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Sediment Sources and Terminal Pleistocene Geomorphological Processes Recorded in Rockshelter Sequences in North-west Greece

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INTRODUCTION

The sedimentary sequences preserved in rockshelters can provide valuable records of past geomorphological processes (e.g. Farrand, 1979; Patton and Dibble, 1982; Gillieson et al., 1986). This chapter is concerned with shallow rockshelters and cave-mouth environments in limestone terrains (rather than deep caves and subterranean karstic caverns) which offer a degree of protection from subaerial processes but which can also trap and retain clastic sediments from a variety of off-site (allogetic) sources. Some rockshelters in limestone karst environments have formed long-term depositional sinks for materials derived from a wide range of allogenic and autogenic sources with sedimentary records occasionally extending back to the Middle Pleistocene (see Farrand, 1979; Laville et al., 1980; Butzer, 1981; Huxtable et al., 1992). Thus, as landscape features, many rockshelters demonstrate considerable longevity and this is commonly due to the presence of a resistant host limestone bedrock. These hard limestones usually contain only very small amounts (< 1%) of insoluble material (Butzer, 1981; Ford and Williams, 1989; Woodward, 1997a) and this purity means that the potential for the on-site production of fine-grained residues from chemical weathering is limited. Furthermore, as such sound rocks tend to liberate few fines – even where frost action is important – allogenic fine sediments often dominate the fine components of the rockshelter sedimentary record (e.g. Butzer, 1981; Woodward, 1990; Bar-Yosef, 1993; Gale et al., 1993). The importance and variety of allogenic sediment inputs within cave and rockshelter sequences have been recognised for many years. For example, Schmid (1969: 156) pointed out the following:
"Observation of the geological conditions in the neighbourhood of a cave enables one to judge from where and how alien substances got into the cave: because a cave impinged upon another rock formation inside the hill or because particles reached the cave floor through crevices and in percolating water from an overlying rock formation, or when gravel, erratic pieces, loess or soil were washed in from the hillside through cracks in the walls of the cave."

Using an appropriate range of sediment properties to trace the provenance of the sediment imports and their variation through time, it is possible to relate them to the operation of particular geomorphological processes in the wider environment and, with good dating control, such rockshelter sediment records can assume considerable palaeoenvironmental significance.

It is well known that rockshelter environments were attractive habitation and activity sites for prehistoric humans, and their sedimentary sequences can contain rich assemblages of faunal remains, stone tools and other artefacts (e.g. Gamble, 1986; Bailey, 1997a). Thus, rockshelter sediments are commonly studied as part of the archaeological excavation of Palaeolithic, Mesolithic and Neolithic sites. The value of sediment studies is widely appreciated and the analysis of rockshelter sediments is now an established part of geoarchaeology. Many geologists and geomorphologists have participated in archaeological projects to provide stratigraphical and environmental context for the archaeological record. Indeed, several analytical and interpretative frameworks have evolved (Farrand, 1975, 1985; Laville, 1976; Collett, 1979; Bar-Yosef, 1993; Goldberg et al., 1993) and recent developments in the micromorphological and sedimentological study of rockshelter sequences have allowed detailed reconstructions of past site conditions and human activities (Macphail and Goldberg, 1995; Tsatskin et al., 1995; Woodward, 1997a,b). Nonetheless, it can be argued that many studies of rockshelter sediment records have tended to focus on the site sediments without fully considering the wider environmental context and the nature, composition and age of adjacent sedimentary environments and the possibility of material exchanges between them (see Laville et al., 1980). In a discussion of the work on the classic Palaeolithic sites in the Perigord region of south-west France, Vita-Finzi (1978: 44) observed that 'the growing concern with climatic chronology came to divert attention into caves and shelters and away from their environs'.

This chapter aims to highlight the importance of viewing rockshelter sediments as part of wider and dynamic geomorphological systems and to show how careful integration of on-site and off-site sequences – through a consideration of fine sediment provenance – can improve our understanding of rockshelter sediment records and the geomorphological processes involved in their formation. Such an approach can also aid our understanding of the relationship between the cultural record and environmental change, but these archaeological issues will not be pursued here (see Woodward, 1997a). To illustrate these themes and some of the problems involved in the interpretation of rockshelter sediment records, data are presented from two neighbouring yet contrasting rockshelter sites: Klithi and Megalakkos in the Pindus Mountains of north-west Greece. These sites contain important Late Upper Palaeolithic records and sedimentary sequences spanning the last glacial–interglacial transition (Bailey, 1997a,b).
ROCKSHELTER SEDIMENT RECORDS AND ENVIRONMENTAL CHANGE: COARSE AND FINE SEDIMENT COMPONENTS

Rockshelter sediments are typically composed of a range of poorly sorted coarse and fine clastic materials, with the former often produced on-site from mechanical weathering of the host limestone strata (Figure 27.1). However, the palaeoclimatic significance of the sedimentary units containing coarse angular rock fragments (commonly termed éboulis) and the significance of any variations in shape and calibre within them has been strongly debated and their interpretation is fraught with uncertainty (see Laville, 1976; Collcutt, 1979; Farrand, 1981, 1985; Bailey and Woodward, 1997).

Figure 27.1 Poorly sorted, coarse-grained angular limestone rock fragments with a fine-grained sediment matrix. These sediments were exposed in the upper 2 m of the Late Pleistocene sedimentary fill at the rockshelter site of Klithi in the Voidomatis Basin. They were exposed in the deep section that was excavated in 1983 (see Bailey and Woodward, 1997 and Figure 27.8)
Some workers have associated their presence with a single geomorphological process such as frost action (e.g. Laville, 1976). However, several authors have observed that a wide range of mechanisms can liberate coarse angular rock fragments from a bedrock wall and it is unwise to read too much into such deposits in terms of palaeoclimatic conditions (Vita-Finzi, 1978; Collett, 1979; Farrand, 1981), especially when the frequency of bedding planes and joints is highly variable and rockfall-triggering seismic activity is important (Bailey and Woodward, 1997). This debate will not be elaborated here, but it is relevant because it can be argued that in many contexts the fine sediment fraction within a rockshelter sequence offers a more reliable basis for reconstructing past environments and geomorphological processes for the following reasons:

- Fine sediments within rockshelters may be protected from the subaerial weathering processes that affect surface materials; in certain contexts these deposits can provide a sensitive record of local and regional environmental change.
- As they can be dominated by materials derived from a range of proximal and distal allogenic sources, the fine sediments constitute a potentially important interface between the rockshelter sediment record (and the archaeological data within it) and the off-site Quaternary sedimentary record.
- The fine sediments within the rockshelter sequence may contain evidence of geomorphological events and sediment fluxes that have not been preserved in the wider environment because of erosion and weathering.
- In contrast to the poorly sorted coarse-grained products of host bedrock breakdown, many primary fine sediment properties display limited lateral variation within coeval depositional units.

