Inglis, RH, French, C, Farr, L, Hunt, CO, Jones, SC, Reynolds, T and Barker, G

Sediment micromorphology and site formation processes during the Middle to Later Stone Ages at the Haua Fteah Cave, Cyrenaica, Libya

http://researchonline.ljmu.ac.uk/7656/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Inglis, RH, French, C, Farr, L, Hunt, CO, Jones, SC, Reynolds, T and Barker, G (2017) Sediment micromorphology and site formation processes during the Middle to Later Stone Ages at the Haua Fteah Cave, Cyrenaica, Libya. Geoarchaeology. ISSN 0883-6353

Sediment Micromorphology and Site Formation Processes During the Middle to Later Stone Ages at the Haua Fteah Cave, Cyrenaica, Libya

Robyn H. Inglis

Department of Archaeology, University of York, UK; Department of Environmental Sciences, Macquarie University, Australia

Charles French

Department of Archaeology and Anthropology, University of Cambridge, UK

Lucy Farr

McDonald Institute for Archaeological Research, University of Cambridge, UK

Chris O. Hunt

School of Natural Sciences and Psychology, Liverpool John Moores University, UK

Sacha C. Jones

McDonald Institute for Archaeological Research, University of Cambridge, UK

Tim Reynolds

Department of History, Classics and Archaeology, Birkbeck, University of London, UK

Graeme Barker

McDonald Institute for Archaeological Research, University of Cambridge, UK

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, as 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 alsongside 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 correlating with MIS 5, MIS 3). 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 30s, 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. %$CaCO_3$ 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 in some cases overlap.

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. 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.

ACKNOWLEDGEMENTS

RHI's PhD research was funded by an Arts and Humanities Research Council Doctoral Award and Magdalene College, Cambridge. We also thank in particular the Department of Antiquities of Libya for its permission to undertake the new excavations at the Haua Fteah, and their logistical support for the fieldwork. The project was initially termed the Cyrenaican Prehistory Project, with the excavation permit arranged by and funding provided by the Society for Libyan Studies, whose support is gratefully acknowledged. From 2009, it has also been termed the TRANS-NAP project from the acronym of the European Research Council grant to GB (Advanced Investigator Grant 230421: “Cultural Transformations and Environmental Transitions in North African Prehistory”), which has provided the major funding for the project that is also gratefully acknowledged. The support of the Natural Environment Research Council’s Radiocarbon Facility is also acknowledged. The authors thank Geoff Bailey for his valuable comments on a draft of this manuscript, and the three anonymous reviewers for their helpful comments.

