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Sedimentation, re-sedimentation and chronologies in archaeologically-important caves: problems and prospects

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Abstract

Excavations in the photic zones of caves have provided cornerstone archaeological sequences in many parts of the world. Before the appearance of modern dating techniques, cave deposits provided clear evidence for the antiquity, relative ages and co-occurrence of ancient human remains, material culture and fauna. Earlier generations of archaeologists had generally rather limited understanding of taphonomic and depositional processes, but the twentieth century saw considerable improvement in excavation and analytical techniques. The advent of modern dating and chronological methodologies offers very powerful tools for the analysis of cave fill deposits and this has resulted in the recognition of chronological incoherence in parts of some sites, with consequent re-evaluation of previous archaeological disputes. Obtaining multiple dates per context provides a means to assess the integrity and coherence of the archaeological and environmental records from cave fills. In the case of the Haua Fteah (Libya), this technique allowed the recognition of chronological coherence in low-energy depositional environments and limited recycling in high-energy contexts. We provide a conceptual model of the relationship between recycling, sedimentation rate and process energy. High-resolution investigation enables recognition of the complexity of the formation of cave sequences, thus an increasingly sophisticated understanding of human behaviour and environmental relationships in the past, and potentially gives a new life to old data.

Keywords

Caves; sedimentation; dating; chronology; recycling; taphonomy; Haua Fteah

Introduction

This paper deals with issues arising from the mobility and re-deposition of predominantly-clastic sediments in the photic zones (areas reached by at least diffuse daylight), of archaeologically-important caves, particularly from the perspective of chronology and chronological integrity. It therefore complements the paper by Canti and Huisman (this volume) which deals with site formation and diagenesis in anthropogenic and biological sediments in cave fills. The majority of archaeologically-important caves are karst (dissolution) features in limestone or dolomite and the following discussion mostly addresses caves in these lithologies, although caves also form in gypsum, rock salt, sandstone, quartzite and granite, among others. Further, virtually all rock types - other than the very weakest mechanically - can give rise to rock shelters, and these share many properties and issues with caves.

In the early days of Archaeology, caves provided some of the most important evidence for human antiquity, such as the demonstration by Pengelly et al. (1873) of the association of humanly-shaped artefacts with the bones of extinct animals. Caves were the source of the first Neanderthal skeletal material (e.g. Schaffhausen 1861; Fraipont and Lohest 1887), indicating for the first time that other human species had existed in the past, thus being seen to validate early evolutionary theory (e.g. Huxley 1863). The recognition of changing material culture through time, although partly realised from open-air sites, was also further demonstrated and refined from cave excavations. Some of the most important early expositions of regional Palaeolithic and later sequences came from caves in France (Lartet and Christie 1875; de Mortillet 1886; Laville et al. 1980) and the UK (Pengelly et al. 1873; Dawkins 1874). Examples among many influential later expositions of key cave sequences are those for La Ferassie, France (Peyrony 1934; Delporte 1984), Taforalt, Morocco (Roche 1953), Shanidar Cave, Iraq (Solecki 1955, 1963), the Haua Fteah, Libya (McBurney 1967), Niah Cave, Borneo (Harrisson 1964, 1970) and Franchthi Cave, Greece (Jacobsen and Farrand 1987).

The three-dimensional complexities of past processes, sedimentation and chronology reflected by cave fills were not suspected by many early researchers - and indeed many had little idea of, or interest in, the processes which gave rise to the sediment accumulations that they excavated. While, for instance, the excavations at Creswell Crags by Dawkins (1874) were truly ground-breaking at the time, their execution reflected the contemporary limitations of knowledge, with skilled coal miners employed to cut and work back a vertical face in the cave sediments, while the excavator sat in a chair at the cave mouth and selected items visible in the barrows as sediments were cast from the cave, with minimal attention to the details revealed by the shifting exposure and the provenance of the 'finds'. Not all early work was this crude: Pengelly et al. (1873) used what they termed 'prisms' (arbitrary excavation units) to demonstrate the close proximity of lithics and bones of extinct animals in the Brixham Cave, Devon (MacFarlane and Lundberg 2005). Again, no detailed attention was paid to stratification, other than to demonstrate that all finds were stratified beneath a flowstone floor. This is hardly surprisingly given the lack of adequate and safe lighting and the extremely difficult conditions under which the excavators worked.