In addition, silts and clays are commonly abundant throughout rockshelter sequences and recent developments in coring techniques for sampling rockshelter sequences (which yields small samples; see Bailey and Thomas, 1987) and micromorphological analysis (Courty et al., 1989), have focused attention on the significance of the fine sediment fraction (Woodward, 1997a). It is important to bear in mind, however, that both penecontemporaneous and post-depositional (diagenetic) processes (chemical and biological – including human activity) can influence the nature of the fine sediment fraction (Butzer, 1982; Bull, 1983; Bar-Yosef, 1993; Macphail and Goldberg, 1995; Tsatskin et al., 1995). The nature and intensity of these modifications will vary spatially and temporally in accord with the geomorphological context. At sites where prehistoric occupation has been intensive, one of the main challenges facing such investigations is the development of approaches which allow the natural and anthropogenic signatures in the sedimentary record to be decoupled (see Ellwood et al., 1997; Woodward, 1997a). This is rarely straightforward, but the potential for rockshelter fine sediments to provide a bridge between the on-site archaeological record and the off-site sedimentary record (as in alluvial, lacustrine, aeolian, marine or glacial sequences) has yet to be fully exploited; the use of sediment provenance techniques is an important way of exploring this potential.

The value of these environmental archives is enhanced considerably when the fine sediment sources can be identified and related to the operation of particular geomor-
phological processes in the wider Pleistocene or Holocene environment. As far as the study of rockshelter sediment records is concerned, it is also worth noting that recent developments in AMS radiocarbon, luminescence, ESR and uranium-series dating techniques (e.g. Schwarcz et al., 1988; McDermott et al., 1993; Mercier and Valladas, 1994; Gowlett et al., 1997) have not only allowed issues of temporal resolution, rates of sedimentation and the significance of unconformities to be addressed with much greater precision, but they have also meant that on-site/off-site and inter-site correlations can be established with some confidence (Campy and Chaline, 1993; Bailey 1997a,b). It is important to appreciate that sedimentation rates can be highly variable both within and between individual rockshelter sites (Bailey et al., 1983; Campy and Chaline, 1993) and episodes of erosion can remove portions of the stratigraphic record. Good dating control is therefore essential to identify the significance of any unconformities and the duration of any major gaps in these records (see Farrand, 1993). Furthermore, in order to establish the wider geomorphological and stratigraphical context of a particular rockshelter sequence, and the character of potential sediment sources (and their variation over time), the study of such records has to be accompanied by geological and geomorphological investigations of the surrounding area (see Vita-Finzi, 1978; Farrand, 1985; Woodward et al., 1994, 1995; Macklin et al., 1997).

**SOURCES AND PATHWAYS FOR ROCKSHELTER FINE SEDIMENTS**

All rockshelters lie within a catchment for both proximal and distal fine sediment source components which is broadly defined by the aspect, geometry and geomorphological setting of the site. Fine sediments can be delivered to the rockshelter via a series of processes and vertical and lateral pathways (Figure 27.2). For a given site this could involve contributions from, for example, aeolian activity, fluvial and colluvial transport, and vertical infiltration through karst conduits. Some examples of these fine sediment delivery mechanisms reported from rockshelter sites in various environments are listed in Table 27.1. The importance of these sources and transfer processes will vary over time and between sites as environmental conditions change. The following sections discuss the nature of rockshelter sediment records and the processes and pathways involved in fine sediment accumulation.

Fine-grained sediments (silts and clays) are the most widespread clastic deposits in caves and rockshelters and their origins are the most diversified (Ford, 1975; Jennings, 1985; Ford and Williams, 1989; Table 27.1). Indeed, it is often helpful to differentiate between proximal and distal sources for alloigenic fine sediments (Woodward, 1997a). For example, while aeolian processes can rework local silts and sands from a seasonally dry braided floodplain or littoral zone and deposit them within a neighbouring rockshelter site (Farrand, 1975), wind action can also deliver fine dust and tephra from distant sources hundreds of kilometres away (Vitaliano, et al., 1981; Pye, 1987, 1992; Table 27.1).

At this point it is useful to consider a simple sediment budget for the various potential fine sediment sources and sinks involved in the transfer of material into and through a typical karst environment (Figure 27.2). This approach serves to
Figure 27.2  Rockshelter sediment sources and pathways and associated geomorphological processes. See text and Table 27.1 for explanation. (This hypothetical example shows a limestone rockshelter in a riparian or littoral setting. Rockshelters and caves can develop in a range of ways and may also form in granites, sandstones and other lithologies)

highlight the dynamic nature of the karst sediment system and this broader framework should be borne in mind when considering the origin of a rockshelter or cave-mouth sequence which includes a considerable fine sediment component. Indeed, much of the fine fraction may represent the end-product of a complex series of sources, pathways, stores and reworking episodes over an unknown timescale. For example, the subsurface karst environment forms just one component of the sediment delivery system portrayed in Figure 27.2 for which White (1993) has identified three main sources of fine sediment:

- Sinking streams draining from allogenic recharge areas carry a clastic load which is discharged into swallow holes and carried through the conduit system.
- Weathering debris derived from the insoluble residue of the limestone dissolved at the soil–bedrock contact is flushed into sinkholes and joints to the underlying conduit system.
- The enlargement of caves and conduits by solution in the subsurface also leaves behind the insoluble fraction of the bedrock.

