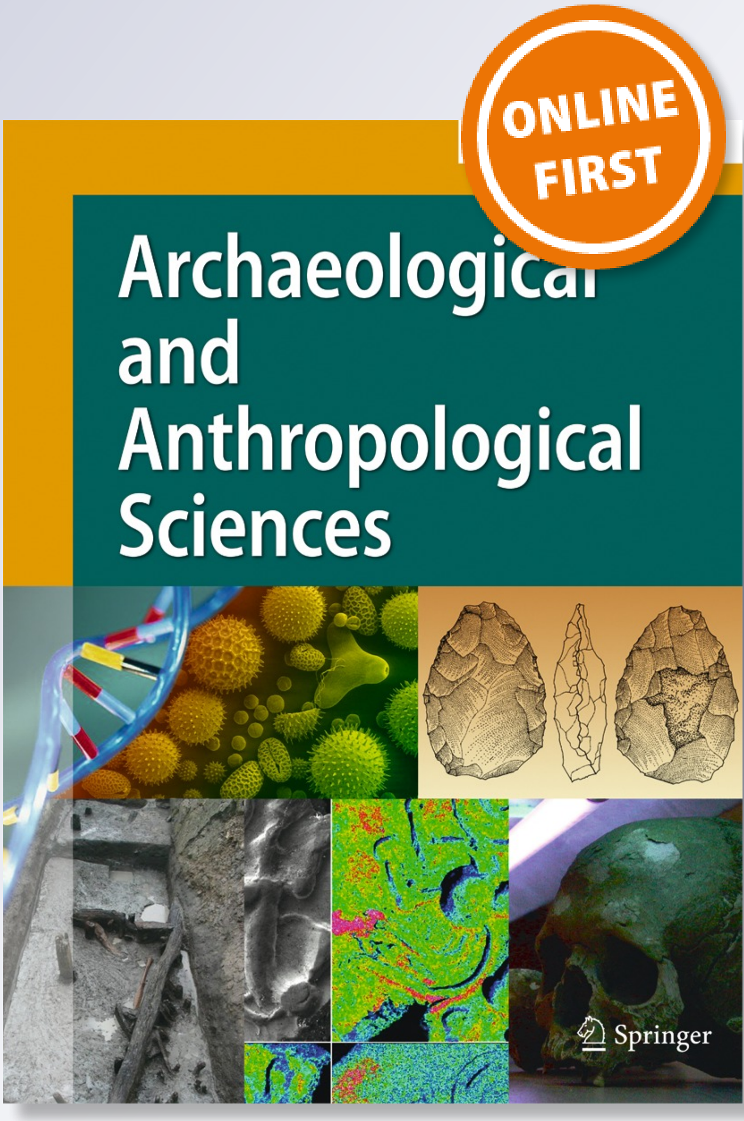
Contacts under the lens: Perspectives on the role of microstratigraphy in archaeological research

Carolina Mallol & Susan M. Mentzer

Archaeological and Anthropological Sciences

ISSN 1866-9557

Archaeol Anthropol Sci
DOI 10.1007/s12520-015-0288-6



Archaeol Anthropol Sci
DOI 10.1007/s12520-015-0288-6

ORIGINAL PAPER

Contacts under the lens: Perspectives on the role of microstratigraphy in archaeological research

Carolina Mallol[1,4] · Susan M. Mentzer[2,3]

Received: 21 January 2014 / Accepted: 20 August 2015

Abstract Achieving an accurate perception of time and context remains a major challenge in archaeology. This paper highlights the potential benefits of microstratigraphic study to address this goal, drawing on case studies from Lower, Middle, and Upper Paleolithic, Neolithic, and Iron Age archaeological sites. First, we discuss the importance of site formation reconstruction and the ways in which current field methods approach the sedimentary record. Then, we focus on both field identification and high-resolution study of stratigraphic contacts, which are ubiquitous in archaeological deposits. Examples are presented to highlight the role of microstratigraphy in characterizing the nature of contacts and their significance for archaeological interpretation. A microstratigraphic approach is especially useful for distinguishing between contacts that originate from changes in depositional processes and contacts that form as a result of post-depositional processes such as pedogenesis, diagenesis, or burning. Further examples show how "invisible" anthropogenic surfaces and different kinds of occupation deposits can come to light at a microscopic scale of observation. Finally, we illustrate cases in which what appeared to be sterile layers in the field yielded anthropogenic elements. In the end, we discuss how archaeological projects might incorporate microstratigraphic analyses and their results within broader research frameworks that prioritize site formation process reconstruction.

Keywords Micromorphology · Stratigraphy · Occupation surfaces · Excavation methods

✉ Susan M. Mentzer
susan.mentzer@ifu.uni-tuebingen.de

1 Departamento de Prehistoria, Antropología e Historia Antigua, Campus de Guajara, Universidad de La Laguna, La Laguna 38071, Tenerife, Spain

2 Institute for Archaeological Sciences, University of Tübingen, Rümelinstr. 23, 72070 Tübingen, Germany

3 School of Anthropology, The University of Arizona, 1009 E. South Campus Dr, Tucson, AZ 85721, USA

4 Instituto Universitario de Bio-Orgánica Antonio González (IUBO), Avenida Astrofísico Francisco Sánchez, La Laguna 38206, Tenerife, Spain

Introduction

The essential goal of archaeological stratigraphic analysis is to identify individual archaeological contexts and understand their chronological relationships. In practice, this goal is not always achieved. Archaeologists and paleoanthropologists working on Pleistocene sites typically struggle with chronology, in particular issues of precision. As sites become older, absolute ages obtained using radiometric dating methods exhibit error ranges spanning several centuries or even millennia. Statistical tools, such as Bayesian analyses, can be employed to minimize some of these uncertainties (Millard 2004; Ramsey 2006, 2009); however, the outcomes of Bayesian analyses are strongly dependent on a thorough and often high-resolution understanding of site formation processes. In prehistoric and historic sites alike, it is often difficult to verify that dated materials (such as charcoal, shell, bone, ceramic, or sediment) were recovered from primary depositional positions, which adds further uncertainty to the resulting age and limits statistical manipulation. Besides dating issues, the palimpsest effect (sensu Binford 1981), present in the majority of archaeological sites to different degrees (Bailey 2007), represents an added obstacle to the sequential reconstruction of past human activities using the archaeological material record (Bailey and Galanidou 2009; Henry 2012; Hosfield 2005; Malinsky-Buller et al. 2011; Sullivan 2008; Vaquero 2008).

Published online: 05 November 2015

Archaeologists thus faced with the dual and interconnected challenges posed by broad uncertainties in dating and the presence of palimpsests generally approach the development of a relative chronological framework using geostratigraphy. That is, the temporal relationships between archaeological remains are understood based on the relative positions of their encasing sedimentary layers. This approach is especially prevalent in prehistoric sites, where it is warranted because archaeological remains seldom exhibit discrete and laterally continuous distributions; instead, they are frequently scattered within a sedimentary mass from which it is difficult to determine the position of primary occupation surfaces. Thus, we compare two successive layers from an evolutionary perspective; we seek differences between layers that might correlate with archaeologically meaningful change; and we isolate archaeological assemblages by layers. In this framework, identifying stratigraphic contacts—which mark the boundaries between sedimentary layers (Table 1)—becomes an important stage of archaeological fieldwork.

The practice of using stratigraphic contacts to subdivide archaeological assemblages is not without criticism. Dibble et al. (2005) argue that this approach may lead to interpretive error because in many cases, visible stratigraphic contacts reflect geogenic processes largely disconnected from human activity. In addition, visible sedimentary strata can form in sites as a result of both depositional and post-depositional processes. Unfortunately, while some excavators correctly identify the difference between depositional and post-depositional strata in the field, these distinctions are more frequently made by geoarchaeologists. Depending on the complexity of the site

Table 1 Definitions of terms used throughout the text

Sediment (n.)	Natural or anthropogenic material broken down by weathering, erosion, or burning and (re)deposited by gravity, water, wind, ice, or animals on a surface
Stratum (n.)	Layer of sedimentary material with internally consistent characteristics (e.g., texture, color, cohesion) that distinguish it from other layers. *Stratigraphic*: Relating to entities within a sequence of strata
Conformity (n.)	Transition between two strata that are parallel to each other without interruption and belonging to the same style of sedimentation
Unconformity (n.)	A missing interval in the sedimentary record of time and produced either by an interruption in deposition or by the erosion of conformable strata followed by renewed deposition of sedimentary material with different characteristics than before
Depositional (adj.)	Relating to deposition or accumulation of sediment on a surface
Post-depositional (adj.)	Relating to processes or events occurring *after* deposition. These can be physical or chemical in nature.
Horizon (n.)	A broadly horizontal unit of sediment defined based on its sedimentary (*geological horizon*), pedological (*soil horizon*), or archaeological (*archaeological horizon*) characteristics
Soil horizon	A type of stratum in which the distinguishing textural, compositional or structural characteristics arise from post-depositional processes. Horizons are typically oriented parallel to the ground or weathering surface
Abrupt conformable contact	Sudden, distinct lithological change between two conformable layers, usually expressed as well-defined, linear stratification planes or zones or mixed elements from below and above
Gradational conformable contact	Progressive lithological change, often subtle and difficult to identify. It is expressed as either progressive lithological change or intercalations of the over- and underlying lithologies
Unconformable contact	Lithological change reflecting a great amount of time and associated with erosion, soil formation, or significant change in the sedimentary environment. In geology, unconformities are further subdivided into (1) *angular unconformities*, with over and underlying beds dipping at different angles, (2) *disconformities*, with parallel beds separated by an erosional surface or paleosol, (3) *paraconformities*, lacking signs of erosion but consisting in parallel beds with a temporal gap in between (as determined by dating or paleontological evidence), and (4) *nonconformities*, expressing major erosion followed by high-order lithological change (i.e., from igneous or metamorphic to sedimentary lithology)
Hiatus; stasis (n.)	Period of time in which there is a break or interruption in sedimentation. Weathering may or may not occur during a sedimentary hiatus (Farrand 2001).
Micro-	Of a size not visible without the aid of a microscope
Facies[a] (n.)	The term "facies" originally meant the lateral change in lithologic aspect of a stratigraphic unit. Its meaning has been broadened to express a wide range of geologic concepts: environment of deposition, lithologic composition, geographic, climatic or tectonic association, etc.
Interfacies (adj.)	Occurring between and related to multiple stratigraphic units (e.g., an interfacies event). In Spanish, the term interfacies is a noun (*las interfacies*). In archaeological stratigraphy, an *interface* (n.) may simply refer to the dividing line between deposits (Harris 1989), which is normally equivalent to a stratigraphic contact in the geological sense

[a] According to the ICS Stratigraphic Guide: http://www.stratigraphy.org/index.php/ics-stratigraphicguide

formation processes, identifications may come long after excavations have ceased. Therefore, many systems of excavation and analysis account for the disconnect between visible sedimentary changes that guide excavations and those stratigraphic units that are relevant to reconstructing human activities.

Current archaeological field methods vary according to site type, site age, location, and time constraints. As outlined in Table 2, different excavation systems utilize different strategies for identifying visible changes in sedimentary characteristics and incorporating these observations into named or numbered stratigraphic units (strata) and their contacts. The different methods of excavation can be broadly grouped into those that remove sediment in packages defined by sedimentary characteristics, those that remove sediment in arbitrary spits, and those that combine both strategies. Many systems also employ post-excavation spatial analysis of artifact assemblages to overcome or minimize the limitations of field observation. For instance, in the "Corinth System," the broadly horizontal units of excavation, termed *baskets*, are the primary units of provenience for most archaeological materials (Williams, unpublished). Strata are also defined during or following excavation, and multiple baskets may be combined into a single stratum. Analyses of the archaeological materials, grouped foremost by *basket*, typically proceed by strata. This system allows for redefinition of strata—perhaps as a result of a more nuanced understanding of site formation processes—and therefore regrouping of archaeological materials during later stages of analysis.

In both of the systems common to Paleolithic excavations ("arbitrary spits" and "natural stratigraphy"), findings are normally piece plotted, and post-excavation artifact distributions or additional grouping variables such as archaeological horizons can be used to define analytical units independent of geogenic stratigraphic contacts (e.g., Dibble et al. 2005). Nonetheless, the older practice of using sedimentary strata visible in the field as the smallest analytical units is still widespread, and researchers often compare groups of materials from different geogenic layers hoping to identify changes in the use of activity areas, subsistence strategies, settlement patterns, technology, and other such aspects of human culture. In our opinion, this practice may contribute to common difficulties in identifying cultural transitions in stratified sites and correlating them with broader "technocomplex" successions. Nevertheless, subdividing a lithic assemblage by strata can be done effectively when knowledge of site formation processes is used (e.g., Porraz et al. 2013), particularly when the geoarchaeological component of the project includes a microstratigraphic approach (e.g., Miller et al. 2013).

The microstratigraphic approach, widely demonstrated to be an important aid to interpreting the past, is geoarchaeology conducted at millimeter to centimeter scales (Fig. 1). Its practitioners pursue the same goals as their colleagues working at site and landscape scales (i.e., reconstruction of site formation processes, paleoenvironments, and human activities). Geoarchaeologists, either working alone or in collaboration with others, increasingly employ a number of techniques borrowed from the geosciences, chemistry, and botany and apply them to microstratigraphic investigation. These techniques include micromorphology, elemental analysis, mineralogy, phytolith analysis, and lipid analysis. Coupling multiple techniques yields especially robust datasets. This strategy has been applied to numerous archaeological sites of different nature and age, from Pleistocene open air hominin sites (e.g., Albert et al. 2009; Ashley and Driese 2002; Bamford et al. 2008; Liutkus and Ashley 2003; Macphail 1999; Mallol 2006) to Holocene urban settings (e.g., Macphail et al. 2003, 2007a, b; Milek and Roberts 2013; Nicosia et al. 2012; Shillito et al. 2011; Shillito 2011).

Each of these studies have provided significant information about the nature and degree of integrity of geogenic, biogenic, and anthropogenic components (sensu Farrand 2001) of archaeological deposits. Some notable works have yielded data that are integral to the current understanding of particular sites. For instance, interdisciplinary microstratigraphic analyses at the Levantine Middle Paleolithic site of Kebara Cave (Albert et al. 2012; Berna and Goldberg 2007; Goldberg et al. 2007; Meignen et al. 2007; Schiegl et al. 1994, 1996; Weiner et al. 1993, 2007) provided detailed knowledge about diagenetic alteration of the deposits and their components, as well as information about different aspects of Neanderthal pyrotechnology. At Tel Dor, a Bronze and Iron Age urban site in Israel, a team of geoarchaeologists, botanists, and chemists employed integrated microstratigraphic analyses to reconstruct the formation processes of floors, walls, building fill, and pits, as well as the primary and post-depositional impacts of fire on anthropogenic sediments (Albert et al. 2008; Berna et al. 2007; Chu et al. 2008; Eliyahu-Behar et al. 2008; Shahack-Gross et al. 2005).

Interestingly, a frequent outcome of microstratigraphic study is that certain sedimentary aspects of sites become significantly more complex than they initially seemed in the field. For example, high-resolution studies might reveal that seemingly sterile layers contain archaeological material, massive deposits conceal substantial microstratification, and visible stratigraphic contacts might be archaeologically irrelevant. These findings do not imply that field observations are incorrect, but they do not give us the entire story. Here, we present a series of examples to illustrate the diversity of information that can be brought to light using microstratigraphic investigations. These examples can be used as cues for archaeological research design and field strategy planning or adjustment, as well as for avenues of hypothesis testing.