Later researchers such as Leslie Armstrong, who dug at Creswell Crags from the early 1920s, typically controlled their excavation by measured units. Armstrong controlled his excavation in Pinhole Cave by 1 foot 'boxes' with distances measured in from a datum at the cave mouth and down from a prominent flowstone floor which capped the deposits, enabling recognition of distinct cultural and faunal horizons in the cave fill (Jenkinson 1984; Hunt 1989; Jacobi et al. 1998).

The advent of radiometric dating methods has completely changed approaches to the chronology of cave fills and their archaeology. The first radiocarbon dates required the collection of several hundred grams of charcoal and were extremely expensive, but they revolutionised understanding of the antiquity of modern humans in many parts of the world (Wood, this volume). Thus, for example, the dating of charcoal associated with the 'Deep Skull' of Niah to ~42,000 (radiocarbon) years ago (Harrisson 1959) made this for many years the oldest human remains known anywhere on the planet (Barker et al. 2007a).

Lack of attention to sediments, stratification and stratigraphy is evident in some publications up to the middle of the last century, and even as late as McBurney (1967) and Harrisson (1964, 1970). Thus, McBurney (1967) recognised natural layering in his trench sides in the Haua Fteah (Libya) but his arbitrary excavation units cut across this. Similarly, at Niah, Harrisson (1964, 1970) rejected the complex stratigraphy visible in the baulks of his excavations. In both cases, linear extrapolation of a handful of dates resulted in very simple vertical-accretion models which did not recognise the complexity and discontinuity of sedimentation in these caves (Hunt et al. 2010; Gilbertson et al. 2005, 2013). Their chronological systems relied on observations of a 'continuous drizzle' of material falling from cave roofs and this was extrapolated as a continuing process operating at broadly steady rates for millennia. This type of uniformitarian approach and the assumptions behind it were not uncommon in analyses of cave sedimentation at this time (Anderson 1997). Work of significantly higher quality was done, however, by some mid-Century archaeologists and their geoarchaeologist colleagues (e.g. Movius 1963, 1975, 1977; Farrand 1975).

More recently, excavation by sedimentary context has become widespread, although by no means universal. This important innovation enabled sampling at the level of the depositional event in geomorphologically-active caves, enabling the sophisticated analysis of archaeological site formation and thus a fine-resolution dissection of human behaviour (for instance Movius 1977; Butzer 1984, 1986; Farrand 2001).

In recent years, as the general quality of excavation, stratigraphic work and recording has risen, the capabilities and resolution of dating techniques have also improved. The average number of dates per project has sharply increased because dating laboratories have increased capacities and relatively reduced costs for dates. Innovations including the now almost-universal Accelerator Mass Spectrometry, the ABOX stepped-combustion technique for charcoal (Bird et al. 1999), the ultrafiltration technique for bone (Higham et al. 2006) and dating the bone-specific amino acid hydroxyproline (Marom et al. 2013) have decreased sample sizes, considerably increased the accuracy of radiocarbon dating and the range of reliably datable materials. The INTCAL project has enabled radiocarbon dates to be calibrated to calendar years back to 50,000 years ago (Reimer et al. 2013; Hogg et al. 2013; Wood, this volume).

