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Chapter 18

Late Pleistocene Rockshelter Sedimentation at Klithi

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From the earliest days of the Klithi project it was apparent that the sedimentary sequence at Klithi would play a central role in any attempt to compare the environmental and archaeological records. The purpose of this section, therefore, is to describe and interpret the sedimentary sequence within the rockshelter depositional environment of Klithi, and to attempt to place these deposits within a broader environmental context. In contrast to the detailed examination of lateral variation presented previously (Bailey & Woodward, Chapter 4), this contribution is primarily concerned with a vertical or temporal sequence and especially the properties and origin of the pre-occupation sediments in comparison with the sediments in the upper part of the sequence associated with human occupation. By focusing on the full stratigraphic succession, and by drawing comparisons with the Quaternary alluvial sediments and soils in the vicinity of the rockshelter site, the aim is to establish the wider stratigraphic and environmental context of the Klithi sequence (cf. Woodward 1990; 1996).

To this end, this chapter focuses on the sedimentary sequence recovered from the cores and on the fine sediment fraction of this material. Unlike the excavated trenches, the core sequences actually penetrate the pre-occupation deposits and form a potentially valuable record of Late Pleistocene conditions prior to, and during, human occupation of the site. Palaeoenvironmental interpretation of rockshelter sediments often relies heavily on measured variation in the size and form of the coarse limestone clasts within a sequence (e.g. Goldberg 1972; Laville 1976; Laville et al. 1980). Nonetheless, there are good reasons for departing from this traditional approach and for concentrating sedimentological analysis on the fine sediment fraction in the present study. Such an approach is adopted here partly because of evidence presented earlier for considerable lateral variation in the particle size characteristics of the coarse limestone rock fragments at Klithi (Bailey & Woodward, Chapter 4), and also because a coarse sediment based methodology is precluded by the small diameter of the cores, which does not yield large enough samples for coarse sediment analysis to be conducted on the entire sequence.

Numerous investigations have shown that Quaternary sediments can provide both stratigraphic control and environmental context for many kinds of archaeological materials in a range of depositional settings (e.g. Hassan 1978; Rapp & Gifford 1982; Stein & Farrand 1985; Waters 1988). In the case of rockshelter and cave-mouth environments, it has been recognized for well over a century that cultural and faunal remains are often preserved within considerable thicknesses of Quaternary sediment. Yet realization of the potential provided by rockshelter sediments (rather than the artefacts and fossils within them) as a basis for reconstructing past environments and solving archaeological problems represents a comparatively recent innovation (cf. Farrand 1975; Gamble 1986). During the last three decades the scientific analysis of rockshelter sediments has become a firmly established line of enquiry in environmental archaeology (Colcutt 1979; Farrand 1975; 1979) and now more commonly forms an important consideration in excavation strategy (Stein & Farrand 1985). Indeed, it is now widely recognized that most Palaeolithic materials are found in situations where sediment-based environmental reconstruction must be an integral part of their study. To date, however, many workers have tended to concentrate their attention almost exclusively on the 'site' sedimentary record, without either considering the position of a particular sediment column within a wider environmental framework, or evaluating the nature and composition of adjacent sedimentary environments and the possibility of material exchanges between them. A major goal of this contribution is to show how careful integration of both the 'on-site' and 'off-site'
sedimentary records with the archaeological sequence is essential if we are to advance our understanding of human activity in Pleistocene environments.

Throughout this and the following chapter on Megalakki, the rockshelter or 'on-site' sediments are treated as a component within a larger and dynamic catchment-wide sedimentary system which has responded in a sensitive way to Quaternary environmental change. For example, Chapter 17 gives details of the striking changes that have taken place in the adjacent river environment as both depositional style and sediment lithology shifted in response to the waxing and waning of headwater glacial activity during the Late Pleistocene. It is to be expected that the nature of the sediments deposited at Kliithi was strongly influenced by the immediate geomorphological surroundings and that any changes in the dominant processes operating there can be expected to influence the sedimentary record within the rockshelter. For these reasons it is clearly important to avoid viewing 'on-site' processes and sediments in isolation, and to construct a catchment-wide lithostratigraphic and chronological framework which allows the rockshelter sediments to be placed within an appropriate local and regional environmental setting. The drainage basin of the Voiodamatis forms a convenient unit of study for such an approach (Woodward 1990; Woodward et al. 1995; Bailey et al., Chapter 16).

The rockshelter depositional environment

Almost by definition, rockshelters tend to favour sediment preservation rather than erosion, and in most cases they provide highly favourable sites for sediment accumulation. In most instances this is because rockshelter and cave-mouth locations are largely protected from sub-aerial weathering and form comparatively low-energy geomorphological environments. Thus even though rates of sediment delivery are usually quite modest in most mid-latitude settings, sediment removal capacities are also low, and these locations are able to function as effective repositories for the accumulation and protection of a variety of sediments for extended periods of time. In favourable locations, as for example at Asprochaliko in the Louros valley (Gowlett & Carter, Chapter 23), rockshelter and cave stratigraphies can often represent a considerable portion of late Quaternary time (see Butzer 1981; Huxtable et al. 1992; Laville et al. 1980).

The lithological and textural characteristics of the sediment accumulating on a rockshelter floor are governed by the influence of a number of environmental controls (Farrand 1985; Woodward 1990). These include external macro-scale climatic and tectonic factors such as thermal and precipitation regimes and seismicity, and more local site-specific controls such as host bedrock properties, geomorphological setting (including site geometry, aspect and local karst hydrology), and biological activity. Superimposed on these 'natural' factors may be the influence of human occupation. The principal influence on sedimentation style at any point in the history of a site may be a single dominant control, or more often the product of two or more of these variables. Many of these controls are strongly interrelated and each can influence sediment source, sediment transport mechanisms, and the nature and degree of post-depositional alteration.

In considering the rockshelter depositional environment, it is first useful to make the simple distinction between two principal routes for sediment transfer. Sediment may reach the rockshelter floor either **vertically**, by the action of gravity from the shelter walls and ceiling, or by means of percolating water from the land surface above, or **laterally**, mainly by the action of water, wind and human or animal activity. Each of these routes can deliver sediment particles of various sizes and lithologies from sources which are either **autogenic** (internal) or **allogenic** (external) to the particular rockshelter niche under consideration. It is also helpful, where appropriate, to further differentiate the allogenic contribution into its **proximal** and **distal** components. In reality, all rockshelter sedimentary sequences are composed of a mixture of autogenic and allogenic material although one or the other may dominate as environmental conditions change (between sites and over time). A hypothetical, yet commonly encountered combination, for example, could involve a sediment body composed of coarse limestone debris derived from frost weathering of the rockshelter walls (**vertical, autogenic**) with the inter-clast voids filled with a fine-grained silty matrix of far-travelled loess (**lateral, allogetic, distal**). An example of the latter association is provided by the middle sedimentary units (12-14) at the Cueva Morín cave in Santander, where 'loessic components' are found within coarse deposits described as limestone 'roof rubble accumulation' (Butzer 1981, 148, 175).