Table 2 Examples of different excavation strategies employed on archaeological sites

Excavation system	Frequent applications	Horizontal units of excavation, defining characteristics	Relationship to archaeological materials	Relationship to strata	References
Corinth system	Classical Greek sites and other locations within the Mediterranean; typically large, open-air sites with abundant architectural features	"*Baskets*[a]," variable volumetric units defined by excavators on the basis of characteristics such as sediment color and texture. Nomenclature based on notebook numbers	Most types of materials—recovered during excavation, screening, or floatation—are grouped by *basket*. Significant finds may receive 3-dimensional coordinates in addition to *basket* associations	Strata are identified, generally by trench supervisors, based on sedimentary characteristics following excavation (from profiles). A single stratum may have been excavated as either a single *basket* or multiple *baskets*	Williams (unpublished)
Arbitrary spits	Paleolithic, African Stone Age, Australian Pleistocene, and North and South American Paleoindian caves, rockshelters, and open air sites	"*Spits*," standardized units of volume, typically 25 cm× 25 cm×5 cm; nomenclature typically follows the grid system and elevations or "*Buckets*," standardized units of volume (a full bucket) recovered in 25 cm×25 cm areas; nomenclature based on the grid system Subdivision of these units is possible when sediment characteristics change dramatically.	Variable. Some projects record 3-dimensional coordinates for all materials recovered during excavation, while materials recovered in the screen or float are grouped by spit/bucket. Other projects record coordinates on certain materials. Still other projects do not record coordinates for any materials	Strata are identified, often in consultation with a geologist, independently of excavation units based on sedimentary characteristics described during excavation and following excavation (from profiles). *Spits*/*buckets* are associated with strata during the analytical phase	Dibble et al. (2005)
Single context	Archaeological sites of all time periods excavated by British teams, primarily in Europe, North Africa, and Southwest Asia	"*Contexts*," variable volumetric units or features defined based on physical characteristics (generally color, texture, and/or inclusions), although cuts also receive context numbers	Variable. Some projects record 3-dimensional coordinates for "small finds" and all other materials are collected by context (stratigraphic unit) or soil sample. The volumes of contexts are often recorded to aid in calculation of artifact abundance	Strata and contexts are synonymous although multiple contexts can be combined into a single stratum during analysis or following production of a Harris matrix	Barker (1993), Museum of London (1994)
Natural stratigraphy, *décapage*, French method	Paleolithic and Stone Age caves, rockshelters, and open air sites; North America	"*Stratigraphic layers*, *stratigraphic units*, or *geological horizons*" variable volumetric units defined based on sedimentary characteristics observed during excavation; nomenclature is also variable and can be numerical/alphabetical from the surface downwards or bedrock upwards, abbreviations based on characteristics (such as color, e.g., Wadley and Jacobs 2006: Table 2), arbitrary names (such as people, e.g., Parkington 1976), or a combination thereof (such as alphabetical people names Texier et al. 2010: Fig. 2)	Variable. Some projects record 3-dimensional coordinates for all materials recovered during excavation, while materials recovered in the screen or float are grouped by spit/bucket or layer/unit/horizon. Other projects record coordinates on certain materials. Still other projects do not record coordinates for any materials. Archaeological provenience may include, in addition to the groupings mentioned above, feature numbers, or archaeological horizon (see Conard, this volume)	The excavation units, identified by excavators, are typically equal to strata, although multiple units may be later combined into single stratum	Browman and Givens (1996)
Wheeler-Kenyon method	Open air sites with architectural features, tells	"*Units*," variable volumetric units defined by excavators on the basis of characteristics such as sediment color and texture	Most types of materials—recovered during excavation, screening, or floatation—are grouped by *unit*. Significant finds may receive	*Units* and strata are synonymous. As in its Paleolithic counterpart, the Wheeler-Kenyon method allows for multiple units to be combined into single strata at a later point, often	Chapman (1986), Dever (1974), Wheeler (1954)

Table 2 (continued)

Excavation system	Frequent applications	Horizontal units of excavation, defining characteristics	Relationship to archaeological materials	Relationship to strata	References
			3-dimensional coordinates in addition to *unit* associations	in conjunction with characteristics observed in the baulks that subdivide the site	
Locus-to-stratum method, Israeli method	Open air sites with architectural features, tells	"*Loci*," variable volumetric units defined by excavators on the basis of characteristics such as sediment color and texture. Can be subdivided into *baskets*, which are roughly equivalent to a portion of a locus that can be excavated in a single work day	Most types of materials—recovered during excavation, screening, or flotation—are grouped by both *locus* and *basket* or *unit*. Significant finds may receive 3-dimensional coordinates in addition to *locus/basket/unit* associations	*Loci* and strata can be synonymous. A single stratum may have been excavated as either a single *locus* and multiple *baskets* or multiple *loci* and *baskets*. In the latter case, a single stratum may denote one occupation phase	Aharoni (1973), Chapman (1986), Wright (1966)

This list is not exhaustive but is meant to illustrate a range of approaches to excavating, in particular, roughly horizontal units of sediment (as opposed to features). Some projects utilize multiple approaches for different areas of a site or to obtain data at different scales. Many of these systems employ very similar strategies but differ in their terminology. Selected references either present these methods or discuss them in more detail

[a] Named after the baskets used to remove sediment from sites. This term was originally associated with a quasi-standardized volume of sediment

The nature of stratigraphic contacts

In geology, stratigraphic contacts can be conformable or unconformable, with the former ranging in expression from abrupt to gradational (Fig. 2 and also Table 1). Formal geological definitions of stratigraphic contacts refer to changes in rock types on a large (geologic) time scale. Instead, in archaeological sites, both the encasing sedimentary bodies and their contacts can be geogenic, pedogenic, biogenic, or anthropogenic in origin (see Fig. 2d–f), and stratigraphic units represent exceptionally short periods of time. Although archaeologists employ stratigraphic principles developed in geology, such as the principle of superposition (Steno 1669), terminology specific to the field of archaeology can vary according to the excavation and analytical systems employed at a site. In systems that rely heavily on Harris matrices, for example the "single context" system (see Table 2), stratigraphic contacts are termed "interfaces" (see also Brown and Harris 1993; Harris 1989). Archaeologists using other systems may conceptualize them as unit, layer, or horizon boundaries (see Table 2). Nevertheless, the basic principle remains the same: stratigraphic units and their contacts reflect particular depositional and post-depositional events that are relevant to understanding the position of archaeological materials within the sequence. Therefore, one of the most important aspects of the study of stratigraphic contacts is their identification as depositional or post-depositional in origin.

Contacts, interfaces, and primary depositional processes

Depositional contacts mark interruptions in sedimentation, discrete depositional events, or significant changes in the composition of the sediment source. In the former case when sedimentation is renewed following erosion or stasis (see Table 1), a depositional contact is formed. The identification of depositional contacts is an important element of archaeological analysis because these types of contacts can coincide with the upper portions of sedimentary deposits or formerly exposed surfaces (paleosurfaces). Logically, human occupation takes place on a stable surface in the interval between two deposits. Thus, archaeological living floors are positioned on natural paleosurfaces except in cases in which building or preparing the floor involved earthworks or another modification of the natural substrate.

Primary anthropogenic accumulations ought to be found either at or slightly below depositional contacts (David et al. 1973; Gé et al. 1993). Experimental studies indicate that the ground beneath an occupation floor can serve as a sink for microscopic anthropogenic debris (Gifford-Gonzalez et al. 1985; Nielsen 1991; Villa and Courtin 1983). Also, the sedimentary substrate may be modified microstructurally by trampling or be diagenetically altered by the addition of chemicals derived from human activity.

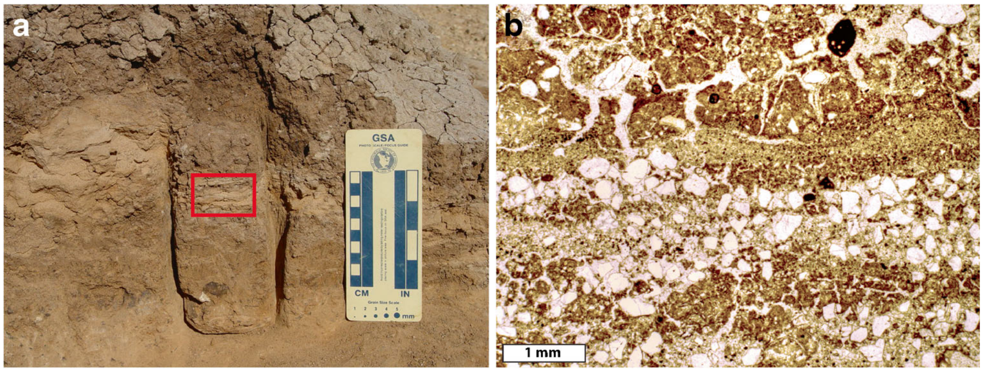


Fig. 1 Often, sedimentary layers that appear massive and homogeneous in the field contain stratification visible only at microscopic scales of observation. **a** Field view of a sediment block carved into a profile during micromorphological sampling from Bizat Ruhama, a Lower Pleistocene site located in Israel. The pale brown sandy lens framed in the *red box*, which appeared massive in the field, showed complex microstratification when viewed at magnification. **b** The sandy lens at ×2 magnification. The microlaminations formed when different beds of well-sorted aeolian sand were redeposited by low energy runoff. Image in plane-polarized light (PPL)

An approach to corroborating the primary depositional nature of archaeological assemblages found at or near contacts is to carry out microstratigraphic analysis of the sediment using a range of different high-resolution techniques. For example, ongoing biomarker research aimed at the reconstruction of Neanderthal living contexts has yielded a positive identification of coprostanol, the human fecal biomarker, in sediment from the top of one of the facies of El Salt stratum X (Sistiaga et al. 2014). Further micromorphological investigations will test for the presence of trampling features in that same unit.

Microscopic evidence for human trampling of sedimentary surfaces include microstructural features such as compaction, fissuring, and development of granular aggregates and in situ breakage of brittle materials such as charcoal or bone. Cases of trampling have been identified in prehistoric contexts of varied age (e.g., Dibble et al. 2009; Gé et al. 1993; Goldberg et al. 2009; Ismail-Meyer et al. 2013; Karkanas 2006; Miller et al. 2013; Zerboni 2011) and corroborated with experiments (Balbo et al. 2010; Banerjea 2011; Macphail et al. 2004; Miller et al. 2009; Rentzel and Narten 2000; Wallace 2003). Comparisons with these cases will be used in future work at El Salt.

In the same way that microstratigraphic analysis has the potential to aid in the identification of depositional contacts that coincide with ancient living floors, it can be used to document hiatuses or changes in sedimentation that have little archaeological significance. For example, our micromorphological and geochemical analyses at Obi-Rahkmat, a Middle Paleolithic rock shelter site in Uzbekistan, showed that a large portion of the sequence is associated with a cyclical style of sedimentation involving primary freshwater spring carbonate precipitation and local reworking of fresh tufa fragments (Mallol et al. 2009). Lithic artifacts and bone remains from concomitant human occupation of this environment were first locally translocated and redeposited via water from the spring, and then were activity and subsequently cryoturbated. This dynamic fluvial sedimentation regime produced visible sharp, subhorizontal contacts (Fig. 3) containing archaeological remains in secondary position.

In Obi-Rakhmat, the contacts visible in the field mark the boundaries between different strata and were used by researchers to separate different archaeological assemblages. It is now safe to assert that these assemblage divisions are not significant for reconstructing hominin behavior or cultural change at the site, since the remains are in secondary position. Furthermore, given the possibly seasonal nature of the deposition, the human occupations documented in this part of the sequence might represent a relatively narrow timeframe, and the remains recovered from different layers might actually derive from a single primary source. Accordingly, post-excavation analyses of the remains showed that subsets of the lithic and faunal assemblages are fairly homogenous when compared across strata (Derevianko et al. 2001, 2004).

In this example, microstratigraphic analysis provided the necessary information that enabled us to move away from comparisons between geogenic layers and instead turn to other areas of the rock shelter in search for primary occupation contexts. The depositional contacts, although abrupt, do not represent living floors or long hiatuses in sedimentation that might relate to site abandonment.

Other visible stratigraphic contacts related to primary geogenic deposition are relevant to understanding human behavior at a site. At the previously mentioned Middle Paleolithic rockshelter site of El Salt (Alicante, Spain), there is a sharp contrast between the top and bottom portions of the stratified deposit (Fig. 4). An ongoing microstratigraphic study (Mallol, in preparation) reveals that the bottom portion (sedimentary strata XII–VI) comprises a mildly phosphatized detrital, gravitational deposit derived from three main sources: (1) breakdown of the limestone bedrock; (2) breakdown of

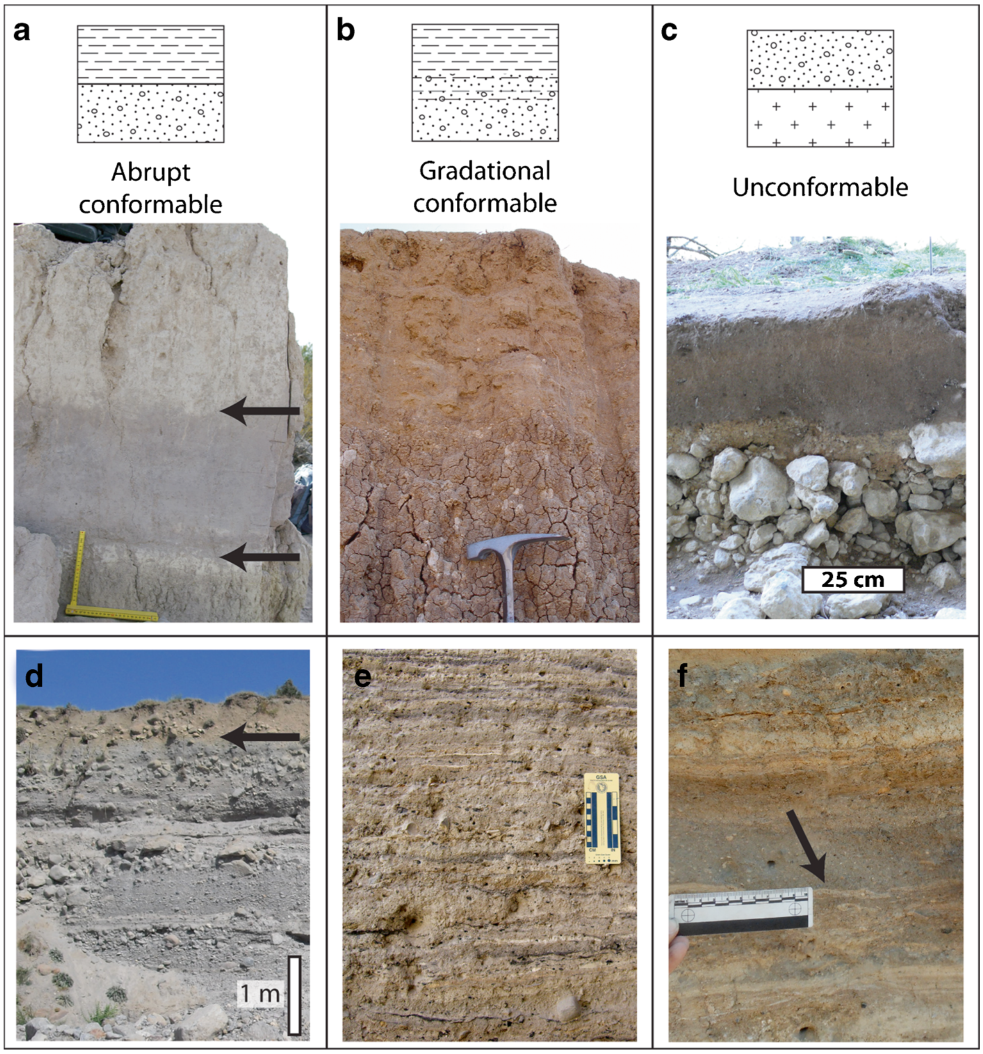


Fig. 2 Example of different types of stratigraphic contacts that are visible at the site scale in both geogenic (**a**-**d**) and anthropogenic sediments (**e**-**f**) (see Table 1 for definitions). **a** Abrupt conformable contact in geogenic sediment. Profile from a wetland deposit in El Fin del Mundo, a Late Pleistocene/Early Holocene Clovis site located in Mexico (Sanchez et al. 2014). The lower visible contact (*arrow*) formed as a result of a change in the bioproductivity and/or the seasonal exposure of a pond. The upper visible contact (*arrow*) formed when the chemical conditions within the wetland shifted. **b** Gradational conformable contact in geogenic sediment. Profile from Bizat Ruhama, a Lower Pleistocene site located in Israel. This contact formed as a result of progressive desiccation of a pond coupled with increasing contribution of aeolian sediment to the basin. These changes at the site scale were coincident with regional climatic change towards dry conditions. **c** Unconformable contact in geogenic sediment. Profile from Abric del Pastor, a Middle Paleolithic site located in Spain. The abrupt contact between the lower blocky deposit and the upper fine-grained, dark gray deposit separates the Pleistocene and Holocene portions of the sequence. The Pleistocene deposit was formed through successive episodes of roof spall (the cave roof is composed of Miocene conglomerate), while the Holocene deposit contains sheep dung reworked by bioturbation. **d** A sharp contact (*arrow*) in geogenic sediment that formed as a result of post-depositional weathering processes. The contact marks the base of a sub-surface soil horizon formed on a sequence of colluvial strata. Non-archaeological deposits of Holocene age, central Turkey. **e** "Conformable" contacts between strata of anthropogenic origin. The discrete layers are composed of domestic refuse. The entire sequence formed as a result of many individual dumping events. Neolithic midden from Aşıklı Höyük, Turkey. **f** "Unconformable" contact between strata of biogenic and anthropogenic origin. The sharp contact (*arrow*) marks the upper surface of an herbivore dung layer overlain by construction debris. Neolithic open space, Aşıklı Höyük, Turkey

tufa from a freshwater spring system that existed at the site throughout the Upper Pleistocene; and (3) organic debris sourced from surrounding plants and incipient soil formation. In contrast, the top portion (stratum V), which is separated from the underlying deposit by an abrupt depositional contact, is a calcareous, largely inorganic, aeolian deposit consisting of diffusely bedded strata and microstrata.