Many other dating methodologies have also been refined, for instance the single grain technique (Olley et al. 1999; Murray and Wintle 2000) has dramatically improved the accuracy of optically-stimulated luminescence. Careful application of individual dosimetry for flints, together with investigation of their localised mineralogical context has improved the reliability and precision of the Thermoluminescence technique, (Mercier et al. 2007), while application of a variation on the SAR protocol has enabled use of smaller and older samples, fewer dose points and less machine time for dates (Richter and Krbetschek (2006). The use of laser ablation has enabled microsampling and refined dating of bone, teeth and flowstone using the Uranium-series technique (e.g. Pike et al. 2005; Grün et al. 2005), while Diffusion-Adsorption Modelling (Millard and Hedges 1996; Pike et al. 2002) has enabled the post-depositional uptake of uranium in bone to be allowed for (Grün et al. 2014). The U-Pb method has extended the range of Uranium-series dating well beyone the first hominins (Pickering and Hellstrom this volume). Electron Spin Resonance (Grün 1989; Schwartz and Grün 1992) has provided dates beyond the range of the Uranium/Thorium technique and is often used in conjunction with Uranium-series dating (e.g. Grün et al. 2005), Amino-acid racemisation, which has had a chequered history, is now providing reliable relative dates on bird eggshell, mammalian tooth dentine and mollusc shell (e.g. Clarke et al. 2007; Penkman et al. 2008; Torres et al. 2014).

Developments of modelling and statistical techniques have also resulted in advances in dating resolution and chronology construction. The outstanding example is the widely-used Oxcal Bayesian program (Ramsey 1995) which enables modelling of dates and construction of chronologies, but alternative Bayesian and non-Bayesian modelling approaches are also available (e.g. Blaauw 2010; Blaauw and Christen 2011; Shao et al. 2014).

Chronological patterns in cave fills – indications of complex taphonomies

It is becoming increasingly apparent that the chronological pattern in some archaeologically-important caves is not straightforward (e.g. Jacobi et al. 1998; Barker et al. 2007a; David et al. 2007; Mallol et al. 2009; Kourampas et al. 2009; Higham et al. 2010; Bar-Yosef and Bordes 2010; Bordes and Teyssandier 2012; Russell and Armitage 2012; Hunt and Barker 2014; Yravedra and Gómez-Castanedo 2014). Similar conclusions may be drawn from some high-resolution analyses and refitting studies of archaeological artefacts (e.g. Jacobi et al. 1998; Bordes 2003; Bernatchez et al. 2010; Staurset and Coulson 2014) and from detailed sediment and micromorphological analysis (e.g. Bar-Yosef et al. 1996; Albert et al. 1999; Karkanas et al. 2000; Goldberg 2000; Weiner et al. 2002; Karkanas and Goldberg 2010; Berna et al. 2012; Inglis 2012).

Recognition of complex chronological patterns may have major implications for archaeological understanding. For instance, the recognition of mixing of younger and older materials in the Chatelperronian layers at Grotte de Renne by Higham et al. (2010) removes the security of the association of Neanderthal fossils from artefactual evidence for behavioural complexity that had been claimed previously at this site. At the Abri Pataud, high-precision dating provides compelling evidence for the shortness of the occupation phases (Higham et al. 2011). Dating can also explore evidence of contemporaneity. Thus, the Deep Skull of Niah was dated to ~35 ka BP but dates on adjoining contexts were dated to ~42 ka BP. The dating complements geochemical, mineralogical and palynological evidence that this important fossil is an early burial (Hunt and Barker 2014).

Fundamentally, any assessment of the archaeology of a cave relies on the detailed understanding of the chronology of sedimentation (and re-sedimentation). The next section outlines new evidence for chronological incoherence caused by erosion and re-deposition at the Haua Fteah. This type of chronological incoherence is widely seen as problematical, but it is, in fact, highly informative in terms of site formation processes and taphonomy.

New high-resolution work at the Haua Fteah

The Haua Fteah (NE Libya), originally excavated by McBurney (1967) has been the subject of recent reinvestigation using carefully-controlled single-context excavation augmented by a large-scale scientific program (Barker et al. 2007b, 2008, 2009, 2010, 2012; Simpson and Hunt 2009; Hunt et al. 2010, 2011; Inglis 2012; Russell and Armitage 2012; Rabett et al. 2013; Douka et al. 2014; Hill 2014; Simpson 2014). Re-analysis of the sedimentary sequence shows the prevalence of wash and small-scale mudflow in the accumulation of the Haua sequence (Hunt et al. 2010, Inglis 2012).

