red, clayey context (520) with a sharp lower boundary and stipple-speckled b-fabric (Micro-

Fabrics 2000:1).

Facies 4 (Middle Trench): ~ 68–47ka

Facies 4 (Contexts 517–513, West-Facing Profile; Contexts 567–513, North-Facing) was characterised in the field by limestone gravel in a pale, friable orange to grey silty matrix. On the North-Facing Profile it was capped by a combustion feature (Contexts 513 and 535) that sloped down to the east. Only Context 513 continued across both profiles, grading from grey on the North-Facing Profile to orange on the West-Facing. Micromorphologically (Supplementary Table 2), the micro-fabrics in Facies 4 exhibited more distinct variation than those in Facies 5. On the West-Facing Profile, Context 517 (516 was not sampled) is a pale, limestone-dominated sandy silt loam/silt loam, with some dung lenses and a stipple speckled/micritic crystallitic b-fabric (Micro-Fabrics 2666:1 & 2). Similar micro-fabrics were observed on the North-Facing Profile, in layers of greyish, limestone-sand sandy silt loams with horizontal orientation of the coarse material (e.g. Contexts 567, 536), sometimes containing small red clayey stringers and crusts as well as calcitic hypocoatings. These micro-fabrics were interstratified with lenses of redder sandy clay loams with interleaved/sharp lower boundaries, indicating major variation in depositional energy and character. These layers are capped by a large, weathered combustion feature (Contexts 535, 513) consisting of a series of ash and phytolith-rich layers (Inglis, 2012), potentially formed by combustion of grass-rich fuel (S. E. Jones, pers. comm. 2012).

Facies 3 (Middle Trench): ~ 48–34ka

Facies 3 (Contexts 509–440, West Facing Profile; Contexts 508–440 North-Facing Profile)

consisted of silt layers varying in the field in compactness, colour, and texture, with dense,

reddish layers of silty clay that stood proud of cleaned profiles interspersed with friable, pale

yellow and orange silt layers. On the West-Facing Profile, some layers (both silty and clayey)

were indurated by carbonate (e.g. Context 490). The horizontal layers largely continued across

both profiles. Gravel layers became thicker and more frequent towards the overlying, gravel-

dominated Facies 2. Facies 3 contained both MSA and LSA layers, separated by Layer XXV

which is argued to have contained interleaved MSA and LSA artefacts (McBurney, 1967). For

ease of discussion, description of the results for Facies 3 is divided here into sediment

characterised by these cultural artefacts.

The **Facies 3 MSA ("Levalloiso-Mousterian") contexts (509–498)** (Supplementary Table

3) were commonly pale orange-brown and yellow silts with little limestone gravel, with a shift

towards a higher frequency of redder and more compact layers from Contexts 503–499, some

of which were restricted to the West-Facing profile, and lensing out towards the back wall of

the cave, indicating that they had originated from the cave mouth (e.g. Context 491). The

Facies 3 MSA layers were sampled for micromorphological analysis on the West-Facing

Profile only. Whilst containing less limestone sand and gravel than Facies 4, the

micromorphological observations of the fine material were consistent with the underlying

facies, that is, they varied between pale, sandy silt loams/silt loams containing dung lenses and

stringers of fine material and other, redder, clay loams/silty clay loams with chaotically-

arranged coarse material and clear lower boundaries that, in places, crossed both profiles (e.g.

Contexts 508, 499, 498). A third group contained chaotically-arranged pale silty loams with

micritic crystallitic to stipple-speckled b-fabrics (e.g. Contexts 506, 505). On the West-Facing

Profile, all contexts from the upper part of 505 to 498 contained calcitic hypocoatings or, as in

Context 503, micritic calcitic concretion of large areas of the groundmass.

McBurney's Layer XXV was defined from the 1950s section drawings as Contexts 497–

491 in the West-Facing Profile and Contexts 470–458 in the North-Facing Profile), covering a

greater depth than defined during excavation due to discrepancies on the published 1950s

profile drawings. Layer XXV contains markedly red, clayey layers that alternate with paler

silty layers. Those layers that were traceable across the two profiles were sampled on both. The

micromorphology of the Layer XXV contexts (Supplementary Table 4) was dominated by silt

loams/silty clay loams that contained fine material lamination, dung lenses and horizontal

orientation of coarse material, although Micro-Fabric 2521:2, the lower part of Context

494/459 on the North-Facing Profile, had a chaotic arrangement towards its base. Context

493/458 had a clear lower boundary and a similarly chaotic arrangement on both the West-

Facing Profile (Micro-Fabric 1014:2), and North-Facing Profile (Micro-Fabrics 2521:1,

2529:2), where it is redder. Context 491, restricted to the West-Facing Profile, was a reddish

silty clay loam with a clear lower boundary, and lensed out towards the back wall of the cave,

indicating it had originated in a movement from the cave entrance. Micritic calcitic void

hypocoatings were present in most West-Facing Profile contexts in Layer XXV.

The Facies 3 LSA ("Dabban") layers (Contexts 490–236, West-Facing Profile; Contexts

455–202, North-Facing Profile) contained an increasing frequency of gravel lenses towards the

top (most prominent on the North-Facing Profile), interrupting otherwise red-orange silty

layers. The recorded stratigraphy varied between profiles, with some contexts on the West-

Facing Profile divided into finer layers on the North-Facing. Contexts 490–442 (West-Facing

Profile) and Contexts 547–461 (North-Facing Profile) were sampled for micromorphological

analysis. The LSA layers (Supplementary Table 5) were largely pale, silty loams/silty clay

loams with varying amounts of gravel and horizontal orientation to the fine and coarse material

as well as dung lenses, and occasional clay stringers and crusts. These contrasted with reddish

silty clay loams with sharp lower boundaries (Contexts 490, 461), some with reticulate b-

fabrics (e.g. Micro-Fabric 762:1, Context 461). Micro-Fabric 754A:2 in Context 453 is unique

in the Haua Fteah observations in that it contains distinct laminations and dung lenses as well

as mosaic and reticulate b-fabrics, dendritic manganese staining and semi-dissolved bone

associated with neoformed minerals. On the West-Facing Profile, some contexts were heavily

cemented by micritic calcite (e.g. Contexts 442, 445), and contained calcitic pedofeatures.

Interpretation of micromorphological observations

The differences in micromorphological characteristics within the Haua Fteah are subtle and the features are often undiagnostic when considered in isolation. The observed features were therefore interpreted in relation to each other and field observations. Interpretation of structure in these layers was hampered by compression by up to 4 m of overlying sediments. In addition, the excavation history of the site – excavation, burial, re-excavation – may have altered existing, or produced new, redoximorphic features (e.g. dendritic manganese nodules), hampering interpretation of whether these features are related to the depositional environment of the layers or more ancient redox fluctuations.

The micro-fabrics were divided into three main groups through micromorphological observation. The first consists of pale, sandy silt to silt loams containing varying amounts of often horizontally-orientated limestone sand and gravel (Figure 6a), probably produced by roof-spalling (Farrand, 1975; Laville, 1976; Woodward & Goldberg, 2001; Goldberg & Sherwood, 2006). They have largely stipple-specked b-fabrics, implying a lack of mechanical processes to orient clays, e.g. shrink-swelling (Kovda & Mermut, 2010), with a micritic crystallitic fine component (10–30%) (Figure 6c) interpreted as the inclusion of aeolian sediment or spalling of the cave walls. Micritic calcitic crystallitic b-fabrics may also mark precipitation of micrite following sediment wetting and drying (Figure 6d) (Durand et al., 2010; Goldberg, 1979; Guo & Fedoroff, 1990), as well as the inclusion of ash within the sediments (Canti 2003). The nature of the micritic b-fabric in each case was therefore assessed

via observation of related pedofeatures such as the presence of calcitic wood ash

pseudomorphs (in the case of ash inclusion), or micritic calcitic void hypocoatings formed by

percolation of carbonate-rich water (suggesting post-depositional precipitation). In Context 490

(Facies 3 Dabban) the formation of micrite and sparite crystals within the groundmass and

pores suggests prolonged dripping onto, and wetting of the cave floor, with extensive

concretion of Micro-Fabrics 2621:2–4. In Micro-fabric 2621:3 (Figure 6d), this calcitic crystal

formation was so extensive that it produced a platy microstructure reminiscent of that formed

by ice crystals in freeze-thaw sediments (e.g. van Vliet-Lanoë, 1998; van Vliet-Lanoë et al.,

1984).

This group of micro-fabrics often contained subtle, sub-millimetre-thick laminations in

the fine material, mirrored in the horizontal orientation of limestone sand and gravel clasts as

well as the presence of horizontal dung lenses (Figure 6e). These features were interpreted as

resulting from punctuated, low-energy, aeolian deposition of fine material, producing

ephemeral surfaces upon which dung was trampled, and limestone clasts fell (Goldberg, 2000).

The dung, which often contains faecal spherulites (Figure 6f), is likely derived through the

activity of herbivores in the cave (Brochier et al., 1992; Canti, 1998, 1999). The wide cave

mouth provides easy access to wild animals seeking shelter. These surfaces may have been

sporadically wetted, producing surface crusts (Goldberg, 2000; Valentin, 1991), or subject to

small-scale washes of clay-rich material from inside the karstic system or through the cave

mouth, leaving depositional crusts (Figure 7a) (Bresson & Valentin, 1994; Pagliai & Stoops,

2010; West et al., 1990). Fragments of both sets of crusts were observed, indicating post-

formation trampling or bioturbation. In addition, iron-impregnated aggregates within the

sediments with a groundmass, internal structure and b-fabric different from the surrounding

material (Figure 7b) were interpreted as fragments of soil, 'pedorelicts', trampled into or

around the cave by animals or people (Boschian 1997; Goldberg 1979; Macphail and McAvoy

2008). Micro-fabrics within this first group of features were therefore interpreted as the

product of aeolian deposition and reworking on a 'dusty', mainly dry, cave floor, similar to the

modern cave floor.

The second main group of deposits examined were silty clay to silty clay loams, generally

reddish in colour (difficult to assess where slides vary in thickness). Their b-fabrics were

largely stipple-speckled with some mosaic-speckling (Figure 6b), the latter indicating a limited

impact of shrink-swell processes, such as drying of a saturated sediment (Cremeens, 2005), and

were thus interpreted as wet movements of clayey, potentially soil, material. Some contained a

partially micritic crystallitic b-fabric, usually related to calcitic infillings and hypocoatings and

therefore interpreted as post-depositional calcite precipitation. Coarse material was often

arranged chaotically, consistent with a mass depositional event, and the lower boundaries of

these micro-fabrics are often clear, sharp (Figure 7c) and therefore potentially erosive. On

occasion, silty clay coatings to voids were present in micro-fabrics directly below these layers

(Figure 7d), marking the drainage of water through the profile (French et al., 2009; Kuhn et al., 2010); their depth restriction suggests that they were linked to short periods of small-scale illuviation, consistent with clayey water draining from a slurry. The similarity of these micro-fabrics to the reddish, clayey local soils led to them being interpreted as resulting from inwash of soil material through the cave mouth or elsewhere via the karstic system.

Not all observed micro-fabrics fitted perfectly into these two groups. A third group of micro-fabrics consisted of silty fine material, coarse limestone sand and partially micritic crystallitic b-fabric similar to the 'dusty' micro-fabrics, yet their chaotic arrangement and sharp lower boundaries suggest deposition by mass movement, indicating that these layers represented reworking of cave-floor material by mass movements. Micro-Fabric 754A:2 (Context 453) contained a unique combination of features, including distinct horizontal laminations and dung lenses, with a mosaic/reticulate b-fabric, dendritic manganese staining and partially-dissolved bone (Figure 7e, f). These suggested a layer formed through aeolian deposition and reworking that had been subject to prolonged wetting, perhaps marking repeated dripping in this area from the cave roof.

Anthropogenic and biogenic impacts on the sediments were observed micromorphologically, with combustion features in Facies 4 and 5 containing layers of finely commuted charcoal and ash (Figures 8a, b). Rare charcoal fragments, bone splinters and ash lenses were observed throughout, marking a continually reworked 'background' of cultural

debris. Vesicular silica aggregates observed micromorphologically (Figure 8c) mirrored 'slag'

fragments recovered in the 1950s (McBurney, 1967), formed from the melting of a silica-rich

fuel such as grasses (Canti, 2003; Macphail & Cruise, 2001). Distinct from rounded,

potentially geogenic clasts, angular splinters of chert were interpreted as knapping micro-

debitage (Figure 8d, Angelucci, 2010). In the large feature from 513/535, ash layers containing

calcitic wood ash pseudomorphs (Figure 8e) indicated the use of wood as fuel (Canti 2003),

and the presence of calcitic hypocoatings (Figure 8f) within these ash layers suggest that the

feature had been subject to post-depositional wetting and weathering, indicating its prolonged

exposure on a surface at the top of Facies 4.