This simple classification based on sediment provenance provides a useful framework for the interpretation of rockshelter sediment records. It serves to highlight their position within a wider sedimentary system and underscores the fact that such sites can
provide sinks for a wide variety of sediment imports. In attempting to make linkages between the rockshelter sediment record and the climatically-driven changes in the wider Pleistocene environment, it is suggested that a thorough consideration of sediment source is essential to achieve a proper appreciation of the wider stratigraphic and environmental significance of rockshelter sediments.

General features of the sediments

In very general terms the Klithi rockshelter deposits are composed largely of unconsolidated angular limestone clasts of various sizes within a predominantly silt-grade calcareous fine matrix (see Bailey & Woodward, Chapter 4). These coarse sediments are typically roughly stratified and very poorly sorted. The following discussion is largely based on information derived from detailed analyses of the two longest sediment cores collected during the site drilling programmes in 1986 and 1988 (Bailey et al., Chapter 3), and on the fine sediment fraction (<63 µm). Most attention has been concentrated on core Y25, which was collected in 1986, and which provides the most complete record of the pre-occupation deposits. The sedimentological characteristics of this core were first reported in Woodward (1990), and the second sediment core (CC27) was analyzed in 1992 to provide an independent test of the results from core Y25. From the results of the coring programme we know that the sedimentary fill is at least 7 m in thickness. It is likely, though not certain, that the Y25 core reached bedrock, and the total depth of the Pleistocene deposits may therefore be greater than 7 m, although the external geometry of the site suggests that the sediment fill is unlikely to be much deeper than this.

Silt-sized and clay-sized particles account for a significant part of the sediment matrix across the entire site and throughout both cores. They are of particular interest because they can provide a detailed record of changing environmental conditions and post-depositional alterations (Farrand 1975; Birkeland 1984; Woodward et al. 1994). In most rockshelter settings the fine sediments are derived from a wider range of sources than the coarse sediment fraction (e.g. Butzer 1981; Farrand 1975) and even where a significant proportion of the fine fraction has been derived from an allochthonous or ‘off-site’ source, such materials can be expected to display considerable textural and lithological homogeneity within coeval sedimentary units. This is often the result of sorting prior to, and during, deposition within the site. As the transport processes commonly involve wind or water, this will often effect a fairly even distribution of such material across the site. Human occupation can also contribute to this process, although it is recognized that site activities can result in marked lateral changes in some primary and secondary fine sediment properties (Butzer 1981).

In comparison to the coarse limestone rock fragments, whose particle size characteristics can vary substantially across the site within coeval sedimentary units due to the influence of various factors (see Bailey & Woodward, Chapter 4; Farrand 1975, fig. 3), the primary attributes of the fine matrix are likely to be much more uniform across the site and less susceptible to local variation. The fine sediments forming the matrix within a coarse limestone gravel unit may be very similar in composition and texture to the fine sediments within a stratigraphically-equivalent, but much coarser-grained, limestone gravel unit a few tens of centimetres away. This is also the case in many ‘off-site’ colluvial deposits, particularly ‘stratified scree’ (see DeWolf 1988). Such observations place a question mark against the usefulness of approaches which rely heavily on variations in the calibre of limestone rock fragments as a basis for palaeoenvironmental reconstruction (cf. Laville 1976). This is not to say that fine sediments will not display some degree of primary spatial variability, only that fine sediments often display less lateral variation than coarse sediments in rockshelter environments. Ideally, of course, and wherever possible, the information derived from both coarse and fine sediments should be used together for the purpose of section description and site interpretation (Woodward, Chapter 19). At least at Klithi, however, it is the argument of this section that the fine sediments provide both a more reliable indicator of temporal changes in the local Late Pleistocene palaeoenvironment, and a valuable means of establishing correlations with ‘off-site’ sedimentary environments.

Field and laboratory methods

Coring the Klithi sequence

The particular logistical and engineering considerations posed by the Klithi rockshelter deposits in this exercise are reported in detail elsewhere (Bailey & Thomas 1987; Bailey et al., Chapter 3). During the 1986 field season three boreholes were drilled into the Klithi fill — the longest and most successful (Y25) reaching a depth of 6.93 m below the surface. The sediments were retrieved using 1 m coring tubes of 75 mm and 60 mm diameter. Following extraction and sediment description, the cores were photographed, drawn and sampled on-site at 5 cm intervals in the upper, archaeologically-rich, sediments, and then mostly at 10 cm intervals to the base of the sequence. Although the 7 m core contained 8 voids, the sequence forms an internally consistent, stratigraphic succession of great significance as it provided the
first detailed insight into the nature of the pre-occupation horizons. Core CC27 was recovered during the 1988 drilling programme.

Laboratory procedures
Core Y25 was sub-divided into 56 sediment samples which were air-dried in the laboratory at room temperature for 48 hours prior to screening through a 1 mm mesh sieve. Magnetic susceptibility measurements were conducted on the <2 mm component of all sediment samples using a standard Bartington Instruments meter and sensor (Thompson & Oldfield 1986). The analytical procedure involved placing approximately 10 g of sediment into pre-weighed cylindrical plastic sample pots of 10 cm³ volume. These samples were firmly packed using cling film to prevent particle movement. Magnetic susceptibility is a non-directional magnetic parameter which provides a measure of the ‘magnetizability’ of sediment. This is in turn largely determined by the concentration of magnetic minerals within a sediment sample. The minerals of major interest in magnetic studies are the iron oxides including haematite, goethite, maghemite and magnetite (see Maher 1986). Magnetic susceptibility represents the ratio of the magnetization produced in a sediment sample to the intensity of the magnetic field to which it is subject and is measured within a small magnetic field of about 0.1 mT (millitesla). This parameter can be measured at low or high frequency using a dual frequency susceptibility sensor (measured at 1 and 10 kHz), and the difference between the two readings can be expressed as a percentage of the low frequency reading and is referred to as frequency dependent susceptibility (Maher 1986). Measurements were taken on all the samples in core Y25. Magnetic susceptibility results are expressed on a mass specific basis (m³/ kg') and frequency dependent values are expressed here as a percentage of low frequency susceptibility.