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

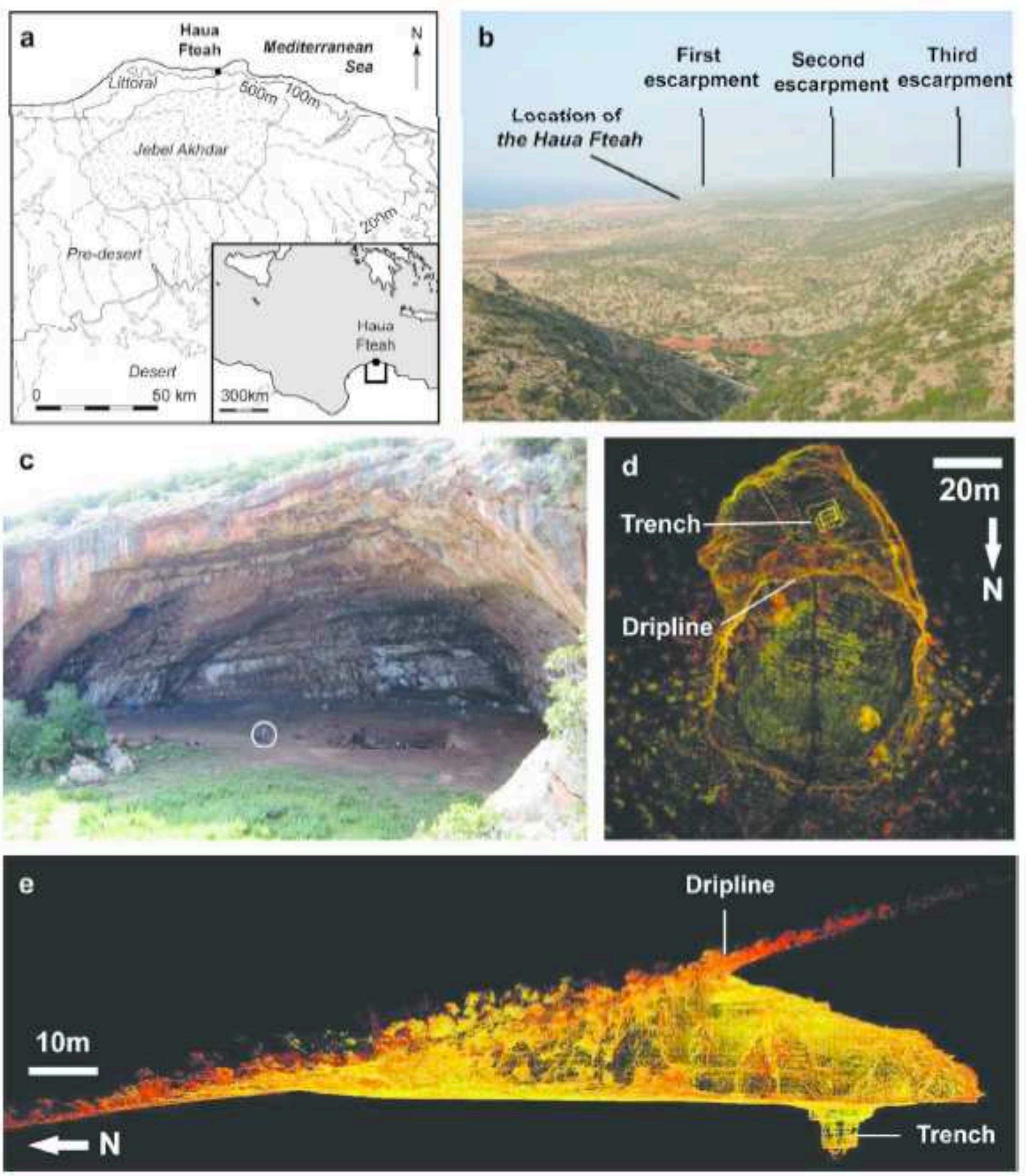

Figure 1: (a) Location of the CPP study area and the Haua Fteah. Drawing by D. Kemp; (b) Looking East along the northern escarpment of the Gebel Akhdar towards the Haua Fteah. Photo: R. Inglis. (c) View into the Haua Fteah shelter from North. Figure circled for scale. Laser scans of the inside of the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