The amount of sediment generated from each of these sources will vary in time and space as environmental conditions and host bedrock properties change. All of these
Table 27.1 Examples of geomorphological (1 to 5) and anthropogenic (6) processes and the fine sediment deposition associated with them in rockshelter sites

1. Infiltration  Fine sands, silts and clays can be flushed through joint spacings, enlarged bedding plane partings and conduits such as roof cracks in the limestone bedrock. The sediments are commonly derived from soils and sediments washed into the karst system or from 'stratigraphic leakage' from overlying rocks. Reworked loess and terra rossa may be introduced into rockshelters by this process (see Bar-Yosef, 1993). The infiltration mechanism has been reported by several workers including Jancin and Clark (1993), Farrand (1988) and Woodward (1997b).

2. Colluvial processes  These may involve a range of sediment transfer mechanisms including periglacial processes, mass movements and slope wash processes. The latter may include fines washed down gorge walls during storm events which may have exited the karst drainage system via flood-filled conduits. There may be some overlap with infiltration processes. Butzer (1981) identified the erosion and transport of sands and silts by wash processes from external slopes into the rockshelter entrance as an important geomorphological process in Cantabrian Spain.

3. Aeolian processes  Sands, silts and clays can be deposited within rockshelter settings by wind activity. These materials can be derived from a wide range of proximal and distal sources. Tephra and loess can be transported long distances (Pye, 1987) and local deflation zones can be important (Farrand, 1975; Woodward, 1997a). The sedimentary sequence at Franchthi Cave in southern Greece contains the Late Pleistocene Y5 tephra which originated over 800 km away in the Campanian volcanic Province of Italy (Vitaliano et al., 1981).

4. Fluvial processes  Fluvial processes can deposit suspended load and bedload sediments within rockshelter sites and the calibre of the sediments will depend on the magnitude of the fluvial events and the local geomorphological setting. Rockshelter environments may form important slackwater sedimentation zones and such deposits have been reported at Boi la in the Voidomatis basin (Macklin et al., 1988; Hamlin et al., see Chapter 25). At the Arenosa rockshelter in the Pecos River in west Texas, USA, Patton and Dibble (1982) report the presence of slackwater sediments intercalated with aeolian sediments and archaeologically rich layers in a sequence that spans much of the last 10,000 years.

5. Littoral zone processes  Coastal, estuarine, or lake shore environments with short- and long-term fluctuations in water level can inundate rockshelters producing sequences of marine or lacustrine sediments. These may interdigitate with aeolian or colluvial sediments. The basal sediments at Danger Cave in Utah were deposited by Lake Bonneville before it dried out at the end of the last cold stage. The sequence at Kastritsa rockshelter near Lake Ioannina in northwest Greece contains beach sediments dated to the Last Glacial Maximum when the site was located on the lake shore (see Bailey et al., 1983).

6. Human activity  Fine sediments resulting from human activities take a range of forms and are present in many sites. These may include fine alluvial sediments dragged into a site on wet carcasses and the waste products of flint tool manufacture (microdebitage). The latter may also be considered as allogenic materials as the raw materials (flint or chert) would have been imported into the site. Butzer (1981) has identified distinctive sedimentary units in Cantabrian rockshelters where the contribution from flint napping debris is close to 100 percent. Between c. 11,500 and 9500 years BP at Franchthi Cave, human imports and debris markedly increased the sedimentation rate (Farrand, 1988). Human occupation will also increase the organic content of the sediments, and ash deposits from hearths can form a significant component of the fine matrix (see Bailey and Woodward, 1997).

\* This list is not exhaustive and coarse sediments (>2 mm), organic materials and chemical precipitates, for example, are not considered here. The aspect and geometry of the site and the local geomorphological setting are important controls on sediment flux, sediment source and the nature and extent of any post-depositional modifications. It is also important to appreciate that many rockshelters do not contain sedimentary records because of limited sediment supply or removal by erosion.
materials can be deposited within a rockshelter or cave entrance setting by infiltration and washing through the limestone mass or via external pathways such as slopewash down the cliff face above the site or within the suspended load of a resurgent stream. Unweathered fine sediments may also enter the karst drainage system via ‘stratigraphic leakage’ from unconsolidated clastic rocks which overlie the limestone beds (Jancin and Clark, 1993). For the rockshelter depositional environment – especially in the case of large sites in exposed settings – it is particularly important to consider the non-karstic pathways for sediment transfer (Figure 27.2) and the textural and lithological properties of the rockshelter fine sediment can be used to identify the sources involved (Woodward, 1990; Gale et al., 1993).

A CASE STUDY: THE ROCKSHELTERS OF THE LOWER VIKOS GORGE, NORTH-WEST GREECE

The Kliathi and Megalakkos rockshelters are both located at an altitude of c. 430 m above sea level in the Lower Vikos Gorge of the Voidomatis River, north-west Greece, in Palaeocene to Eocene limestone bedrock (Figure 27.3). The aspect, geometry and geomorphological setting of the two rockshelters are quite different and their main characteristics are listed in Table 27.2. The headwater catchments of the Voidomatis lie in some of the formerly glaciated limestone terrain of the Northern Pindus Mountains and in lower elevation flysch terrains to the south (Woodward et al., 1995; Smith et al., 2000; Figure 27.3). The geology and geomorphology of this catchment has been described by Bailey et al. (1997) and Hamlin et al. (see Chapter 25) and will only be presented in outline here. Kliathi is located in the main Lower Vikos Gorge at a level approximately 30 m above the right bank of the Voidomatis River (Figures 27.3 and 27.4(a)). The site of Megalakkos is located in a narrow, steep-sided tributary ravine approximately 100 m upstream of the point where it joins the main channel of the Voidomatis River (Figures 27.3 and 27.4(b)). Flysch rocks are present above the limestone bedrock on both sides of the Lower Vikos Gorge and these areas are drained by a series of steep tributary streams (Figure 27.3).