As part of the work on the cave, previously-unpublished high-resolution dating of the Holocene and Late Pleistocene sequence was carried out by Evan Hill. Exploratory dates on charred seeds showed a considerable spread suggestive of recycling (Hunt et al. 2010; J. Morales pers. comm 2011). Land snails were therefore selected for this exercise because they were judged to be significantly less durable and thus less likely to survive recycling than charred plant macrofossils. Multiple samples, each consisting of a single land snail (*Helix melanostoma* Drap.) were AMS radiocarbon dated from each sedimentary context. The samples were calibrated using Calib 7.1 and dates were adjusted for metabolic fractionation using a method based on assessment of fractionation in modern specimens. Details are given in Hill (2014).

An OxCal plot (Fig. 1) shows that most contexts studied show a considerable range of dates. Some layers, most notably contexts 11001-11011, contained spreads of dates of as much as 6000 years. Other contexts contained very tight clusters of dates. There is a distinct tendency for those contexts which accumulated through high-energy processes such as debris-flows – the origin for contexts 11001-11010 – to contain comparatively large spreads of dates. Those contexts which accumulated in quieter conditions, such as the silts of context 11018, in contrast, contain very tight clusters of dates.

Fig. 1. Oxcal plot of radiocarbon dates on *Helix melanostoma* showing recycling and redeposition in the upper part of Trench M in the Haua Fteah (data from Hill 2014).

Where there is a spread of dates, the youngest date in each context most probably provides a point in time shortly before the context accumulated in its present location. Older specimens in the context likely accumulated on the cave floor or were present in previously-deposited sediments and were then incorporated in their present context by erosion and deposition by high-energy processes.

This data thus most probably indicates episodes of erosion and relocation of stored sediment in the Haua Fteah. Erosion went no deeper than sediments accumulated over the 6000 years prior to the terminal deposition event for a context. Alternatively there were stillstands of up to 6000 years between depositional events, where land snails and other material accumulated as a palimpsest on the cave floor, as suggested by Farrand (2001). In either case, it is likely that recycling of sediments and molluscs was accompanied by localised recycling of other materials including artefacts, faunal and floral remains.

As an example of other material involved in recycling, we provide an excerpt of the previously-unpublished palynological work by David Simpson (Fig. 2). This covers approximately the same stratigraphic interval as shown in Fig. 1. Low-impact preparation methods were used to minimise damage to poorly-preserved palynomorphs (details in Simpson 2014). Sampling in this work followed sedimentary contexts but used a 5 cm sample interval in contexts thicker than this distance.

Fig. 2. Summary pollen diagram of the upper part of the Middle Trench in the Haua Fteah. The diagram covers approximately the same stratigraphic interval as that in Fig. 1. Data from Simpson 2014).