In accordance with the absolute dates obtained for the base of stratum V, which coincide with the global cooling of Heinrich Event 5 at 47 ka cal BP (Galván et al. 2014), our

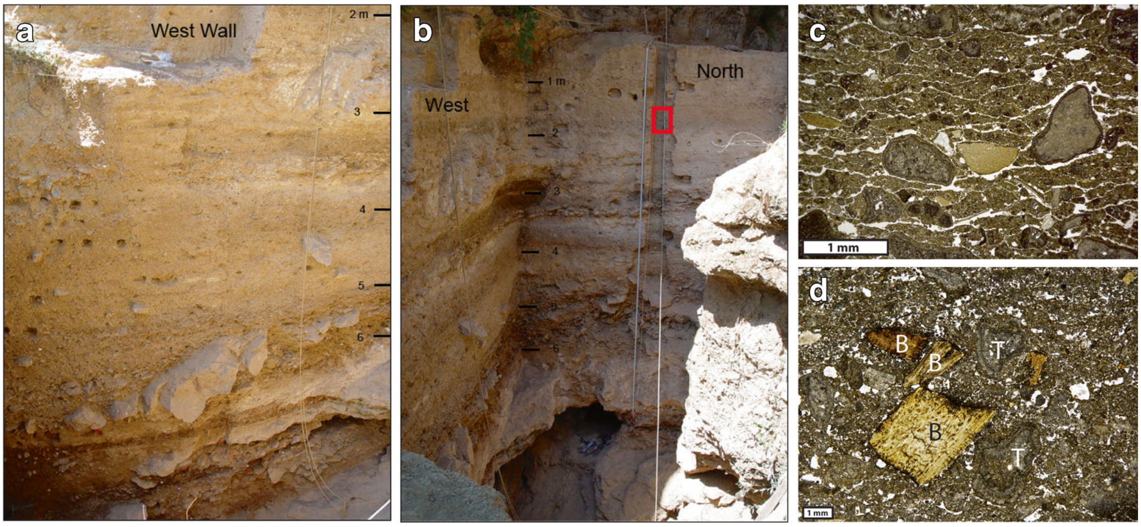


Fig. 3 Stratigraphic contacts between depositional units that are unrelated to archaeological stratigraphy. **a** The west wall of the main excavation from the Middle Paleolithic rock shelter site of Obi-Rahkmat (Uzbekistan). Note the division of the stratigraphic sequence into subhorizontal units; some are more readily visible than others. This division was made primarily on the basis of sediment color, texture, and degree of cementation. **b** The north wall of the main excavation area. Microstratigraphic analysis of the sequence showed that units 1 through 14 involved cyclical freshwater spring sedimentation with formation, breakdown, and local redeposition of tufa clasts and subsequent cryoturbation. In this case, the archaeological units, which were delimited based on visible geostratigraphic contacts, do not represent primary human occupations but locally reworked materials. The macro-scale differences between individual geostratigraphic units mainly reflect changes in the depositional regime of the spring. The *red box* indicates the location of samples illustrated in **c**–**d.** **c** Micrograph from the upper portion of the spring deposit illustrating a lenticular microstructure indicative of post-depositional freezing and thawing. PPL. **d** Bone in secondary position (*B*) and fragments of reworked tufaceous material (*T*) embedded in variably cemented clotted calcite. PPL.

working hypothesis is that the change in sedimentation marked by the abrupt contact between strata V and VI reflects a climatic shift towards dry, locally windy conditions. This change in depositional regime at the site has archaeologically relevant implications. The base of stratum V yielded significantly fewer remains when compared with all of the underlying units. The middle of stratum V, which is composed of well-sorted, fine aeolian sand, is archaeologically sterile. The top of the stratum yielded scattered lithics ascribed to an Upper Paleolithic technocomplex (Galván et al. 2014). Hence, the geogenic sediments that comprise the base of stratum V enclose anthropogenic materials associated with the latest Middle Paleolithic of the region. Sedimentation continued during a period of abandonment coincident with a cold climate, and subsequent Upper Paleolithic human occupation occurred during a period of decreasing aeolian input. Although the entire stratum exhibits uniform sedimentary characteristics and was deposited as a result of aeolian inputs to the site, the archaeological materials contained within derive from multiple occupations of the site. These data are contributing to ongoing debates regarding the nature of the Middle-to-Upper Paleolithic in Iberia.

This type of positive relationship between geostratigraphic contacts and human behavioral change is a common outcome of geoarchaeological studies. It is not surprising that changes in the sedimentary environment reflect climate changes, which are important factors that influenced human behavior. Nonetheless, the exact nature of geogenic processes is often not perceptible at a macroscopic scale, a caveat that necessitates high-resolution investigations such as those carried out at El Salt and a growing number of other sites.

In anthropogenic depositional settings, the contacts between major and minor sedimentary units can be conformable or unconformable, and these distinctions may be key to reconstructing shifts in human activity. In these cases, microstratigraphic study can help determine whether differences in sedimentary composition, fabric, or texture between individual units mark continuity or change in depositional mode. At the Upper Paleolithic site of Üçağızlı Cave I (Turkey), primary ash deposits formed from the complete combustion of wood are overlain by dumped ash layers sourced from rake-out activity (Goldberg 2003; Mentzer 2011). In this example, both sedimentary units are composed of ash, but microscopic fabric elements such as differences in porosity reveal that the depositional mechanisms are different. The unconformable contact thus marks a shift in the space from a zone of primary human activity to that of secondary deposition. The length of time between activities in this case is not known but could be short. In Fig. 5 (see also Fig. 2e), midden layers in the Neolithic site of Aşıklı Höyük (Turkey) vary in composition but not depositional mode. Here, a basal unit of degraded construction materials is overlain by a unit of

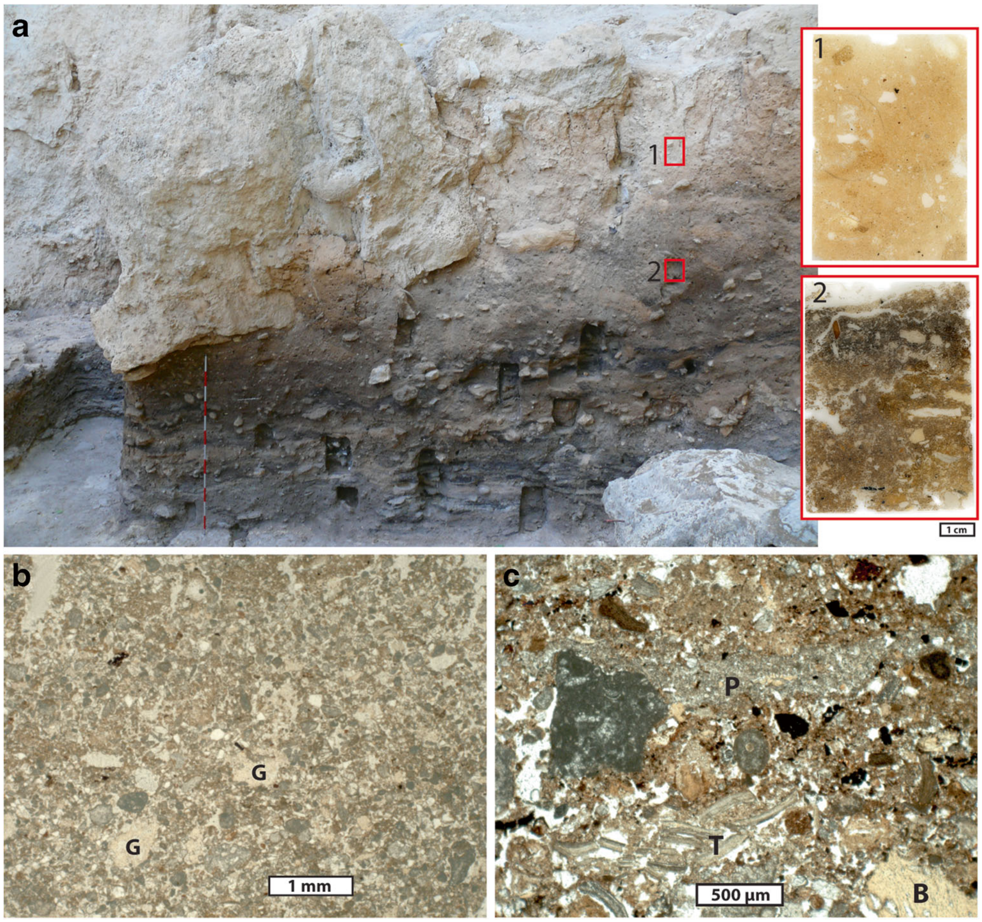


Fig. 4 Contacts that originate from geogenic depositional processes that are relevant to human activity at the site. **a** General field view of the El Salt excavation in 2008. Note the sharp contrast between the basal dark (strata VI–XII) and overlying light (stratum V) portions of the site's sequence and the large block at the left corner of the deposit, which fell before the onset of stratum V sedimentation. In this area of the excavations, the contact between V and VI is gradational. Two thin sections (*1*) and (*2*) were produced from this sequence. **b** Micrograph showing the inorganic, calcitic, sandy nature of stratum V. The yellow grains (*G*) are phosphatic, possibly bird guano residues. **c** Micrograph showing the organic-rich composition of stratum VIII, which is representative of strata VI–XII from this site. Microscopic observation allowed identification of a wide variety of components, including phytolith lamina (*P*) representing decayed plant beds, bone fragments (*B*), and trampled plant residues (*T*). Micrographs in PPL

mixed anthropogenic debris that is consistent in composition with floor sweepings and other domestic refuse. The contact between the two units is sharp. Other examples of conformable contacts in anthropogenic settings include those between individual deposits in loaded and zoned fills that comprise the Late Holocene monumental earthen mounds of North America (Sherwood and Kidder 2011). In these cases (e.g., Sherwood and Kidder 2011: Fig. 13), dumped deposits may vary in color and texture, yet the overall mode of deposition remains constant.

Contacts, interfaces, and post-depositional processes

As any excavator familiar with modern ground surfaces knows, visible stratigraphic contacts can result from post-depositional processes. Depending on their environmental and archaeological setting, post-depositional processes can generate soil horizons, zones of chemical diagenesis or cementation, zones of variable groundwater saturation, and alteration contacts of anthropogenic origin. The associated weathering features can yield abrupt and significant changes in sediment composition, color, and texture; their boundaries can be quite distinctive and may be used by archaeologists to define stratigraphic units during excavation. Only after careful study can the relationship between visible sedimentary changes of post-depositional origin and archaeological assemblages be understood.

The most common types of post-depositional stratigraphic contacts that form in archaeological sites are soil horizons. Soil horizons are typically associated with the present-day ground surfaces in open-air sites, but they may also be encountered at significant depths depending on the intensity of weathering processes or the presence of buried landscapes. An example of soil horizons that were initially incorporated into

Fig. 5 Contacts that result from anthropogenic depositional processes. **a** View of a micromorphology sample in a midden feature at Aşıklı Höyük, Turkey. The middens in this site are composed of decimeter to millimeter scale horizontal layers of dumped anthropogenic debris interbedded with occasional deposits related to primary activities. A thin section (from the *red box*, and visible on the *right*) targeted a visible stratigraphic contact (*arrow*). **b** Under magnification, the contact is sharp and marks the boundary between a lower unit composed of degraded construction materials and an upper unit composed of domestic refuse. The lower unit contains abundant rounded fragments of *kerpiç* (*k*), a material that was used to produce an array of architectural elements, including mud bricks. The upper unit contains abundant burned materials, as well as fragments of bone (*b*), charcoal (*ch*), and *Celtis* sp. endocarps. PPL **c** The fine matrix of the debris layer contains abundant ashes (*a*), here concentrated in the pores of the fragment of spongy bone (*b*) pictured in (**b**) and aggregates of burned dung (*d*). This composition is very similar to primary occupation debris located on top of floors in residential structures, and this layer could thus be derived from building maintenance activities. Cross-polarized light (XPL)

archaeological assemblage groupings comes from the Iron Age deposits in the Greek ritual site of Mt. Lykaion. During excavation of the open-air "Ash Altar to Zeus," differences in sediment color and texture prompted separate collection of archaeological materials associated with a surface layer of black sediment, a buried lens of limestone gravel, and an underlying layer of silty gray sediment (Fig. 6).

Subsequent microstratigraphic analyses revealed that portions of the visible stratigraphy resulted from the post-depositional formation of a soil within the ritual deposit (Mentzer et al. 2015). The uppermost black layer and underlying concentration of gravel contain microscopic features consistent with post-depositional decalcification. In contrast, the underlying gray sediments are located beneath the surficial weathering zone and are rich in calcareous materials including wood ashes and limestone fragments. Therefore, the visible stratigraphic contacts in this portion of the sequence mark the gradational boundary between the surface soil horizon (A horizon) and the underlying subsurface horizon (B horizon). Based on these observations, it is advisable that archaeological materials recovered from the three "layers," better termed "sedimentary bodies," be analyzed as a single group. Indeed, analysis of the *baskets* from each of the three sedimentary bodies yielded similar assemblages of burned animal bone and ceramics dating to the same period (Romano and Voyatzis 2014).

In caves and rockshelters, typical soil horizons may be absent. However, weathering processes that occur near the ground surface do impact cave and rockshelter sediments, and the types of weathering and their expression in the field

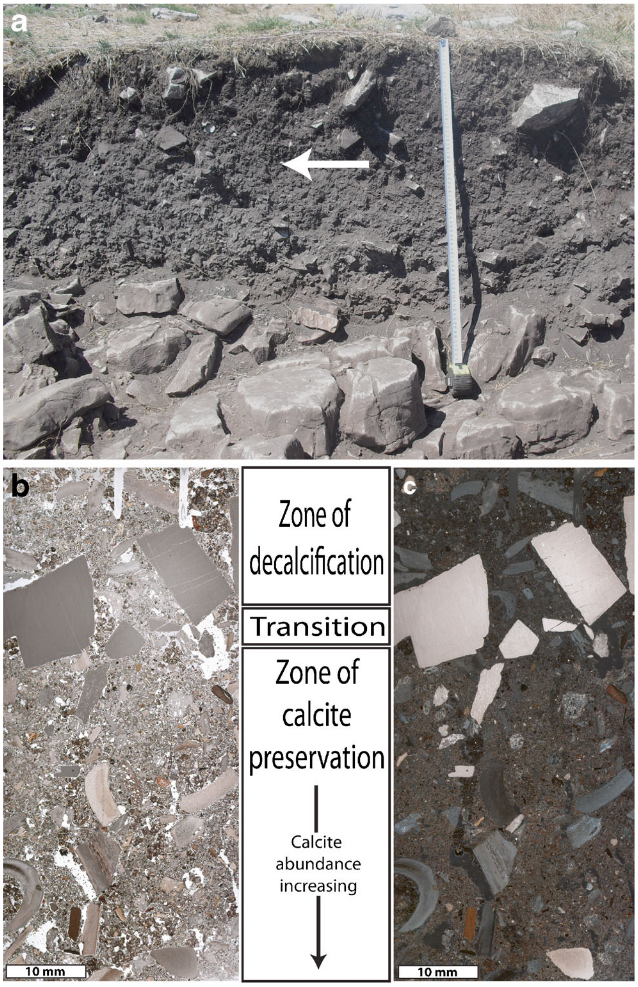


Fig. 6 Contacts that form as a result of soil formation. **a** Formation of a surface soil horizon within the "Ash Altar to Zeus" on Mt. Lykaion (Greece) resulted in a decalcified zone that was included in the stratigraphic sequence. Field photograph of a stratigraphic profile with the lower boundary of the soil horizon indicated by an *arrow.* The depth of this boundary averages 20–30 cm from the ground surface and is marked by a shift in color of the fine sediment from *black* to *gray* and a concentration of gravel-sized fragments of limestone with powdery surfaces. During excavation, archaeological materials from the black sediment, the zone of limestone gravel, and the gray sediment beneath are collected separately. **b** Sediment in thin section associated with the boundary (field of view 3×6.5 cm). The upper 10 mm of the image corresponds to the black sediment. A portion of the limestone gravel layer is visible 10–35 mm from the *top* of the image. The gray sediment comprises the base of the image. PPL **c** Same view as **b**, XPL Under XPL, the presence and abundance of calcite in the sedimentary fine fraction is apparent. The source of this calcite is ashes. Ashes are absent in the black sediment and present in the gray sediment. Decalcification pedofeatures, including etched limestone fragment edges, are visible in the areas identified here as the "zone of decalcification" and the "transition." These observations indicate that the presence and absence of ash in the upper "Ash Altar" sediments are determined primarily by post-depositional weathering processes. Ashes were likely originally present at the ground surface and associated with archaeological materials recovered from this portion of the sequence

can be highly variable (Farrand 2001). For example, phosphatization is a common diagenetic process that has been widely documented in prehistoric sites using a variety of methods (e.g., Karkanas et al. 2000; Karkanas 2001).