Bulk Sedimentology

Particle size analysis

The particle size distributions (PSDs) of the non-carbonate <2mm fractions of the Haua

Fteah sediments were largely consistent (Figure 9). Whilst there was variation in mode particle

sizes, the distributions were all bimodal, with a clay peak around 0.17μm and a 15.63–44.19μm

silt peak. The soil pit distribution (Pit T) shared this bimodal distribution with the Haua Fteah

samples, and, bar a ~353μm sand peak, the limestone residue lay within the size ranges of the

Haua Fteah samples.

The consistency in particle size distributions in the non-carbonate fraction indicates that this

fraction of the Haua Fteah sediments did not vary extensively in source or transport mode

throughout Facies 5–3. Similarity between the Haua Fteah samples and those from the soil pits suggest that the local soils, formed on the local limestone, were the primary source of the non-carbonate sediment, and/or that both shared a common origin. The more marked coarse silt peak in the particle size distribution in the soil pit, when compared with that from the limestone residue, indicates another potential input to the soil. The strong sorting in the silt peak may represent a far-field input of aeolian material, common in Mediterranean soils (Muhs et al., 2010; Yaalon, 1997). It is possible that the similarity between the limestone residue and the non-carbonate fraction may be influenced by the dissolution of limestone sand during sample preparation sample producing non-carbonate residue, yet as mentioned earlier, the very low non-carbonate content of the limestone (<1%) suggests this addition would not be enough to skew the PSD. The removal of carbonate from the samples prior to measurement does, however, raise the possibility that a carbonate-dominated aeolian input directly into cave has been removed in this analysis.

% Loss On Ignition

All the Facies 5–3 %LOI values from the Haua Fteah were at or below those of the modern soils (Table 1), suggesting a relative reduction in the organic content of the material after deposition, or a lower initial organic content to the source material. The values were very consistent (Standard deviation = 0.5%), rising slowly towards the upper part of the sequence (Figure 5), with only two small distinct peaks on the North-Facing Profile, one corresponding

to combustion features (Contexts 568 and 564) and a context containing frequent dung lenses

(Micro-Fabric 2058:4, Context 536). Such low values and narrow standard deviation means

that it is impossible to infer that these peaks are meaningful. These contexts, which from

micromorphological observations should have contained significant amounts of organic

material, had values similar to the modern soils, indicating that in sediments of this age

(>30,000 years old) %LOI values have, unsurprisingly, decayed to the point at which they are

no longer meaningful, and little weight should be placed on their interpretation.

%CaCO$_3$

The Haua Fteah samples contained markedly higher %CaCO$_3$ values than the soil (Table 1),

indicating the likely addition of carbonate to the sediments if, as appears from the PSDs and

field observations, that they are dominated by reworked soil material. This addition is likely

the result of cave wall weathering and post-depositional carbonate precipitation (Goldberg &

Sherwood, 2006; White, 2007), although it is possible that an aeolian carbonate component

may also be contributing to the %CaCO$_3$. Fine clastic carbonate material may also have been

transported into the shelter in mudflow events. Micromorphological observations of ash, which

may also have contributed carbonate (Canti 2003) to the sediments are restricted to the thin

lenses of anthropogenic material in Facies 4 and 5. Broadly, the largest %CaCO$_3$ peaks

corresponded to observations of frequent/common coarse sand in the late Facies 5/4 sediments

(Contexts 520–516, West-Facing Profile; Contexts 537–536, North-Facing Profile, Figure 5),

yet West-Facing Profile contexts cemented with calcite also corresponded to $\%CaCO_3$ peaks

(Contexts 504–503, 445–442), indicating an equifinality irresolvable without field or

micromorphological data.

Magnetic Susceptibility

Magnetic Susceptibility values varied widely between the soil pits (mean values of 365.45

and 584.8 m^3kg^{-1}), yet these were still largely higher than the cave values (Table 1). Peaks in

magnetic susceptibility corresponded largely to contexts identified micromorphologically as

inwashed soil material (e.g. Contexts 508, 498, 493/458–490, Figure 5), yet others were

associated with 'dusty' cave floor environments (e.g. Contexts 521–523, 563), suggesting that

another mechanism had raised the values: anthropogenic influence on the sediments, or, less

likely in caves where pedogenic process are weaker, weathering of the sediments. This

equifinality meant that the nature of the large jumps in magnetic susceptibility at the top of the

sampled area, beyond micromorphological sampling, remain ambiguous. Given field

observations of charcoal in Context 441, these peaks may have been related to burning.

A negative correlation (-0.588) between $\%CaCO_3$ and magnetic susceptibility reflects the

major peaks of magnetic susceptibility being largely accompanied by low $\%CaCO_3$ values and

vice versa. This, and the relatively lower magnetic susceptibility of most of the Haua Fteah

sediments compared to the soil, may result from the magnetic susceptibility of consistent soil

material in the cave being 'diluted' by variable amounts of diamagnetic carbonate sand and silt

(Dearing et al., 1985) from the cave walls. Yet correlation of the variables was only moderately

negative, and an R^2 value of 0.35 indicates a broad spread of the data - the impact of the coarse

fraction can, in future be assessed by restricting measurements to the <83um fraction

(Woodward, 1997a, b). It is also possible that variability in magnetic susceptibility may have

been influenced by source material variation (Ellwood et al., 1997) such as incorpration of

allochonthous carbonate material, or post-deposition burning or weathering (Tite & Mullins,

1971).

DISCUSSION

Methodological Observations: Integrating Field Observations, Micromorphology and Bulk Sedimentology

The effectiveness of particle size analysis in distinguishing between aeolian and colluvial

deposition at the Haua Fteah appears to have been hampered by the apparent local sediment

source, as the variation between aeolian-dominated and colluvial/inwash deposition observed

in the micromorphology was not identifiable in the particle size distributions. Removal of the

carbonate fraction may have removed a well-sorted aeolian carbonate component, yet it is

unlikely that this component would be solely carbonate - a non-carbonate aeolian element

would be expected to remain identifiable. A poorly-developed lack of a far-field aeolian

signature in the Haua Fteah would be unsurprising given its position on the northern side of the

Gebel Akhdar facing away from the Sahara. The lack of a large area exposed continental shelf

during periods of low sea level also limited another past source of aeolian sediment (Lambeck

& Purcell, 2005; GEBCO_14). In addition, the fine material composition observed

micromorphologically is relatively consistent through the sequence (though more clayey within

the 'mudflow' group); marked variations in fine material source indicating pulses of, for

example, carbonate beach dune sands might be expected to be visible in the thin sections, but

are not. The lack of variability seen in the non-carbonate PSDs between layers with quite

different micromorphologically-observed depositional histories indicates that whilst this data

can inform on the local source of the non-carbonate fraction, micromophological observation is

required to understand the process of deposition.

Small peaks in bulk %LOI organics appeared to correlate with field and

micromorphological observations of charred material and dung (Context 536), yet given the

low values and restricted variation of the dataset, the %LOI values can add little confidence to

the interpretation of the sequence; the variation may even be influenced more by variation in

sediment lithology than organic content (Santisetban et al., 2004).

Magnetic susceptibility peaks corresponded frequently with layers interpreted thorough

micromorphology and field observations as soil inwash (e.g. Contexts 498 and 508), rather

than parts of the stratigraphy that had been burnt. An exception may have occurred at the top of

Facies 3 (Context 441), where charcoal observed in the profiles and an increase in occupation

material (McBurney, 1967) may account for large magnetic susceptibility peaks. In addition,

not all contexts interpreted micromorphologically as colluvial/wash events were accompanied

by peaks; contexts interpreted micromorphologically as colluvial mass reworking of cave-floor

sediment (e.g. Contexts 497 and 563) lacked high magnetic susceptibility values, confirming

that magnetic susceptibility may inform on sediment source, but not depositional context.

Given the range of processes identified through field observations and micromorphology

that added carbonate to the sediments, it is largely impossible to interpret the bulk %CaCO$_3$

data in isolation. Broad peaks in %CaCO$_3$ corresponded to increased limestone sand and gravel

in Facies 4, whilst some of the lowest %CaCO$_3$ readings corresponded to contexts with high

magnetic susceptibility interpreted as soil inwash (e.g. Contexts 490 and 498). Yet other

%CaCO$_3$ peaks marked contexts containing secondary calcite precipitation (Contexts 503 and

504) and little limestone sand. No distinct peaks accompanied calcitic ash deposition linked to

anthropogenic activity in Facies 5, although this may have been due to the small quantities of

ash involved.

It is clear that the bulk sedimentological parameters measured here are subject to issues

of equifinality. Further clarity of the composition of the bulk sediments through the

investigation of variation in sedimentological characteristics between different sediment

fractions (e.g. that of the <63μm fraction following Woodward and Bailey, 2000) or sediment

sourcing using SEM, XRD or FTIR could, in future, be carried out to understand more fully

the sources of the material and properties measured. Micromophological analysis of the Haua

Fteah sediments, however, appears the most robust method of analysis and interpretation of the

final depositional processes that ultimately shaped its stratigraphy.

Site Formation Processes at the Haua Fteah in Their Mediterranean Context

The Haua Fteah sediments show repeated shifts between fine material deposition dominated

by dry, 'dusty' conditions and sporadically wetted surfaces, sometimes with limestone clast

deposition from the cave walls, and episodic wet, colluvial mass movements. These processes

are expressed in numerous other Mediterranean Quaternary cave sequences (Frumkin et al.,

2016; Woodward & Goldberg, 2001), many of which contain archaeological sequences key to

understanding regional population dynamics and change.

Mass colluvial deposition of soil material is a common mode of sedimentation noted in

Mediterranean caves (Albert et al., 1999; Aldeias et al., 2014; Bar-Yosef et al., 1992; Boscian,

1997; Frumkin et al., 2016; Goder-Goldberger et al., 2012; Goldberg & Bar-Yosef, 1998; Hunt

et al., 2010, 2011; Woodward & Goldberg, 2001). Whether driven by climate change and/or

human impact, these movements mark landscape destabilisation (Frumkin et al., 2016;

Wainwright, 2009), and are largely recorded in caves opening in shallow inclines, or those with

chimneys such as Konispol, Albania (Schuldenrein, 1998, 2001) and Tabun, Israel (Albert et

al., 1999). At the Haua Fteah these processes did not dominate the Facies 5–3 sediments, but

instead occasionally punctuated an otherwise dry cave floor environment. Whilst this reflects

the susceptibility of the cave to collecting colluvially-deposited sediments, this process was

only one of a small number of sedimentation processes that also included aeolian

deposition/reworking and roof spalling.

The aeolian nature of the 'dusty' deposits likewise have Mediterranean parallels. Whilst the

Haua Fteah lacks wind-deposited beach sand in contrast to caves adjacent to shorelines such as

Vanguard and Gorham's Caves, Gibraltar (Macphail et al., 2000), fine-grained, aeolian

sediments were reported from Akrotiri Aetokremnos, Cyprus (Mandel & Simmons, 1997),

Khef el Ahmmar, Morocco, (Barton et al., 2005), Abri Pataud, France (Farrand, 1975), and

Klithi, Greece (Woodward 1997a) variously attributed to local sources such as floodplain

sediments or, as in the Haua Fteah, surrounding hillsides.

The physical weathering of limestone from cave walls and roofs has long been documented

in the Mediterranean (Collcutt, 1979; Farrand, 1975; Laville et al., 1980), with

micromorphological attributes suggesting freeze-thawing as the driver of physical weathering

at Theopetra, Greece (Karkanas, 1999, 2001), Abric Romani, Spain, and Grotte des Pigeons,

Taforalt, Morocco (Courty & Vallverdu, 2001). Elsewhere, for example at Ksar Akil, Lebanon

and Franchthi Cave, Greece (Farrand, 2001b), independent evidence suggests that these sites

did not experience freezing temperatures and that chemical weathering or wetting/drying

cycles drove weathering (Goldberg & Sherwood, 2006). Micromorphological structures

produced by freeze-thawing (e.g. lenticular structures, van Vliet-Lanoë, 1998) were not

observed in the Haua Fteah, yet its largely dry cave floor may have inhibited their formation.

There is often snow on the Gebel Akhdar in winter and current winter temperatures in Shahat,

on the second escarpment, have been recorded as low as 3˚C (Libyan National Meteorological

Centre). Regional cooling during glacials and stadials would have further lowered

temperatures, and Pleistocene thermoclastic scree is widespread along the Cyrenaican littoral

(Hey 1963), suggesting that freeze-thaw could have contributed to physical weathering at the

Haua Fteah during certain periods or seasons in addition to ongoing chemical weathering.