The proportion of insoluble residue (i.e. non-carbonate material) present within seven limestone rock samples from Klihi was determined by weighing following dissolution in dilute hydrochloric acid (cf. Macleod 1980). All the core sediment samples were also screened through a 63 μm mesh sieve to obtain the silt and clay component. This fraction was then analyzed for total calcium carbonate (CaCO₃) content and detailed particle size analyses were also undertaken. CaCO₃ determinations were carried out following dissolution in dilute hydrochloric acid (Gross 1971). Prior to particle size analysis all samples were treated with hydrogen peroxide to remove the organic component and then chemically dispersed using sodium hexametaphosphate (McManus 1988). The particle size characteristics of the fine sediment fraction (<2 μm) of core Y25 and of the bedrock insoluble residues were measured in the Department of Earth Sciences at the University of Cambridge using the computer-interfaced Sedigraph 5000ET system reported by Jones et al. (1988). This apparatus provides detailed particle size information within the silt fraction (i.e. the 63 μm to 2 μm range) as well as total clay content (i.e. the proportion <2 μm). Within the silt fraction the proportion of coarse silt, 63 μm to 16 μm, medium silt, 16 μm to 8 μm, and fine silt, 8 μm to 2 μm can also be determined (Table 18.1). For Core CC27 the particle size characteristics of the sediment fraction <63 μm were measured in 1992 at the University of Exeter using a Malvern Mastersizer laser diffraction particle size analyzer (Agrawal et al. 1991). Previous studies of the particle size characteristics of rockshelter fine sediments have used traditional and time-consuming sieving methods based on particle settling velocities, such as the hydrometer and pipette methods (e.g., Butzer 1981). The methods employed in this study are less prone to operator error and allow rapid and precise particle size determination on a large number of samples. This has facilitated perhaps the first detailed investigation of changing fine sediment size modes in a rockshelter environment.

Local bedrock properties
In order to determine the source of the rockshelter fine sediments it is necessary to consider the lithological composition of likely source materials and the form and size of their erosional products. In the cave-mouth or rockshelter environment this must begin with an evaluation of local bedrock structure and composition.

General features of the Klihi limestone
The limestone bedrock at Klihi (and throughout the Lower Vikos Gorge) is Palaeocene to Upper Eocene in age. These limestones are massive resistant rocks and the upper members have been described as sublithographic (IGME 1968), indicating a hard and resistant lithology. These dense crystalline limestones contain occasional chalk bands, are of low primary porosity, and solutional weathering processes predominate, mainly concentrating along bedding planes. These rocks form near-vertical cliffs, deep gorges and steep-sided tributary ravines (Bailey et al., Chapter 16). In places these rocks are tectonically deformed and fractured, providing a major source of coarse alluvial and colluvial material in a wide range of particle sizes. It is apparent that limestone bedding and joint frequency exerts an important control on the size of rock fragments detached from a rock wall, and bedding frequencies in the Lower Vikos Gorge may vary from a few centimetres to several metres. In lithological terms the limestone bedrock at Klihi is very pure, yielding only tiny amounts of residual material following solution (Woodward 1990). The acid insoluble residue (non-carbonate fraction) of seven rock samples collected

<table>
<thead>
<tr>
<th>phi (mm)</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>-11</td>
<td>2016</td>
</tr>
<tr>
<td>-10</td>
<td>2024</td>
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<td>-9</td>
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<td>2</td>
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<tr>
<td>0</td>
<td>1</td>
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<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.125 V. fine</td>
</tr>
<tr>
<td>4</td>
<td>0.063 V. coarse</td>
</tr>
<tr>
<td>5</td>
<td>0.032 Coarse</td>
</tr>
<tr>
<td>6</td>
<td>0.016 Medium</td>
</tr>
<tr>
<td>7</td>
<td>0.008 Fine</td>
</tr>
<tr>
<td>8</td>
<td>0.004 V. fine</td>
</tr>
<tr>
<td>9</td>
<td>0.002 Clay</td>
</tr>
</tbody>
</table>
from various levels within the Klithi sequence and from the rockshelter wall range from 0.32 per cent to 1.04 per cent with a mean value of 0.57 per cent. The host strata is thus extremely pure and dominated by CaCO₃ (>99.4 per cent) in the form of calcite, with quartz and mica grains accounting for most of the limestone impurities. A typical particle size distribution of this insoluble residue fraction is shown in Figure 18.1. This material is composed almost exclusively (>75 per cent) of clay particles (<2 μm) and fine silt particles, with a silt/clay ratio of 0.32. It is worth noting that the residual portion of the bedrock is effectively free of coarse silt-sized and sand-sized particles (see Table 18.1).

Flysch mineralogy and texture

On either side of the Lower Vikos Gorge the limestone rocks are overlain by flysch rocks of Late Eocene to Miocene age (see Bailey et al., Chapter 16). These rocks consist of thin beds (10–20 cm in thickness) of hard, graded sandstones interbedded with softer, brown to buff-coloured, fissile siltstones. Microscopic examination of thin sections and X-ray diffraction analysis of powdered bedrock samples has shown that the flysch rocks are rich in quartz, plagioclase, mica and other phyllosilicates, with a calcite content of between 10 and 15 per cent. The flysch beds are readily erodible and the siltstones break down relatively easily into their primary particles, and thus represent an important source of fine sediment for the modern river system (Woodward et al. 1992) and frequently form the matrix material in colluvial sediments. Many of the flysch-derived fine sediments in the Voidomatis basin show a distinctive size mode in the coarse silt range (63 μm–16 μm).

Lithology and texture of the core sediments

In the following descriptions of the core sediments, particular attention is focused on downcore changes in the lithology and particle size characteristics of the sediment and on contrasts between the pre-occupation and occupation horizons.

Calcite carbonate and organic matter content

The fine sediment fraction is rich in CaCO₃ throughout the entire core sequence, with all values >50 per cent and a mean value of 64 per cent (Fig. 18.2). The CaCO₃ profile may be divided into two main parts: above 2.5 m the CaCO₃ values range from 54 per cent to 64 per cent with a mean value of 58.5 per cent, while the lower section of the profile has a range of 61.4 per cent to 80.6 per cent with a mean of 71.7 per cent (Table 18.2). In the upper section the fine sediments show a variety of reddish brown to brown and grey colours, reflecting the increase in non-carbonate minerals and the variable presence of human habitation debris including sediments rich in ash and organic detritus. In marked contrast, the fine sediments in the lower section of the core sequence contain only very small amounts of organic material and display a distinctive creamy-white colouration reflecting the dominance of silt-grade CaCO₃.

Clay content

The insoluble residue of the fraction <63 μm is composed of clay particles and non-carbonate silt material. The CaCO₃ boundary identified at 2.5 m is also equivalent to the lowest clay content in the sequence, where two successive samples, representing 15 cm of the deposit, record the highest silt/clay ratios in core Y25. The lower portion of the core sequence (4.2–7 m) is quite rich in clay grade (<2 μm) material with values up to 28 per cent. The largely clay-free bed at the base of the archaeological horizons is a distinctive feature of the sequence since this horizon marks the end of a gradual decline in the profile clay component in the central part of the sequence which begins at 4.2 m (Fig. 18.2). It is of particular interest to note that the rather abrupt transition between the CaCO₃ zones and the profile clay minima coincides with the base of the cultural horizons. Low clay values are a distinctive feature of the lower part of the occupation horizons.