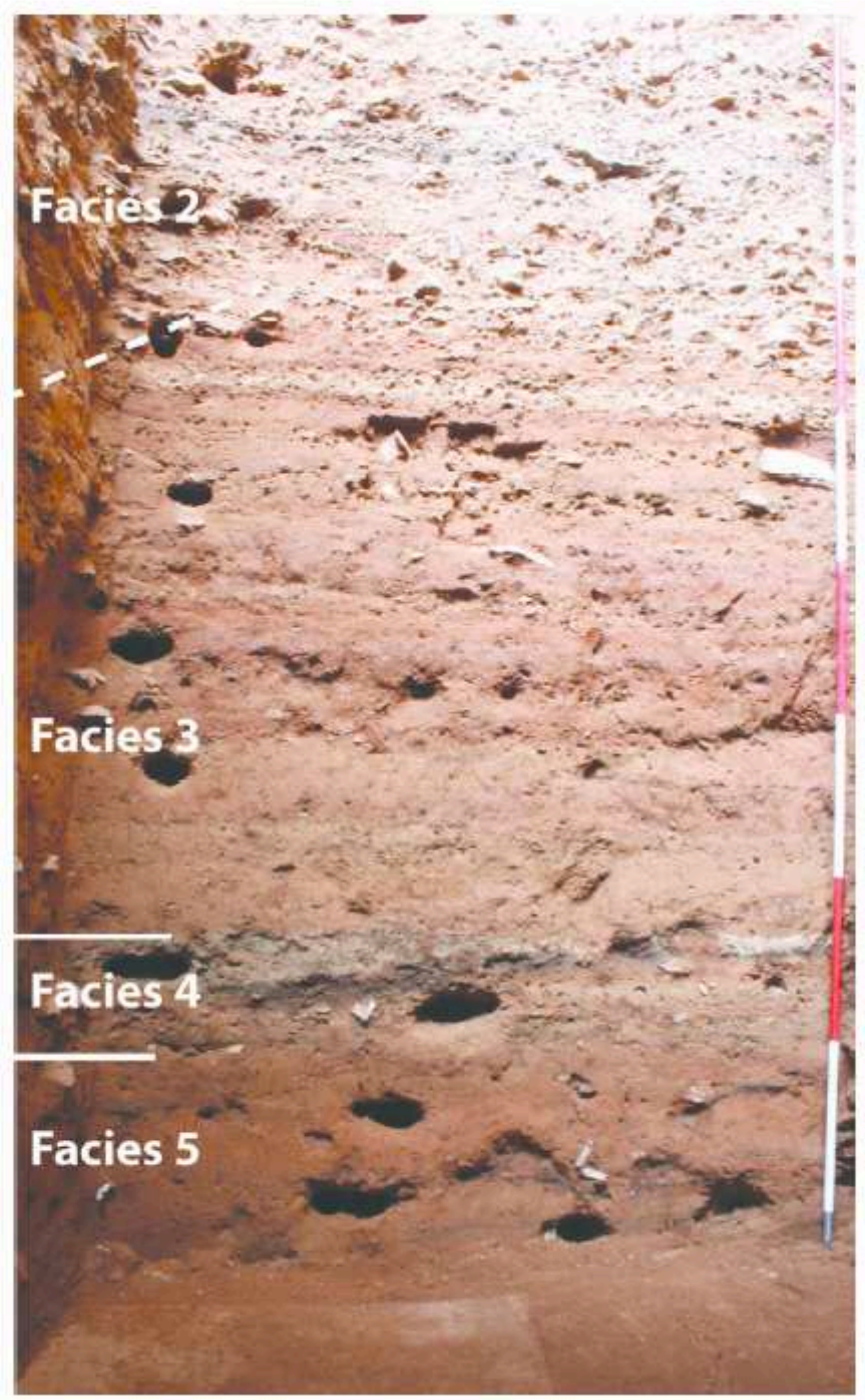

Figure 2: Photo of the Middle Trench North-Facing Profile, showing the sedimentological facies distinguished and discussed in this paper. Sediments vary between limestone gravel-dominated facies (Facies 2 and 4) and those with fine, silty sediment (Facies Three and Five). Note large burning feature extending 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.