The sediments investigated here show limited carbonate concretion or flowstone

development on the West- and North-Facing Profiles, unlike caves such as Qesem Cave

(Gopher et al., 2010; Karkanas et al., 2007) or Emanuel Cave (Goder-Goldberger et al., 2012),

Israel. The South-Facing Profile sediments, however, and the adjacent northernmost end of the

West-Facing Profile, are heavily cemented, probably because of their proximity to the modern

dripline. The timing of calcite deposition remains unclear, and may considerably post-date the

deposition of the units. This spatial variability suggests that even within a few metres, the

impact of depositional processes can vary, and is dependent on cave morphology as well as

environment.

The processes that deposited the Haua Fteah sediments are observed in caves across the

Mediterranean. Whilst the dominant processes vary from site to site based on cave morphology

and setting, the variability in sediment energy and rate of deposition between the processes

highlight the necessity of understanding site formation processes at each and every site in order

to understand the archaeology and palaeoenvironmental sequences within them.

The Haua Fteah Sediment Sequence and Environmental Drivers

Whilst the detailed consideration of the environmental drivers of sedimentation at the Haua

Fteah with regards to Late Quaternary regional environmental change is beyond the scope of

this paper, there are general trends that show broad correlation with environmental data (Douka

et al., 2014; Inglis, 2012). The Facies 5 sediments in the Middle Trench, with a modelled age

of deposition between 75–64 ka (Douka et al., 2014), correspond to the end of MIS 5a and

early MIS 4, and consist predominantly of aeolian-deposited fine material, interrupted by

reworking of cave-floor material in mudflows indicating occasional landscape instability.

There is limited physical weathering of the cave walls shown in occasional limestone clasts,

yet the sediments are dominated by fine material, indicating that the cave reached the low

temperatures necessary to accelerate physical weathering of the cave walls through freeze-thaw

processes. The combustion features appear to have been deposited on dry, unconsolidated

surfaces, consistent with an environment of aeolian deposition and reworking.

The Facies 4 sediments, with a modelled age of deposition between 68–47 ka,

(corresponding to MIS 4 and the start of MIS 3), are dominated by limestone gravel and sand,

the result of increased physical weathering, and reflected in higher $\%CaCO_3$ values.

Depositional environments remained similar to those of Facies 5, but with increased roof-

spalling along with fine aeolian deposition and reworking, likely the result of MIS 4 driven

cooling that activated freeze-thaw weathering. Sporadic wetting of the largely dry sediments

continued, but more numerous mudflows into the cave (compared with Facies 5), marked

increased frequency of landscape instability. At the top of the facies, extended exposure and

weathering of a large burning event supports a sediment hiatus that is also suggested by the

chronology (Douka et al., 2014; Inglis, 2012).

Facies 3 sediments, with a modelled age of between 48–34 ka (falling within equivalent

MIS 3), were marked by smaller quantities of carbonate gravel and sand indicating an overall

reduction in physical weathering, and therefore potentially warmer temperatures than in MIS 4.

Limestone clast deposition in contexts towards the top of the facies indicate shorter-lived drops

in temperatures. As in Facies 4, the deposition of fine material varied between 'dusty'

environments and mudflow deposition. The red, clayey, mudflow sediments with high

magnetic susceptibility towards the top of the facies, accompanying the layers containing

limestone clasts, suggest the increasingly frequent transport into the cave of well-developed

soils or subsoil horizons from the landscape during periods of landscape instability, potentially

driven by increasingly cool periods along a downward temperature trend towards the gravel-

dominated MIS 2.

Site Formation Processes and Assessment of the Haua Fteah Stratigraphy

The analysis of the Haua Fteah sediments has identified two predominant modes of deposition, fine aeolian deposition/reworking, and mudflows of external or internal material. These represent very different taphonomic pathways, and major interpretative implications, for the archaeological and palaeoenvironmental material preserved within them, with significant implications for similar 'cornerstone' archaeological sequences established from cave stratigraphies.

In terms of the impact on the interpretation of palaeoenvironmental proxies, 'dusty' deposition, with its continual small-scale surface reworking of fine material on a dry cave floor, would, with its slow net rate of deposition, allow sediments to blow into and around the cave over an extended period of time, mixing with material already deposited in the cave. These layers likely contain assemblages of environmental proxies that have been subject to 'time averaging'. For example, rapid vegetation change may not have been recorded if the mode of deposition in the cave remained constant; new proxy assemblages would be mixed with those already within the cave, creating assemblages that did not bear direct relation to the outside environment, and which masked shorter-term environmental fluctuations. In contrast, the rapid deposition of the mudflow events would avoid this degree of time averaging, but may also have transported and re-deposited pollen or phytoliths or other material inherited from soils or sediments already existing in the landscape (e.g. Hunt et al., 2015). Abrupt changes identified in palaeoenvironmental indicators as recorded in the CPP sample columns may

therefore be more due to changes in taphonomic pathway than environment, whilst periods of

consistency may mask a more complex picture, highlighting the need to ground

palaeoenvironmental interpretation within the detailed stratigraphic framework that this study

has provided.

The varying rates and modes of deposition would have had similar effects on the

archaeological assemblages within them. Low energy, aeolian depositional environments and

their slow net rate of aggradation may have meant that artefacts were exposed on, or very near

to, the surface for variable periods of time, during which they may have been trampled or

distrubed by animals and/or humans. In addition, during their exposure, artefacts may have

been moved, recycled or completely removed by humans (Bailey, 2007; Vaquero et al., 2012).

Material on these slowly aggrading surfaces may have been deposited in a single episode of

activity, or through multiple episodes during low net sedimentation, thus forming palimpsests

of increasing time depth (Bailey & Galanidou, 2009; Stern, 2008). These 'dusty' layers

therefore have relatively low chronological and behavioural resolution, even if the artefacts

have not been moved by the sedimentation processes or later activity, and they may even

contain artefacts from different cultural groups, blurring cultural transitions that were in fact

quite abrupt. In contrast, the mudflow layers were deposited in single, or a series of very

temporally constrained depositional, events (e.g. days), potentially burying artefacts soon after

deposition, but also potentially producing archaeologically 'sterile' layers that could appear to

represent occupation hiatuses, but may only mark a day or less of rapid deposition. Such

movements may rework archaeological material from elsewhere in the cave, or from the

surface of the landscape outside the cave. Again, the taphonomic impact of the sediments must

be borne in mind when interpreting the changing densities of archaeology throughout the

sequence, and their behavioural implications.

These changing processes, and their changing depositional energies, are crucial to

understanding the stratigraphic integrity of the MSA/LSA 'transition' in Layer XXV of the

Haua Fteah. McBurney identified reworking, or population turnover, as a potential reason for

the apparent interstratification of Levalloiso-Mousterian and Dabban material in Layer XXV.

The identification of mudflow deposits within Layer XXV provides support to the reworking

hypothesis, yet Layer XXV also contains layers built up through dusty/aeolian sedimentation –

if the different artefact assemblages were contained within these layers, they may not have

been reworked or mixed by mudflows. Correlation of the McBurney archaeological archive

with specific CPP contexts, with the degree of resolution required to resolve the question of the

integrity of the transitional layers, poses a major challenge for the CPP investigations. The

renewed investigations provide the increased stratigraphic resolution which could address these

issues, yet the Facies 3 layers in the news excavations (Trench M) have yielded a very low

number of artefacts (Farr et al., 2014). We are left with, on the one hand, a poorly

stratigraphically constrained archive with enough artefacts – though one still low in number in

these levels (McBurney 1967) – to identify shifts in technology, and on the other, a well stratigraphically well-constrained record which contains few artefacts that are unable to pinpoint robustly where in the stratigraphy this transition occurred. An enhanced understanding of the taphonomy of the key MSA/LSA layers, and its implications for the archaeological record within them, may therefore remain challenging.

CONCLUSION

Detailed geoarchaeological analysis of the Haua Fteah sediments integrating field observations, micromorphology and bulk sediment analyses has demonstrated the modes of formation of the sediments comprising the late MSA–early LSA layers of one of the key North African cultural sequences. Sedimentation throughout this period, characterised as Facies 5–3, was dominated by low-energy, slow net aeolian sedimentation and reworking, interrupted by mass movements of material from outside or inside the cave. These changing depositional environments have important implications for understanding the archaeological sequence and the cultural transitions within it, because the layers represent different taphonomic histories. Whilst the reconstruction of the environmental drivers behind the changing sedimentation processes at the Haua Fteah require more discussion than is possible here, this work demonstrates that the environmental conditions in which caves were inhabited had profound implications for the nature of the record that is preserved of these occupations.

The varying site formation processes observed through the MSA and LSA levels, the

limited archaeological resolution of the sequence excavated by McBurney, and the low

numbers of stratigraphically-constrained artefacts from the new excavations, mean that a

higher-resolution assessment of the MSA/LSA transition and its palaeoenvironmental

conditions through the Haua Fteah sequence remains difficult. Full analysis of the findings

from the new excavations will improve the stratigraphic understanding of the newly-recovered

artefacts, their sedimentological context, and the extent to which reworking may have affected

the observed sequence, though it remains possible that, given issues of sediment redeposition,

the Haua Fteah sequence may not preserve a 'high-resolution' record of the nature, conditions

and timing of some of the key cultural transitions that took place within the ca. 140,000-year

human frequentation of the site. Most importantly, the sediment formation processes

recognised in the Haua Fteah, and the issues of archaeological interpretation raised by these

findings, are consistent with those of many other human occupation caves in the Mediterranean

region (and indeed beyond), highlighting the necessity to employ a battery of

geoarchaeological analyses to establish the limitations and potential of the archaeological and

palaeoenvironmental records contained within them, and the regional and global chronologies

they underpin. The complex relationship between changing sedimentation processes at the

Haua Fteah and the iconic cultural record in it established by the 1950s excavations is a

powerful case study demonstrating that the environmental conditions in which caves were

inhabited has profound implications for the nature of the human occupation records that are preserved in them, and for the wider cultural interpretations that are built on such records.

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REFERENCES

Albert, R.M., Lavi, O., Estroff, L., Weiner, S., Tsatskin, A., Ronen, A., Lev-Yadun, S. (1999).
Mode of occupation of Tabun Cave, Mt Carmel, Israel during the Mousterian period: A
study of the sediments and phytoliths. *Journal of Archaeological Science*, 26, 1249–
1260.

Aldeias, V., Goldberg, P., Dibble, H.L., & El-Hajraoui, M. (2014). Deciphering site formation
processes through soil micromorphology at Contrebandiers Cave, Morocco. *Journal of
Human Evolution*, 69, 8–30.

Ambrose, S.H. (1998). Late Pleistocene human population bottlenecks, volcanic winter, and
differentation of modern humans. *Journal of Human Evolution*, 34, 623–651.

Ambrose, S.H. (2003). Did the super-eruption of Toba cause a human population bottleneck?
Reply to Gathorne-Hardy and Harcourt-Smith. *Journal of Human Evolution*, 45, 231–
237.

Angelucci, D.E. (2010). The recognition and description of knapped lithic artifacts in thin
section. *Geoarchaeology*, 25 (2), 220–232.

Bailey, G.N. (2007). Time perspectives, palimpsests and the archaeology of time. *Journal of
Anthropological Archaeology*, 26, 198–223.

Bailey, G.N., & Flemming, N. (2008). Archaeology of the continental shelf: Marine resources,
submerged landscapes and underwater archaeology. *Quaternary Science Reviews*,
27(23–24), 2153–2165.

Bailey, G.N., & Galanidou, N. (2009). Caves, palimpsests and dwelling spaces: examples from
the Upper Palaeolithic of south-east Europe. *World Archaeology*, 41(2), 215–241.

Bailey G.N., Woodward, J.C. (1997) The Klithi deposits: sedimentology, stratigraphy and
chronology. In: Bailey G.N. (ed) *Klithi: Palaeolithic Settlement and Quaternary
Landscapes in Northwest Greece*, vol 1. (pp. 61–94) Cambridge: McDonald Institute
for Archaeological Research.

Bar-Yosef, O., Vandermeersch B, Arensburg, B., Belfer-Cohen, A., Goldberg, P., Laville, H.,
Meignen, L., Rak, Y., Speth, J.D., Tchernov, E., Tillier, A.-M., & Weiner, S. (1992).
The excavations in Kebara Cave, Mt. Carmel. *Current Anthropology*, 33(5), 497–550.

Barham, L., & Mitchell, P. (2008). *The First Africans*. Cambridge: Cambridge University
Press.

Barker, G., Hunt, C.O., Reynolds, T., Brooks, I., & el-Rishi, H. (2007). The Haua Fteah,
Cyrenaica (Northeast Libya): renewed investigations of the cave and its landscape,
2007. *Libyan Studies*, 38, 93–114.