Kliathi was excavated between 1983 and 1988 as part of the Kliathi Project and less extensive excavations were carried out at Megalakkos in 1986 and 1987 (Bailey, 1997a). The rockshelter site of Boila is located at the downstream end of the Lower Vikos Gorge near the Konitsa Basin (Figure 27.3) and this site was excavated between 1993 and 1997 (Kotjabopoulou et al., 1997). The excavations at Kliathi and Megalakkos were accompanied by a wide range of off-site studies into the Quaternary history of the Voidomatis basin and the wider Epirus region (see Bailey, 1997a,b). This included a detailed investigation into the nature and timing of Late Pleistocene river behaviour and alluvial sediment source variations (Lewin et al., 1991; Woodward et al., 1992) and this work has continued as fresh approaches and dating techniques have been developed (Woodward et al., 1994; Macklin et al., 1998; Hamlin et al., see Chapter 25).
Figure 27.3 (a) A simplified map of the Voidomatis River basin showing the major terrain units, the main rock types and the drainage network. (b) The Lower Vikos Gorge in the Voidomatis River basin and the location of the major rockshelters of Klithi, Megalakkos and Boila (modified after Gowlett et al., 1997). Each site contains Late Pleistocene sediments and Late Upper Palaeolithic lithic and faunal materials. The sediments at Boila are being studied by D. Panagiotis Karkanias and this work is still in progress. (c) The location of the study basin in Epirus, north-west Greece.

FIELD AND LABORATORY METHODS AND FINE SEDIMENT TRACER PROPERTIES

The Megalakkos sequence was logged, photographed and sampled in the field from both natural exposures and those revealed during the archaeological excavations (Figure 27.4(c)). The sedimentary sequence at Klithi has been described in detail by Bailey and Woodward (1997). The upper 2 m of the Klithi sediments are extremely rich in Late Upper Palaeolithic stone tools, faunal remains and other cultural materials,
### Table 27.2 The main features of the Klithi and Megalakkos rockshelters in the Lower Vikos Gorge of the Voidomatis River basin

<table>
<thead>
<tr>
<th></th>
<th>Klithi</th>
<th>Megalakkos</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Main gorge wall</td>
<td>Tributary ravine</td>
</tr>
<tr>
<td><strong>Aspect</strong></td>
<td>South facing</td>
<td>South-west facing</td>
</tr>
<tr>
<td><strong>Host bedrock</strong></td>
<td>Palaeocene to Late Eocene</td>
<td>Palaeocene to Late Eocene</td>
</tr>
<tr>
<td></td>
<td>limestone</td>
<td>limestone</td>
</tr>
<tr>
<td><strong>Floor area</strong></td>
<td>300 m²</td>
<td>&lt;30 m²</td>
</tr>
<tr>
<td><strong>Maximum width of shelter</strong></td>
<td>30 m</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td><strong>Height of shelter brow</strong></td>
<td>c. 10 m</td>
<td>c. 6 m</td>
</tr>
<tr>
<td><strong>Altitude (a.s.l.)</strong></td>
<td>c. 430 m</td>
<td>c. 430 m</td>
</tr>
<tr>
<td><strong>Elevation above local valley floor</strong></td>
<td>30 m</td>
<td>c. 10 m</td>
</tr>
<tr>
<td><strong>Sediment thickness</strong></td>
<td>&gt; 7 m</td>
<td>&gt; 5.5 m</td>
</tr>
<tr>
<td><strong>Archaeology</strong></td>
<td>Late Upper Palaeolithic</td>
<td>Late Upper Palaeolithic</td>
</tr>
<tr>
<td><strong>Period of occupation (years BP)</strong></td>
<td>c. 16500 to 10000</td>
<td>c. 16500 to 10000</td>
</tr>
<tr>
<td><strong>Intensive LUP occupation</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Number of $^{14}$C dates</strong></td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 27.4  The geomorphological setting of Klithi and Megalakkos rockshelters in the Lower Vikos Gorge (see Figure 27.3 and Table 27.2).  

(a) Klithi is located 30 m above the main channel of the Voidomatis River in the central part of the Lower Vikos Gorge. The river flows to the left beneath the site and the gorge wall is approximately 150 m high at this point.  

(b) Megalakkos is located in a narrow right bank tributary ravine which joins the main Voidomatis channel upstream of Klithi.  

(c) Part of the Late Pleistocene sedimentary sequence at Megalakkos. Note that some of the fill has been eroded away.
while all the available evidence suggests that the older sediments below (before c. 16 500 years BP) are sterile. The Klithi sequence was studied from sections exposed during the archaeological excavations and from a series of sediment cores obtained from drilling programmes conducted in 1986 and 1988. Core Y25 was obtained in 1986 and reached a depth of approximately 7 m (Bailey and Thomas, 1987). This core was subdivided into 56 sediment samples and this sequence is discussed below and compared to the Megalakkos fine sediments.

In order to determine the provenance of the rockshelter fine sediments at each site, a range of analyses were undertaken (Table 27.3). All the sediment samples from Klithi and Megalakkos were screened through a 63 μm sieve to obtain the silt and clay fraction. Particle size analysis of the <63 μm fraction was carried out using the computer-interfaced SediGraph 5000ET system described by Jones et al. (1988). This provided detailed information on the silt (63 – 2 μm) fraction at half phi intervals as well as total clay content. All samples were dispersed in calgon and organic materials were removed by hydrogen peroxide using standard methods prior to particle size analysis. The proportion of insoluble residue in bedrock and Quaternary sediment samples was determined by weighing following dissolution in dilute hydrochloric acid (see Gross, 1971; Macleod, 1980; Pye, 1992). The proportion of non-carbonate silt present in the <63 μm fraction was estimated by subtracting the clay content from the insoluble residue fraction for each sample. X-ray diffraction (XRD) analysis of bulk (<63 μm) sample powders was carried out following the methods described by Woodward et al. (1992) and low-frequency magnetic susceptibility measurements were made on the <1 mm fraction of the Klithi core sediments using a standard Bartington meter.