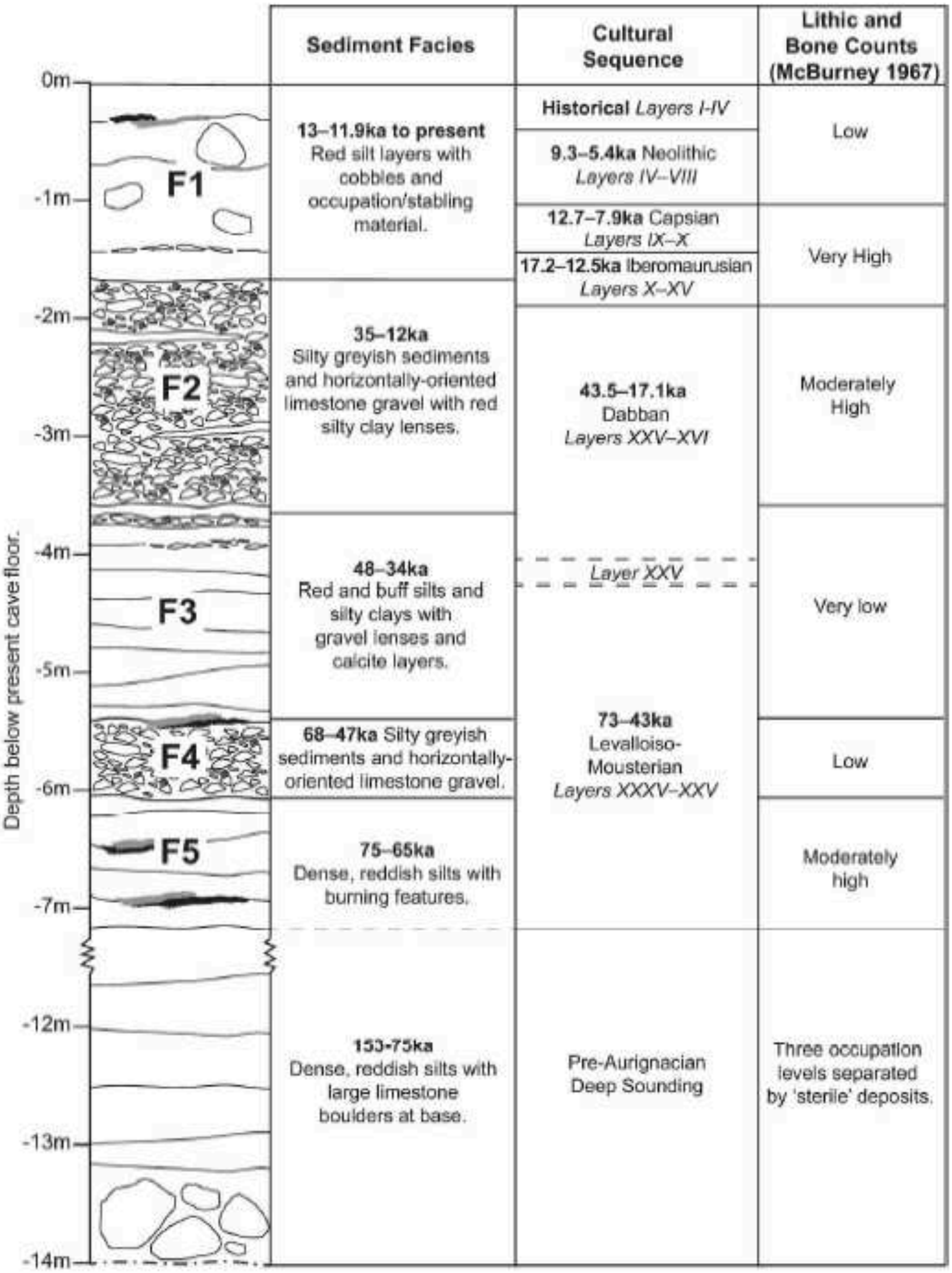

Figure 3: Summary of field facies, existing cultural divisions from McBurney (1967), and dates from Douka et al. (2104).

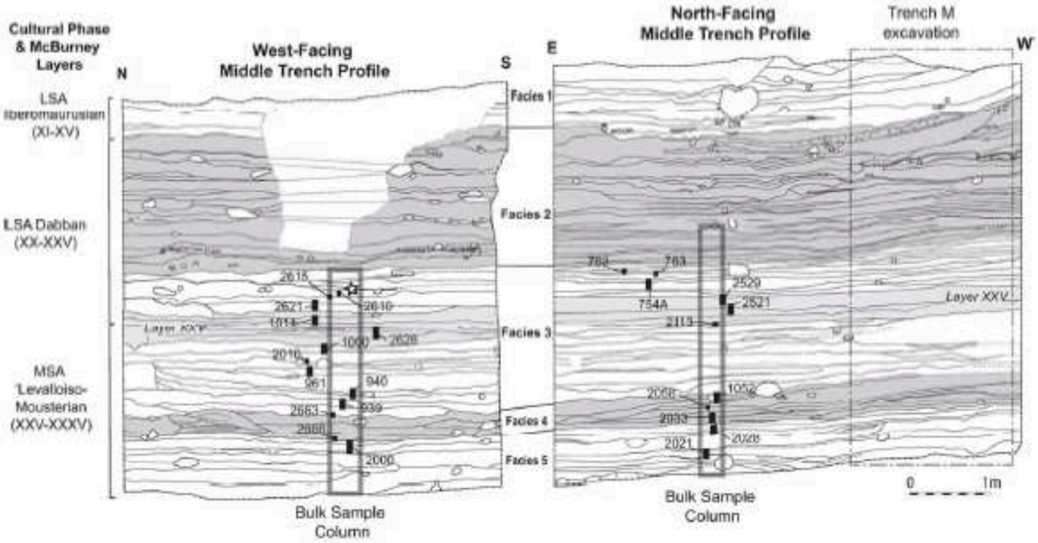

Figure 4: Profile drawings of the West and North-Facing profiles showing locations of samples discussed in this paper. Large grey rectangles show location of bulk sedimentological sample columns, the area of new CCP excavations, Trench M, and black rectangles mark individual micromorphology samples.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