Barker, G., Basell, L., Brooks, I., Cartwright, C., Cole, F., Davison, J., Farr, L., Grün, R.,
Hamilton, R., Hunt, C., Inglis, R.H., Jacobs, Z., Legge, T., Leitch, V., Morales, J.,
Morley, I., Morley, M., Pawley, S., Pryor, A., Roberts, R., Reynolds, T., el-Rishi, H.,

Simpson, D., Twati, M., & van der Veen, M. (2008). The Cyrenaican Prehistory Project 2008: the second season of investigations of the Haua Fteah cave and its landscape, and further results from the initial (2007) fieldwork. *Libyan Studies*, 39, 175–221.

Barker, G., Antoniadou, A., Barton, H., Brooks, I., Candy, I., Drake, N.A., Farr, L., Hunt, C., Ibrahim, A.A., Inglis, R., Jones, S., Morales, J., Morley, I., Mutri, G., Rabett, R., Reynolds, T., Simpson, D., Twati, M., & White, K. (2009). The Cyrenaican Prehistory Project 2009: the third season of investigations of the Haua Fteah cave and its landscape, and further results from the 2007–2008 fieldwork. *Libyan Studies*, 40, 55–94.

Barker, G., Antoniadou, A., Armitage, S., Brooks, I., Candy, I., Connell, K., Douka, K., Drake, N., Farr, L., Hill, E., Hunt, C., Inglis, R., Jones, S., Lane, C., Lucarini, G., Meneeley, J., Morales, J., Mutri, G., Prendergast, A., Rabett, R., Reade, H., Reynolds, T., Russell, N., Simpson, D., Smith, B., Stimpson, C., Twati, M., & White, K. (2010). The Cyrenaican Prehistory Project 2010: the fourth season of investigations of the Haua Fteah cave and its landscape, and further results from the 2007–2009 fieldwork. *Libyan Studies*, 41, 63–88.

Barker, G., Bennett, P., Farr, L., Hill, E., Hunt, C., Lucarini, G., Morales, J., Mutri, G., Prendergast, A., Pryor, A., Rabett, R., Reynolds, T., Spry-Marques, P., & Twati, M. (2012). The Cyrenaican Prehistory Project 2012: The fifth season of investigations at the Haua Fteah cave. *Libyan Studies*, 43, 115–136.

Barton, R.N.E., Bouzouggar, A., Collcutt, S., Gale, R., Higham, T., Humphrey, L.T., Parfitt, S., Rhodes, E., Stringer, C., & Malek, F. (2005). The Late Upper Palaeolithic occupation of the Moroccan Northwest Maghreb during the Last Glacial Maximum. *African Archaeological Review*, 22(2), 77–100.

Barton, R.N.E., Bouzouggar A., Hogue J., Lee S., Collcutt S.N., & Ditchfield P. (2013). Origins of the Iberomaurusian in NW Africa: New AMS radiocarbon dating of the Middle and Later Stone Age deposits at Taforalt Cave, Morocco. *Journal of Human Evolution,* 65, 266-281.

Barton, R.N.E., Lane, C.S., Albert, P.G., White, D., Collcutt, S.N., Bouzouggar, A., Ditchfield, P., Farr, L., Oh, A., Ottolini, L., Smith. V.C., Van Peer, P., & Kindermann, K. (2015). The role of cryptotephra in refining the chronology of Late Pleistocene human evolution and cultural change in North Africa. *Quaternary Science Reviews*, 118, 151–169.

Barton, R.N.E., Bouzouggar, A., Collcutt, S.N., Carrión Marco, Y., Clark-Balzan, L., Debenham, N.C., Morales, J. (2016). Reconsidering the MSA to LSA transition at Taforalt Cave (Morocco) in the light of new multi-proxy dating evidence. *Quaternary International,* 413, 36–49

Benazzi, S., Douka, K., Fornai, C., Bauer, C.C., Kullmer, O., Svoboda, J., Pap I., Mallegni, F., Bayle, P., Coquerelle, M., Condemi, S., Ronchitelli, A., Harvati, K., & Weber, G.W. (2011). Early dispersal of modern humans in Europe and implications for Neanderthal behaviour. *Nature*, 479(7374), 525–528.

Boscian, G. (1997). Sedimentology and Soil Micromorphology of the Late Pleistocene and Early Holocene Deposits of Grotta dell'Edera (Trieste Karst, NE Italy). *Geoarchaeology*, 12(3), 227–249.

Bresson, L.M., & Valentin, C. (1994). Soil surface crust formation: contribution of micromorphology. In A.J. Ringrose-Voase & G.S. Humphreys (Eds.), *Soil Micromorphology: Studies in Management and Genesis. Proceedings of the IX International Working Meeting on Soil Micromorphology, Townsville, Australia, July 1992.* (pp. 737–757). Amsterdam: Elsevier.

Brochier, J. E., Villa, P., & Giacomarra, M. (1992). Shepherds and Sediments: geo-ethnoarchaeology of pastoral sites. *Journal of Anthropological Archaeology,* 11, 42–102.

Bullock, P., Fédoroff, N., Jongerius, A., Stoops, G., & Tursina, T. (1985). *Handbook for Soil Thin Section Description*. Wolverhampton: Waine Research Publications.

Butzer, K.W. (1971). *Environment and Archeology: An Ecological Approach to Prehistory.* London: Meuthen.

Cancellieri, E., Cremaschi, M., Zerboni, A., & di Lernia, S. (2016). Climate, environment and population dynamics in Pleistocene Sahara. In S.C. Jones & B.A. Stewart (Eds.), *Africa from MIS 6–2: Population Dynamics and Paleoenvironments* (pp. 123–145). Dordrecht: Springer.

Canti, M. G. (1998) The micromorphological identification of faecal spherulites from archaeological and modern materials. *Journal of Archaeological Science*, 25, 435–44.

Canti, M. G. (1999) The production and preservation of faecal spherulites: animals, environment and taphonomy. *Journal of Archaeological Science*, 26, 251–58.

Canti, M. G. (2003) Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. *Catena*, 54, 339–61.

Campy, M., & Chaline, J. (1993). Missing records and depositional breaks in French Late Pleistocene cave sediments. *Quaternary Research*, 40, 318–331.

Canti, M.G. (2003). Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. *Catena,* 54, 339–361.

Collcutt, S.N. (1979). The analysis of Quaternary cave sediments. *World Archaeology*, 10(3), 290–301.

Coudé-Gaussen, G., & Rognon, P. (1993). Contrasting origin and character of Pleistocene and Holocene dust falls on the Canary Islands and southern Morocco: genetic and climaic

significance. In K. Pye (Ed.), *The Dynamics and Environmental Context of Aeolian Sedimentary Systems* (pp. 277–291). London: The Geological Society.

Courty, M.-A., & Vallverdu, J. (2001). The microstratigraphic record of abrupt climate changes in cave sediments of the Western Mediterranean. *Geoarchaeology*, 16(5), 467–500.

Courty, M.-A., Goldberg, P., & Macphail, R.I. (1989). *Soils and Micromorphology in Archaeology*. Cambridge: Cambridge University Press.

Cremeens, D.L. (2005). Micromorphology of Cotiga Mound, West Virginia. *Geoarchaeology*, 20(6), 581–597.

Dearing, J.A., Maher, B.A., & Oldfield, F. (1985). Geomorphological linkages between soils and sediments: the role of magnetic measurements. In K.S. Richards, R.R. Arnett & S. Ellis (Eds.), *Geomorphology and Soils* (pp. 245–267). London: George Allen & Unwin.

Di Vito, M.A., Sulpizio, R., Zanchetta, G., & D'Orazio, M. (2008). The late Pleistocene pyroclastic deposits of the Campanian Plain: new insights into the explosive activity of Neapolitan volcanoes. *Journal of Volcanology and Geothermal Research*, 177, 19–48.

Douka, K., Grün, R., Jacobs, Z., Lane, C., Farr, L., Hunt, C., Inglis, R.H., Reynolds, T., Albert, P., Aubert, M., Cullen, V., Hill, E., Kinsley, L., Roberts, R.G., Tomlinson, E.L., Wulf, S., & Barker, G. (2014). Redating the Haua Fteah cave (Cyrenaica, northeast Libya) and its implications for North African prehistory. *Journal of Human Evolution*, 66, 39–63.

Drake, N., & Breeze, P. (2016). Climate Change and Modern Human Occupation of the Sahara from MIS 6-2. In S.C. Jones & B.A. Stewart (Eds.), *Africa from MIS 6–2: Population Dynamics and Paleoenvironments* (pp. 103–122). Amsterdam: Springer Verlag.

Drake, N.A., Breeze, P., & Parker, A. (2013). Palaeoclimate in the Saharan and Arabian Deserts during the Middle Palaeolithic and the potential for hominin dispersals. *Quaternary International*, 300, 48–61.

Durand, N., Monger, H.C., & Canti, M.G. (2010). Calcium carbonate features. In G. Stoops, V. Marcelino & F. Mees (Eds.), *Interpretation of Micromorphological Features of Soils and Regoliths* (pp. 149–194). Amsterdam: Elsevier.

Ellis, S., & Mellor, A. (1995). *Soils and Environment*. London: Routledge.

Ellwood, B.B., Harrold, F.B., L, B.S., Thacker, P., Otte, M., Bonjean, D., Long, G.J., Shahin, A.M., Hermann, R.P., & Grandjean, F. (2004). Magnetic susceptibility applied as an age–depth–climate relative dating technique using sediments from Scladina Cave, a Late Pleistocene cave site in Belgium. *Journal of Archaeological Science*, 31, 283-293.

Ellwood, B.B., Petruso, K.M., Harrold, F.B., & Schuldenrein, J. (1997). High-resolution paleoclimatic trends for the Holocene identified using magnetic susceptibility data from archaeological excavations in caves. *Journal of Archaeological Science*, 24, 569–573.

Farr, L., Lane, R., Abdulazeez, F., Bennett, P., Holman, J., Marasi, A., Prendergast, A., Al-Zweyi, M., & Barker, G. (2014). The Cyrenaican Prehistory Project 2013: the seventh season of excavations in the Haua Fteah cave. *Libyan Studies*, 45, 163–173.

Farrand, W.R. (1975). Sediment analysis of a prehistoric rockshelter: the Abri Pataud. *Quaternary Research*, 5, 1–26.

Farrand, W.R. (2001). Archaeological sediments in rockshelters and caves. In J.K. Stein (Ed.), *Sediments in Archaelogical Context* (pp. 29–66). Salt Lake City: University of Utah Press.

Foley, R.A., & Lahr, M.M. (1997). Mode 3 technologies and the evolution of modern humans. *Cambridge Archaeological Journal*, 7(1), 3–36.

Folk, R.L. (1966). A review of grain-size parameters. *Sedimentology*, 6, 73–93.

French, C.A.I., Sulas, F., & Madella, M. (2009). New geoarchaeological investigations of the valley systems in the Aksum area of northern Ethiopia. *Catena,* 78, 218–233.

Frumkin, A., Langford, B., Marder, O., & Ullman, M. (2016). Paleolithic caves and hillslope processes in south-western Samaria, Israel: Environmental and archaeological implications. *Quaternary International*, 398, 246–258.

Gale, S., & Hoare, P.G. (1991). *Quaternary Sediments: Petrographic Methods for the Study of Unlithified Rocks.* London: Bellhaven.

Garcea, E.A.A. (2004). Crossing deserts and avoiding seas: Aterian North African-European relations. *Journal of Anthropological Research,* 60, 27–53.

Garcea, E. E A. (2010). The Lower and Upper Later Stone Age of North Africa. In Garcea E.A.A. (Ed.) *South-Eastern Mediterranean Peoples Between 130,000 and 10,000 Years Ago* (pp. 66–88). Oxford: Oxbow.

Garcea, E.A.A. (2012). Successes and failures of human dispersals from North Africa. *Quaternary International*, 270, 110–128.

Garcea, E.E.A. (2016). Dispersals out of Africa and back to Africa: Modern origins in North Africa. *Quaternary International,* 408, 79–89.

Garcea E.A.A., Giraudi C. (2006) Late Quaternary human settlement patterning in the Jebel Gharbi. *Journal of Human Evolution*, 51(4), 411–421

GEBCO_14 (2014). *General Bathymetric Chart of the Oceans 30-Arc Second Grid.* British Oceanographic Data Centre.

Geyh, M.A., & Thiedig, F. (2008). The Middle Pleistocene Al Mahrúqah formation in the Murzuq Basin, northern Sahara, Libya: evidence for orbitally forced humid episodes during the last 500,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 257(1), 1–21.

Giraudi, C. (2005). Eolian sand in peridesert northwestern Libya and implications for Late Pleistocene and Holocene Sahara expansions. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 218, 161–173.

Goder-Goldberger, M., Edwards, R.L., Marder, O., Peleg, Y., Yeshurun, R., Frumkin, A., & Grigson, C. (2012). Emanuel Cave (Israel): The Site and its Bearing on Early Middle Paleolithic Technological Variability. *Paléorient*, 38(1), 203–225.