The pollen assemblages from this sequence are dominated either by *Pinus* or Asteraceae or a combination of these taxa. Also present are pollen of grasses, a wide variety of herbs, some maquis species and some desertic taxa (Fig. 2). These assemblages are highly unusual and unlike soil pollen and pollen-trap assemblages in the region around the Haua (Simpson 2014), so present difficulties for interpretation. *Pinus* is a prolific generator of wind-dispersed pollen. Stunted (usually less than 2 m high) *Pinus halepensis* is today very sparse in dry coastal steppe between el Atroun and Derna, to the east of the Haua Fteah, so it is conceivable that high percentages of *Pinus,* with Poaceae and other herbs, might be consistent with some sort of arid pine-scrub steppe, if the pine-dominated assemblages are taken at face value. Asteraceae, on the other hand, are often relatively concentrated in cave sediments because of the activities of ground-nesting bees (Bottema 1975), so it is by no means clear that the peaks of Asteraceae reflect anything more than periods where insects colonised the cave floor. *Pinus* and Asteraceae are, however, extremely resistant to degradation in soils compared with most pollen types (e.g. Havinga 1984). It is therefore argued that elements resistant to corrosion and bacterial degradation such as *Pinus* and Asteraceae would tend to survive burial, exhumation and recycling during erosion episodes better than less resistant taxa. These recycled grains would then have become re-incorporated into the sequence together with pollen relating to the environment at the time of final deposition, thus leading to the extremely high percentages for *Pinus* and Asteraceae (Fig. 2). Fluorescence microscopy (Hunt et al. 2007) was used to attempt a test of this hypothesis, but pollen from assemblages from the Haua did not fluoresce in visible wavelengths, probably because of its general degradation in the cave sediments. Issues relating to the archaeopalynology of caves are further explored in Edwards et al. (this volume).

Processes of cave-mouth sediment deposition and re-deposition and their implications for chronologies

All caves are unstable and complex environments, not least because in geological terms they are ephemeral features that go through a lifecycle of inception, formation, continued modification, unroofing and finally complete erosional removal. Sediment generation, transport and deposition are mediated by the cave morphology, parent rock lithology, bedding and joint patterns, by climate, and by the activities of, and materials produced by plants, animals and people. The predominant sediment sources, transport and depositional media in cave photic zones are:

1. From the cave walls and roof, from which material may be detached by dissolution, granular disintegration, running water, action of ice and/or mineral salts, rockfall and stoping (detachment of rock or indurated sediment slabs from the cave roof)

2. From external sources, by wind, rivers, the sea, glacial ice and/or mass-movement

3. From solutes in groundwaters and meteoric waters through chemically and biochemically-mediated deposition

4. From the actions of animals, plants and humans in introducing and sometimes processing inorganic and organic materials including lithics, nesting materials, bedding, food items, droppings, scats, dung, firewood etc. and in introducing sediments on their feet.

The combined actions of these media and processes result in a considerable variety of sediments, with deposition of particular facies resulting from the actions of particular groups of processes operating in spatially-restricted areas (e.g. Goldberg and Sherwood 2006; Hunt et al. 2010; Canti and Huisman this volume).

Cave sediments are inherently unstable and often prone to post-depositional movement and erosion including by running water, the sea, mass movement, slumping, excavation by animals and people, partial dissolution and subsurface erosion by running water, cavern collapse and, in tectonically active zones, by faulting (Glover 1979; Gilbertson 1989; 1996; Bar-Yosef et al. 1996; Goldberg 2000; Gilbertson et al. 2005, 2013; Dykes 2007; Soficaru et al. 2007; Burney et al. 2008; Yravedra and Gómez-Castanedo 2014). Erosive processes often truncate sequences. The solubility of ash, carbonate and phosphatic minerals and prevalence of mineral-rich groundwater in karst landscapes is of considerable importance for our understanding of cave sediment stratigraphies (Canti and Huismann, this volume). Minerals may dissolve and reprecipitate as a result of changes in carbon dioxide partial pressure, dilution in pore and surface waters, concentration by evaporation and as a response to acidity and redox gradients caused by the presence of decaying organic matter (Karkanas et al. 2000, Goldberg 2000; Weiner et al. 2002; Shahack-Gross et al. 2004; Stephens et al. 2005; Canti and Huisman, this volume). Mineral dissolution and organic decay may cause major changes to sediment volume (Glover 1979; Karkanas et al. 2000; Goldberg 2000) and consequent slumping. A further key issue associated with the circulation of chemically-active fluids within cave sediments is the often-deleterious impact of these fluids on the preservation of organic remains, through dissolution, disruption by crystal growth and so forth (e.g. Shahack-Gross et al. 2004; Stephens et al. 2005; Canti and Huisman this volume).