<table>
<thead>
<tr>
<th>Table 27.3</th>
<th>The textural and lithological properties used to establish the source of the fine sediments at Klithi and Megalakkos rockshelters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment property</td>
<td>Size fraction</td>
</tr>
<tr>
<td><strong>Particle size modes &lt;63 μm</strong></td>
<td></td>
</tr>
<tr>
<td>Coarse silt content</td>
<td>16–63 μm</td>
</tr>
<tr>
<td>Fine silt content</td>
<td>2–8 μm</td>
</tr>
<tr>
<td>Clay content</td>
<td>&lt; 2 μm</td>
</tr>
<tr>
<td><strong>Lithological properties</strong></td>
<td></td>
</tr>
<tr>
<td>Non-carbonate silt content</td>
<td>63–2 μm</td>
</tr>
<tr>
<td>CaCO₃ content</td>
<td>&lt; 63 μm</td>
</tr>
<tr>
<td>Bulk mineralogy (XRD)</td>
<td>&lt; 63 μm</td>
</tr>
<tr>
<td>Magnetic susceptibility (X)</td>
<td>&lt; 1 mm</td>
</tr>
</tbody>
</table>

**LOCAL BEDROCK PROPERTIES**

The limestone bedrock in the Lower Vikos Gorge can be classified as extremely pure (Bögli, 1980) with a mean insoluble residue content of just over 0.5 percent (Table 27.4). The particle size characteristics of the acid-insoluble residues from two bedrock samples are shown in Figure 27.5(a). This non-carbonate material is dominated by clay and fine silt, and coarse silt is almost absent. The clay content of these bedrock
residues from Kliithi and Megalakkos is 75.6 percent and 68.5 percent respectively. On either side of the Lower Vikos Gorge the resistant limestone rocks are overlain by Late Tertiary flysch sediments (Figure 27.3) which comprise thinly bedded alternations of hard sandstones and softer, fissile siltstones (Bailey et al., 1997). The flysch rocks are susceptible to gullyling and fluvial erosion and are an important source of suspended sediment in the modern river (Woodward et al., 1992). Flysch-derived materials commonly form the matrix in stratified limestone scree deposits. In the Voidomatis River basin, as in many other Mediterranean mountain karst environments, lithological variability is limited and the major rock formations (limestone and flysch in this case) can be differentiated on the basis of simple bulk mineralogy (Figure 27.5(b)) and the particle size characteristics of the non-carbonate fraction. The mineral suite in the flysch rocks includes quartz, plagioclase, calcite and various clay minerals.

THE MEGLALAKKOS ROCKSHELTER SEDIMENTS

Megalakkos is a small rockshelter with a narrow opening less than 5 m wide (Figure 27.4(b) and (c)). It contains at least 5.5 m of Late Pleistocene and Holocene sediments.

Figure 27.5(a) The particle size characteristics of the acid-insoluble residue of the host limestone bedrock at the Kliithi and Megalakkos rockshelters. Note the virtual absence of coarse silt in these residues. (b) Bulk XRD traces of powdered limestone and flysch bedrock and a sample of fine-grained sediment from Unit 7 in the Megalakkos sequence (see text and Figure 27.6)
Part of the deposit has been removed by recent slope failure, producing excellent natural sections in almost the entire sequence (Figure 27.4(c)). The sediments at Megalakkos have been subdivided into 12 lithostratigraphic units (Figure 27.6) and these comprise four facies types:

1. **Facies A**: a finely laminated yellow/brown clayey-silt facies devoid of coarse limestone clasts and forming sharp contacts with adjoining units. Units 3, 5, 7, 10 and 12.
2. **Facies B**: a poorly stratified, matrix-supported, angular limestone debris facies characterised by poorly sorted, angular clasts with a significant proportion of clayey-silt matrix. Units 1, 4, 6 and 9.
3. **Facies C**: a well-sorted, stratified deposit of angular limestone clasts, partly clast-supported with a yellow/brown silty matrix. Units 2 and 11.
4. **Facies D**: a fine fluvial gravel facies of well-rounded flysch clasts up to 25 mm (b axis). Some evidence of imbrication and largely matrix-supported. Unit 8.
The Megalakkos sequence is noteworthy because it contains sediments characterised by coarse angular limestone clasts that are rich in Late Upper Palaeolithic materials (Units 4, 6 and 9) interbedded with distinctive, fine-grained sedimentary units that are archaeologically sterile (Figure 27.6). The fine-grained Facies A sediments are of particular interest and a number of approaches were employed to establish their depositional context and source.

The lithological and textural characteristics of the fine sediments at Megalakkos indicate that they are derived from the local flysch rocks and flysch-derived soils that lie above the limestone karst mass (Figure 27.3). XRD traces illustrate the close similarity between the mineralogy of the flysch bedrock and the fine-grained sediments at Megalakkos (Figure 27.5(b)). In contrast to the limestone bedrock residues
(Figure 27.5(a)), the fine sediments within the Megalakkos sequence are characterised by a pronounced mode in the coarse silt range (Figure 27.7). The main tributaries in the Lower Vikos Gorge drain catchments with headwaters in the local flysch terrain (Figure 27.3) and samples of fine-grained bed sediment were collected from a number of these tributaries. Typical particle size curves for these sediments are also shown in

**Figure 27.7** Typical particle size curves for the fine-grained sediments at Megalakkos and for contemporary fine bed sediments from several tributaries in the Lower Vikos Gorge (compare with Figure 27.5)
Figure 27.7. These samples have been sorted by fluvial action and the average clay content is c. 9 percent. For each of these samples, the proportion of fine, medium and coarse silt is very similar to the fine sediments at Megalakkos (Figure 27.7).

It could be argued that the Facies A sediments have much in common with typical loess sediments as described by Pye (1987), but Megalakkos is in a deep, sheltered ravine which is not conducive to the receipt of aeolian materials. Moreover, field observations and micromorphological analysis of the fine-grained units at Megalakkos have shown that these sediments are finely laminated and were deposited from suspension in a shallow, low-energy ponded environment (see Bretz, 1942; Bull, 1981). These flysch-derived sediments are infiltrates and were washed through the karst system by sediment-laden waters into shallow pools of standing water (Woodward, 1997b). Infiltrated fine sediments are present in limestone conduits in and around the site of Megalakkos and throughout the Lower Vikos Gorge. The absence of coarse sands and fine gravels within all the Facies A units and the low-energy conditions indicated by the laminated microstructures argue against deposition by the tributary stream. Moreover, Unit 12 at the top of the Megalakkos sequence is Holocene in age (and is probably still accumulating today) and is approximately 15 m above the present bed of the tributary channel. The only evidence of direct fluvial deposition within the site by the Megalakkos tributary stream is provided by Unit 8 (Facies D) which contains some imbricated rounded flysch gravel. This unit represents either an extreme flood event or a temporary damming of the tributary ravine during a high flow event. The sedimentary sequence at Megalakkos forms a valuable source of comparison with the main rockshelter site of Klithi and the nature of the fine sediments at Megalakkos will be discussed further below.