Goldberg, P. (1979). Micromorphology of Pech-de-I'Azé II Sediments. *Journal of Archaeological Science*, 6, 17–47.

Goldberg, P. (2000). Micromorphology and site formation at Die Kelders Cave I, South Africa. *Journal of Human Evolution*, 38, 43–90.

Goldberg, P., & Bar-Yosef, O. (1998). Site formation processes in Kebara and Hayonim caves and their significance in Levantine prehistoric caves. In T. Akazawa, K. Aoki & B.-Y. O (Eds.), *Neanderthals and Modern Humans in Western Asia* (pp. 107–126). New York: Plenum Press.

Goldberg, P., & Sherwood, S.C. (2006). Deciphering human prehistory through the geoarcheological study of cave sediments. *Evolutionary Anthropology*, 15, 20–36.

Gopher, A., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Karkanas, P., Shahack-Gross, R. (2010) The chronology of the late Lower Paleolithic in the Levant based on U-Th ages of speleothems from Qesem Cave, Israel. *Quaternary Geochronology*, 5, 644–656

Guo, Z.T., & Fedoroff, N. (1990). Genesis of calcium carbonate in loess and in palaeosols in central China. In L.A. Douglas (Ed.), *Soil Micromorphology: A Basic and Applied Science. Proceedings of the VIIIth International Working Meeting on Soil Micromorphology, San Antonio, Texas, July 1988* (pp. 355–359). Amsterdam: Elsevier.

Harris, E. (1989). *Principles of Archaeological Stratigraphy* (2nd ed.). London: Academic Press.

Hey, R.W. (1963). Pleistocene screes in Cyrenaica. *Eiszeitalter und Gegenwart,* 14, 77–84.

Higham, T.F.G., Compton, T., Stringer, C.B., Jacobi, R., Shapiro, B., Trinkaus, E., Chandler, B., Gröning, F., Collins, C., Hillson, S., O'Higgins, P., FitzGerald, C., Fagan, M., & Taçon, P.S.C. (2011). The earliest evidence for anatomically modern humans in northwestern Europe. *Nature*, 479, 521–524.

Hoffmann, D.L., Rogerson, M., Spötl, C., Leutscher, M., Vance, D., Osborne, A.H., Fello, N.M., & Moseley, G.E. (2016). Timing and causes of North African wet phases during the last glacial period and implications for modern human migration. *Scientific Reports* 6, 36367.

Hublin, J.J. (1992). Recent human evolution in northwestern Africa. *Philosophical Transactions: Biological Sciences* 377(1280) 185–91.

Hublin, J.J. (2001). Northwestern African Middle Pleistocene hominids and their bearing on the emergence of *Homo sapiens*. In L. Barham & K. Robson-Brown (Eds).. *Human Roots: Africa and Asia in the Middle Pleistocene* (pp 99–122). Bristol: Western Academic & Specialist Press.

Hunt, C., Davison, J., Inglis, R., Farr, L., Reynolds, T., Simpson, D., el-Rishi, H., &
Barker, G. (2010). Site formation processes in caves: The Holocene sediments of the Haua
Fteah, Cyrenaica, Libya. *Journal of Archaeological Science*, 37, 1600–1611.

Hunt, C., Brooks, I., Meneeley, J., Brown, D., Buzaian, A., & Barker, G. (2011). The
Cyrenaican Prehistory Project 2011: Late-Holocene environments and human activity
from a cave fill in Cyrenaica, Libya. *Libyan Studies*, 42, 77–88.

Hunt, C.O., Gilbertson, D.D., Hill, E.A., & Simpson, D. (2015). Sedimentation, re-
sedimentation and chronologies in archaeologically-important caves: problems and
prospects. *Journal of Archaeological Science*, 56, 109–116.

Inglis, R.H. (2012). *Human Occupation and Changing Environments During the Middle to
Later Stone Ages: Soil Micromorphology at the Haua Fteah, Libya*. Unpublished
doctoral dissertation, University of Cambridge.

Jacobs, Z., Li, B., Farr, L., Hill, E., Hunt, C.O., Jones, S., Rabett, R., Reynolds, T., Roberts,
R.G., Simpson, D., & Barker, G., (2017). The chronostratigraphy of the Haua Fteah
cave (Cyrenaica, northeast Libya) Optical dating of early human occupation during
Marine Isotope Stages 4, 5 and 6. *Journal of Human Evolution,* 105, 69–88.

Jones, S., Antoniadou, A., Barton, H., Drake, N., Farr, L., Hunt, C., Inglis, R., Reynolds, T.,
White, K., & Barker, G., (2016). Patterns of hominin occupation and cultural diversity
across the Gebel Akhdar of Northern Libya over the last ~200 ka. In S. Jones, & B.
Stewart. (Eds.) *Africa from MIS 6–2: Population Dynamics and Palaeoenvironments,
Springer* (pp. 77–99). Dordrecht: Springer.

Jones, S.C. & Stewart, B.A. (Eds.) (2016). *Africa from MIS 6–2: Population Dynamics and
Palaeoenvironments*. Dordrecht: Springer.

Karkanas, P. (1999). Lithostratigraphy and micromorphology of Theopetra Cave deposits
Thessaly, Greece: Some Preliminary Results. *British School at Athens Studies*, 3, 240–
251.

Karkanas, P. (2001). Site formation processes in Theopetra Cave: a record of climatic change
during the Late Pleistocene and Early Holocene in Thessaly, Greece. *Geoarchaeology*,
16(4), 373–399.

Karkanas, P., & Goldberg, P. (2010). Site formation processes at Pinnacle Point Cave 13B
(Mossel Bay, Western Cape Province, South Africa): resolving stratigraphic and
depositional complexities with micromorphology. *Journal of Human Evolution*, 59(3–
4), 256–273.

Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A.,
Gopher, A., & Stiner, M. C. (2007) Evidence for habitual use of fire at the end of the
Lower Paleolithic: Site-formation processes at Qesem Cave, Israel. *Journal of Human
Evolution*, 53, 197–212.

Klein, R.1994. The Problem of Modern Human Origins. In: M. Nitecki & D. Nitecki, *Origins of Anatomically Modern Humans* (pp 3–17*)*. New York, Plenum Press, 3–17.

Klein, R., & Scott, K. (1986). Re-analysis of faunal assemblages from the Haua Fteah and other Late Quaternary archaeological sites in Cyrenaican Libya. *Journal of Archaeological Science*, 13, 515–542.

Kovda, I., & Mermut, A.R. (2010). Vertic Features. In G. Stoops, V. Marcelino & F. Mees (Eds.), *Interpretation of Micromorphological Features of Soils and Regoliths* (pp. 109–127). Amsterdam: Elsevier.

Kuhn, P., Aguilar, J., Miedema, R. (2010). Textural Features and Related Horizons. In G. Stoops, V. Marcelino & F. Mees (Eds.), *Interpretation of Micromorphological Features of Soils and Regoliths* (pp. 217–250). Amsterdam: Elsevier.

Lambeck, K., & Purcell, A. (2005). Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. *Quaternary Science Reviews*, 24(18–19), 1969–1988.

Laville, H. (1976). Deposits in calcareous rockshelters: analytical methods and climatic interpretation. In D.A. Davidson & M.L. Shackley (Eds.), *Geoarchaeology* (pp. 137–155). London: Duckworth.

Laville, H., Rigaud, J.-P., & Sackett, J. (1980). *Rockshelters of the Perigord*. London: Academic Press.

Macphail, R.I., & Cruise, G.M. (2001). The soil micromorphologist as team player: A multianalytical approach to the study of European microstratigraphy. In P. Goldberg, V.T. Holliday & C.R. Ferring (Eds.), *Earth Science and Archaeology* (pp. 241–267). New York: Kluwer Academic/Plenum Publishers.

Macphail, R.I., & McAvoy, J.M. (2008). A micromorphological analysis of stratigraphic integrity and site formation at Cactus Hill, an early Paleoindian and hypothesized Pre-Clovis occupation in South-Central Virginia, USA. *Geoarchaeology*, 23(5), 675–694.

Macphail, R.I., Goldberg, P., & Linderholm, J. (2000). Geoarchaeological investigations of sediments from Gorham's and Vanguard Caves, Gibraltar: microstratigraphical (soil micromorphological and chemical) signatures In C.B. Stringer, R.N.E. Barton & J.C. Finlayson (Eds.), *Neanderthals on the Edge* (pp. 183–200). Oxford: Oxbow.

Macphail, R.I., Cruise, G.M., Allen, M.J., Linderholm, J., & Reynolds, P. (2004). Archaeological soil and pollen analysis of experimental floor deposits; with special reference to Butser Ancient Farm, Hampshire, UK. *Journal of Archaeological Science*, 31, 175–191.

Mallol, C., Mentzer S.M., Wrinn P.J. (2009). A micromorphological and mineralogical study of site formation processes at the late Pleistocene site of Obi-Rakhmat, Uzbekistan. *Geoarchaeology* 24 (5):548–575.

Mallol, C., Hernández, C.M., & Machado, J. (2012). The significance of stratigraphic discontinuities in Iberian Middle-to-Upper Palaeolithic transitional sites. *Quaternary International*, 275, 4–13.

Mandel, R.D., & Simmons, A.H. (1997). Geoarchaeology of the Akrotiri Aetokremnos Rockshelter, Southern Cyprus. *Geoarchaeology*, 12(6), 587–605.

McBurney, C.B.M. (1967). *The Haua Fteah (Cyrenaica) and the Stone Age of the South-East Mediterranean. Cambridge*: Cambridge University Press.

McBurney, C.B.M., & Hey, R.W. (1955). *Prehistory and Pleistocene Geology in Cyrenaican Libya*. Cambridge: Cambridge University Press.

McBurney, C.B.M., Trevor, J.C., & Wells, L.H. (1952). The Haua Fteah Fossil Jaw. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland,* 83(1), 71–85.

McBurney, C.B.M., Trevor, J.C., & Wells, L.H. (1953). A Fossil Human Mandible from a Levalloiso-Mousterian Horizon in Cyrenaica. *Nature*, 172(4385), 889–891.

Mitchell, P. (2016). Africa from MIS 6–2: Where do we go from here? In S.C. Jones & B.A. Stewart (Eds.), *Africa from MIS 6–2: Population dynamics and paleoenvironments* (pp. 407–416). Dordrecht: Springer.

MOLAS. (1994). *Archaeological Site Manual* (3rd ed.). London: Museum of London.

Moyer, C. (2003). *The Organisation of Lithic Technology in the Middle and Early Upper Palaeolithic Industries at the Haua Fteah, Libya.* Unpublished doctoral dissertation, University of Cambridge, UK.

Muhs, D.R., Budahn, J., Avila, A., Skipp, G., Freeman, J., & Patterson, D. (2010). The role of African dust in the formation of Quaternary soils on Mallorca, Spain and implications for the genesis of Red Mediterranean soils. *Quaternary Science Reviews*, 29, 2518–2543.

Olivieri, A., Achilli, A., Pala, M., Battaglia, V., Fornarino, S., Al-Zahery, N., Scozzari, R., Cruciani, F., Behar, D.M., Dugoujon, J.M., Coudray, C., Santachiara-Benerecetti, A.S., Semino, O., Bandelt, H.J., & Torroni, A. (2006). The mtDNA legacy of the Levantine early Upper Palaeolithic in Africa. *Science*, 314(5806), 1767–1770.

Osborne, A.H., Vance, D., Rohling, E.J., Barton, N., Rogerson, M., & Fello, N. (2008). A humid corridor across the Sahara for the migration of early modern humans out of Africa 120,000 years ago. *Proceedings of the National Academy of Sciences*, 105(43), 16444–16447.

Pagliai, M., & Stoops, G. (2010). Physical and biological surface crusts and seals. In G. Stoops, V. Marcelino & F. Mees (Eds.), *Interpretation of micromorphological charactersitics of soils and regoliths* (pp. 419–440). Amsterdam: Elsevier.

Pereira, L., Silva, N.M., Franco-Duarte, R., Fernandes, V., Pereira, J.B., Costa, M.D., Martins, H., Soares, P., Behar, D.M., Richards, M.B., & Macaulay, V. (2010). Population

expansion in the North African late Pleistocene signalled by mitochondrial DNA haplogroup U6. *BMC Evolutionary Biology*, 10, 390.

Powell, A., Shennan, S., & Thomas M.G. (2009). Late Pleistocene demography and the appearance of modern human behavior. *Science* 324, 1298–1301.

Prendergast, A.L., Stevens, R.E., O'Connell, T.C., Hill, E.A., Hunt, C.O., & Barker, G.W. (2016). A late Pleistocene refugium in Mediterranean North Africa? Palaeoenvironmental reconstruction from stable isotope analyses of land snail shells (Haua Fteah, Libya). *Quaternary Science Reviews*, 139, 94–109.