Non-carbonate silt content

The proportion of non-carbonate silt at each point in the sequence may be estimated by subtracting the clay component from the total insoluble residue content of all samples (assuming little or no CaCO₃ in the clay fraction). At each level in core Y25 the proportion of non-carbonate fine sediment (i.e. the acid insoluble residue of the <63 μm fraction) is always greater than the clay component, indicating the variable presence of non-carbonate (quartz-rich) silt throughout the sequence (Fig. 18.2). This non-carbonate silt fraction is a minor component in the lower core (below 4.2 m) ranging from 0.9 per cent to 14.8 per cent (mean = 4.9 per cent). However, in the central section of the core (2.5–4.2 m), CaCO₃ content declines slightly (but still averages 69 per cent), while total silt content increases markedly to almost 90 per cent (Fig. 18.2). As these data refer to the fraction <63 μm, the clear divergence of these curves at 4.2 m records a significant influx of non-carbonate silt material, signalling a major transition in the nature of the Klithi fine sediments. The non-carbonate silt component increases steadily in the central part of the sequence to a maximum of 43.9 per cent at the base of the archaeological horizons. In the upper section of the core (above 2.5 m) the non-carbonate silt component is always greater than 21.1 per

![Figure 18.1. Typical particle size distribution curve for the insoluble residue fraction of the host limestone bedrock at Klithi. Note the fine-grained nature of this material and the virtual absence of coarse silt. 4 φ (63 μm) is the sand/silt boundary and 9 φ (2 μm) is the silt/clay boundary (see Table 18.1).](image-url)
Figure 18.2. Downcore changes in various sedimentological parameters and magnetic susceptibility for the Y25 core sediments. Laboratory numbers for radiocarbon dates from top to bottom: OxA-1155, OxA-1091, OxA-1092. The horizontal dashed lines mark the probable boundary between full glacial conditions (lower), transitional climatic conditions (middle), and milder climatic conditions (upper).

Table 18.2. Selected sediment properties from core Y25, showing ranges and mean values for the sediment fraction <63 μm from each core section (Fig. 18.2). The proportion of non-carbonate silt has been estimated as the difference between the total insoluble residue fraction and the clay content of each sample. Bulk magnetic susceptibility measurements (low frequency) were carried out on a mass specific basis on the <1 mm sediment fraction using a standard Bartington system.

<table>
<thead>
<tr>
<th>Sediment property</th>
<th>Upper section (0-2.5 m)</th>
<th>Central section (2.5-4.2 m)</th>
<th>Lower section (4.2-7 m)</th>
<th>Whole core (0-7 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃ (%)</td>
<td>54.0-64.0</td>
<td>61.4-78.1</td>
<td>65.2-80.6</td>
<td>54.0-80.6</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>3.2-81.4</td>
<td>11.4</td>
<td>22.2</td>
<td>11.5</td>
</tr>
<tr>
<td>Non-carbonate silt (%)</td>
<td>2.1-63.9</td>
<td>8.2-35.4</td>
<td>9.5-43.9</td>
<td>8.5-43.9</td>
</tr>
<tr>
<td>16-32 μm (%)</td>
<td>26.3-37.9</td>
<td>23.8-30.7</td>
<td>13.3-25.9</td>
<td>13.3-25.9</td>
</tr>
<tr>
<td>Magnetic susceptibility (m³ kg⁻¹)</td>
<td>143.3</td>
<td>27.3</td>
<td>39.0</td>
<td>95.7</td>
</tr>
</tbody>
</table>

cent and averages 31.1% per cent.

Summarizing the Y25 sedimentological data, the Kili sequence can be divided broadly into three lithologically and texturally distinctive sections (Fig. 18.2; Table 18.2): a lower section between 7 m and 4.2 m with high values of CaCO₃, a high clay content, and low values of non-carbonate silt; a middle section, from 4.2 m to 2.5 m, characterized by declining values of CaCO₃ and clay content — the latter reaching a minimum at the top of this middle section — and a marked increase in non-carbonate silt; and an upper section, from 2.5 m to the top of the sequence, coinciding with the archaeological deposits, and characterized by lower values of CaCO₃, increased clay content and high values of non-carbonate silt (Fig. 18.2).

Core CC27
To provide an independent test of the wider significance of the sequence derived from Y25, a limited analysis of the second long core, CC27, was undertaken. The downcore changes in the coarse silt fraction (63 μm–16 μm) are shown in Figure 18.3. While some differences between the two cores are to be expected, there is a good general agreement between the two cores in terms of the overall sequence, with CC27 also clearly showing the three main sections identified in Core Y25. Coarse silt varies from 26 per cent at the base of the sequence in the pre-occupation sediments to a maximum value of 44 per cent in the sediments associated with human occupation. In common with the non-carbonate silt trend in core Y25, the smoothed curve in Figure 18.3 also indicates that the influx of coarse silt particles decreased towards the end of the period of human occupation in the upper 1 m of the core.

Sediment sources and sediment transfer processes
In the following discussion, the dominant lithological character of specific sediment size fractions within the Y25 sequence is used to provide a basis for determining the major sediment sources and modes of sediment transfer.
Relationships between sediment texture and composition

Relationships between the textural and lithological parameters described in the above section are shown in Figure 18.4. The source of the non-carbonate silt fraction, which represents an important component of the core sediments (up to 43.9 per cent), is of particular interest. This material correlates strongly with the coarse silt fraction, 63 μm–16 μm (Fig. 18.4, r = 0.79), and this coarse silt component reaches a maximum of 59.6 per cent of the total fine sediment fraction (< 63 μm) at a depth of 95 cm. The strong positive relationship between the coarse silt and non-carbonate silt fractions, and the abundance of this coarse silt material throughout the sequence (mean = 44.9 per cent), shows that a considerable proportion of the fine sediments at Kithi are allochthonous and cannot be a breakdown product of in situ limestone weathering. The strong negative relationship between coarse silt and fine silt (Fig. 18.4, r = −0.75) suggests that these materials derive from different sources.

The role of limestone solution in fine sediment production

As the non-carbonate portion of the limestone bedrock accounts for <0.5 per cent of its mass, the significant proportion of non-carbonate material within the rockshelter fine sediments would seem to argue against a limestone source for this material. The insoluble residue component of the Y25 core sediments ranges from 19.4 per cent to 46 per cent with a mean value of 36 per cent. Most significantly, however, the textural of the Kithi fine sediments argues against a limestone source as the bedrock is effectively free of non-carbonate coarse silt material (Fig. 18.1) and this is a major component of the core sequence (Fig. 18.2; Table 18.2). The absence of non-carbonate coarse silt in the local bedrock rules out limestone solution as a major fine sediment (<63 μm) source in this context and also removes the need to invoke perhaps geologically unreasonable amounts of limestone solution to account for the rockshelter fine sediments.