In summary, the Megalakkos clayey-silts in the Facies A and B sediments are the product of a low-energy sedimentation mechanism associated with local hydrological processes within the karst drainage system. This flysch-derived material is transferred through the surrounding limestone strata via sediment-laden groundwater flows. Megalakkos has served as an effective location for the deposition and store of externally derived fine sediments for a considerable part of Late-glacial and Holocene time. The sharp contacts between the sedimentary units at Megalakkos and the repeated alternation of markedly different facies provides evidence for fluctuating climatic conditions in the region after the Last Glacial Maximum between c. 16,500 and 10,000 years BP (Woodward, 1997b). The Facies A sediments were deposited during humid and warm conditions not unlike the present day, while the Facies B deposits (which include coarse angular limestone clasts) probably indicate cooler conditions (see Woodward (1997b) for a discussion).

THE KLITHI ROCKSHELTER SEDIMENTS

Klithi faces almost due south and this aspect, together with the overhang of the limestone roof, provides excellent shelter from the elements (Bailey, 1997c). The shelter was probably formed by fluvial erosion of the bedrock wall when the Voidomatis flowed at a considerably higher level than at present (Figure 27.4(a)). The sediment fill takes the form of a cone with its apex towards the western end of the
shelter. This reflects intra-site variation in host bedrock properties as the western portion of the shelter wall contains numerous joints and beds and is more prone to breakdown – whereas the shelter overhang is more massive and resistant (Bailey and Woodward, 1997). The upper part of the fill has been truncated and levelled, forming a flat, near-horizontal surface, with a 10 cm layer of modern goat dung resting unconformably on the Palaeolithic deposits.

Figure 27.8 shows a section exposed in 1983 during the first season of excavation at Klithi. The sediments evidence a wide range of particle sizes, and boulder- and cobble-sized clasts are present throughout the sequence. These materials are roughly stratified scree incorporating alternations of coarse and finer grade angular limestone debris. There is considerable vertical and lateral variation in particle calibre, sorting, sediment fabric and void ratio. A closed, clast-supported fabric is common (Figure 27.1) as these rockshelter sediments contain a significant proportion of fine-grained (sand, silt and clay) matrix (Bailey and Woodward, 1997; see Figure 27.1). Archaeological materials are extremely abundant throughout the upper part the Klithi fill. This sequence contrasts markedly with the sedimentary record at Megalakkos where the units containing archaeological material are separated by distinctive fine-grained archaeologically sterile units (Facies A). The sequence shown in Figure 27.8 represents the upper 2 m or so of the Klithi deposit, which is associated with the Late Upper Palaeolithic use of this site. The main period of occupation took place between c. 16 500 and 13 500 uncalibrated radiocarbon years BP, perhaps extending at latest to about 12 400 BP, with traces of re-occupation at about 10 400 years BP (Bailey and Woodward, 1997). Below c. 2 m, the rockshelter sediments are archaeologically sterile and the coring programme provided the only available windows into the nature of the earlier sedimentary record.

The source of the fine (<63 μm) sediments in the full Klithi sequence and the processes involved in their deposition have been studied in detail from the Y25 core samples using the suite of textural and lithological parameters described above (Table 27.3). The sequence from Y25 is shown in Figure 27.9 and this can be subdivided into three main sections. The upper part of the core (0–2.5 m) corresponds to the Late Upper Palaeolithic occupation of the site and is believed to be broadly time equivalent to Units 2 to 11 at Megalakkos (Figure 27.6). It can be shown that most of the fine sediment within the core sequence is derived from allogetic sources. The textural and lithological parameters shown in Figure 27.9 all refer to the sediment fraction <63 μm while the magnetic susceptibility data refer to the fraction <1 mm. Thus, the lower core (4.2–7 m) is dominated by CaCO₃-rich silts and clay-grade material with mean values of 73 percent and 22 percent respectively. Indeed, clay-grade (<2 μm) material accounts for much of the insoluble residue fraction in this part of the sequence. An important feature of the Klithi core sequence is the divergence of the CaCO₃ and clay curves above 4.2 m and this persists throughout the rest of the record. This pattern marks a major change in sediment source as non-carbonate silt becomes an important component of the fine sediments in the site. The non-carbonate silt curve is shown in Figure 27.9.

In order to explain the marked lithological and textural changes in the Late Pleistocene fine sediment record at Klithi, the relationship between key sedimentological parameters was investigated and several of these are shown in Figure 27.10.
Figure 27.8 Schematic diagram of the east-facing section exposed in the deep trench at Klithi based on an original field drawing by Janusz Kozlowski and Colette Roubet. This figure highlights the spatial and temporal variations in coarse sediment calibre, fabric and sorting evident in the Klithi sequence (after Bailey and Woodward, 1997). The upper unit (shaded) represents contaminated layers affected by goat trampling in modern times. Compare with Figure 27.6. W33C, W33A, W32C and W32A refer to the site excavation grid (see Bailey, 1997c).
Figure 27.9  Textural and lithological data from the Y25 core at Klithi. The non-carbonate silt parameter has been estimated by subtracting the clay content from the insoluble residue of the fraction < 63 μm. The full suite of radiocarbon dates from Klithi is discussed in detail by Bailey and Woodward (1997). Note that the depths given in this figure are relative to the site datum and not the top of the core.
Figure 27.10  The relationship between various lithological and textural parameters from the Y25 (Klithi) core sediments. All values are percentages of the fraction < 63 μm (n = 56)
In terms of sediment sources, a number of important points can be gleaned from these plots. First, the strong positive relationship between non-carbonate silt and coarse silt ($r = 0.79$) and the 5.5–5 $\phi$ size range ($r = 0.84$) indicate that this is flysch-derived material (Figure 27.7). The negative relationship between fine silt and coarse silt ($r = -0.75$) suggests that these materials derive from different sources. In contrast, the fine silt is rich in CaCO$_3$ ($r = 0.61$) and is likely to contain a significant limestone-derived component. This is discussed further in the next section. The strong negative relationship between non-carbonate silt and clay is also of interest and could indicate that flysch-derived silts and clays are sorted during transport and follow different transfer pathways. This relationship may also suggest that other (proximal and/or distal) sources of clay material are important.