Conversely, precipitation of minerals may armour surfaces against erosion and provide complete or patchy stability to what otherwise would be structurally-weak sediments. Dissolution or erosional removal of unconsolidated sediments may leave 'bridges' of indurated material behind: later infill of the voids under these 'bridges' may lead to stratigraphic inversions (Coles 1989; Rowe et al. 1989).

Modern geoarchaeological techniques provide ways to identify evidence of past instability and sediment movement, solution and reprecipitation (Canti and Huisman, this volume). Various taphonomic indicators may also provide indications: these include

- ecologically-incoherent faunas and floras,
- the presence only of chemically-resistant body parts such as teeth,

- the presence of indicators of transport such as abrasion, rounding and disarticulation of elements,
- winnowed assemblages, where, for instance there are concentrations of dense, large elements at the bottom of layers laid down by high-energy processes, or concentrations of light, easily-transported elements, typically in fine-grained deposits resulting from ponding.

Close-interval dating provides another tool in the cave geoarchaeologist's toolkit, since it will provide evidence of dating reversals and of chronological incoherence, as discussed above (Fig. 1). In this case the archaeologist must consider the degree to which the archaeology from layers with evidence of chronological incoherence may be *in-situ*, and the chronological resolution possible, when assessing evidence for human behaviour.

There is a general relationship between the energy of processes of deposition, the sedimentation rate and the degree of chronological resolution (caricatured in Fig. 3). At very low sedimentation rates, poor chronological resolution is likely. In many sites, most of the time encompassed by depositional sequences is not recorded in the sedimentary record except as hiatuses between layers. For instance Hunt et al. (2010) recognised no more than 22 depositional episodes, most lasting for not more than a few minutes, during the Holocene in the Haua Fteah. This leads to the possibility that several phases of human activity may be condensed into a palimpsest (Farrand 2001). With low sedimentation rates and high process energy, particularly with water flows, there is a good chance that lighter artefacts will be removed (winnowed) from the deposition site, leaving only a lag of large artefacts and the heavier skeletal elements. As sedimentation rate rises, if process energy remains low, then chronologically-defined horizons will become more widely separated. With increasing process energy, however, there is an increasing probability that erosion of previously – deposited sediment will occur, and that the resulting contexts will contain recycled as well as *in-situ* material.

Fig. 3. Conceptual model of the relationship between sedimentation rate, process energy and the probability of chronologically-resolved in-situ archaeology.

Conclusion

It is quite probable that the days of heroic-scale cave excavations are limited, simply because in the current climate of financial austerity the level of resources necessary for a major cave excavation will be only very infrequently available. Further, most of the early cave excavations took place with almost total disregard for health and safety, something that we could not contemplate today.

Cave sediments are often staggeringly rich in a very wide variety of material and are likely to be complex chronologically and in three dimensions. The quantities of material preserved in cave fills can be enormous: it is estimated that over half a million finds were generated during McBurney's (1967) excavation of the Haua Fteah (G. Barker, pers. comm. to COH, 2006). It is essential that new excavations are embarked upon with the expectation of recovering this range and abundance of material and to take account of the sheer richness and unpredictability of the cave record, with detailed plotting in three dimensions of sedimentary facies, fossils and artefacts and high-resolution dating and geoarchaeological sampling. It follows that archaeological materials should be analysed in conjunction with the chronological, environmental and taphonomic datasets from excavations, rather than becoming detached from them. This approach will enable us to focus our attention on the human behaviours in the context of environmental change and the physical, chemical and biotic processes which together led to the formation of the cave archaeological record.

We suggest that reappraisal of many previously-excavated cave fills and the assessment of new excavations using the sophisticated dating and modelling methods now available will result in the increasing recognition of chronological complexity. Quantifying this complexity in any depositional unit will become important in assessing the degree of interpretation which may be applied to the archaeology from that context.