At the Middle Paleolithic site of El Salt (Spain), archaeologists initially interpreted a zone of chemical diagenesis as a primary depositional layer. Stratum VIa (Fig. 7a, indicated by a red box) shows sharp upper and lower contacts and was described in the field as a dark brown lens within a massive sandy clay deposit. Fumanal (1994) interpreted this subunit as an organic-rich anthropogenic layer. However, recent micromorphological analysis of a sample from this location (Mallol, in preparation) shows that the VIa sediment is comprised of moderately weathered calcitic silty sand in a matrix of speckled phosphatic clay with abundant phosphatic grains. This subunit is different from the over- and underlying sediment, which exhibits the same basic lithological composition but contains relatively fresh calcitic elements and a calcitic matrix. Furthermore, the over- and underlying strata lack pedofeatures associated with weathering.

In this case, what appeared to the naked eye as a possible anthropogenic deposit—owing to its peculiar dark color—is instead the phosphatized upper portion of the underlying stratigraphic unit. Although the particular source and nature of the phosphate diagenesis remains unknown, no clear micromorphological markers of strong human impact (such as microstructures indicative of trampling or accumulations of microscopic bone, charcoal, and/or flint) have been identified.

The information provided by this microstratigraphic study has implications for both understanding the associated archaeological materials and future excavation strategies of Unit VIa at El Salt. First, its upper contact could represent a stable surface on which accumulation of phosphorous-rich material took place. Second, the position of its bottom contact seems to be arbitrary, conditioned by the extent of phosphate diagenesis downwards. Hence, any archaeological material imbedded in the altered layer possibly belongs to human occupation atop the aforementioned stable surface or others below it. Archaeological remains from a single occupation might randomly fall above and below the bottom contact, but this should not be a criterion to separate them into different assemblages.

Contacts that originate from post-depositional processes may also occur at depth within sites. In sequences impacted by fluctuations in the position of perched or true groundwater tables, portions of the deposit may develop redoximorphic features, becoming stained, gleyed, or both. For example, Stein (2008) provides a robust example of the impacts of subsurface groundwater on the composition of late Holocene shell midden deposits located on the Pacific coast of North America. In her study, Stein measured the abundance of

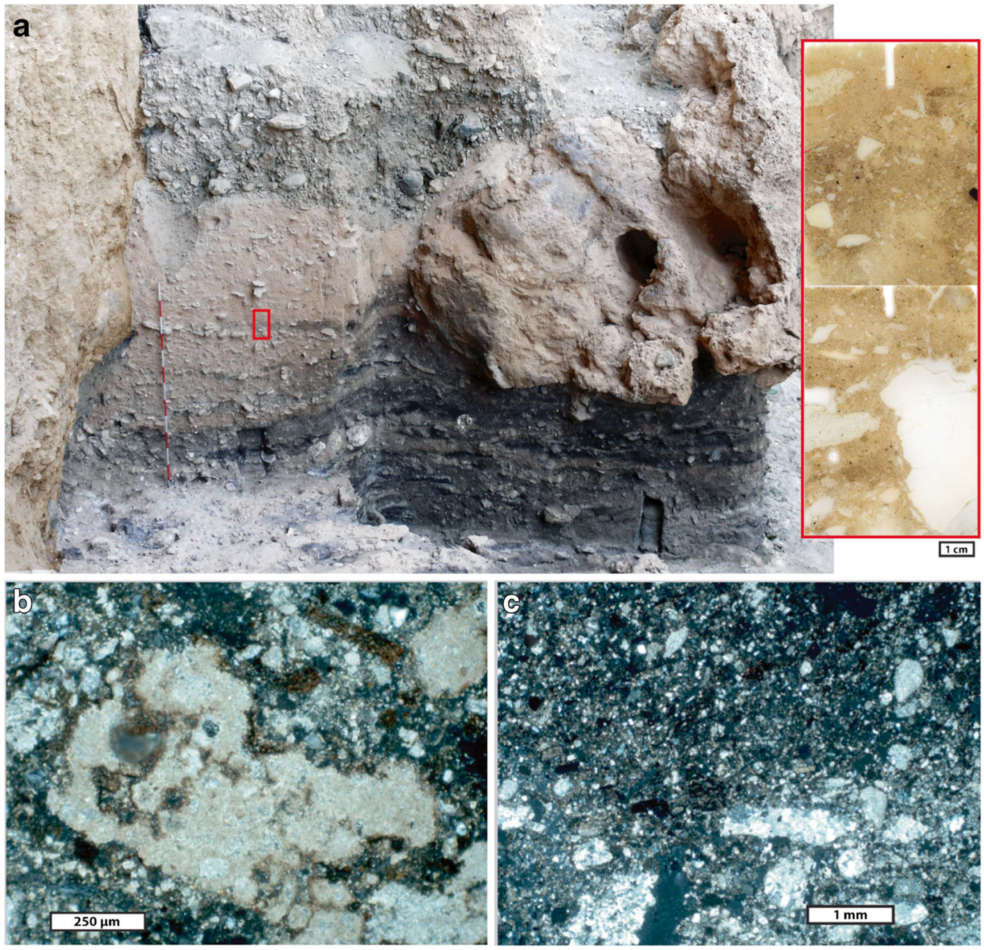


Fig. 7 Contacts that form as a result of chemical diagenesis in a sheltered environment. **a** Profile from El Salt (2012 season) showing unit VIa (*dark gray* layer at the position of the *red box*), bound by abrupt contacts and assumed to mark a change in deposition and the presence of an organic-rich anthropogenic layer. Micromorphological analysis of a sample from this lens (*red box* and corresponding thin sections to *the right*) shows that the VIa sediment is comprised of weathered tufa grains imbedded in phosphatic clay, with abundant phosphatic grains. **b** Weathered tufa grains (XPL). **c** Micrograph showing the bottom contact of the phosphatic lens. Note the presence of fresh calcitic grains in the underlying deposit. These grains are absent in the lens. XPL

calcium carbonate in the sediment and determined that a subsurface contact that was expressed in the field as a sharp and striking difference in sediment color formed as a result of post-depositional carbonate dissolution. Furthermore, she concluded that the practice of subdividing the archaeological materials recovered from the midden by their association with these layers was not warranted.

Groundwater processes can also result in chemical enrichment of sediment. For example, one of the layers in the Lower Paleolithic lakeshore site of ‘Ubeidiya, Israel is characterized in the field by a striking orange-brown color (Fig. 8). Iron impregnation features can be readily recognized at micro-scale using micromorphology (see also Mallol 2006). These features allow us to distinguish between post-depositional iron remobilization and a primary iron-rich deposit. Again, in such cases, caution must be taken in isolating archaeological assemblages based on the basal contacts of such layers, as the position of these basal contacts is governed by geogenic post-depositional processes.

Finally, post-depositional contacts can develop as a result of human activity. An example of this phenomenon comes from combustion structures in the previously mentioned Middle Paleolithic site of El Salt (Spain). In the field, excavators noted the distinct black layers that are present at the base of the (presumed) hearth features, and interpreted the levels of the abrupt lower contacts as the surfaces of former living floors (Fig. 9). This interpretation was based on a number of published studies that describe a typical combustion feature profile consisting of an altered substrate overlain first by black layers containing charcoal and second by white or gray layers containing ashes (e.g., Meignen et al. 2001, 2007). Thus, in the field, archaeological materials retrieved from the combustion features and their adjacent sediment were systematically separated into three different assemblages: (1) materials contained in the ash and black layers (thought to be related to anthropogenic combustion); (2) materials adjacent to the black layer (thought to be unrelated to combustion but contemporary with it); and (3) materials underlying the black layer (thought to be derived from human occupation preceding the other two assemblages).

Following excavation, a microstratigraphic study of experimental fires and of archaeological sediment from Unit X of this site showed that the black layers

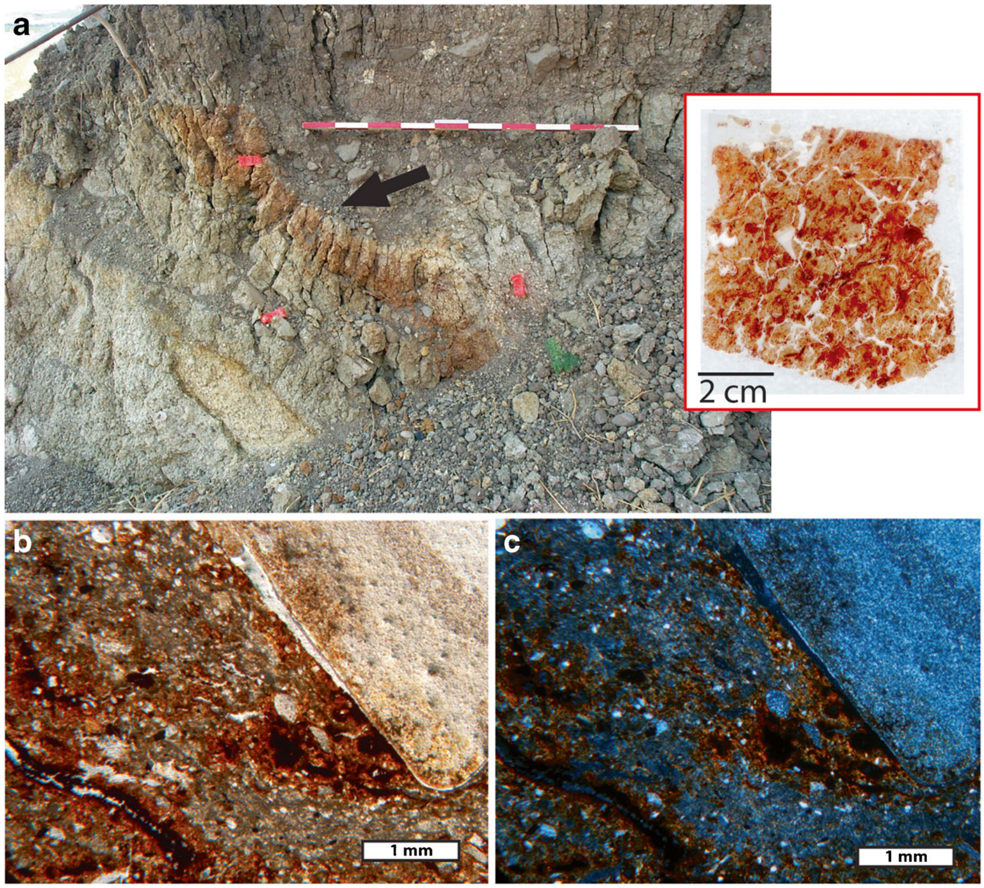


Fig. 8 Contacts that form beneath the surface as a result of groundwater processes. **a** Field view of a profile from the Lower Paleolithic site of 'Ubeidiya, Israel. Note the strong orange-brown color of layer III22b, indicated with the *arrow* and visible in the thin section scan (*right*). Micromorphological analysis of thin sections from this profile showed iron mottling and gley indicative of waterlogging. These features suggest the former presence of a temporarily waterlogged, depressed zone (backswamp or pond) in this part of the site. **b** Micrograph showing mobilized iron, particularly concentrated on fissure walls. The *pale gray color* of the clayey groundmass is characteristic of gleyed sediment, which results from loss of iron upon waterlogging. Note the presence of a flint object at the *top right* of the micrograph. View in PPL. **c** Same view as (*B*), XPL

probably represent the charred topsoil on which the fires were made (Mallol et al. 2013). Hence, the occupation floor was likely positioned at the top—not bottom—contact of the black layer. Subsequent three-dimensional mapping of the lithic and faunal remains grouped by their degree of thermal alteration and by their technological and taxonomic nature corroborates this result. The maps illustrate coherence between the lithic and faunal remains found in the black layer and those found in adjacent and underlying sediment and also a difference between those and the material found within the ash layer. In this case, the abrupt contact between the base of the black layer and the underlying sediment resulted from the effect of fire and cut (post-depositionally) across a single, older archaeological deposit.

Similar formation sequences were identified in a series of stacked combustion features from the Late Levantine Mousterian cave site of Üçağızlı II. In the field, interbedded black and white layers appeared consistent with couplets of charcoal and ash that have been identified in other Levantine sites (Fig. 10). Under magnification, the white layers contain laminated ashes and are structurally consistent with intact burned materials. In contrast, the black layers are composed of fragments of variably burnt bone mixed with other types of anthropogenic debris. Within the black layers, microscopic features indicative of post-depositional bioturbation, as well as inclusions of autochthonous detrital materials such as speleothem fragments, are suggestive of brief periods of anthropogenic debris accumulation and surficial weathering in between combustion events.

In the above examples which are drawn from our own research, as well as similar features reported by others (e.g., Friesem et al. 2014), the lateral extents of the anthropogenic alteration zones were limited. In contrast, microstratigraphic studies conducted at the Middle Stone Age sites of Sibudu Cave (Goldberg et al. 2009; Miller and Sievers 2012; Wadley et al. 2011) and Diepkloof Rockshelter (Miller et al. 2013) in South Africa have revealed evidence for extensive alteration of buried occupation surfaces as a result of the periodic burning of plant bedding layers. Similarly, in Holocene sites containing *fumiers* (burned herbivore stabling deposits), incomplete combustion of annual dung layers can yield what appear to be multiple strata associated with a single depositional event (Angelucci et al. 2009).

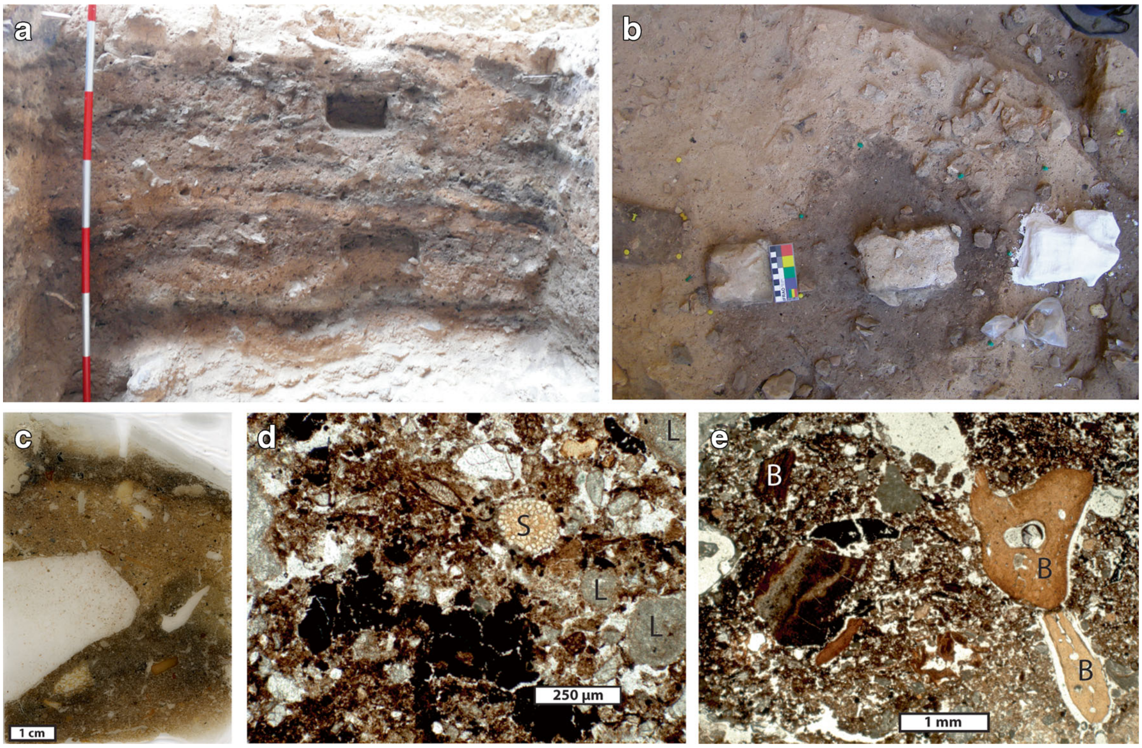


Fig. 9 Contacts that form as a result of heat alteration. **a** Profile from the El Salt excavation (2012) showing the common presence of black and dark gray lenses bounded on their undersides by abrupt contacts. The bases of these lenses were initially assumed to mark the position of the human occupation floor, on which fuel (represented by the black lens) was deposited and burnt. However, microstratigraphic analysis showed that the black lens represents the top few centimters of the substrate on which the fire was made. Thus, the occupation floor surface coincided with the *top* of the black or dark gray lens. **b** Photograph taken during micromorphological sampling of archaeological combustion structures from El Salt stratum X. Note the clear-cut boundaries of the "black" (*very dark brown*) lenses exposed at the base of the samples. **c** An incident light scan of thin section from one of the combustion structures (H32) with its visible black layer at the base and at the top part of the black layer belonging to an overlying hearth. **d** Micrograph of the H32 black layer (seen at the base of *C*). Note the diverse composition including sand-sized fragments of limestone (*L*), residues from plant decay silt-sized black particles and large black fragment and fungal sclerotia (*S*). **e** Image of the basal contact between the black layer and the underlying sediment, which is gradational and conformable. Note how the materials, such as bone fragments (*B*), change in color from *dark* (carbonized) at the *top* of the image to *light brown* (less affected by the heat source) at the *base of the image*. Views in plane-polarized light (PPL)

Things may not be what they seem: integrating depositional and post-depositional processes

Interfacies events

Many different authors have pointed out the difficulty in dividing archaeological palimpsests into assemblages that are correctly sequenced in time (e.g., Bailey 2007; Goldberg and Macphail 2006; Lucas 2012; Schiffer 1987; Yellen 1977). Nevertheless, there are numerous examples of geoarchaeological studies that have brought to light clear, well-preserved microstratification in what initially appeared as generally indistinct, texturally, or compositionally homogeneous sedimentary layers (e.g., Goldberg 2000, 2001, 2003; Goldberg et al. 2009; Karkanas et al. 2012; Macphail et al. 1998; see also Fig. 1). These microstrata, which can include bedded laminations and crusts, are normally too thin to be correlated with archaeological remains. Nevertheless, they provide important information that can be incorporated into the archaeological description of sites.