The magnetic susceptibility profile for the upper core shown in Figure 27.9 is independent of the other sedimentological parameters discussed above as it reflects the impact of human activity in the site through sediment firing. This enhancement in magnetic susceptibility due to burning in the archaeologically rich sediments within the rockshelter contrasts markedly with the magnetic susceptibility profiles observed from Late Pleistocene alluvial soils in the vicinity of the site. In the pedogenic weathering environment off-site (where the parent materials are very similar in composition and age), high susceptibility values are associated with strongly weathered, decalcified horizons (Woodward et al., 1994), whereas the rockshelter sediments evidence high susceptibilities in association with CaCO$_3$-rich sediments (Figure 27.9). Such comparisons between the on-site and off-site environments are important as they can help to decouple the natural and anthropogenic signals in rockshelter sediment records. It is also worth noting that several samples in the middle and lower core sections evidence susceptibility values that are higher ($>20$ m$^3$kg$^{-1}$) than would be expected for unweathered, archaeologically sterile materials. These features and the rest of the sedimentary sequence from Core Y25 are discussed further below and compared to the Megalakkos record.

**TERMINAL PLEISTOCENE SEDIMENT SOURCES AT KLITHI AND MEGALAKKOS**

The Y25 core sequence at Klithi reveals a series of major changes in fine sediment texture and lithology during the course of the Late Pleistocene. The major sediment sources can be characterised on the basis of lithology and distinctive particle size assemblages. These changes can be related to shifts in the dominant off-site sediment sources which reflect the dramatic environmental changes associated with the last glacial–interglacial transition in the region (Macklin et al., 1997).

Aeolian sediments have been reported in many rockshelter sites (Table 27.1) and Pleistocene loess has been identified in the Dolianna basin between 5 and 10 km to the west of Klithi. A number of sedimentological comparisons were made between the Klithi and Megalakkos sediments and samples of yellow loess collected from an exposure in the Dolianna basin (Woodward, 1990). Figure 27.11(a) illustrates the relationship between CaCO$_3$ content, clay content and non-carbonate silt for these materials. These parameters show a clear separation between the three sample groups.
The Megalakkos deposits are generally finer grained (richer in clay) and contain more CaCO₃ than the Dolianna loess sediments. The provenance of the Dolianna basin loess is not known and it contrasts markedly with the Kliithi fine sediments.

During the last cold stage the suspended sediment load of the Voidomatis River was dominated by limestone-derived fine sediments from the glaciated limestone headwaters (Woodward et al., 1992; Hamlin et al., see Chapter 25). During periods of low flow, this fine material (local loess) was blown into the rockshelter site from the wide, braided channel system beneath the site (Woodward, 1997a). The cold stage river was at least 10 m higher than at present. Experimental work has shown that hard limestone lithologies like the bedrock at Kliithi do not produce silt and clay-grade material during mechanical weathering (see Lautridou, 1988). Furthermore, the fine matrix of cold stage alluvial gravels preserved in the Lower Vikos Gorge is rich in calcareous silt (Lewin et al., 1991). It is interesting to note that micromorphological observations of the Facies A sediments at Megalakkos have provided evidence of some secondary deposition of calcium carbonate (Woodward, 1997b). Since the average CaCO₃

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**Figure 27.11 (a)** Ternary plot showing the lithological and textural composition of the fine sediments from Kliithi and Megalakkos and samples of loess from the Dolianna Basin. (b) Plot highlighting the lithological and textural groupings evident within the Kliithi fine sediments of Core Y25 and the changes in fine sediment composition that took place during the Late Pleistocene (see Figure 27.9). Fine sediment samples from the four facies at Megalakkos are also shown. Note the high clay content of the Facies A units
content of the fine sediments at Klithi is 64 percent (54–80 percent) compared with 36 percent (25–54 percent) at Megalakkos, this provides further support for the import of calcareous loess at Klithi (Figure 27.11(a)). The lower core sediments contain a significant amount of fine (2–8 μm) silt (Figure 27.10).

The amount of clay in the lower core (mean 22 percent) is too high to be the product of in-situ host rock weathering (Table 27.4) and it is likely that this material represents far-travelled aeolian dust with only a minor contribution from local limestone bedrock. The magnetic susceptibility data for the lower core discussed above may partly reflect the input of naturally fired or weathered allogetic materials and give further support to the suggestion that far-travelled dust could be an important component of the lower core (see Pye, 1992). There is also some evidence for the accumulation of clay-rich aeolian dust within soil profiles developed on Late Pleistocene alluvial sediments in the Lower Vikos Gorge (Woodward et al., 1994). Some of the clay material in the lower part of the core may have been reworked from terra rossa soils developed on the limestone strata and its deposition in the site may result from a combination of aeolian and infiltration processes. Ford and Williams (1989) report winnowing of terra rossa in southern France during the infiltration process to form clay-rich cave earths. Rockshelters may form important natural long-term dust traps and the precise mineralogical and elemental composition of this clay-grade material is
currently under investigation. Apart from the clay material at Klithi discussed above, much of the fine sediment at both sites appears to be dominated by local off-site sources.

The middle section of Y25 (2.5–4.2 m) at Klithi marks a major change in fine sediment sources as the clay component declines significantly (to almost zero) and non-carbonate silts begin to dominate the insoluble residue. These non-carbonate silts are similar in composition to the silts at Megalakkos and they appear to be derived mainly from flysch sediments (Figure 27.11(a)). The hydrogeological settings of the two rockshelters and the nature of the stratigraphic records indicate that infiltration processes are dominant at Megalakkos. The flysch-derived silts were introduced into Klithi after the Last Glacial Maximum in two main ways. The suspended sediment load of the Voidomatis River contained a higher flysch component at this time as the input of glacially comminuted limestone silts declined (Woodward et al., 1992). It is likely that this material could also have been redistributed by aeolian activity in the Lower Vikos Gorge and the significant CaCO₃ content (>50 percent) of the Klithi fine sediments provides additional support for this mechanism during this period. At present, flysch-derived fines are commonly washed down the walls of the Lower Vikos Gorge during heavy rainstorms, and high-velocity sediment-laden flows have been observed exiting conduits in cliff faces. It is not possible to disentangle the roles of infiltration and external bedrock slope wash processes in the middle and upper core with any certainty, but each is likely to have been an increasingly important source of non-carbonate silt material as the main channel of the Voidomatis incised after c. 16,000 years BP (Macklin et al., 1997) and the valley floor was colonised by vegetation. These changes on the valley floor would have limited the production of fine sediment by aeolian activity from the floodplain system. Figure 27.11(b) shows that the Y25 sediments fall into three or four main groupings, highlighting both the contrast in the nature of the major sediment inputs to Klithi and Megalakkos and how the geomorphological changes of the Late-glacial in the Voidomatis are recorded at Klithi.