At present, innovation in dating and chronology-building techniques applicable to cave sediment sequences appears to be in a healthy state. The new methodologies mentioned in this short review offer enormous possibilities for archaeological research, particularly when applied in conjunction with the geoarchaeological methodologies described by Canti and Huisman (this volume) and the multitude of other archaeological science techniques recorded in the pages of this journal.

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List of Figures

Fig. 1: Oxcal plot of radiocarbon dates on *Helix melanostoma* showing recycling and redeposition in the upper part of Trench M in the Haua Fteah.

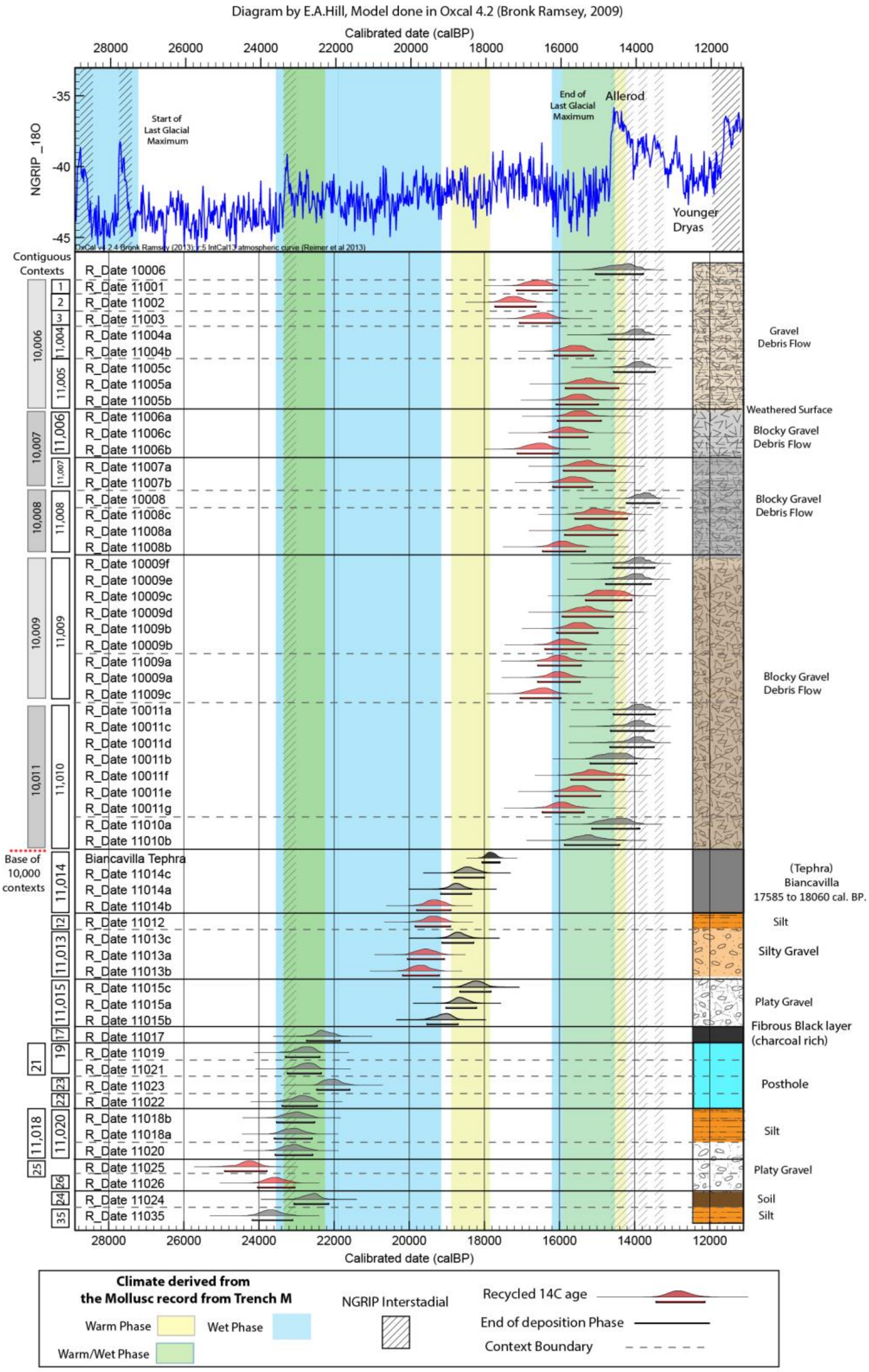

Fig. 2. Summary pollen diagram of the upper part of the Middle Trench in the Haua Fteah. The diagram covers approximately the same stratigraphic interval as that in Fig. 2.