Stratigraphic contacts are the physical expression of interfacies events (see Table 1), a concept that symbolizes an interval of time between two deposits. However, interfacies events are not always marked in the field by visible contacts. For example, some archaeological sites contain thick deposits that appear homogeneous, yet analyses of the macro-scale materials recovered from them reveal vertical trends that are suggestive of behavioral change over time. In the case study from El Salt described above, stratum V likely contains at least two interfacies events that, due to the similar nature of geogenic deposition that produced gradational conformable contacts between deposits, are not identifiable, even at micro-scale. Exposed deposits can be affected by a wide variety of processes that do not leave behind visible traces, and if the time between periods of active sedimentation is brief, successive deposits can be welded together and appear massive. Exposed surfaces in archaeological sites are impacted not only by human activities but by natural processes that occur during periods, however brief, of "non-occupation" (Gé et al. 1993,

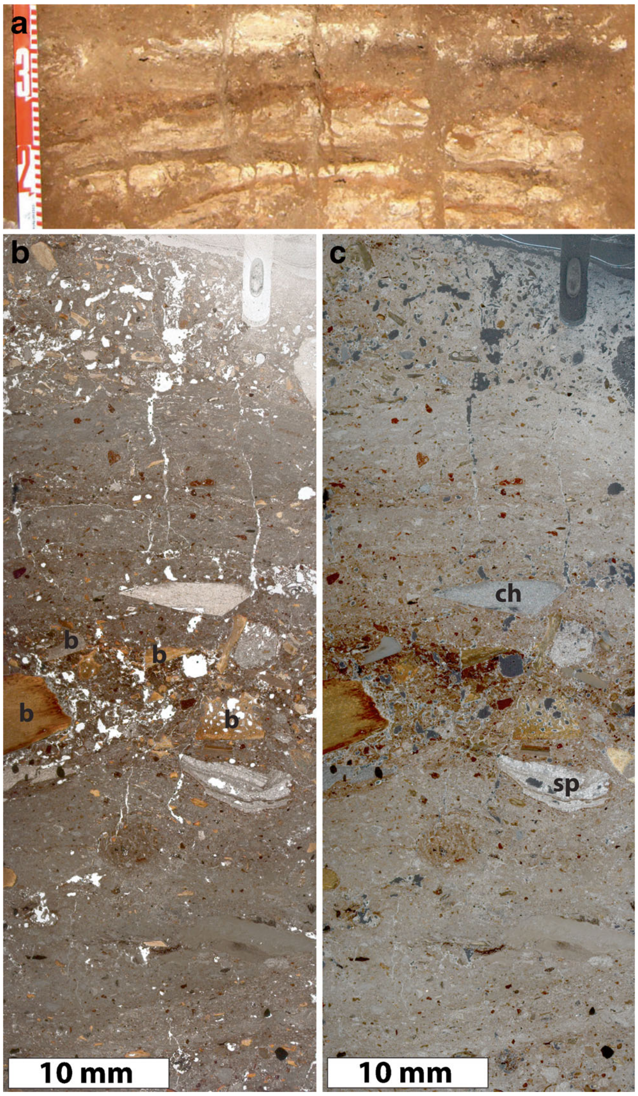


Fig. 10 Reinterpretation of a hearth layer. **a** A series of stacked combustion features from the site of Üçağızlı Cave II (Turkey) contain black layers with formation processes that are similar to the black lenses at El Salt, in that they are ancient surfaces rather than components of a hearth. Detail of the combustion features in the field. The sequence appears to contain a typical Levantine sequence of stacked hearths consisting of basal charcoal layers overlain by ashes. However, the contacts between the "charcoal" and "ash" layers are sharp and irregular. **b** Example of a "basal charcoal layer" between two multiple layers of intact and cemented ashes. The *dark layers* are composed of occupation debris—mainly bone fragments (*b*)—in a matrix of fine sediment that has been impacted by bioturbation. The sequence is therefore composed of many ashy hearths interbedded with lenses of butchery waste. The multiple hearths that comprise each white layer in the field are only visible at high magnification. PPL. **c** Same view as (**b**), XPL. The gravel-sized materials in the dark layer include an angular fragment of chert (*ch*) and a fragment of speleothem (*sp*). The presence of these inclusions is further evidence that the black layers contain generalized occupation debris, as opposed to fuel

p. 151). Being able to identify such periods can be of great importance to understanding human activity and site chronology.

Homogeneous deposits can also arise from post-depositional processes. In the Middle Paleolithic site of Üçağızlı Cave II (Turkey), an upper portion of the sedimentary sequence (layer B) spans up to 1 m in total thickness. From a macro-sedimentary perspective, this portion of the sequence is homogeneous in appearance, particularly within the western and northern portions of the excavated area (Fig. 11). Stacked combustion features are present in a southeastern zone (see also Fig. 10). Following excavation, the layer B was divided into three units (two of these arbitrary and based only on depth below datum) for the purposes of provenience of lithic artifacts and bone remains. Analyses of the faunal and lithic assemblages initially recovered in arbitrary spits, and later grouped according to the three units reveal differences in the prey species abundance, as well as the ratio of flakes to finished tools (Baykara et al. 2015). Microstratigraphic analyses were informative here as to the nature of the homogeneous appearance of the layer in the field. Micromorphology revealed that layer B contained both fine sediment and coarse sediment of dominantly anthropogenic origin. The microstructure of the sediment—in particular the channel and chamber voids and aggregates—was consistent with post-depositional bioturbation. This process obliterated much of the original microstratification related to burning activities, or depositional surfaces, yet left the broader vertical distributions of faunal and lithic materials intact.

Natural processes such as secondary cementation or chemical diagenesis, when limited in volumetric impact, can also be used as markers for identifying and characterizing interfacies events in the archaeological record. For example, in the early Upper Paleolithic deposits of Üçağızlı Cave I (Turkey; Kuhn et al. 2009), individual millimeter- to centimeter-thick layers of ashes within stacked combustion sequences vary in their degrees of secondary cementation, presumably due to variability in surface exposure time following burning (Fig. 12; Mentzer 2011). Similar features indicative of natural alteration within anthropogenic surfaces have been identified at the Middle Stone Age site of Diepkloof Rockshelter (Miller et al. 2013), as well as in experimental contexts.

In younger sites, a classic example of an interfacies event is the constructed floor and its overlying crust (sensu Macphail et al. 2004) or its microstratigraphic zones (sensu Gé et al. 1993). According to Gé et al. (1993), floors can be divided into passive, active, and reactive zones. Microstratigraphic and geochemical methods can be used to identify these zones, an approach that has been successful in certain sites (e.g., Hutson and Terry 2006; Matthews et al. 1997; but see Goldberg and Macphail 2006 and Matarazzo et al. 2010); however, the typical zone thickness of millimeters to centimeters typically prevents implementation of excavation strategies that can isolate discrete archaeological assemblages. Figure 13 illustrates how microstratigraphic methods can be used to identify the reactive zones of floors at the Aceramic

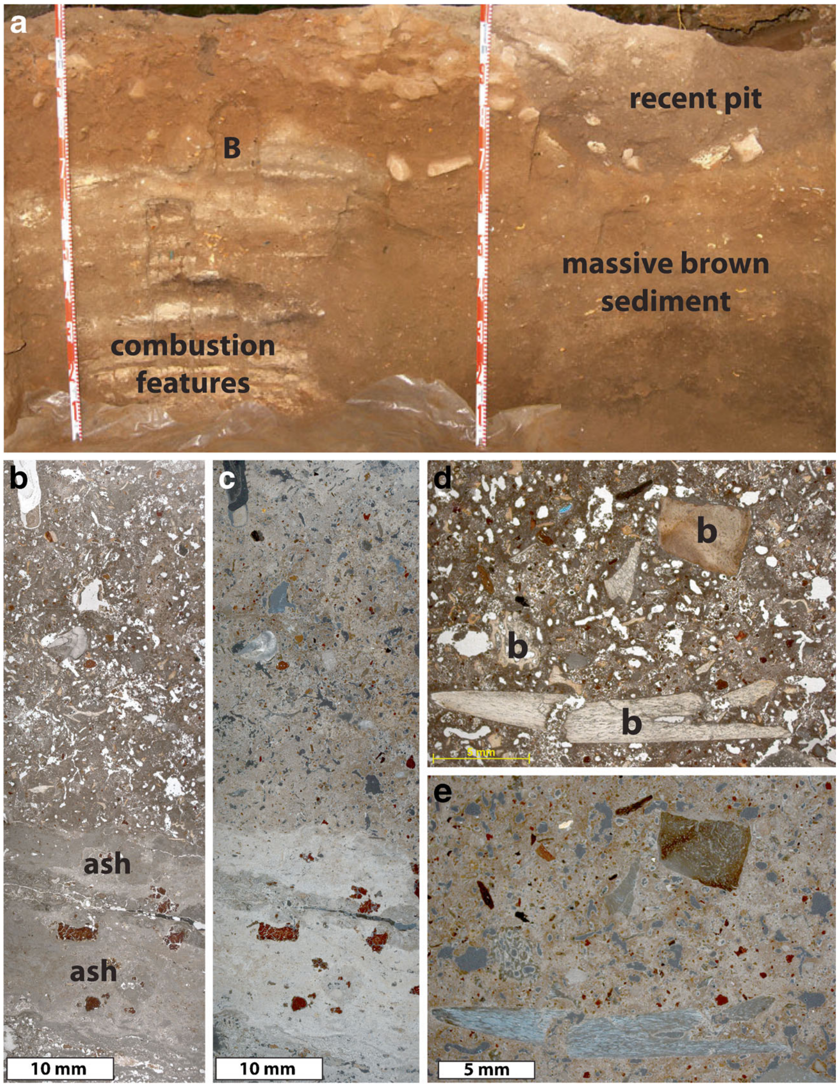


Fig. 11 Massive deposits. **a** Massive strata in the site of Üçağızlı II contain anthropogenic sediment homogenized by bioturbation. Despite the loss of much of the original stratification and microstratification, vertical trends in the lithic and faunal materials are present. A composite photograph of an excavation profile showing intact sediment (combustion features; *lower left*) juxtaposed against the massive brown deposits that are more typical of the site (*right*). The massive brown deposits contain "stringers" of ashes that are the remnants of intact combustion features. A recent pit feature is visible in the *upper right corner* of the image. The location of the sediment pictured in (**b**) is labeled. **b** Two intact ashy combustion features (ash) overlain by the bioturbated anthropogenic sediment that comprises the massive brown areas of the profile, PPL. **c** Same view as (**b**), XPL. The bioturbated sediments are calcareous and composed of ashes mixed with geogenic sediment and sand- and gravel-sized fragments of bone. **d** Detail of bioturbated sediment containing abundant fragments of bone (*b*). Post-depositional insect activity caused rounding of bone fragment edges, an increase in sediment porosity in the form of channel and chamber voids, and microaggregation (fecal pellets containing ash and bone). Larger archaeological materials were less significantly impacted by these processes and likely experienced little vertical movement, as evidenced in this image by a large piece of bone that has been fragmented in place. It is possible that bioturbation has obscured features indicative of in situ burning, trampling, and rake-out or other maintenance activities. **e** Same view as (*D*), XPL. The sedimentary matrix is rich in reworked ashes, as evidenced by the birefringence

Neolithic site of Aşıklı Höyük (Turkey). The reactive zones at this site contain fine anthropogenic debris associated with use of the structures. This debris contains silt-sized calcareous ashes, silt-sized calcareous spherulites derived from dung fuels, silt- to sand-sized fragments of charcoal, and sand-sized siliceous phytoliths. In contrast, the passive and reactive zones of the floors are composed of plaster made from mud, lime, or ash (Mentzer and Quade 2013).

At Aşıklı Höyük, and in similar sites, it is important to distinguish between floor reactive zones and the passive and active zones. First, due to the presence of many types and colors of plaster at these sites, the thin, fine-textured layers of debris can be mistaken in the field for plaster paving layers. Thus, without compositional data from micromorphology, the number of replastering events in a single floor sequence can be overestimated. Replastering sequences are important for

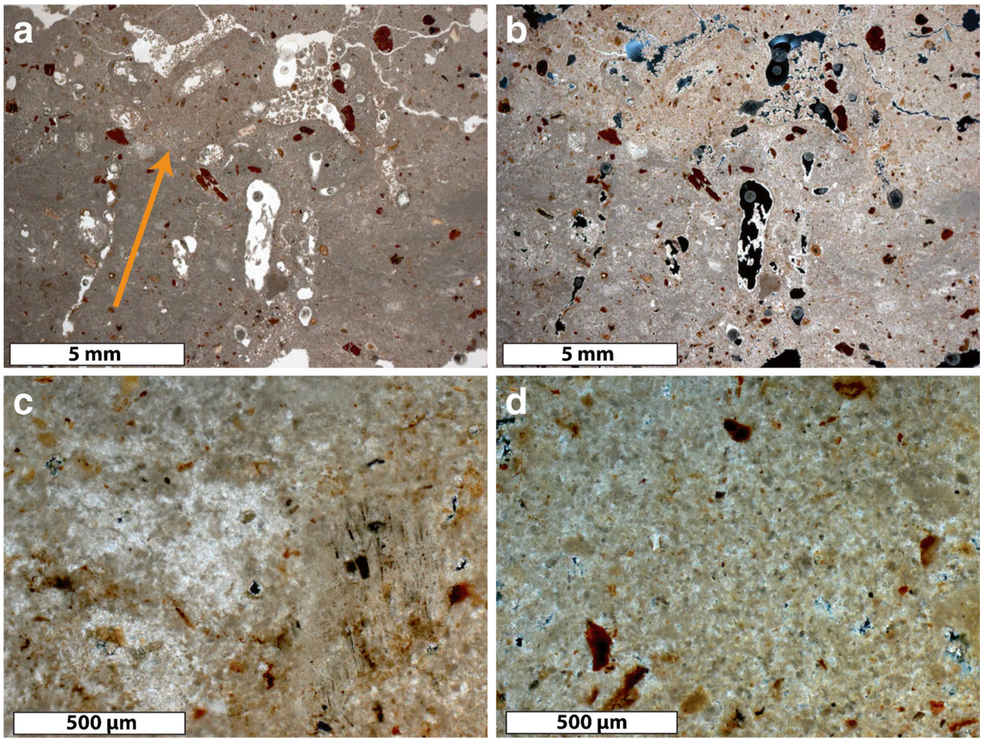


Fig. 12 Surface alteration and interfacies events. **a** Two-centimeter-thick layers of ashes within the anthropogenic deposits in Üçağızlı I Cave can be distinguished at microscale by differences in the degree of secondary carbonate cementation and recrystallization. The photomicrograph illustrates a contact between two ashy layers (*arrow*). The upper layer is browner in color and exhibits more abundant bioturbation pedofeatures. **b** Same view as (**a**), XPL. **c** The lower ashy layer is highly cemented and contains zones of recrystallization (*left side of image*) wherein the individual ash rhombs are no longer present, although some articulated ashes and plant tissues are locally preserved (*left*). XPL. **d** The upper ashy layer is cemented by secondary carbonate but to a lesser degree. Individual ash rhombs are preserved and abundant. XPL

understanding and comparing the life histories of structures and areas within structures (Boivin 2000; Hodder 2006; Hodder and Cessford 2004; Karkanas and Efstratiou 2009; Matthews 2005a, b). Furthermore, maintenance activities such as sweeping can remove active floor zones, while restrictive use of space or protection of floors can prevent their development. Thus, the presence or absence of active zones within floors can be interpreted in terms of space cleanliness and function (Hodder 2006).