Pye, K., & Blott, S. (2004). Particle size analysis of sediments, soils and related particulate materials for forensic purposes using laser granulometry. *Forensic Science International*, 144(1), 19–27.

Rabett, R., Farr, L., Hill, E., Hunt, C., Lane, R., Moseley, H., Stimpson, C., & Barker, G. (2013). The Cyrenaican Prehistory Project 2012: the sixth season of excavations in the Haua Fteah cave. *Libyan Studies*, 44, 113–125.

Reade, H., O'Connell, T.C., Barker, G., & Stevens, R.E. (2016). Pleistocene and Holocene palaeoclimates in the Gebel Akhdar (Libya) estimated using herbivore tooth enamel oxygen isotope compositions. *Quaternary International*, 404, 150–162.

Rebollo, N.R., Weiner, S., Brock, F., Meignen, L., Goldberg, P., Belfer-Cohen, A., Bar-Yosef, O., &Boaretto, E. (2011). New radiocarbon dating of the transition from the Middle to the Upper Paleolithic in Kebara Cave, Israel. *Journal of Archaeological Science*, 38(9), 2424–2433.

Sampson, C.G. (1967). Coarse granulometric analysis of the Haua Fteah deposits. In C.B.M. McBurney (Ed.), *The Haua Fteah (Cyrenaica) and the Stone Age of the South-East Mediterranean* (pp. 50–54). Cambridge: Cambridge University Press.

Sànchez Vizcaíno, A., & Cañabate, M.L. (1999). Identification of activity areas by soil phosphorus and organic matter analysis in two rooms of the Iberian sanctuary "Cerro El Pajarillo". *Geoarchaeology*, 14, 47–62.

Santisetban, J.I., Mediavilla, R., López-Pamo, E., Dabrio, C.J., Ruiz-Zapata, M.B., Gil García, J., & Martínez-Alfaro, P.E. (2004). Loss on ignition: a qualitative or quantitative method for organic matter and carbonate mineral content in sediments? *Journal of Palaeolimnology,* 32, 287–299.

Schuldenrein, J. (1998). Konispol Cave, Southern Albania, and correlations with other Aegean caves occupied in the Late Quaternary. *Geoarchaeology*, 13(5), 501–526.

Schuldenrein, J. (2001). Stratigraphy, Sedimentology and Site formation at Konispol Cave, Southwest Albania. *Geoarchaeology*, 16(5), 559–602.

Simpson, D.J. (2014). *The Palynology of the Haua Fteah, Libya.* Unpublished doctoral dissertation, Queen's University, Belfast.

Stein, J.K. (1987). Deposits for archaeologists In M.B. Schiffer (Ed.), *Advances in Archaeological Method and Theory* (pp. 337–395). San Diego: Academic Press.

Stein, J.K. (1992). Organic matter in archaeological contexts. In V.T. Holliday (Ed.), *Soils in Archaeology: Landscape Evolution and Human Occupation* (pp. 193–216). Washington: Smithsonian Institution Press.

Stein, J.K. (2001). Archaeological Sediments in Cultural Environments. In J.K. Stein & W.R. Farrand (Eds.), *Sediments in Archaeological Context*. Salt Lake City: University of Utah Press.

Stern, N. (2008). Time Averaging and the Structure of Late Pleistocene Archaeological Deposits in Southwest Tasmania. In S.J. Holdaway & L. Wandsnider (Eds.), *Time in Archaeology: Time Perspectivism Revisited* (pp. 134–178). Salt Lake City: University of Utah Press.

Sternberg, R.S. (2001). Magnetic properties and archaeomagnetism. In D.R. Brothwell & A.M. Pollard (Eds.), *Handbook of Archaeological Sciences* (pp. 73–80). Chichester: John Wiley & Sons Ltd.

Stoops, G. (2003). *Guidelines for Analysis and Description of Soil and Regolith Thin Sections.* Madison, Wisconsin: Soil Society of America Inc.

Thompson, R., & Oldfield, F. (1986). *Environmental Magnetism*. London: Allen & Unwin.

Timmermann, A., & Friedrich, T. (2016). Late Pleistocene climate drivers of early human migrations. *Nature*, 538, 92–95.

Tite, M.S., & Mullins, C. (1971). Enhancement of the magnetic susceptibility of soils on archaeological sites. *Archaeometry*, 13(2), 209–219.

Tjallingii, Claussen, M., Stuut, J.-B., Fohlmeister, J., Jahn, A., Bickert, T., et al. (2008). Coherent high- and low-latitude control of the northwest African hydrological balance. *Nature Geoscience*, 1, 670–675.

Tobias, P.V. (1967). Appendix 1B: The hominid skeletal remains of Haua Fteah. In: C.B.M. McBurney (Ed.) *The Haua Fteah (Cyrenaica) and the Stone Age of the South-East Mediterranean (*pp338–352) Cambridge: Cambridge University Press.

Trevor, J.C., & Wells, L.H. (1967). Appendix 1A: Preliminary report on the second mandibular fragment from Haua Fteah, Cyrenaica. In: C.B.M. McBurney CBM (Ed.) *The Haua Fteah, Cyrenaica and the Stone Age of the South-East Mediterranean* (pp336-337). Cambridge: Cambridge University Press.

Tryon, C.A., & Faith, J.T. (2016). A demographic perspective on the Middle to Later Stone Age transition from Nasera rockshelter, Tanzania. *Philosophical Transactions of the Royal Society B, Biological Sciences,* 371, 1698.

Valentin, C. (1991). Surface crusting in two alluvial soils of northen Niger. *Geoderma*, 48, 201–222.

Van Peer, P. (1998). The Nile Corridor and the Out-of-Africa Model: An examination of the archaeological record. *Current Anthropology*, 39(2), S115–S140.

Van Peer, P. (2016). Technological Systems, Population Dynamics, and Historical Process in the MSA of Northern Africa. In: S.C. Jones, & B.A. Stewart (Eds) *Africa from MIS 6-2: Population Dynamics and Paleoenvironments (pp147–159).* Amsterdam: Springer Verlag.

Van Peer, P. & Vermeersch, P.M. (2007).The place of Northeast Africa in the early history of modern humans: new data and interpretations on the Middle Stone Age. In: P. Mellars, K. Boyle,). Bar-Yosef, C. Stringer, (Eds) *Rethinking the Human Revolution (*pp 187–198). McDonald Institute Monographs. Cambridge: McDonald Institute.

Van Peer, P., Vermeersch, P.M., & Paulissen, E. (2010). *Chert quarrying, lithic technology and a modern human burial at the Palaeolithic site of Taramsa 1, Upper Egypt* (Egyptian Prehistory Monographs No. 5). Leuven: Leuven University Press.

van Vliet-Lanoë, B. (1998). Frost and soils: implications for paleosols, paleoclimates and stratigraphy. *Catena*, 34, 157–183.

van Vliet-Lanoë, B., Coutard, J.-P., Pissart, A. (1984). Structures caused by repeated freezing and thawing in various loamy sediments: a comparison of active, fossil and experimental data. *Earth Surface Processes and Landforms*, 9, 553–565.

Vaquero, M., Alonso, S., García-Catalán, S., García-Hernández, A., Gómez de Soler, B., Rettig, D., & Soto, M. (2012). Temporal nature and recycling of Upper Paleolithic artifacts: the burned tools from the Molí del Salt site (Vimbodí i Poblet, northeastern Spain). Journal of Archaeological Science, 39(8), 2785–2796.

Vermeersch P.M. (2010). Middle and Upper Palaeolithic in the Egyptian Nile Valley. In: Garcea EAA (ed) *South-Eastern Mediterranean Peoples Between 130,000 and 10,000 Years Ago*. (pp 66–88). Oxbow, Oxford.

Vermeersch, P.M. & Van Neer, W. (2015). Nile behaviour and late Palaeolithic humans in Upper Egypt during the Late Pleistocene. *Quaternary Science Reviews,* 130, 155–167.

Wainwright, J. (2009). Weathering, soils and slope processes. In J.C. Woodward (Ed*.), The Physical Geography of the Mediterranean* (pp. 169–202). Oxford: Oxford University Press.

West, L.T., Bradford, J.M., & Norton, L.D. (1990). Crust morphology and infiltrability in surface soils from the southeast and mideast USA. In L.A. Douglas (Ed.), *Soil Micromorphology: A Basic and Applied Science. Proceedings of the VIIIth International Working Meeting on Soil Micromorphology, San Antonio, Texas, July 1988* (pp. 107–113). Amsterdam: Elsevier.

White, W.B. (2007). Cave sediments and palaeoclimate. *Journal of Cave and Karst Studies*, 69(1), 76–93.

Woodward J.C. (1997a) Late Pleistocene Rockshelter Sedimentation at Klithi. In: Bailey GN
　　　　(ed) *Klithi: Palaeolithic Settlement and Quaternary Landscapes in Northwest Greece,
　　　　vol 2.* (pp 361–376). Cambridge: McDonald Institute for Archaeological Research.

Woodward J.C. (1997b) Late Pleistocene Rockshelter Sedimentation at Megalakkos. In: Bailey
　　　　GN (ed) *Klithi: Palaeolithic Settlement and Quaternary Landscapes in Northwest
　　　　Greece, vol 2.* (pp 377–393) Cambridge: McDonald Institute for Archaeological
　　　　Research.

Woodward J.C., & Bailey G.N. (2000) Sediment Sources and Terminal Pleistocene
　　　　Geomorphological Processes Recorded in Rockshelter Sequences in North-west
　　　　Greece. In: Foster I.D.L. (ed) *Tracers in Geomorphology* (pp 521–551). John Wiley &
　　　　Sons, London,

Woodward, J.C., & Goldberg, P. (2001). The sedimentary records in Mediterranean
　　　　rockshelters and caves: archives of environmental change. *Geoarchaeology*, 16(4),
　　　　327–354.

Yaalon, D.H. (1997). Soils in the Mediterranean region: What makes them different? *Catena*,
　　　　28, 157–169.

FIGURES

Figure 1: (a) Location of the CPP study area and the Haua Fteah. Drawing by D. Kemp; (b) Looking East along the northern escarpment of the Gebel Akhdar towards the Haua Fteah. Photo: R. Inglis. (c) View into the Haua Fteah shelter from North. Figure circled for scale. Laser scans of the inside of the cave showing (d) an aerial view and (e) cross-section looking East. Scans: J. Meneely and B. Smith.

Figure 2: Photo of the Middle Trench North-Facing Profile, showing the sedimentological facies distinguished and discussed in this paper. Sediments vary between limestone gravel-dominated facies (Facies 2 and 4) and those with fine, silty sediment (Facies 3 and 5). Note large burning feature extending across the section from the left at the top of Facies Four. Holes from the removal of the first phase of micromorphological sampling are visible ~2.5m from the base of the trench (ranging pole divisions are 50 cm), whilst the holes to the left of the section were made through removal of samples for OSL dating. Photo: G. Barker.

Figure 3: Summary of field facies, existing cultural divisions from McBurney (1967), and dates from Douka et al. (2014).

Figure 4: Profile drawings of the West and North-Facing Profiles showing locations of samples discussed in this paper. Large grey rectangles show location of bulk sedimentological sample columns. Area of new CCP excavations (Trench M) marked in dashed rectangle. Black rectangles mark individual micromorphology samples. Star on West-Facing Profile shows location of Campanian Ignimbrite/Y5 tephra. Section drawings: L. Farr.

Figure 5: Schematic diagram of Facies Five–Three West- and North-Facing Profiles showing relationship between the interpreted site formation processes and bulk sedimentological variables. Where they correspond to micromorphological samples (grey squares), the sediment interpretations are based on micromorphological observations discussed in the text, and where they were not sampled for micromorphological analyses, are based on field observations. Grey lines on bulk sedimentology graphs show mean soil pit values. For colours see online version.

Figure 6: Photomicrographs of key features in the Haua Fteah sediments I: (a) limestone sand and gravel interpreted as roof spall, in silty clay material, PPL (Micro-Fabric 961:2; Context 504; Facies 3 MSA); (b) Stipple- to mosaic-speckled b-fabric, indicating lack of shrink-swelling processes, XPL (Micro-Fabric 939:2; Context 508; Facies 3 MSA); (c) Stipple speckled to micritic crystallitic b-fabric – the micritic calcite may be linked to aeolian deposition, roof spalling, or post-depositional precipitation. XPL (Micro-Fabric 2028:2; Context 521; Facies 5); (d) Micritic and sparitic calcitic precipitation linked to persistent wetting of the sediments, the formation of crystals leading to the development of a platy structure, XPL (Micro-Fabrics 2621:2–4; Context 490; Facies 3 Dabban); (e) dung lenses and fine mineral material laminations marking ephemeral surfaces, PPL (Micro-Fabric 2021:2;

Context 563; Facies 5); and (f) faecal spherulites in dung lens, XPL (Micro-Fabric 2521:2; Context 459; Facies 3 Layer XXV).