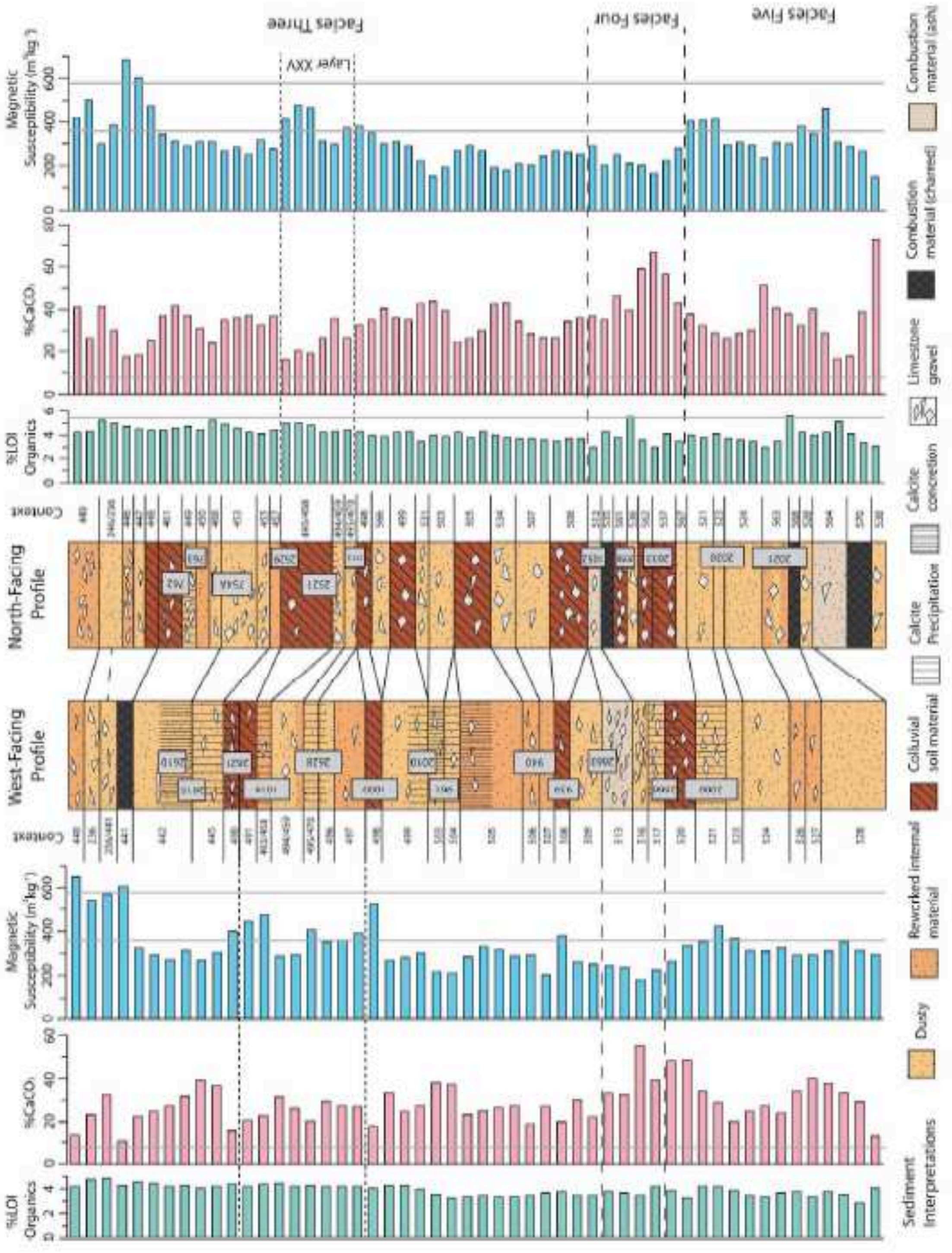

Figure 5: Schematic diagram of Facies Five–Three West- and North-Facing Profiles showing relationship between the interpreted site formation processes and bulk sedimentological variables. Where they correspond to micromorphological samples (grey squares), the sediment interpretations are based on micromorphological 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.