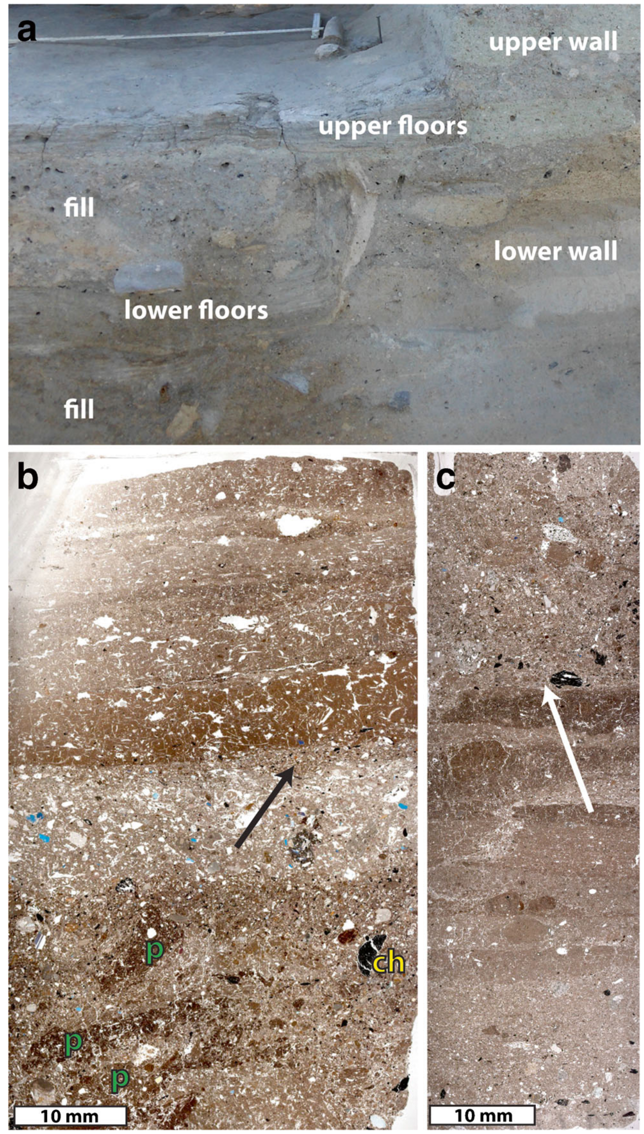
Second, using high-resolution sampling, it is possible to recover micro-botanical remains from both the passive and reactive plasters and the overlying active debris layers. Botanical remains recovered from the plasters, which include fragments of humified plant material and phytoliths, can be indicative of raw material sources (e.g., organic muds) or intentional tempering activities. In contrast, botanical remains recovered from the active zones source from floor coverings and activities conducted within the structures, such as food processing or combustion. Accurate identification of the floor zone from which botanical remains derive therefore has important implications for understanding construction processes and building use, as well as the primary or secondary contexts of radiocarbon dating samples.

As Fig. 13 illustrates, floor active zones are exceptionally difficult to identify in the field. Of the two contexts (between plaster layers, Fig. 13b, and on top of the uppermost plaster layer, Fig. 13c), only the occupation debris on top of the uppermost plaster layer can be feasibly recovered using standard excavation methods. Thus, the difficulty of increasing excavation precision in light of informative microstratigraphic sequences is one of the pitfalls of this analytical approach.

Sterile layers

Contacts that arise from both depositional and post-depositional processes can be associated with so-called archaeologically "sterile" layers. Sterile layers are generally assumed to represent either periods of normal sedimentation without human occupation or episodic geogenic depositional events. In this latter case, the associated contacts would be depositional in nature. Post-depositional processes may also result in archaeologically sterile layers, as in the case of strong degradation of a deposit that contained only organic anthropogenic materials. In this scenario, the sterile layer would *also* be associated with depositional contacts. In either case, a microstratigraphic approach to the study of sterile layers can

Fig. 13 Floor reactive zones in Neolithic residential structures and their archaeological context. **a** A field photograph of a cross section of a building from the site of Asıklı Höyük, Turkey. The floors and walls were refurbished several times during the use of the structure's footprint. The stratigraphy associated with the structure (pictured here) consists of a lower plaster floor sequence that include multiple replastering events, debris associated with use of the structure (the floor reactive zone), fill containing degraded brick and mortar, and an upper plaster floor sequence. **b** Microstratigraphy of a floor sequence. This sample contains construction debris overlain by multiple plaster floors and occupation debris. Construction fill differs from occupation debris in that it contains sand- and gravel-sized fragments of materials, such as brick, mortar, floor plaster, and wall plaster. Here, fragments of plaster (*p*) are mixed with botanical remains, including charcoal (*ch*) that is in secondary position. PPL. The overlying floor replastering sequence contains occupation debris (the reactive zone of the floor; *arrow*) sandwiched between individual layers of plaster. The layer of occupation debris is discontinuous with a maximum thickness of 3 mm. The presence and composition of this type of debris can only be documented using microstratigraphic methods. In the field, this debris is indistinguishable from the passive or active zones of a floor. PPL. **c** Here, a layer of occupation debris (*arrow*) is located on top of a plaster floor and beneath a layer of construction fill. The boundary between the base of the fill and the top of the occupation debris is difficult to trace during excavation, with the two units appearing homogeneous apart from macro-scale artifacts left atop the plaster surface. Using observations from microstratigraphy, fine anthropogenic materials, such as macrobotanical remains, can be recovered and used to understand activities within the structure. PPL



provide significant detail into their formation (i.e., the nature and extent of the geogenic event that produced them, the time range they represent, etc.).

As an example, the early Upper Paleolithic deposits in the site of Üçağızlı Cave I (Turkey) are characterized by striking shifts in the color and nature of sedimentation. The main units visible in the field broadly alternate between those composed of red sediment of geogenic origin and those containing white sediment of anthropogenic origin (Goldberg 2003; Kuhn et al. 2009). This pattern is expressed at all scales of observation and extends to both centimeter-thick lenses visible within the main stratigraphic units and millimeter-thick microstrata visible only in thin section.

High-resolution study of the sterile, and by appearance, massive geogenic unit located at the base of the sequence revealed information pertinent to understanding the formation of the entire site. The basal sterile layer contains several different types of buried surfaces that are visible at micro-scale (Fig. 14). These include former surfaces exposed to bioturbation and/or post-depositional cementation. As illustrated previously (see Fig. 12), the same processes impact anthropogenic surfaces within the sequence, with bioturbation locally obliterating the internal fabrics and contacts between combustion features, and cementation locally preserving them. In extreme cases, secondary calcite formation in the absence of either geogenic or anthropogenic sedimentation produced flowstones that are useful for radiometric dating (Fig. 14f).

"Invisible" stratigraphic contacts within archaeologically sterile deposits can be informative about site formation processes and paleoenvironment. In the Paleoindian site of Hell Gap, the relative abundance and type of microscopic voids were used to define buried soil surfaces that were otherwise undetected (Miller and Goldberg 2009). An example from our own work comes from El Castillo Cave, Spain, a classic site that figures heavily into the debates regarding the nature of the Iberian Middle-to-Upper Paleolithic transition (Bernaldo de Quirós and Maíllo-Fernández 2009; Cabrera et al. 1997). El Castillo Layer 20, which yielded Middle Paleolithic artifacts, is separated from the so-called transitional layer (18) by layer 19, which is massive and archaeologically sterile (Fig. 15). This sterile layer is bounded by abrupt depositional contacts. Micromorphological analysis of this part of the stratigraphic sequence (Mallol et al. 2010) showed that layer 19 is

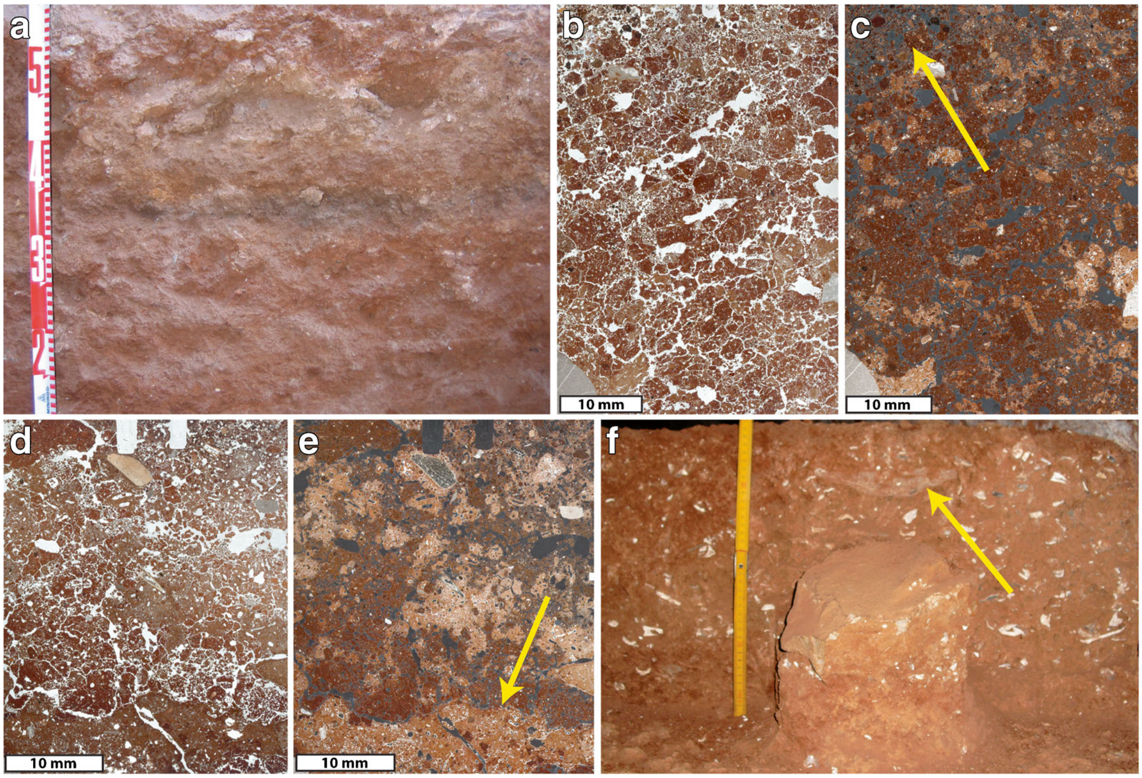


Fig. 14 Post-depositional features visible at microscale can be used to identify former surfaces within broadly homogeneous deposits. **a** Reddish layers in the site of Üçağızlı I are primarily geogenic in origin. Aside from lenses of anthropogenic materials that are present only in the upper 10–20 cm, visible here in the upper half of the image, the red sediments at the base of the sequence appear homogeneous in the field. **b** At microscale, buried surfaces can be identified. Here, the abundance of post-depositional bioturbation features, including channel and chamber voids and fecal pellets, decreases with depth from a former ground surface. PPL. **c** Same view as **b**, XPL. The former surface is indicated with an *arrow*. **d** In a different sample, two units of red sediment deposition and alteration are defined on the basis of porosity and the abundance and nature of secondary carbonate cementation. A buried surface is present at the base of the image. PPL. **e** Same view as **d**, XPL. The top of the lower unit is indicated with an *arrow*. Although the degree of cementation is suggestive of a buried ground surface exposed to dripping karstic water, the exact nature of the contact between the two units is not clear. **f** In some cases, buried surfaces exposed to dripping or flowing karstic waters are capped with speleothems. A flowstone (*arrow*) is visible within a deposit of homogeneous red sediment near the top of the archaeological sequence

composed of waterlain sediments exhibiting redoximorphic pedofeatures indicative of periodic waterlogging, while the under- and overlying deposits are composed of heterogeneous, detrital sediment associated with a dry cave entrance setting. Microscopic bone contained in the sediment from the top of the underlying layer 20 showed strong weathering and bacterial attack (Fig. 15d), suggesting a period of surface exposure prior to the onset of wet conditions associated with layer 19. A thin section from the contact between layers 19 and 18 showed the presence of lithic artifacts within the uppermost "sterile" layer 19 sediment (Fig. 15b). This finding suggests that the earliest human occupations of layer 18 possibly took place on the surface of the layer 19 deposit, which became a sink for fine-grained anthropogenic debris. The El Castillo study illustrates that a high level of detail regarding site formation can be obtained through microstratigraphic analysis of sterile layers and their contacts. Further geoarchaeological investigations at the site will establish the relationship between the interval of wet climatic conditions and the absence of humans in the cave. This particular time interval encompassed the change from the Middle to the Upper Paleolithic in the region.

Microstratigraphic analyses can also reveal that so-called sterile layers are actually anthropogenic in origin. For example, at the aforementioned Neolithic site of Aşıklı Höyük, activity spaces were observed to contain thin (1–2-cm-thick) layers of silty gray sediment interbedded at regular intervals with anthropogenic debris (Fig. 16). A research question was formulated based on these field observations: did the gray layers represent periods of aeolian silt deposition during periodic abandonment of the site? The question was recently addressed using microstratigraphic techniques. Grain mount analyses and micromorphology revealed that the gray layers were composed of calcareous ashes rather than calcareous loess. The deposition of these layers therefore resulted from a perhaps regular burning activity conducted within or near the space, rather than abandonment of the site.

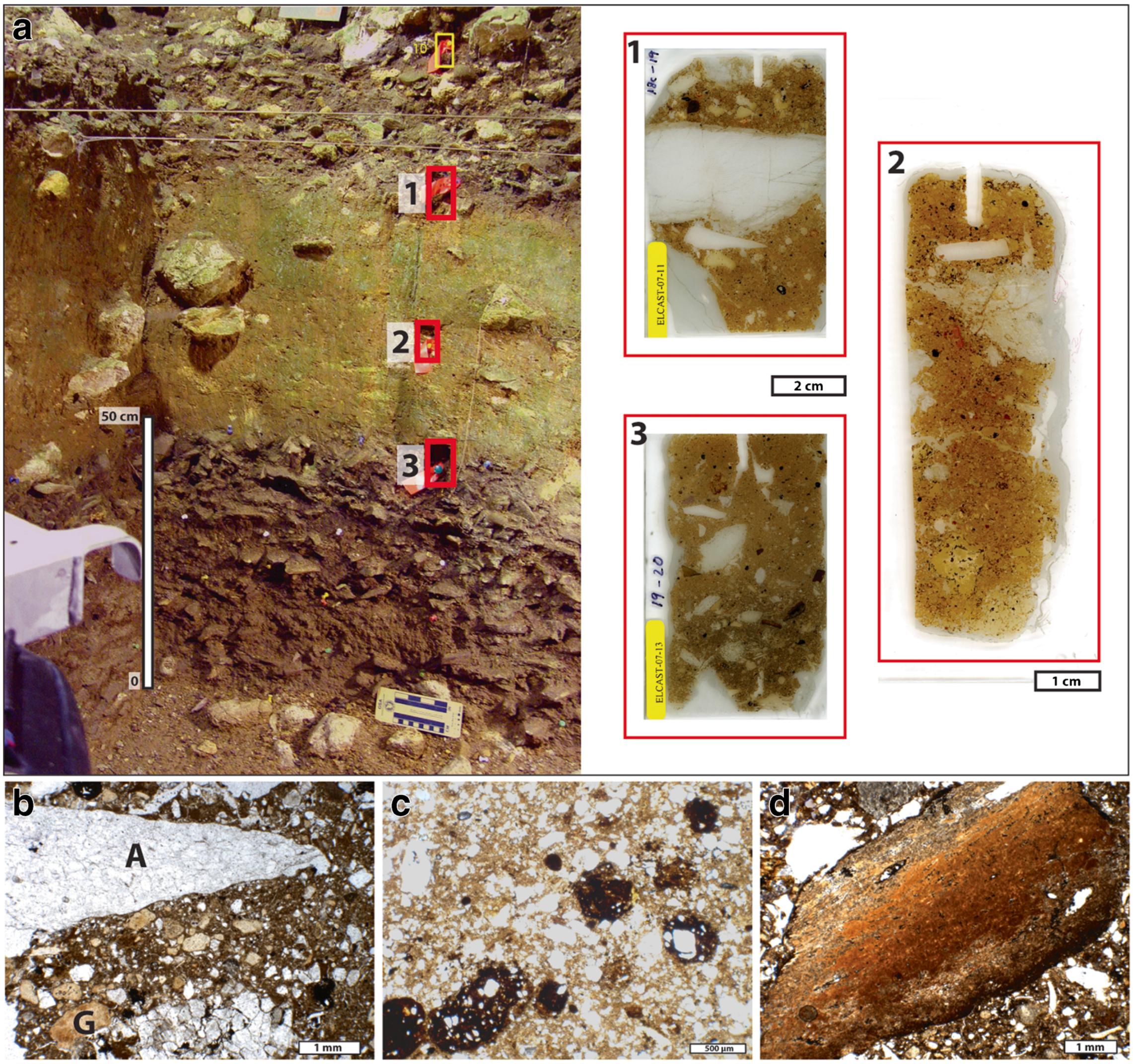


Fig. 15 A sterile layer that contains microscopic features that can be used to reconstruct the environment within the site, as well as previously undocumented archaeological materials. **a** Profile from El Castillo Cave, Cantabria, Spain showing sterile layer 19 (fine-grained, massive layer in the middle of the picture). Note abrupt top and bottom contacts. Analysis of three thin sections corresponding to the top contact, center, and bottom contact of layer 19 (scan views in *red boxes*) showed that this layer comprises a predominantly clayey groundmass with random clay intercalations indicative of a waterlain deposit and pedofeatures indicative of waterlogging (iron nodules and staining). **b** Micrograph of the top of layer 19 near the contact. Note the presence of a lithic artifact (*A*) and phosphatic grains (*G*), reworked from overlying anthropogenic sediment, PPL. **c** Micrograph of layer 19 showing the presence of iron nodules formed in place by periodic waterlogging, PPL. **d** Microscopic bone fragment contained in the sediment from the underlying layer 20 near its contact with layer 19, exhibiting strong weathering and bacterial attack, PPL

Conclusions

Throughout this paper, we have highlighted the importance of stratigraphic contacts in the study of archaeological sequences and stressed how microstratigraphic analysis is necessary to characterize their nature (i.e., whether contacts are depositional or post-depositional and formed by geogenic, biogenic, or anthropogenic processes) and to assess their archaeological relevance. As shown by our examples in the "Contacts, interfaces, and primary depositional processes" and "Contacts, interfaces, and post-depositional processes" sections, establishing whether a contact reflects a change in mode of deposition, a period of erosion, a hiatus in sedimentation or a post-depositional process such as phosphatization or soil formation has important implications for archaeological interpretation. Furthermore, we advocate a microstratigraphic approach as part of a holistic study that includes observations at multiple scales. In order to understand major changes in the depositional system, the microstratigraphic observations must always be linked to the macrostratigraphy, because macrostratigraphic units are the bodies of sediment that archaeologists observe and in many cases excavate.