Figure 7: Photomicrographs of key features in the Haua Fteah sediments II: (a) Crust fragments broken through trampling or bioturbation, PPL (Micro-Fabric 939:3; Context 509; Facies 3 MSA); (b) 'pedorelict' – fragment of soil potentially trampled into the cave by animals or people (Micro-Fabric 940:2; Context 506; Facies 3 MSA); (c) erosive lower boundary (d) clayey infillings indicating drainage of clay and silt –rich water down-profile, PPL (Micro-Fabric 762:2; PPL; Context 449; Facies 3 LSA); (e) phytolith-rich dung with dendritic manganese nodule, PPL (Micro-Fabric 754A:2; Context 453; Facies 3 LSA) and (f) partially-dissolved bone fragments, indicating diagenesis driven by wetting of the sediments, PPL (Micro-Fabric 754A:2; Context 453; Facies 3 LSA).

Figure 8: Photomicrographs of anthropogenic features in the Haua Fteah sediments: (a) mixed ash and charred material, PPL (Micro-Fabric 1052:7; Context 535; Facies 3/4 boundary); (b) lens of combustion material (Micro-Fabric 2021:4; Context 568; Facies 5), containing burnt bone, micro-charcoal and ash, and vesicular silica aggregate in overlying Micro-Fabric 2021:5, PPL (Context 563; Facies 5); (c) vesicular silica aggregate, produced through the burning of silica-rich fuel, e.g. grasses PPL (Micro-Fabric 2021:4; Context 568; Facies 5); and d) humified and charred material accumulated on a surface, including angular flint/chert shard, potential knapping debitage, XPL (Micro-Fabric 938:3; Context 522; Facies 5). (e) calcitic wood ash pseudomorphs, PPL (Micro-Fabric 1052:5; Context 513; Facies 4); Calcitic hypocoatings resulting from movement of calcite-rich water, probably from the dissolution of ash, PPL (1052:6; Context 513; Facies 4).