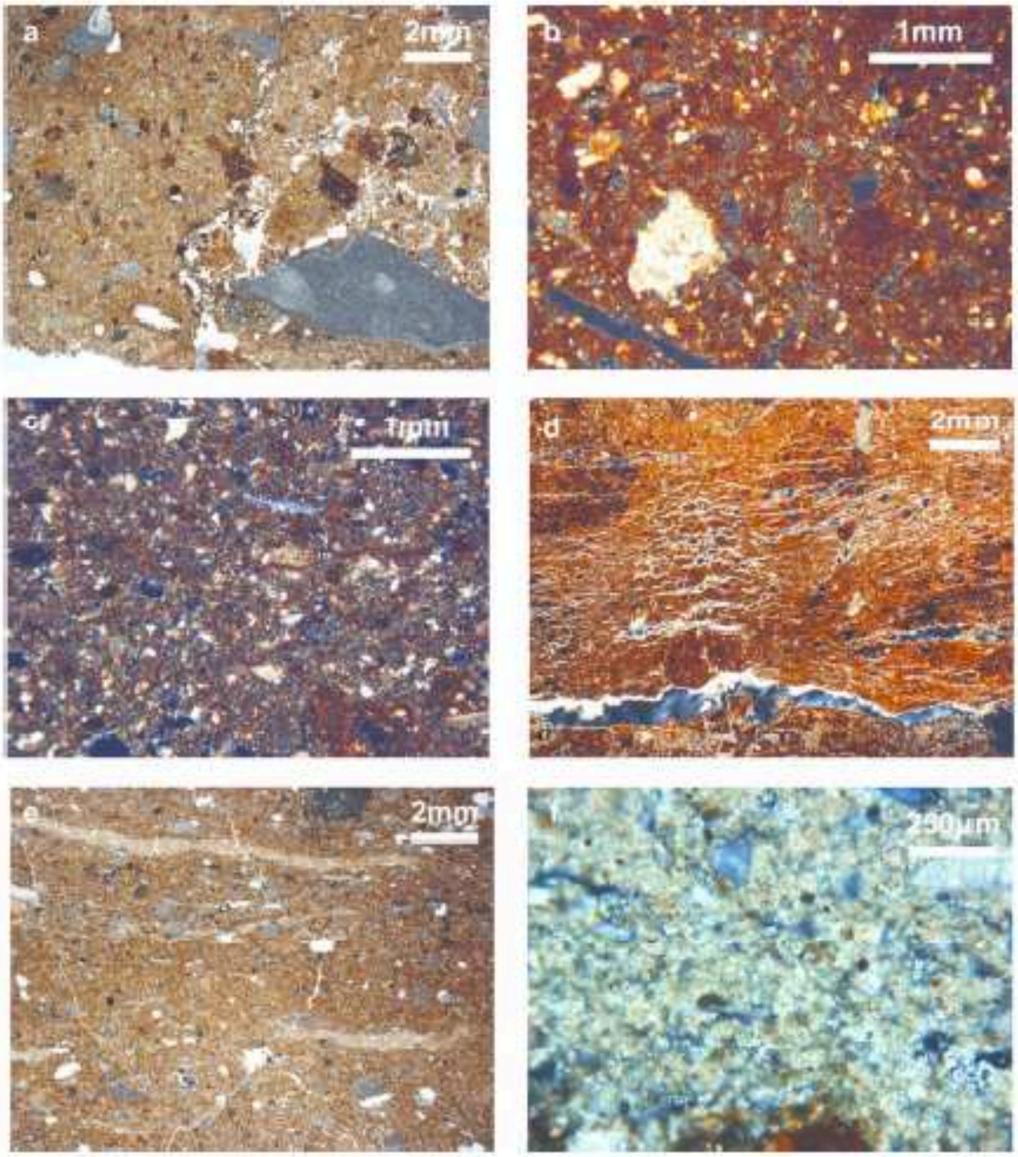

Figure 6: Photomicrographs of key features in the Haua Fteah sediments I: (a) limestone sand and gravel interpreted as roof spall, in silty clay material, PPL (Micro-Fabric 961:2; Context 504; Facies 3 MSA); (b) Stipple- to mosaic-speckled b-fabric, indicating lack of shrink-swelling processes, XPL (Micro-Fabric 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).