In an attempt to identify the dominant size class of the non-carbonate silt fraction, this component was compared with all the size classes at 0.5φ and 1φ intervals within the silt range (4φ to 9φ). The relationships shown in Figure 18.4 suggest that the non-carbonate silt fraction is dominated by coarse silt material and is largely concentrated in the 4φ to 5.5φ range (Table 18.1).

The role of limestone solution in fine sediment production

As the non-carbonate portion of the limestone bedrock accounts for <0.5 per cent of its mass, the significant proportion of non-carbonate material within the rockshelter fine sediments would seem to argue against a limestone source for this material. The insoluble residue component of the Y25 core sediments ranges from 19.4 per cent to 46 per cent with a mean value of 36 per cent. Most significantly, however, the textural of the Kithi fine sediments argues against a limestone source as the bedrock is effectively free of non-carbonate coarse silt material (Fig. 18.1) and this is a major component of the core sequence (Fig. 18.2; Table 18.2). The absence of non-carbonate coarse silt in the local bedrock rules out limestone solution as a major fine sediment (<63 μm) source in this context and also removes the need to invoke perhaps geologically unreasonable amounts of limestone solution to account for the rockshelter fine sediments.

In an attempt to identify the dominant size class of the non-carbonate silt fraction, this component was compared with all the size classes at 0.5φ and 1φ intervals within the silt range (4φ to 9φ). The relationships shown in Figure 18.4 suggest that the non-carbonate silt fraction is dominated by coarse silt material and is largely concentrated in the 4φ to 5.5φ range (Table 18.1).

Coarse silt and non-carbonate silt fractions

Parts of the limestone bedrock wall at the back of the rockshelter show evidence of a thin coating of brown- to buff-coloured fine-grained sediment. This silty material is also present in cracks behind fractured limestone slabs at the nearby site of Mega-lakkos, where XRD analysis has demonstrated that this is flysch-derived sediment (Woodward, Chapter 19). Elsewhere in the Lower Vikos Gorge there is a large body of evidence to suggest that the movement of silts and clays within the interior drainage system of the limestone bedrock is a significant geomorphological process and that this material is dominated by fine sediments eroded from the overlying flysch deposits (Woodward 1990).

Sediment-laden groundwater has been identified.
as a major agency in fine sediment transfer in karst regions across the world (Bull 1981; White 1988; Ford & Williams 1989) and these sediments have been called infiltrates (see Jancin & Clark 1993; White 1988). Infiltrates can often represent an important and even the dominant mechanism of fine sediment delivery to rockshelter and cave-mouth environments, especially in humid, high-relief environments (Butzer 1981; Woodward 1990). The Voidomatis basin currently receives up to 2000 mm of precipitation annually (cf. Furlan 1977) and high intensity rainfall events are not uncommon during the summer months.

Infiltrates are fine-grained clastic sediments transported in suspension by percolating groundwater through the interior drainage system and may be deposited in cave and rockshelter locations under the action of gravity. The chief sources of infiltrates are surface soils which have been washed or slumped into open rock crevices or sinkholes in the limestone surface (White 1988). Infiltrates can be stored within the karst drainage system for extended periods, and later can be remobilized and eventually discharged into interior cavern systems or rockshelter environments with little chemical alteration. While there is little dispute regarding the efficacy of this transport mechanism in karst environments, the original source of the fine sediments in transit has generated considerable debate (see Jennings 1985; White 1988).

The relationships shown in Figure 18.4 suggest that the non-carbonate silt component is composed primarily of coarse silt (63 μm–16 μm) material and that the 50–60, 32 μm–16 μm, size range is especially rich in flysch-derived silt. It has already been noted that many of the flysch-derived fine sediments in the Voidomatis basin show evidence of a distinctive size mode in the coarse silt range (63 μm–16 μm). The unstable flysch slopes on both sides of the Lower Vikos Gorge provide an obvious local source of quartz-rich silty material. The colour, mineralogy and particle size characteristics of the fine matrix fraction of many recent slope and river sediments, as well as cave and rockshelter materials, indicate a flysch origin (Woodward 1990; Woodward et al. 1997).

Medium silt fraction
The medium silt component (16 μm–8 μm) displays only a comparatively small degree of downcore variation with mean values of 18.3, 17.5 and 16.2 per cent in the upper, central and lower core sections respectively. This size fraction does not show a strong positive or negative relationship with any of the other parameters mentioned above. This has precluded an accurate assessment of its lithological characteristics and source, and this parameter is therefore of limited value for purposes of environmental reconstruction.

Fine silt fraction
The positive correlation between CaCO₃ content and fine silt (8 μm–2 μm) and the negative relationship between CaCO₃ and coarse silt suggests that a significant proportion of the fine silt fraction is composed of CaCO₃ (Fig. 18.4). Thus, while the coarse silt material is composed largely of non-carbonate or flysch-derived mineral grains, a significant proportion of the fine silt fraction appears to be dominated primarily by CaCO₃ or limestone-derived material.

At the nearby rockshelter site of Megalakkos, the CaCO₃ content of the fine sediment matrix is generally significantly less than the Klithi sediments and always less than the lower sections of core Y25 (Fig. 18.5). Thus, fine sediments with a CaCO₃ content greater than 60 per cent are not present at Megalakkos, even though micromorphological evidence suggests that some secondary deposition of carbonate has taken place within the Megalakkos fine sediments (Woodward, Chapter 19). If we assume that the chemistry of the groundwater at Megalakkos does not differ substantially from that at Klithi, then we need to invoke an additional source of fine-grained limestone-derived sediment to account for the Klithi material in the lower section of core Y25.

Between c. 28 ka and 24 ka the Voidomatis River was a glacially-fed outwash stream, transporting coarse and fine sediments dominated by limestone-derived material (Lewin et al. 1991; Macklin et al., Chapter 17). The high suspended sediment load of this glacio-fluvial system resulted from the influx of huge amounts of finely comminuted limestone detritus (rock flour) in the Tsepelovon district of the basin (see Woodward et al. 1992; Macklin et al., Chapter 17). During periods of seasonally-reduced discharge, reworking of loosely consolidated fine alluvial sediment by wind action would have been a significant agent of sediment redistribution within the gorge environment. In addition, the absence of an effective vegetation cover on the braided floodplain beneath the site would have fostered an effective deflation surface where aeolian entrainment and redistribution of fine sediment could have

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**Figure 18.4.** Bivariate plots to illustrate the relationship between various sedimentological parameters in the Y25 core sequence. All the product moment correlation coefficients (r) are significant at the 0.001 confidence level (n = 56).
occurred throughout the glacial period. The transfer of fine sediments by wind action from local floodplain sources to rockshelter environments has been reported elsewhere in Europe during the Last Glacial Maximum. At the Abri Pataud in the Dordogne, for example, heavy mineral analysis has indicated the presence within certain sedimentary units of fine sands and silts blown by wind action into the rockshelter site from the floodplain of the nearby Vézère River at around 27 ka (Farrand 1975, 17).