We also illustrated the importance of focusing on interfacies events at a microstratigraphic scale to identify

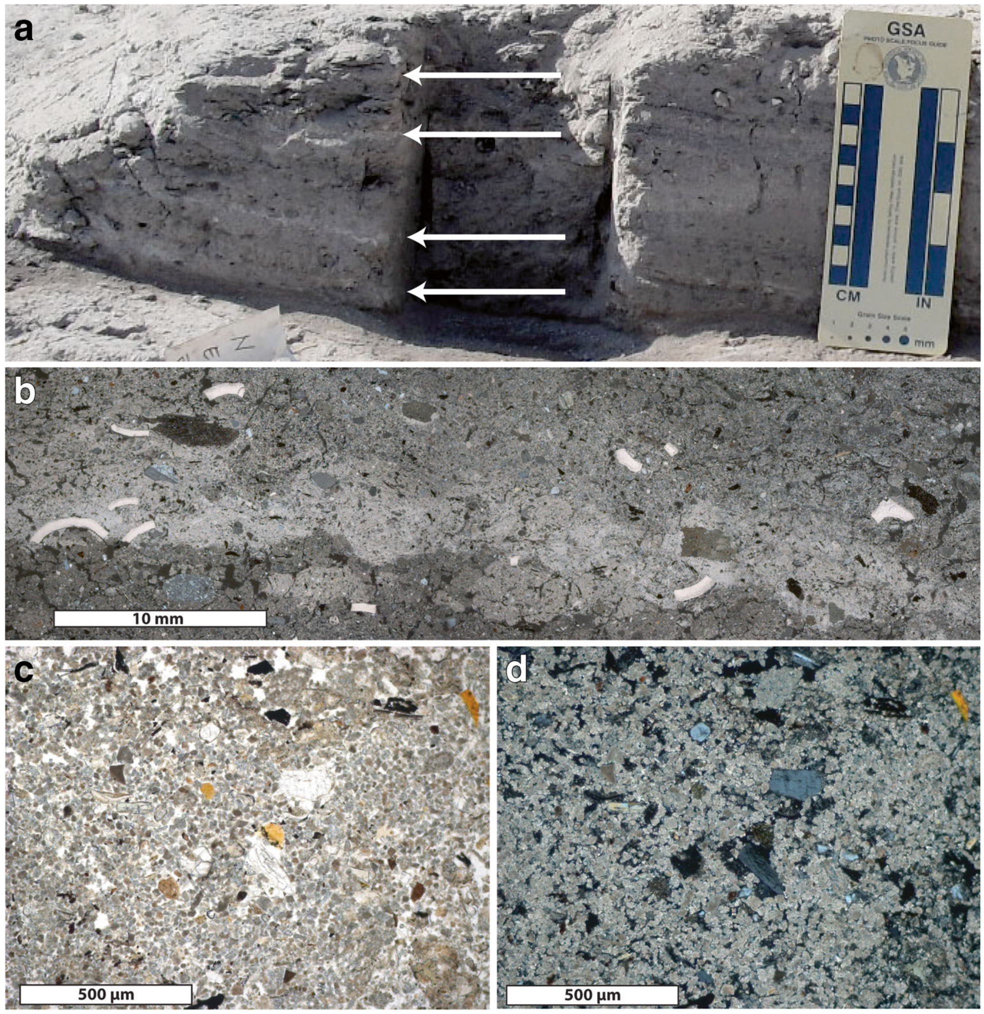


Fig. 16 Reinterpretation of sterile layers as anthropogenic in origin following microstratigraphic analysis. **a** Gray layers in open spaces at the site of Asıklı Höyük were hypothesized to contain sterile, silt-sized aeolian sediment. Micromorphological analyses revealed that the layers are anthropogenic in origin. Thin (1–2-cm-thick) layers of silty gray sediment are visible within the profiles of activity areas. **b** In thin section, the gray layers are highly calcareous, exhibiting sharp contacts with underlying sediment. **c** At high magnification, the layers are composed of wood ashes but lack internal fabric or structural features that would indicate burning of fuels in place. **d** Same view as (**c**), XPL

and characterize occupation surfaces and understand their formation histories (see "Interfacies events" section). Many imprints of human action on the substrate, including accumulation of small-sized refuse, surface trampling, and floor preparation cannot be observed with the naked eye. Furthermore, a microstratigraphic approach allows us to unveil complexity within what may appear in the field as homogeneous, massive archaeological deposits. Finally, we presented a series of examples to show that the microstratigraphic analysis of archaeologically sterile layers and their contacts may provide important information regarding the nature of geogenic processes involved in site formation (see "Sterile layers" section). Likewise, on occasion, apparent sterile layers may turn out to be anthropogenic in origin. In our examples, these revised interpretations were made possible only after conducting microstratigraphic analysis.

How then might we incorporate microstratigraphy into existing and future archaeological research programs? Our examples are only a small sample of what is becoming a large corpus of interdisciplinary studies that emphasize a microstratigraphic approach. Recent studies have demonstrated that high-resolution sedimentological data can be used to address issues of behavioral change *directly.* Goldberg et al. (2009) and Miller et al. (2013), for example, use microstratigraphy to not only establish stratigraphic integrity and understand natural site formation processes, but they focus on interpreting repetitive sequences of microscopic anthropogenic layers (microfacies) in terms of change in human site use during the Middle Stone Age. As the impact of such studies on settlement dynamics and models of behavioral change increases, the need to adjust our research methodologies to incorporate microstratigraphic investigation becomes clearer.

In our view, the key is a geoarchaeology-aware research design that facilitates the production of comprehensive site formation models prior to or during excavation. On many projects, microstratigraphic analyses are conducted after-the-fact. Excavators, working within the frameworks of many of the excavation methods described in Table 2, typically err on the side of caution when they encounter any sedimentary changes. In this manner, geological strata, zones of diagenesis, and soil horizons can and do serve as a first level provenience for archaeological materials. Projects can accommodate revisions of stratigraphic sequences, but these revisions are difficult to manage if arrived at long after other analyses are completed. Thus, microstratigraphic sampling and analysis should be conducted prior to or soon after excavation. In this way, the results can be used to inform later analytical decisions, including criteria for assemblage subdivision and selection of dating samples. Furthermore, we caution that field observations should not bias sampling strategies, which should prioritize both visible stratigraphic contacts as well as homogeneous or massive deposits. Our examples in the "Sterile layers" section show that ignoring a so-called sterile layer in favor of more archaeologically rich sampling localities could result in missing data relevant to human activity at a site.

In sum, we suggest that the microstratigraphic approach can aid archaeologists in shifting from analytical plans grounded in description and assumption to those grounded in empirical inference. This must be done in an integrated manner in which microstratigraphic data are routinely crosschecked against those derived from other kinds of analyses of the human material record. In this way, we can advance towards a fully contextualized approach to understanding archaeological sites.

Acknowledgments Our presentations at the Bridging the Gaps workshop shared a common theme: things may not be what they seem. This paper developed from this idea and from the lively discussion that followed. We would like to thank the organizers of the Bridging the Gaps workshop and its participants for their engaging ideas regarding the position of geoarchaeology—its methods and theory—within the broader field. We are grateful to our colleagues M. Ozbaşaran, G. Duru, M. Voyatzis, D. Romano, S. Kuhn, M. Stiner, P. Goldberg, B. Galván, and F. Bernaldo de Quirós for granting us access to samples and permission to publish case studies drawn from ongoing and unpublished work. Our microstratigraphic analyses at the sites of Üçağızlı Caves I and II, Mt. Lykaion, Aşıklıi Höyük, Obi-Rakhmat, El Salt, 'Ubeidiya, Bizat Ruhama, and El Castillo were supported by the following funding sources: the National Science Foundation (USA), PEO International, the University of Arizona NSF-IGERT Program in Archaeological Sciences, DAAD, INSTAP, the Weiner Lab at the American School for Classical Studies at Athens, the American School of Prehistoric Research, and the Spanish Ministry of Economy and Competitiveness. We would also like to thank D.G. Romano, L. Wallace, C. Miller, and C. Hernández for their insights into excavation methodologies and for providing comments on earlier drafts of this work.

References

Aharoni Y (1973) Remarks on the 'Israeli' method of excavation. Eretz-Israel 11:48–53

Albert RM, Shahack-Gross R, Cabanes D, Gilboa A, Lev-Yadun S, Portillo M, Sharon I, Boaretto E, Weiner S (2008) Phytolith-rich layers from the Late Bronze and Iron Ages at Tel Dor (Israel): mode of formation and archaeological significance. J Archaeol Sci 35(1): 57–75

Albert RM, Bamford MK, Cabanes D (2009) Palaeoecological significance of palms at Olduvai Gorge, Tanzania based on phytolith remains. Quat Int 193:41–48

Albert RM, Berna F, Goldberg P (2012) Insights on Neanderthal fire use at Kebara Cave (Israel) through high resolution study of prehistoric combustion features: evidence from phytoliths and thin sections. Quat Int 247:278–293

Angelucci DE, Boschian G, Fontanals M, Pedrotti A, Vergès JM (2009) Shepherds and karst: the use of caves and rock-shelters in the Mediterranean region during the Neolithic. World Archaeol 41(2): 191–214

Ashley GM, Driese SG (2002) Paleopedology and paleohydrology of a volcaniclastic paleosol interval: implications for Early Pleistocene stratigraphy and paleoclimate record, Olduvai Gorge, Tanzania. J Sediment Res 70(5):1065–1080

Bailey GN (2007) Time perspectives, palimpsests and the archaeology of time. J Anthropol Archaeol 26:198–223

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

Balbo AL, Madella M, Vila A, Estévez J (2010) Micromorphological perspectives on the stratigraphical excavation of shell middens: a first approximation from the ethnohistorical site Tunel VII, Tierra del Fuego (Argentina). J Archaeol Sci 37(6):1252–1259

Bamford MK, Stanistreet IG, Stollhofen H, Albert RM (2008) Late Pliocene fossil grass from Olduvai Gorge, Tanzania. Palaeogeogr Palaeoclimatol Palaeoecol 257:280–293

Banerjea, R (2011) Characterising urban space: a case study from Insula IX, Silchester, Hants, UK. Doctoral Thesis. University of Reading

Barker, P (1993) Techniques of archaeological excavation. Psychology Press

Baykara I, Mentzer SM, Stiner MC, Asmerom Y, Güleç ES, Kuhn, SL (2015) The Middle Paleolithic occupations of Üçağızlı II Cave (Hatay, Turkey): Geoarchaeological and archaeological perspectives. Journal of Archaeological Science Reports 4:409–426 (2015, in press)

Berna F, Goldberg P (2007) Assessing Paleolithic pyrotechnology and associated hominin behavior in Israel. Israel J Earth Sci 56:107–121

Berna F, Behar A, Shahack-Gross R, Berg J, Boaretto E, Gilboa A, Nagar-Hilman O, Sharon I, Weiner S (2007) Sediments exposed to high temperatures: reconstructing pyrotechnological processes in Late Bronze and Iron Age Strata at Tel Dor (Israel). J Archaeol Sci 34(3):358–373

Bernaldo de Quíros F, Maíllo-Fernández JM (2009) The transitional Aurignacian and the Middle-Upper Paleolithic transition model in Cantabrian Iberia. In: Camps M, Chauhan PR (eds) A sourcebook of paleolithic transitions: methods, theories, and interpretations. Springer, USA, pp 341–359

Binford LR (1981) Behavioral archaeology and the "Pompeii premise." Journal of Anthropological Research, 195–208

Boivin N (2000) Life rhythms and floor sequences: excavating time in rural Rajasthan and Neolithic Catalhoyuk. World Archaeol 31(3): 367–388

Browman DL, Givens DR (1996) Stratigraphic excavation: the first "new archaeology". Am Anthropol 98(1):80–95

Brown III MR, Harris EC (1993) Interfaces in archaeological stratigraphy. Practices of archaeological stratigraphy, London, 7–20

Cabrera V, Hoyos M, Bernaldo de Quirós F (1997) The transition from the Middle to the Upper Paleolithic in the cave of El Castillo (Cantabria, Spain). Conceptual issues in modern human origins research. In: Clark, G.A., Willermet, C.M. (Eds.) Aldine de Gruyter, New York. Chapter 13, 177–188

Chapman RL (1986) Excavation techniques and recording systems: a theoretical study. Palest Explor Q 118(1):5–26

Chu V, Regev L, Weiner S, Boaretto E (2008) Differentiating between anthropogenic calcite in plaster, ash and natural calcite using infrared spectroscopy: implications in archaeology. J Archaeol Sci 35(4):905–911

David F, Julien M, Karlin C (1973) Approche d'un niveau archéologique en sédiment homogène. L'Homme, hier et aujourd'hui, Paris, Editions Cujas, 65–72

Derevianko AP, Krivoshapkin AI, Anoikin AA, Islamov UI, Petrin VT, Saifullaiev BK, Suleimanov RH (2001) The initial Upper Palaeolithic of Uzbekistan: the lithic industry of Obi-Rakhmat Grotto (on the basis of materials recovered from strata 2–14). Archaeol, Ethnol & Anthropol Eurasia 4:42–63

Derevianko AP, Krivoshapkin AI, Anoikin AA, Wrinn PJ, Islamov UI (2004) Lithic industry of Obi-Rakhmat Grotto. In: Derevianko AP (ed) Obi-Rakhmat Grotto. Publishing House of the Institute of Archaeology & Ethnography, Siberian Branch, Russian Academy of Sciences, Novosibirsk, pp 5–29

Dever WG (1974) Two approaches to archaeological method—the architectural and the stratigraphic. Eretz-Israel 11:1–8

Dibble HL, Raczek TP, McPherron SP (2005) Excavator bias at the site of Pech de l'Azé IV, France. Journal of Field Archaeology: 317–328

Dibble HL, Berna F, Goldberg P, McPherron SP, Mentzer S, Niven L, Richter D, Sandgathe D, Théry-Parisot I, Turq A (2009) A preliminary report on Pech de l'Azé IV, Layer 8 (Middle Paleolithic, France). PaleoAnthropology 2009:182–219

Eliyahu-Behar A, Shilstein S, Raban-Gerstel N, Goren Y, Gilboa A, Sharon I, Weiner S (2008) An integrated approach to reconstructing primary activities from pit deposits: iron smithing and other activities at Tel Dor under Neo-Assyrian domination. J Archaeol Sci 35(11):2895–2908

Farrand WR (2001) Sediments and stratigraphy in rockshelters and caves: A personal perspective on principles and pragmatics. Geoarchaeology 16(5):537–557

Friesem DE, Zaidner Y, Shahack-Gross R (2014) Formation processes and combustion features at the lower layers of the Middle Palaeolithic open-air site of Nesher Ramla, Israel. Quat Int 331: 128–138

Fumanal MP (1994) El yacimiento musteriense de El Salt (Alcoi, País Valenciano). Rasgos geomorfológicos y climatoestratigrafía de sus registros. Saguntum PLAV 27:39–55

Galván B, Hernández CM, Mallol C, Mercier N, Sistiaga A, Soler V (2014) New evidence of Early Neanderthal disappearance in the Iberian Peninsula. J Hum Evol 75:16–27

Gé T, Courty MA, Matthews W, Wattez J (1993) Sedimentary formation processes of occupation surfaces. Formation processes in archaeological context. Prehistory Press, Madison, pp 149–164

Gifford-Gonzalez DP, Damrosch DB, Damrosch DR, Pryor J, Thunen RL (1985) The third dimension in site structure: an experiment in trampling and vertical dispersal. American Antiquity, 803–818

Goldberg P (2000) Micromorphology and site formation at Die Kelders Cave I, South Africa. J Hum Evol 38(1):43–90

Goldberg P (2001) Some micromorphological aspects of prehistoric cave deposits. Cahiers d'Archéologie CELAT 10:161–75

Goldberg P (2003) Some observations on Middle and Upper Paleolithic ashy cave and rockshelter deposits in the Near East. More than meets the eye: studies on upper Paleolithic diversity in the Near East, 19–32

Goldberg P, Macphail RI (2006) Practical and theoretical geoarchaeology. Blackwell Publishing, Oxford

Goldberg P, Laville H, Meignen L (2007) Stratigraphy and geoarchaeological history of Kebara Cave, Mount Carmel. In: Kebara Cave, volume 2 (Eds O. Bar-Yosef and L. Meignen). Peabody Museum, Cambridge, MA, pp. 49–89.