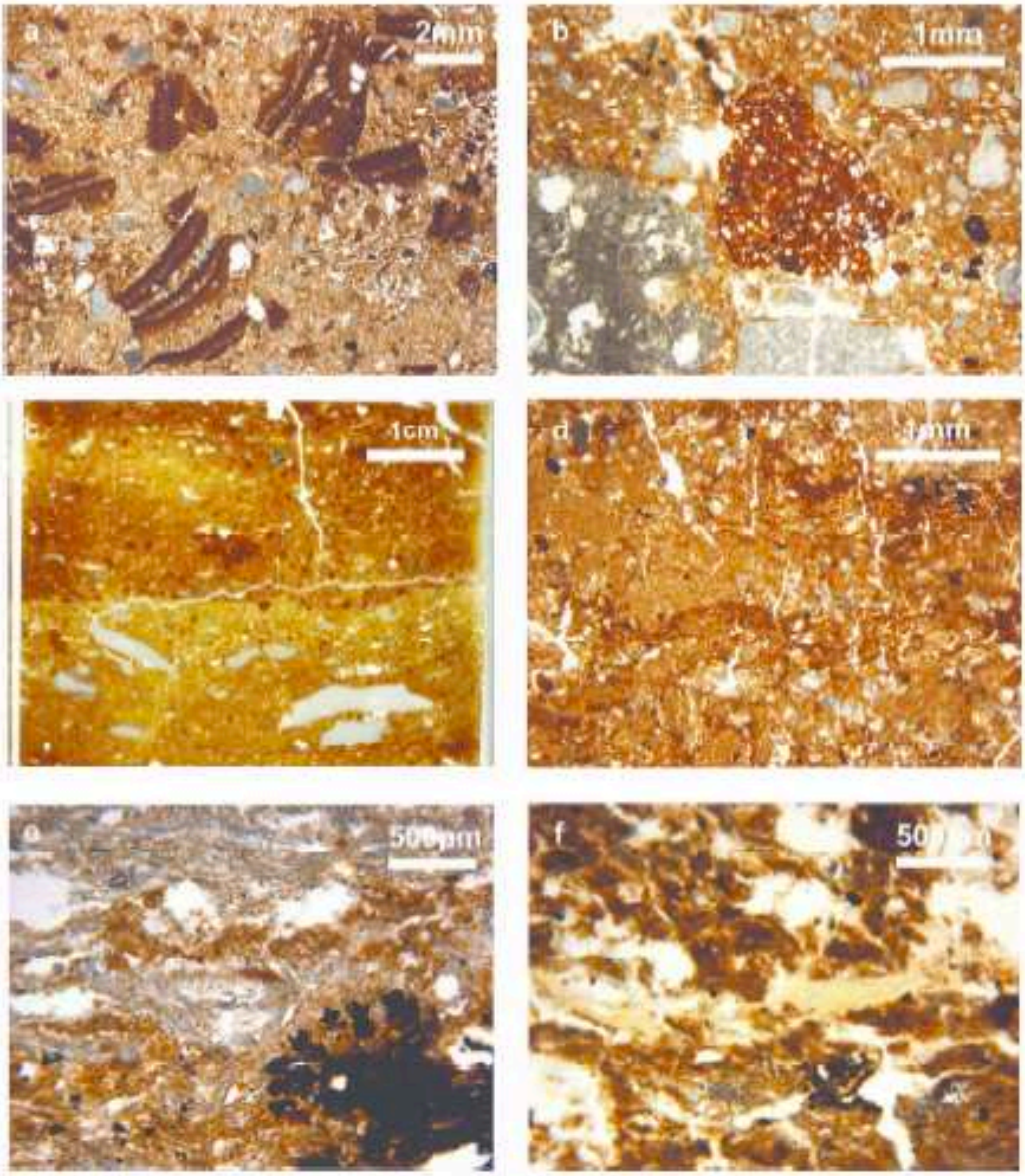

Figure 7: Photomicrographs of key features in the Haua Fteah sediments II: (a) Crust fragments broken through trampling or bioturbation, PPL (Micro-Fabric 939:3; Context 509; Facies 3 MSA); (b) ‘pedorelict’ – fragment of soil potentially trampled into the cave by animals or people (Micro-Fabric 940:2; 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).