It is also important to emphasize that the level of the full glacial 'Aristi' floodplain would have been significantly higher than at present, bringing the valley floor closer to the rockshelter mouth, and so increasing the exposure of the rockshelter to input of such allogenic materials. The modern shelter floor (the top of the Palaeolithic surface) is 29 m above the present-day river level. The Aristi Unit (Macklin et al., Chapter 17) is a striking alluvial terrace reaching maximum elevations of 25.9 m above the level of the modern river bed, with an elevation estimated at about 19 m above the modern level in the immediate vicinity of Klithi. The full glacial river thus flowed at a level some 10 m below the shelter floor (Fig. 18.6).

Further support for an additional allogenic contribution to the rockshelter sequence comes from experimental work on patterns of limestone breakdown. Experimental studies of rock disintegration suggest that the minimum size limit to which lithographic limestone rock particles can be broken down by frost action is approximately 1.0 mm (cf. Lautridou 1988). Most of the CaCO₃-rich material in the rockshelter record at Klithi is much finer (< 63 μm) and a proportion of this is concentrated in the fine silt (8 μm-2 μm) range. Furthermore, it is likely that, except under direct glacial action in the Tsepelovon district — where processes of physical grinding and crushing of bedrock by glacier ice were important — the pure, hard limestones of the Voidomatis basin do not liberate significant amounts of sediment in the <63 μm grade (Woodward et al. 1992). It is probable that a proportion of the fine-grained material within the Klithi sediments is a byproduct of on-site rock reduction processes such as frost action. This mechanism of CaCO₃-rich fine sediment production, however, is thought to be minor in comparison with allogenic aeolian inputs.

Another process that may be important is the deposition of secondary carbonate material by solute-laden percolating waters. It is also important to remember that flysch-derived sediments contain a significant calcite component (Woodward, Chapter 19), and both flysch-derived infiltrates and aeolian sediments contain CaCO₃, thus representing an additional allogenic contribution of fine-grained carbonate material.

In view of these arguments it seems highly likely that a significant proportion of the CaCO₃-rich fine sediments in the Klithi sequence (particularly the fine silt fraction) is also of external origin. The lithology of the fine fraction in the lower part of the sequence (between 4.2 m and 7.0 m) is similar to the fine fraction of unweathered Aristi Unit sediments (Woodward et al. 1994). Both contain up to 80 per cent CaCO₃. Both also clearly pre-date the Palaeolithic occupation at Klithi, and while the lower part of the Klithi sequence is not dated by radiometric means, it is highly likely that it overlaps in time the period of deposition of the Late Würm Aristi alluvial Unit.

![Figure 18.5. Bivariate plot to highlight the contrasting particle size characteristics and lithology of the Megalakchos fine sediments (see Chapter 19) and the Klithi core (Y25) fine sediments. The mean CaCO₃ content of the Klithi core Y25 fine sediments is 64.0 per cent with a range of 54.0 to 80.6 per cent. In contrast, the mean CaCO₃ content of the Megalakchos fine sediments is 36.2 per cent with a range of 25.9 to 54.0 per cent.](image)

**The clay fraction**

The origin of the non-carbonate silt material discussed above appears to be largely unrelated to the source of most of the clay fraction, which forms the remainder of the insoluble residue component. These two size fractions show a negative correlation (Fig. 18.4, r = -0.68), perhaps indicating contrasting sediment sources or the operation of different transfer pathways and depositional processes. The total insoluble residue component in the lower core sediments (below 4.2 m) is dominated by clay grade material (Fig. 18.2). As the flysch rocks contain a
significant clay component, it was first considered that a proportion of this clay grade material could be locally derived. This is unlikely, however, because during the full-glacial period the flysch rocks of the catchment made only a comparatively minor contribution to the suspended sediment load of the Voidomatis River. Also, Aristi Unit fine sediments sampled at the unweathered base of soil profiles are largely free of clay particles (Woodward et al. 1994) and this argues against a local riverine source for this fine material. It is also rather improbable that this clay material is infiltrated sediment, as the pronounced coarse silt mode which characterizes all local flysch-derived sediments is absent in most samples. On balance, then, it is likely that a considerable proportion of the clay within the site sediments is derived from off-site sources and represents the deposition of aeolian dust (see Pye 1992).

There is some evidence to suggest that iron-rich windblown silts and clays were incorporated into alluvial soil profiles in the Lower Vikos Gorge during the Last Glacial (Woodward et al. 1994). From the evidence available, it is not yet possible to pinpoint specific sources for this clay material, but it does seem likely that windblown dust from outside the adjacent river environment provided an important contribution to the fine matrix of the rockshelter sediments — particularly during the full-glacial period (Pye 1987; 1992). A minor authigenic supply of clay from the host limestone bedrock is also to be expected (Fig. 18.1).

In view of the above, the absence of clay particles at the base of the cultural horizons, and the very low values around 2 m depth in core Y25 (Fig. 18.2), would seem to represent a significant change in the wider environment, when the aeolian transfer of very fine particles from both the catchment slopes and from outside the basin was restricted — perhaps by an increase in humidity and vegetation cover at around 16 ka. This scenario receives some support from the pollen record at Tenaghi Philippon (Wijmstra 1969; Turner & Sánchez-Góñi, Chapter 29).

The above discussion impinges directly on the well-worn debate concerning the importance of far-travelled aeolian dust as a soil-forming factor in the soils of Epirus and the wider Mediterranean region (Macleod 1980; Pye 1992). This controversy is ongoing and worth comment here because, if dusts rich in iron oxide were deposited at Kithi during the full-glacial period, then their presence within the sequence would provide an extremely plausible explanation for the magnetic susceptibility values greater than c. 20 m³ kg⁻¹ recorded in the lower core (Fig. 18.2), which are clearly not the result of human occupation. Finally, it is important to appreciate that it is not necessary to invoke a Saharan source for this type of windblown material at Kithi, as outcrops of iron-rich rocks, sediments and soils are widespread in Epirus itself (Woodward 1990; Woodward et al. 1994).