Goldberg P, Miller CE, Schiegl S, Ligouis B, Berna F, Conard NJ, Wadley L (2009) Bedding, hearths, and site maintenance in the Middle Stone age of Sibudu Cave, KwaZulu-Natal, South Africa. Archaeol Anthropol Sci 1:95–122

Harris EC (1989) Principles of archaeological stratigraphy. London: Academic Press

Henry D (2012) The palimpsest problem, hearth pattern analysis, and Middle Paleolithic site structure. Quat Int 247:246–266

Hodder I (2006) The spectacle of daily performance at Çatalhöyük. In Inomata and Coben (eds). Archaeology of performance: theaters of power, community, and politics, 103–1354

Hodder I, Cessford C (2004) Daily practice and social memory at Çatalhöyük. American Antiquity, 17–40

Hosfield R (2005) Individuals among palimpsest data. The hominid individual in context. Routledge, Abingdon, pp 220–243

Hutson SR, Terry RE (2006) Recovering social and cultural dynamics from plaster floors: chemical analyses at ancient Chunchucmil, Yucatan, Mexico. J Archaeol Sci 33(3):391–404

Ismail-Meyer K, Rentzel P, Wiemann P (2013) Neolithic lakeshore settlements in Switzerland: new insights on site formation processes from micromorphology. Geoarchaeology 28:317–339

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 (2006) Late Neolithic household activities in marginal areas: the micromorphological evidence from the Kouveleiki caves, Peloponnese, Greece. J Archaeol Sci 33(11):1628–1641

Karkanas P, Efstratiou N (2009) Floor sequences in Neolithic Makri, Greece: micromorphology reveals cycles of renovation. Antiquity 83(322):955

Karkanas P, Bar-Yosef O, Goldberg P, Weiner S (2000) Diagenesis in prehistoric caves: the use of minerals that form in situ to assess the completeness of the archaeological record. J Archaeol Sci 27(10): 915–929

Karkanas P, Dabney MK, Smith RAK, Wright JC (2012) The geoarchaeology of Mycenaean chamber tombs. J Archaeol Sci 39(8):2722–2732

Kuhn SL, Stiner MC, Güleç E, Özer I, Yılmaz H, Baykara I, Açıkkol A, Goldberg P, Molina KM, Ünay E, Suata-Alpaslan F (2009) The early Upper Paleolithic occupations at Üçağızlı Cave (Hatay, Turkey). J Hum Evol 56(2):87–113

Liutkus CM, Ashley GM (2003) Sedimentology and stratigraphy of an ancient freshwater lake-margin wetland, Olduvai Gorge, Tanzania. J Sediment Res 73(5):691–705

Lucas G (2012) Understanding the archaeological record. Cambridge University Press, Cambridge

Macphail RI (1999) Sediment micromorphology. In: Boxgrove. A Middle Pleistocene hominid site at Eartham Quarry, Boxgrove, West Sussex (Eds M.B. Roberts and S.A. Parfitt), Archaeological Report 17, pp. 118–148. English Heritage, London

Macphail RI, Cruise GM, Mellalieu SJ, Niblett R, Bond S, Dormor I, Reeves K (1998) Micromorphological interpretation of a "turf-filled" funerary shaft at St. Albans, United Kingdom. Geoarchaeology 13(6):617–644

Macphail RI, Galinié H, Verhaeghe F (2003) A future for dark earth? Antiquity 77(296):349–358

Macphail RI, Cruise GM, Allen MJ, Linderholm J, Reynolds P (2004) Archaeological soil and pollen analysis of experimental floor deposits; with special reference to Butser Ancient Farm, Hampshire, UK. J Archaeol Sci 31(2):175–191

Macphail RI, Crowther J, Cruise GM (2007a) Micromorphology and post-Roman town research: the examples of London and Magdeburg. In: Henning J (ed) Post-Roman towns and trade in Europe, Byzantium and the Near-East. New methods of structural, comparative and scientific methods in archaeology. Walter de Gruyter & Co, KG, Berlin, pp 303–317

Macphail RI, Crowther J, Cruise GM (2007b) Microstratigraphy: soil micromorphology, chemistry and pollen. In: Bowsher D, Dyson T, Holder N, Howell I (eds) The London Guildhall. An archaeological history of a neighbourhood from early medieval to modern times. Museum of London Archaeological Service, London

Malinsky-Buller A, Hovers E, Marder O (2011) Making time: 'living floors', 'palimpsests' and site formation processes—a perspective from the open-air Lower Paleolithic site of Revadim Quarry, Israel. J Anthropol Archaeol 30(2):89–101

Mallol C (2006) What's in a beach? Soil micromorphology of sediments from the Lower Paleolithic site of 'Ubeidiya, Israel. J Hum Evol 51: 185–206

Mallol C, Mentzer S, Wrinn P (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, Goldberg P, Bernaldo de Quirós F (2010) Cave entrance microfacies of layers 18–21 of El Castillo, Cantabria, Spain. 16th European Association of Archaeologists Meeting, 1–5 September, The Hague, The Netherlands. (Abstract)

Mallol C, Hernández CM, Cabanes D, Machado J, Sistiaga A, Pérez L, Galván B (2013) The black layer of Middle Paleolithic combustion structures. Interpretation and archaeostratigraphic implications. J Archaeol Sci 40:2515–2537

Matarazzo T, Berna F, Goldberg P (2010) Occupation surfaces sealed by the Avellino eruption of Vesuvius at the Early Bronze Age village of Afragola in southern Italy: a micromorphological analysis. Geoarchaeology 25(4):437–466

Matthews W (2005a) Life-cycle and life-course of buildings. Çatalhöyük perspectives: reports from the 1995–1999 field seasons, 125–149

Matthews W (2005b) Microstratigraphy and micromorphology: contributions to interpretation of the Neolithic settlement at Catalhoyuk, Turkey. In: Fertile ground. Papers in Honour of Susan Limbrey, 108–114

Matthews W, French CA, Lawrence T, Cutler DF, Jones MK (1997) Microstratigraphic traces of site formation processes and human activities. World Archaeol 29(2):281–308

Meignen L, Bar-Yosef O, Goldberg P, Weiner S (2001) Le feu au Paléolithique moyen: recherches sur les structures de combustion et le statut des foyers. L'exemple du Proche-Orient. Paléorient, 9–22

Meignen L, Goldberg P, Bar-Yosef O (2007) The hearths at Kebara Cave and their role in site formation processes. In: Kebara Cave, volume 2 (Eds O. Bar-Yosef and L. Meignen). Peabody Museum, Cambridge, MA, pp. 91–122

Mentzer SM (2011) Macro- and micro-scale geoarchaeology of Üçağızlı Caves I and II, Hatay, Turkey. Doctoral Dissertation. University of Arizona

Mentzer SM, Quade J (2013) Compositional and isotopic analytical methods in archaeological micromorphology. Geoarchaeology 28(1):87–97

Mentzer SM, Romano DG, Voyatzis ME (2015) Micromorphological contributions to the study of ritual behavior at the Ash Altar to Zeus on Mt. Lykaion, Greece. Archaeological and Anthropological Sciences

Milek KB, Roberts HM (2013) Integrated geoarchaeological methods for the determination of site activity areas: a study of a Viking Age house in Reykjavik, Iceland. J Archaeol Sci 40(4):1845–1865

Millard AR (2004) Taking Bayes beyond radiocarbon: Bayesian approaches to some other chronometric methods. In: Tools for constructing chronologies. Springer, London, pp 231–248

Miller CE, Goldberg P (2009) Micromorphology and paleoenvironments. In: Larson ML, Kornfeld M, Frison GC (eds) Hell gap: a stratified Paleoindian campsite at the edge of the Rockies. University of Utah, Salt Lake City, pp 72–89

Miller CE, Sievers C (2012) An experimental micromorphological investigation of bedding construction in the Middle Stone Age of Sibudu, South Africa. J Archaeol Sci 39(10):3039–3051

Miller CE, Conard NJ, Goldberg P, Berna F (2009) Dumping, sweeping and trampling: experimental micromorphological analysis of anthropogenically modified combustion features. In: The taphonomy of burned organic residues and combustion features in archaeological contexts, Théry-Parisot, I., Chabal, L. and Costamagno, S. (eds.). Actes de la table ronde, Valbonne, 27–29 May 2008. Pal@ethnologie, 2 : 25.37

Miller CE, Goldberg P, Berna F (2013) Geoarchaeological investigations at Diepkloof Rock Shelter, Western Cape, South Africa. J Archaeol Sci 40(9):3432–3452

Museum of London. (1994). Archaeological site manual. http://www.museumoflondonarchaeology.org.uk/NR/rdonlyres/056B4AFD-AB5F-45AF-9097-5A53FFDC1F94/0/MoLASManual94.pdf

Nicosia C, Langohr R, Mees F, Arnoldus-Huyzendveld A, Bruttini J, Cantini F (2012) Medieval Dark Earth in an active alluvial setting from the Uffizi gallery complex in Florence, Italy. Geoarchaeology 27:105–122

Nielsen AE (1991) Trampling the archaeological record: an experimental study. American Antiquity, 483–503

Parkington J (1976) Coastal settlement between the mouths of the Berg and Olifants Rivers, Cape Province. The South African Archaeological Bulletin, 127–140

Porraz G, Texier PJ, Archer W, Piboule M, Rigaud JP, Tribolo C (2013) Technological successions in the Middle Stone Age sequence of Diepkloof Rock Shelter, Western Cape, South Africa. Journal of Archaeological Science

Ramsey CB (2006) Radiocarbon calibration and analysis of stratigraphy; the OxCal program. Radiocarbon 37(2):425–430

Ramsey CB (2009) Bayesian analysis of radiocarbon dates. Radiocarbon 51(1):337–360

Rentzel P, Narten G (2000) Zur Entstehung von Gehniveaus in sandig-lehmigen Ablagerungen: experimente und archäologische Befunde, Jahresbericht der Archäologischen Bodenforschung des Kantons Basel-Stadt, 1999 (2000), pp. 107–127

Romano DG, Voyatzis ME (2014) Mt. Lykaion excavation and survey project, part 1: upper sanctuary. Hesperia: The Journal of the American School of Classical Studies at Athens 83(4):569–652

Sanchez G, Holliday VT, Gaines EP, Arroyo-Cabrales J, Martínez-Tagüeña N, Kowler A, Lange T, Hodgins GWL, Mentzer SM, Sanchez-Morales I (2014) Human (Clovis)–gomphothere (Cuvieronius sp.) association ~13,390 calibrated yr BP in Sonora, Mexico. Proc Natl Acad Sci 111:10972–10977

Schiegl S, Lev-Yadun S, Bar-Yosef O, El Goresy A, Weiner S (1994) Siliceous aggregates from prehistoric wood ash: a major component of sediments in Kebara and Hayonim caves (Israel). Isr J Earth Sci 43:267–278

Schiegl S, Goldberg P, Bar-Yosef O, Weiner S (1996) Ash deposits in Hayonim and Kebara Caves, Israel: macroscopic, microscopic and mineralogical observations, and their archaeological implications. J Archaeol Sci 23:763–781

Schiffer MB (1987) Formation processes of the archaeological record. University of New Mexico Press, Albuquerque, NM

Shahack-Gross R, Albert RM, Gilboa A, Nagar-Hilman O, Sharon I, Weiner S (2005) Geoarchaeology in an urban context: the uses of space in a Phoenician monumental building at Tel Dor (Israel). J Archaeol Sci 32(9):1417–1431

Sherwood SC, Kidder TR (2011) The DaVincis of dirt: Geoarchaeological perspectives on Native American mound building in the Mississippi River basin. J Anthropol Archaeol 30(1):69–87

Shillito, L. M. (2011). Daily activities, diet and resource use at Neolithic Çatalhöyük: microstratigraphic and biomolecular evidence from middens (BAR Vol. 2232). Archaeopress

Shillito LM, Matthews W, Almond MJ, Bull ID (2011) The microstratigraphy of middens: capturing daily routine in rubbish at Neolithic Çatalhöyük, Turkey. Antiquity 85(329):1024–1038

Sistiaga A, Mallol C, Galván B, Summons RE (2014) The Neanderthal meal: a new perspective on Neanderthal diet using faecal biomarkers. PLoS ONE 9(6), e101045

Stein JK (2008) Geoarchaeology and archaeostratigraphy: a view from a northwest coast shell midden. In: Case studies in environmental archaeology. Springer, New York, pp 61–80

Steno N (1669) De solido intra solidum naturaliter contento dissertationis prodromus: Florence, Maar, 2(27), 181–227

Sullivan III A.P (2008) Time perspectivism and the interpretive potential of palimpsests: theoretical and methodological considerations. In Holdoway and Wandsnider (eds) Time in archaeology: time perspectivism revisited, pp 31–45, The University of Utah Press

Texier PJ, Porraz G, Parkington J, Rigaud JP, Poggenpoel C, Miller C, Tribolo C, Cartwright C, Coudenneau A, Klein R, Steele T, Verna C (2010) A Howiesons Poort tradition of engraving ostrich eggshell containers dated to 60,000 years ago at Diepkloof Rock Shelter, South Africa. Proc Natl Acad Sci 107(14):6180–6185

Vaquero M (2008) The history of stones: behavioural inferences and temporal resolution of an archaeological assemblage from the Middle Paleolithic. J Archaeol Sci 35(12):3178–3185

Villa P, Courtin J (1983) The interpretation of stratified sites: a view from underground. J Archaeol Sci 10(3):267–281

Wadley L, Jacobs Z (2006) Sibudu Cave: background to the excavations, stratigraphy and dating. South Afr Humanit 18(1): 1–26.

Wadley L, Sievers C, Bamford M, Goldberg P, Berna F, Miller C (2011) Middle Stone Age bedding construction and settlement patterns at Sibudu, South Africa. Science 334(6061):1388–1391

Wallace G (2003) Using narrative to contextualise micromorphological data from Neolithic wetland houses. J Wetland Archaeol 3(1):75–92

Weiner S, Goldberg P, Bar-Yosef O (1993) Bone preservation in Kebara Cave, Israel using on-site Fourier transform infrared spectrometry. J Archaeol Sci 20:613–627

Weiner S, Berna F, Cohen I, Shahack-Gross R, Albert RM, Karkanas P, Meignen L Bar-Yosef O (2007) Mineral distributions in Kebara Cave: diagenesis and its effect on the archaeological record. In: *Kebara Cave, Mt. Carmel, Israel—the Middle and Upper Paleolithic Archaeology—part I* (Eds O. Bar-Yosef and L. Meignen), American School of Prehistoric Research Bulletin 49 - Peabody Museum, Harvard University, 131–146

Wheeler M (1954) Archaeology from the Earth. Clarendon, Oxford

Wright GRH (1966) A method of excavation common in Palestine. ZDPV 82:113–124

Yellen JE (1977) Archaeological approaches to the present: models for reconstructing the past. Academic, New York

Zerboni A (2011) Micromorphology reveals in situ Mesolithic living floors and archaeological features in multiphase sites in central Sudan. Geoarchaeology 26(3):365–391