The upper part of the Y25 sequence is broadly contemporaneous with the bulk of the sedimentary sequence (Units 2 to 11) at Megalakkos (Woodward, 1997a,b) and can be further divided into two sections based on the increase in clay content at the top of the core (Figures 27.9 and 27.11(b)). This could indicate drier conditions and an increase in aeolian dust transport at the end of the Late-glacial period (Woodward, 1997a). This may be equivalent to the Younger Dryas cooling, but poor dating resolution at the top of the sequence does not allow this to be confirmed. At present, the dating control at Megalakkos is not good enough to allow a high-resolution comparison between the two sites, but it is clear from the marked facies changes in the Megalakkos sequence that the Late Upper Palaeolithic occupation of the Lower Vikos Gorge was accompanied by significant environmental changes (Figures 27.6 and 27.11(b)). While the sedimentary record at Klithi is rather longer, the sequences at Klithi and Megalakkos do demonstrate that such changes will be recorded in different ways at different rockshelter sites only hundreds of metres apart (Table 27.5). The major changes in fine sediment sources and geomorphological processes during the Late Pleistocene discussed above are summarised in Figure 27.12 and Table 27.5.
Table 27.5  The processes responsible for fine sediment delivery to the Klithi and Megalakkos rockshelters during the Late Pleistocene\(^a\)

<table>
<thead>
<tr>
<th>Sediment body</th>
<th>Fine sediment delivery mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Klithi rockshelter</strong></td>
<td></td>
</tr>
<tr>
<td>Upper Core</td>
<td>Slope wash/infiltration, aeolian processes (D) and human activity (CALC)</td>
</tr>
<tr>
<td>Middle Core</td>
<td>Slope wash/infiltration, aeolian processes (D and P) (CALC)</td>
</tr>
<tr>
<td>Lower Core</td>
<td>Aeolian processes (D and P), infiltration (CALC)</td>
</tr>
<tr>
<td><strong>Megalakkos rockshelter</strong></td>
<td></td>
</tr>
<tr>
<td>Facies A</td>
<td>Infiltration</td>
</tr>
<tr>
<td>Facies B</td>
<td>Infiltration and human activity (CALC)</td>
</tr>
<tr>
<td>Facies C</td>
<td>Infiltration and human activity (CALC)(^b)</td>
</tr>
<tr>
<td>Facies D</td>
<td>Fluvial processes (large flood)</td>
</tr>
</tbody>
</table>

\(^a\) Each process is listed in Table 27.1. For aeolian inputs: D = distal source and P = proximal source. CALC denotes the presence of coarse angular limestone clasts and these may form the bulk of the sediment body as at Klithi (Figure 27.1).

\(^b\) At Megalakkos, debris from human activity is only present in one of the Facies C units – the upper part of Unit 2.

**CONCLUSIONS**

Rockshelter sequences are composed of sediments derived from a range of allogenic (off-site) and autogenic (on-site) sources and their relative significance will vary over time and between sites as environmental conditions change. The fine-grained components of the sedimentary records preserved in limestone rockshelters are commonly dominated by allogenic materials. It is therefore important to place such sequences in a wider context by establishing the nature and age of off-site sedimentary sequences and to consider all potential sediment sources and transfer mechanisms. Furthermore, sedimentological data from the off-site Quaternary record are often crucial for the palaeoenvironmental interpretation of on-site sediments (Woodward, 1997a). If the provenance of the fine sediment fraction can be established, well-dated rockshelter sequences can provide an important source of information on past geomorphological processes.

In the Lower Vikos Gorge of north-west Greece, marked contrasts in Late Pleistocene sediment sources and depositional processes are apparent between the nearby rockshelter sites of Klithi and Megalakkos. While the fine sediment fraction at each site is dominated by off-site sources, there are marked, stratigraphical, lithological and textural contrasts between the two sites which indicate that the contributions from aeolian, infiltration and other processes have varied between the two sites and over time (Table 27.5). The rockshelter site of Boila is located at the end of the Lower Vikos Gorge only 10 m above the present river channel (Figure 27.3). It provides an additional contrast to Klithi as the Boila record contains slackwater sediments following repeated inundation of this site prior to the onset of Late Upper Palaeolithic occupation (Macklin et al., 1988; Hamlin et al., see Chapter 25). The geomorphological and hydrogeological settings of the rockshelters are particularly important controls on fine sediment provenance and depositional processes. These conclusions are based on a relatively simple approach at Klithi and Megalakkos using textural and
Figure 27.12 Summary diagram showing the non-carbonate silt curve to highlight the changes in terminal Pleistocene sediment sources recorded at Klithi and the associated geomorphological processes. This curve has also been replicated in Core CC27 that was obtained in 1988 (see Woodward, 1997a). The open boxes represent a five-point moving average and provide a useful summary of the major changes that took place during the last glacial-interglacial transition.
lithological parameters, but there is also considerable scope for using multi-parameter tracing methods to produce quantitative estimates of sediment source contributions (see Walling and Woodward, 1995) in such rockshelter sediment records (see Hamlin et al., see Chapter 25). Nonetheless, the data from the Lower Vikos Gorge sites presented here demonstrate that a simple classification based on fine sediment provenance provides a valuable framework for the interpretation of rockshelter sediment records as it serves to highlight their position within a wider geomorphological system and underscores the fact that such sites can provide sinks for a wide variety of sediment imports. When viewed in this way, rockshelter sediment records constitute important geomorphological archives and they offer a direct and valuable link between the archaeological data recovered from excavation and the off-site proxy climate records derived from other Pleistocene and Holocene sequences.

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