Post-depositional alterations

A number of secondary or post-depositional features are apparent in the Kithi rockshelter sediments. These include marked increases in the magnetic susceptibility of the fine sediments in the archaeologically-rich deposits, changes in fine sediment colour, the incorporation of human habitation debris such as organic detritus, charcoal fragments, ashy materials, and lithic and faunal remains. It can be argued that all of the cultural materials within the site should be regarded as primary depositional features. Much of the human activity within the site, however, would have resulted in a degree of sediment reworking and modification. The nature and extent of some of these

Figure 18.6. Altitudinal relationships between the sedimentary sequence at Kithi (core Y25) and the Aristi and Vikos alluvial units. The mean height of the Aristi terrace is 12.4 m and the mean height of the Vikos terrace is 6.8 m (see Chapter 17). The modern river bed is approximately 28 m below the base of the Palaeolithic strata in the Kithi fill. The geomorphological setting of Kithi and the high fine sediment load of the cold stage, braided, glaciofluvial river would have made the site a favourable location for the accumulation and storage of aeolian fine sediment from the adjacent floodplain environment.
alterations can be tested by comparing the occupation sediments with both the pre-occupation deposits and the alluvial sediments and soils in the adjacent floodplain environment. The Pliocene alluvial units of the Lower Vikos Gorge contain sediments of similar age to those at Klithi, and of similar lithological composition, composed principally of coarse limestone clasts in a silty CaCO₃-rich matrix. This allows comparisons to be drawn between the processes operating within the local pedogenic weathering regime (sub-aerial diagenesis) and the processes operating in the rockshelter environment.

Soil development in the Voidomatis basin
The nature of soil profile development in the Voidomatis valley has been described in detail in Woodward et al. (1994). The two alluvial units which broadly correspond to the time interval of the Klithi core sequence are the Vikos and Aristi Units (see Macklin et al., Chapter 17). Both are characterized by the development of mature reddish-brown soils with calcified A horizons and clay-rich B horizons enriched in ferric iron (Fig. 18.7). These profile features are the result of pedogenic alteration in a strong weathering environment over many millennia. Total calcification of these soils to a depth of 50 cm or more is common, and is a necessary prerequisite for the accumulation of pedogenic iron and pedogenic clay and for the development of the distinctive Mediterranean red-brown colouration. Whilst total calcification of surface soil horizons can occur in as little as 1000 years in the soil profile environment (Woodward 1990), the rockshelter environment at Klithi is not exposed to such leaching processes. In contrast to the high solven capacity of the soil moisture derived from direct rainfall input, the solven capacity of the water percolating through the limestone bedrock at Klithi is negligible. Any groundwater that percolates into the Klithi sediments must be too alkaline to remove any CaCO₃. The rockshelter sediments are thus rich in CaCO₃ material in all size fractions throughout the sequence. All the sediment samples from core Y25 contain >50 per cent CaCO₃ in the <63 μm grade. This is in marked contrast to the observed pattern of upper profile calcification which is so pronounced in the soil environment on the local river terrace surfaces (Fig. 18.8). Even though the site has been used in recent years to shelter a herd of goats, which must have produced considerable amounts of uric acid, the rockshelter sediments show no evidence of carbonate removal by solution.

Mineral magnetic properties
Magnetic susceptibility is roughly proportional to the concentration of magnetic minerals within a sediment sample and can be an especially sensitive indicator of weathering and oxidation (Dearing et al. 1985; Thompson & Oldfield 1986). In common with the soil profile environment, a negative relationship exists between magnetic susceptibility and CaCO₃ content in the core sediments (Figs. 18.2 & 18.8). Unlike the soil profile environment, where magnetic susceptibility maxima are always associated with strongly leached and decalcified horizons (Fig. 18.8), in the rockshelter sequence, high magnetic susceptibility values are found in carbonate-rich deposits. The highest values for low frequency magnetic susceptibility clearly coincide with the onset and duration of human occupation. Magnetic susceptibility enhancement of sediments through burning is typical at sites with extensive hearth areas subjected to intensive human occupation (Thompson & Oldfield 1986). Thus it is likely that the highest susceptibility values in the rockshelter sediments are a product of sediment heating as a direct consequence of human occupation.

The magnetic susceptibility values of the pre-occupation sediments range from 8.8 to 68.7 m³ kg⁻¹. The maximum values in the lower core are too high for unweathered, carbonate-rich materials (mean = 35.8 m³ kg⁻¹), especially since similar sediments at the base of the Pleistocene soil profiles have values of <40. Nor can the high values in this part of the core be attributed to burning. The deposition of aeolian dust, however, derived from previously weathered or burnt surfaces (i.e. surfaces with enhanced susceptibilities) or sediments rich in iron oxides could produce such high values. This explanation would also account for the significant proportion of clay in the lower part of the sequence, as discussed above.

The downcore pattern of frequency dependent susceptibility, which is a function of the contribution to total low frequency susceptibility by fine viscous ferrimagnetic grains (cf. Dearing et al. 1985; Maher 1986), has also been determined. These fine grains are significant contributors to total susceptibility in weathered horizons and in sediments affected by high temperatures. In core Y25, the values range from 2.4 per cent to 7.8 per cent, with a mean value of 6.4 per cent. In the upper part of the core, values range from 3.2 per cent to 7.8 per cent with a mean value of 7.1 per cent, whereas in the pre-occupation deposits the values are much lower. Since the rockshelter sediments have not been fully exposed to sub-aerial weathering processes, the high values
in the archaeologically-rich sediments must reflect the impact of sediment firing. The highest value, 7.8 per cent, was recorded for the sample at the top of the core. This surface enhancement, and the reddening of the fine matrix in the uppermost levels of the Klithi fill, could represent the formation of magnetic minerals through the burning of the goat dung surface in recent decades. The formation of maghemite (a fine-grained magnetic mineral) due to burning was first demonstrated by Le Borgne (1955). More recently, Mullins (1977) has proposed a mechanism whereby the combustion of organic detritus produces reducing gases such as carbon monoxide, which reduce finely divided oxides and hydroxides of iron to magnetite. When the sediment cools, air enters and oxidizes the magnetite to maghemite.

It can often prove difficult to differentiate between the primary or natural environmental signal in rockshelter sediments and the secondary or cultural imprint in such archaeologically-rich sequences (see Butzer 1981; 1982; Gillieson et al. 1986). Nevertheless, by analyzing the sedimentary record spanning the pre-occupation history of the site with an appropriate range of techniques, and by comparing sediments of similar composition and age from contrasting local depositional and weathering environments, it has proved possible to begin to decouple the relative importance of cultural and environmental components in the rockshelter sediments. The fine sediments have been strongly influenced by the geomorphological setting of the site, and in particular by the nature of the fine sediment load of the adjacent river, which has changed over time in response to environmental changes, resulting in

![Figure 18.7. Clay-rich B horizons developed in alluvial soils on Pleistocene terrace surfaces in the Lower Vikos Gorge and Konitsa basin (Chapter 17). These soils have formed under long periods of seasonal leaching (Woodward et al. 1994).](image)

**Figure 18.7.** Clay-rich B horizons developed in alluvial soils on Pleistocene terrace surfaces in the Lower Vikos Gorge and Konitsa basin (Chapter 17). These soils have formed under long periods of seasonal leaching (Woodward et al. 1994).