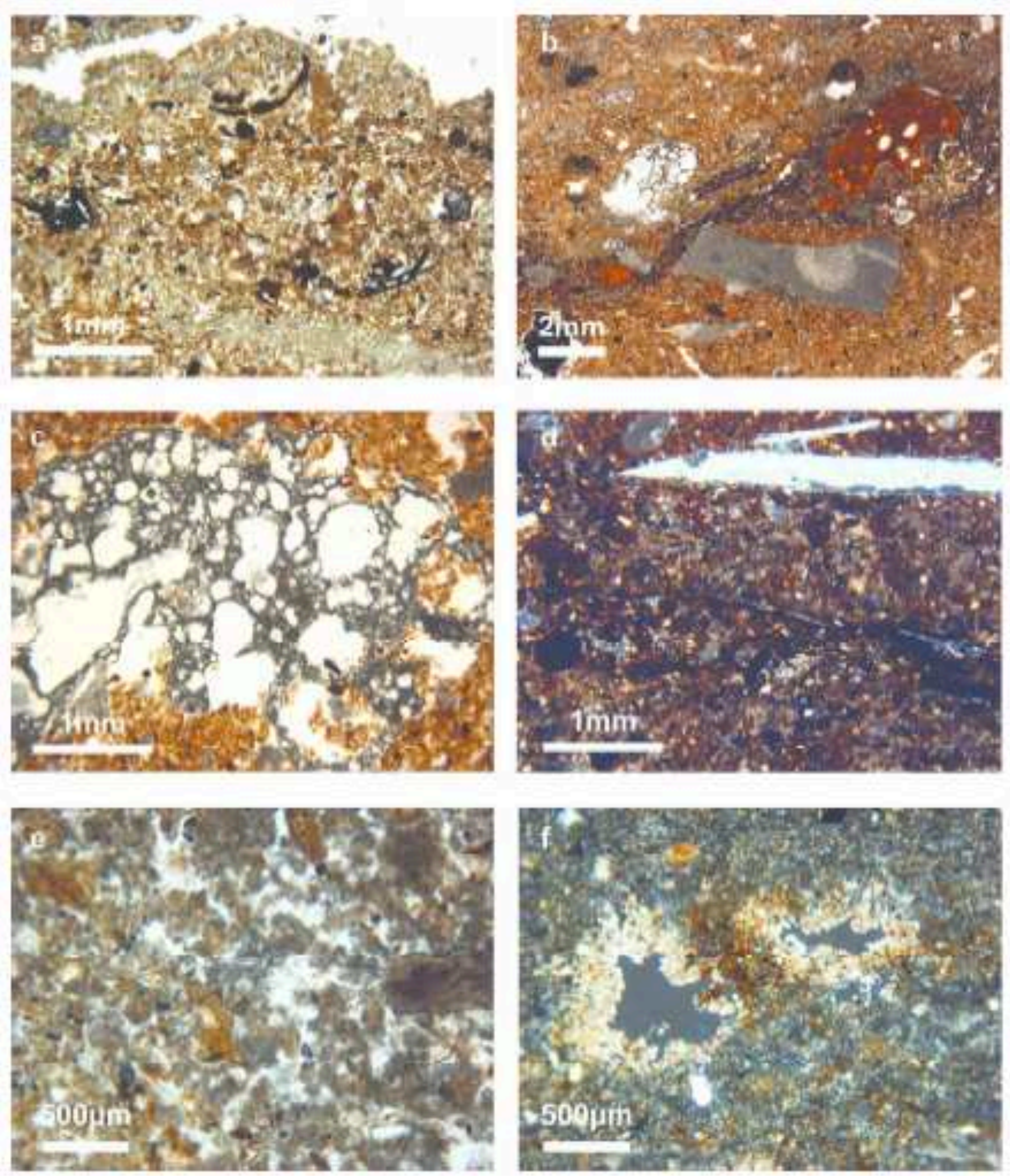

Figure 8: Photomicrographs of anthropogenic features in the Haua Fteah sediments: (a) mixed ash and charred material, PPL (Micro-Fabric 1052:7; Context 535; Facies 3/4 boundary); (b) lens of combustion material (Micro-Fabric 2021:4; Context 568; Facies 5), containing burnt bone, micro-charcoal and ash, 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 Five). (e) calcitic wood ash pseudomorphs, PPL (Micro-Fabric 1052:5; Context 513; Facies Four); Calcitic hypocoatings resulting from movement of calcite-rich water, probably from the dissolution of ash, PPL (1052:6; Context 513; Facies Four).

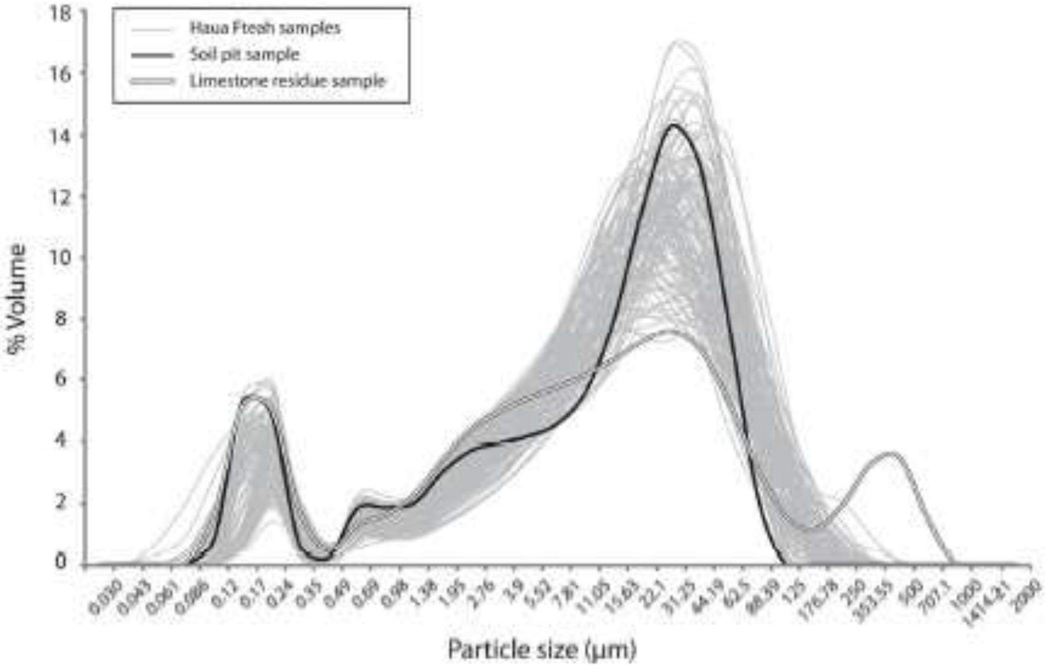

Figure 9: Particle size distributions of the <2mm non-carbonate fraction of the Haua Fteah sediments (grey) compared to that a sample from a local soil pit (black) and limestone residue (white).