Figure 9: Particle size distributions of the <2mm non-carbonate fraction of the Haua Fteah sediments (grey) compared to that a sample from a local soil pit (black) and limestone residue (white).
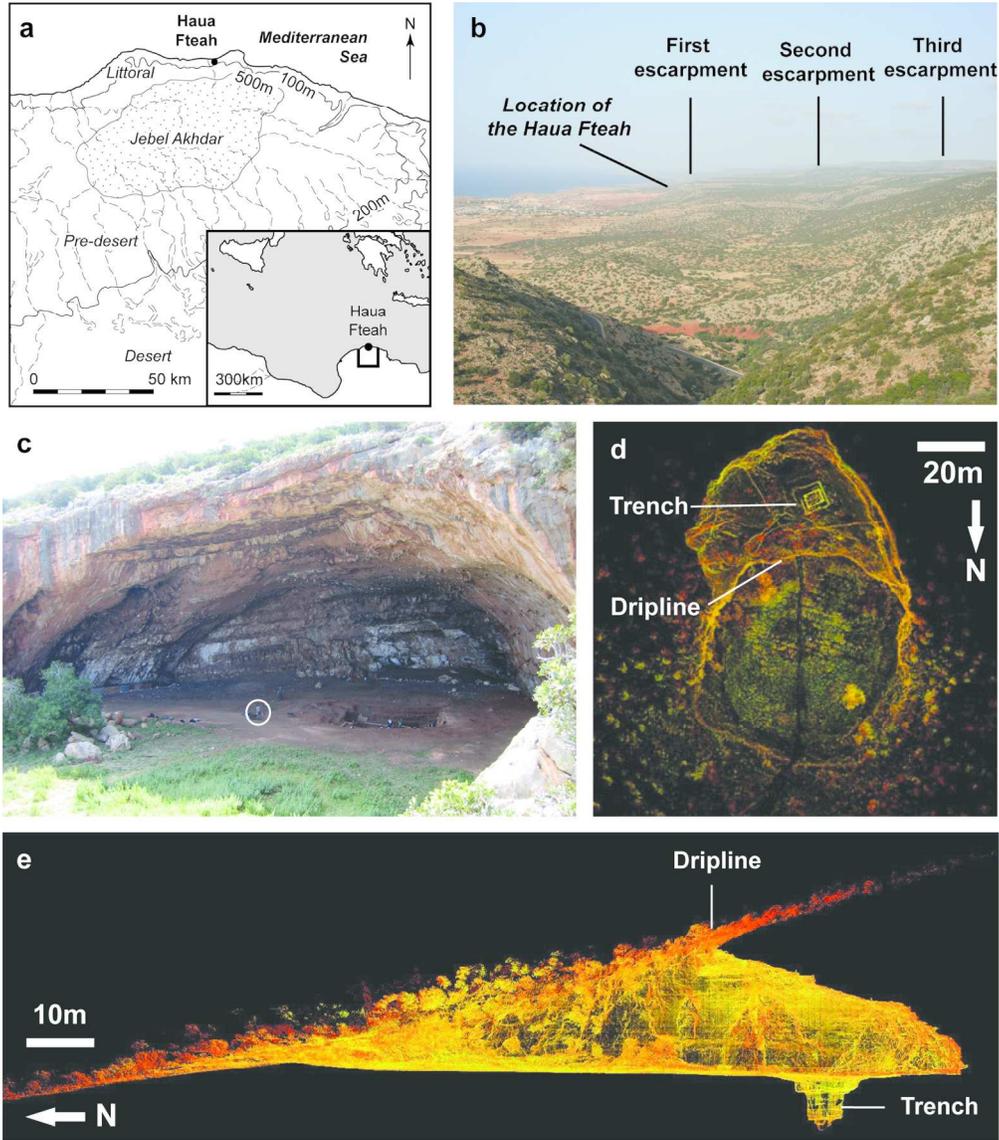
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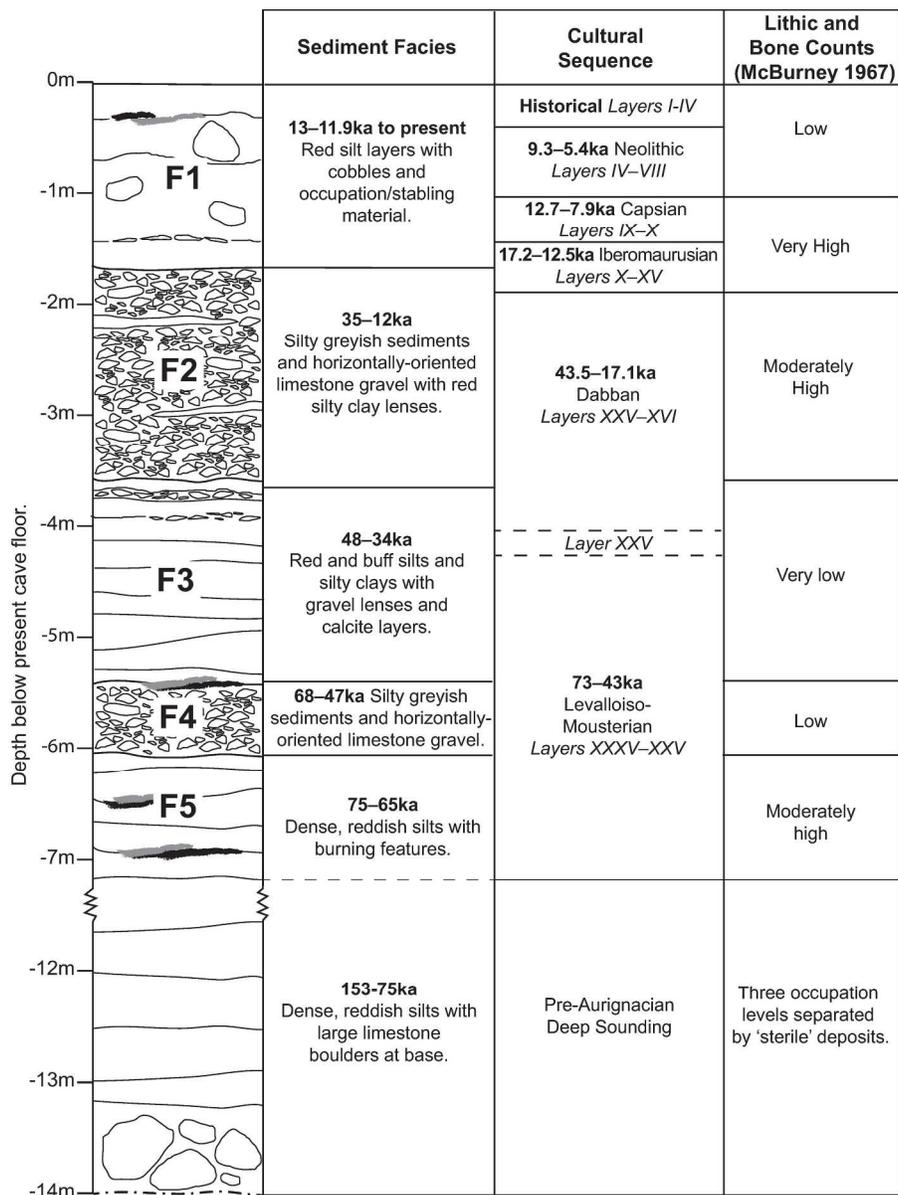
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Figure 3: Summary of sedimentological facies, existing cultural divisions from McBurney (1967), and dates from Douka et al. (2014).
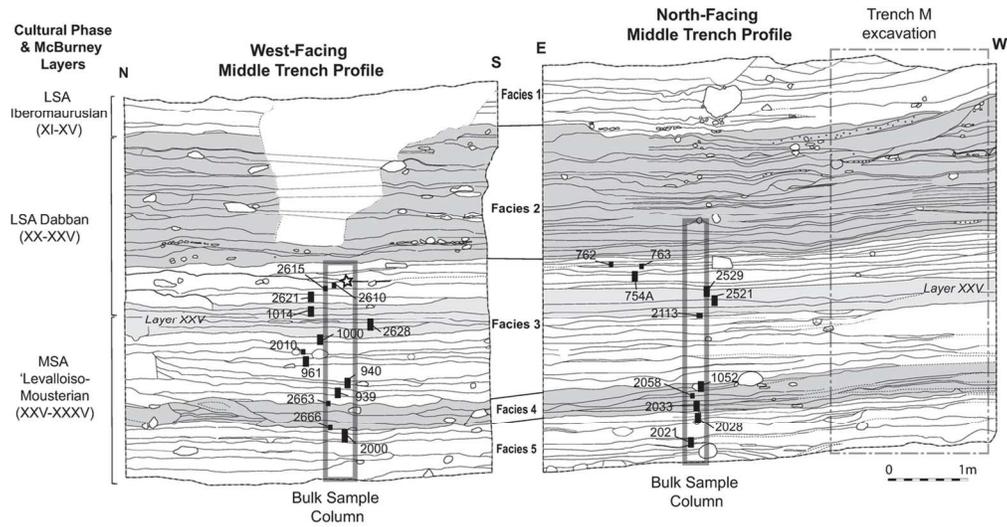
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Figure 5: Schematic diagram of Facies 5–3 West- and North-Facing Profiles showing relationship between the interpreted site formation processes and bulk sedimentological variables. Where they correspond to micromorphological samples (grey squares), the sediment interpretations are based on micromorphological observations discussed in the text, and where they were not sampled for micromorphological analyses, are based on field observations. Grey lines on bulk sedimentology graphs show mean soil pit values. For colours see online version.
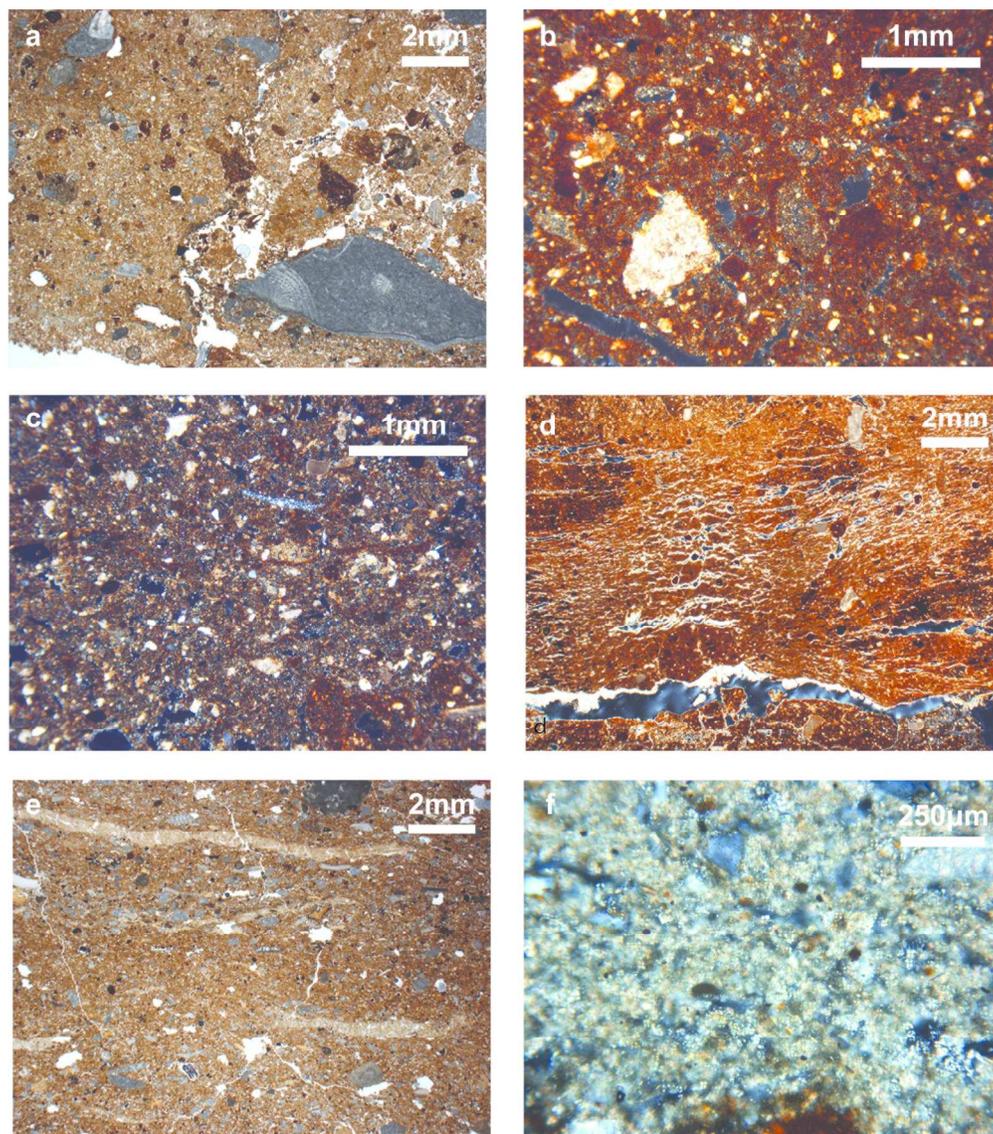
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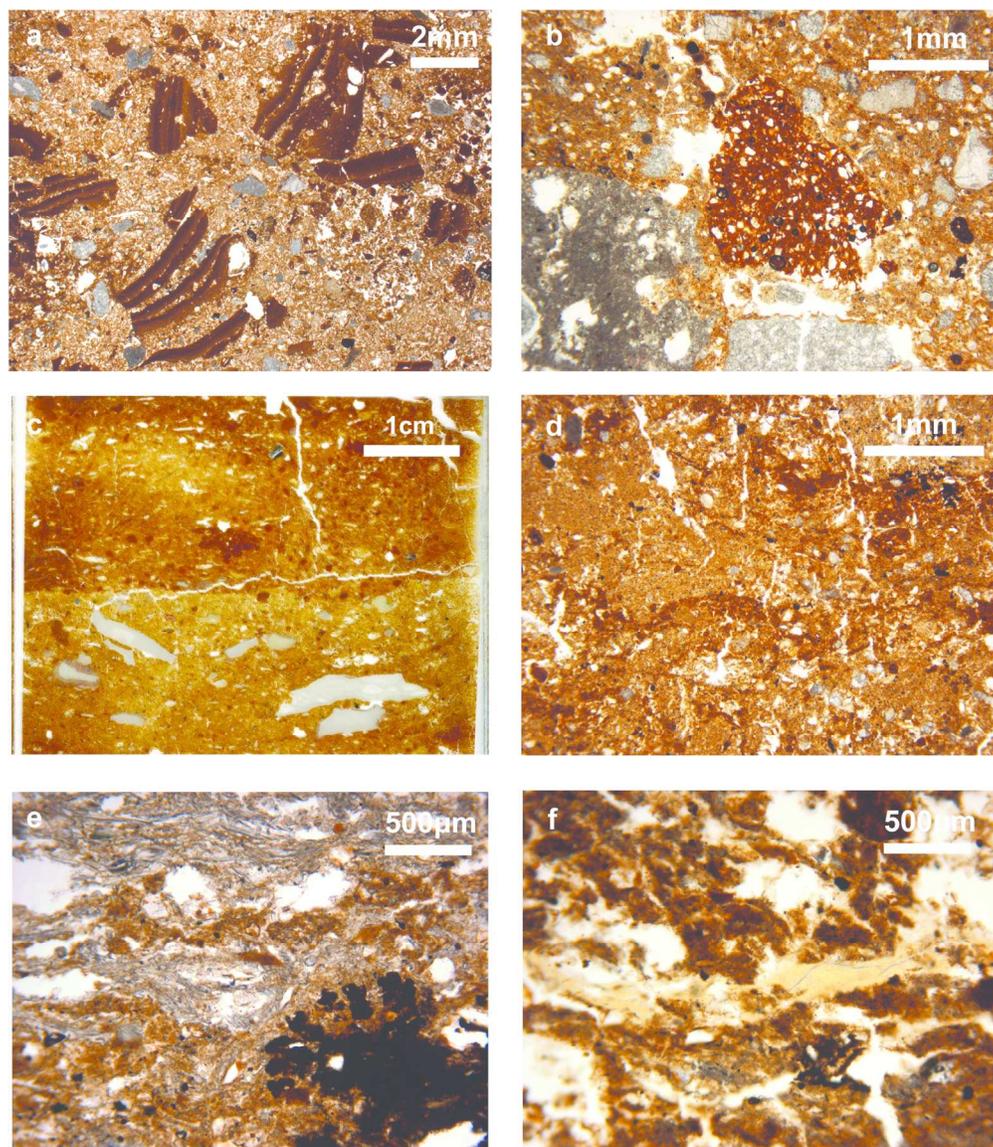
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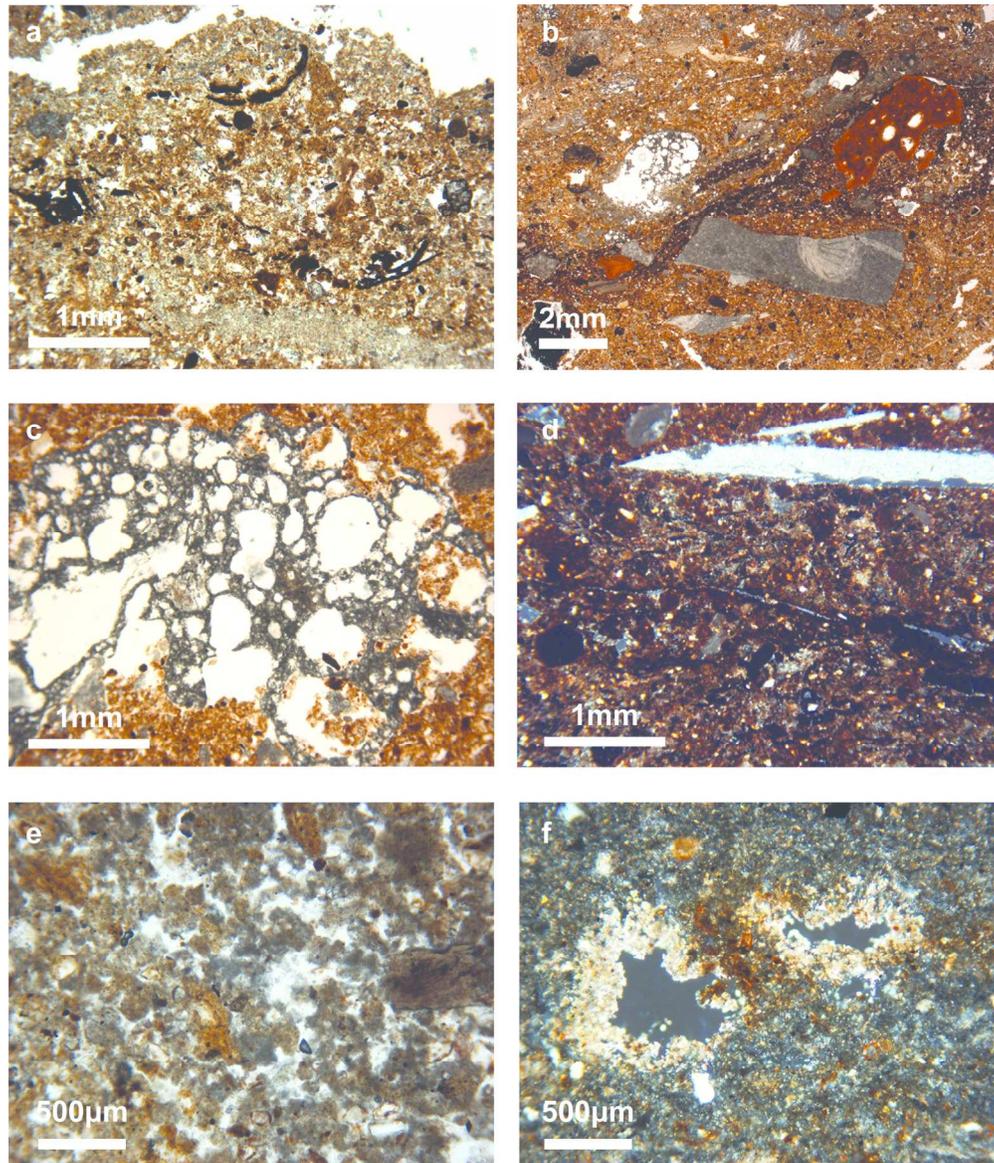
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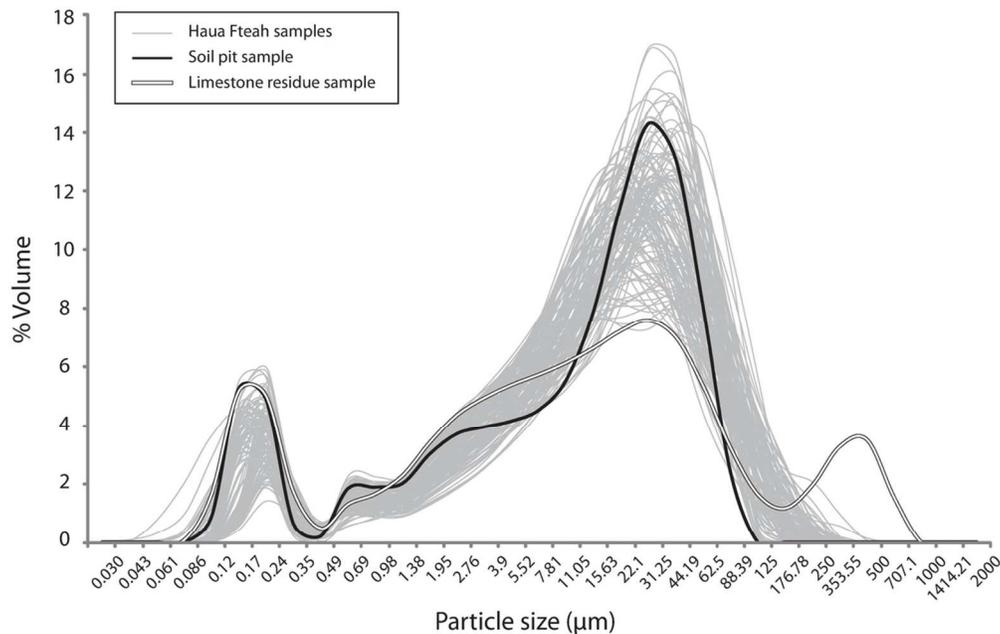
194x227mm (300 x 300 DPI)

Figure 9: Particle size distributions of the <2mm non-carbonate fraction of the Haua Fteah sediments (grey) compared to that a sample from a local soil pit (black) and limestone residue (white).

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	Magnetic Susceptibility (m^3kg^{-1})	**%LOI (organics)**	**%CaCO$_3$**
Soil Pit R			
Sample R2	373.4	5.3	7.8
Sample R3	357.5	5.4	8.1
Soil Pit R Mean	365.45	5.4	8.0
Soil Pit T			
Sample T2	584.0	8.3	8.3
Sample T3	580.6	7.5	8.0
Sample T4	589.8	7.8	8.5
Soil Pit T Mean	584.8	7.9	8.3
Haua Fteah, Facies 5–3			
Mean	321.9	4.0	32.1
Standard Deviation	101.7	0.5	10.5

Table 1: Summary statistics for the soil pit and Haua Fteah Facies 5–3 bulk sedimentological characteristics.