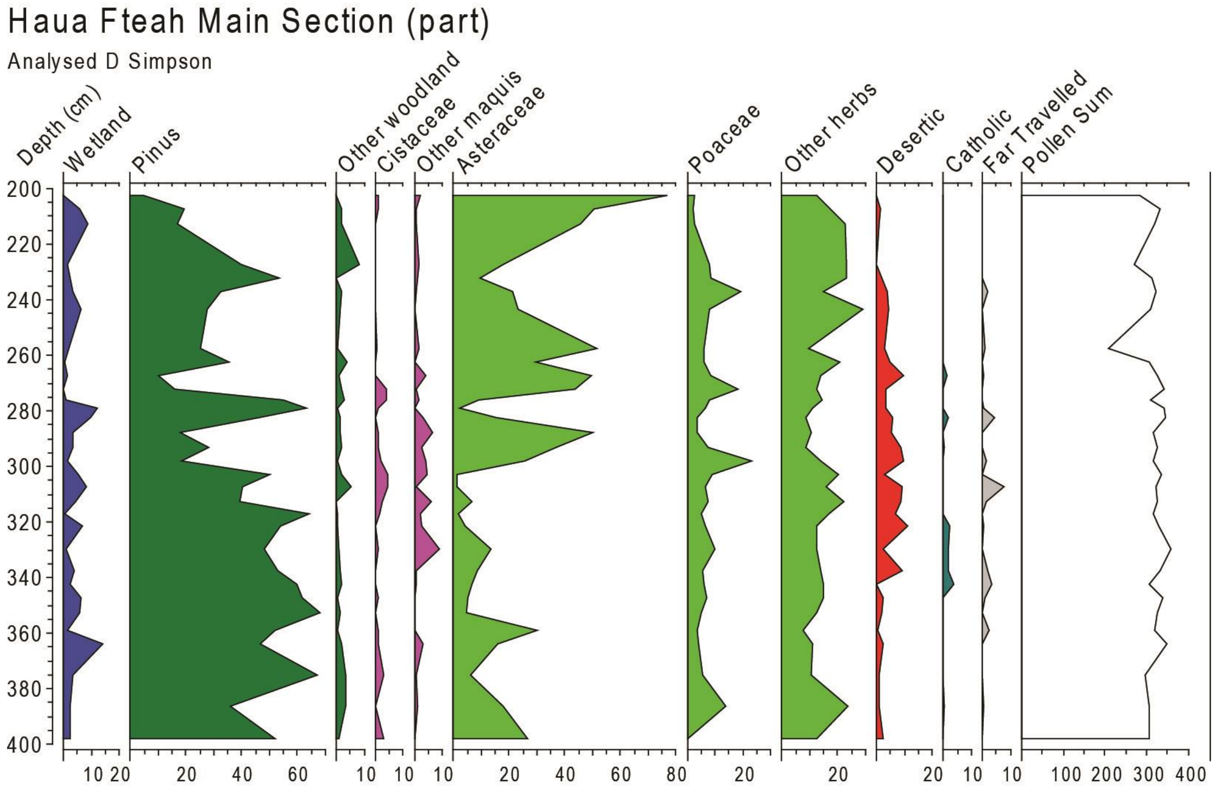

Fig. 3. Conceptual sketch of the relationship between sedimentation rate, process energy and the probability of chronologically-resolved *in-situ* archaeology.