![Figure 18.8. The relationship between the CaCO₃ content and magnetic susceptibility of the Klithi core sediments and the alluvial soils from the local valley-floor environment. The high magnetic susceptibility values in the alluvial soils are the result of pedogenic weathering, whereas the high values in the rockshelter environment are the result of sediment firing.](image)

**Figure 18.8.** The relationship between the CaCO₃ content and magnetic susceptibility of the Klithi core sediments and the alluvial soils from the local valley-floor environment. The high magnetic susceptibility values in the alluvial soils are the result of pedogenic weathering, whereas the high values in the rockshelter environment are the result of sediment firing.
gradual changes in such lithological and textural parameters as CaCO₃ and non-carbonate silt. Superimposed on this environmental signal are cultural changes characterized by abrupt changes in colour and magnetic susceptibility.

Environmental change and sediment sources

The sedimentary sequence at Kliathi records the changing importance of three principal fine sediment sources — namely materials ultimately derived from the limestone and flysch rocks of the catchment and aeolian dust of uncertain provenance. The transfer pathways involved in the delivery of fine sediment to the rockshelter floor are, however, complex, with evidence for the storage, weathering and reworking of materials prior to deposition in the rockshelter. The examples discussed above emphasize the importance of carefully evaluating the local geomorphological setting and the value of drawing comparisons with other local sedimentary environments (including other rockshelters) to provide a more rigorous basis for palaeoenvironmental interpretation. Through careful consideration of the particle size characteristics and lithological composition of the fine sediment fraction it has been possible to establish correlations with other Quaternary sediments in the Voidomatis basin on lithostratigraphic grounds. This approach has been adopted in preference to establishing correlations on the basis of inferred climatic characteristics for particular sedimentary associations, or climatostratigraphy, the use of which has characterized many of the correlation schemes devised from rockshelter sedimentology (cf. Laville et al. 1980).

While it is difficult to estimate the absolute contribution to the fine sediment fraction from in situ limestone weathering, this fine sediment source is thought to be minor in comparison with external sources (see also Jennings 1985; Macleod 1980; White 1988). Sedimentological and geomorphological evidence suggests that the lower portion of the core sequence correlates with the Late Würm Aristi Unit of the Voidomatis alluvial sequence and represents full-glacial conditions in the Voidomatis basin before approximately 24 ka (Lewin et al. 1991; Macklin et al., Chapter 17). During this period two main kinds of aeolian sediment were blown into the rockshelter: CaCO₃-rich silts from the braided floodplain of the Voidomatis River; and significant amounts of clay-rich dust derived from further afield.

The central and upper sections of the core sequence correlate with the Vikos alluvial Unit (Macklin et al., Chapter 17). This unit was deposited following incision and terracing of the Aristi Unit sediments and the associated reduction in suspended sediment load and narrowing and deepening of the channel system would have considerably restricted aeolian activity, especially if the higher parts of the former floodplain were colonized by vegetation. The corresponding parts of the rockshelter sediments record a considerable change in sediment character as the supply of limestone-derived fine sediment from the suspended load of the Voidomatis River eventually waned and the delivery of flysch-derived (quartz-rich) silts increased in importance (Fig. 18.9). This non-carbonate silt component of the fine sediment matrix was transported vertically by karst infiltration processes, and also laterally by local riverine/aeolian processes.

The upper part of the sequence shows evidence of alteration as a result of human occupation. In the upper metre or so of the core sequence, inputs of aeolian dust begin to increase, but do not attain pre-occupation (full-glacial) levels. At the same time the non-carbonate silt component declines towards the upper part of the rockshelter fill, perhaps reflecting a return to cooler and drier conditions and reduced fine sediment infiltration and/or further incision of the Voidomatis River which would have reduced any aeolian inputs by increasing the height difference between the active floodplain and the rockshelter floor.

In summary, the lithological and environmental changes recorded in the Late Pleistocene rockshelter sequence broadly mirror the major changes in the alluvial sediments record of the adjacent river environment. Following the Last Glacial Maximum, run-off and sediment delivery from the flysch terrains of the catchment made an increasingly important contribution to the suspended load of the Voidomatis River. During this period, after about 16 ka, a marked increase in the importance of flysch-derived materials as a fine sediment source is clearly recorded throughout the basin in both the rockshelter and alluvial records (Fig. 18.9).

Conclusions

A central concern of this contribution has been to demonstrate how careful integration of both the 'on-site' and 'off-site' sedimentary records with the archaeological sequence can provide a major contribution to an understanding of the interactions between large-scale changes in the Pleistocene environment and human activity. The sedimentary sequence at Kliathi has provided an important bridge
between the archaeological and environmental records. By focusing on the full stratigraphic succession and by making comparisons with the river sediments and soils in the vicinity of the site, it has been possible to establish the wider stratigraphic and environmental context of the Klithi sequence. In order to fully evaluate the environmental significance of rockshelter sediments, it is important to establish linkages with other sedimentary environments such as well-dated glacial, alluvial and lacustrine successions where the evidence for climatic change is much less equivocal and often incontrovertible. Without a detailed appreciation of the catchment-wide geomorphological changes which took place during the Late Pleistocene, aspects of the rockshelter sequence at Klithi would have appeared puzzling, posing fundamental problems of interpretation. For example, it is difficult to reconcile the general rule that 'sound rocks produce few fines' (DeWolf 1988) with the presence of hard limestone bedrock at Klithi and the abundance of limestone-derived fine silt in the pre-occupation sediments. Furthermore, a major conclusion from experimental research on frost weathering of resistant limestone is that the fine fraction within coarse sediments cannot result solely from the breakdown of the host bedrock (Lautridou 1988).

As far as the rockshelter sediments are concerned, the main conclusions to emerge are as follows:

1. There is a marked contrast between the pre-16 ka deposits and those associated with the human occupation of the site.
2. Allogenic materials dominate the fine sediment component through the sequence.
3. The production of fine sediments through in situ limestone breakdown is a comparatively minor process.

It has only been possible to account for the origin of the allogenic fine material through detailed investigation of local bedrock composition and a range of late Quaternary sedimentary environments throughout the Voidomatis basin. It is clear that a substantial shift in the dominant sediment sources and depositional processes took place between c. 20 ka and 16 ka (middle core section), which can be related to major climatic and basin-wide geomorphological changes. The pre-occupation levels are dominated by limestone erosion products associated with headwater glaciation, fluvial transport and local aeolian reworking. The occupation deposits mark a period of reduced glacial influence, which corresponds to a change in the composition of the Voidomatis suspended sediments, and an increase in fluvial transport and infiltration of flysch-derived sediments. This switch in sediment provenance in the middle part of Y25, prior to human occupation of Klithi, is indicated by a considerable change in the character of the fine sediment as coarse insoluble silt material assumes increasing importance. These sedimentological changes were under way prior to the occupation of the site.

From the available sedimentary data at Klithi,
it is not possible to resolve in detail the nature of environmental fluctuations which may have taken place during the occupation of the site between c. 16 ka and 10 ka. It is of considerable interest, however, to note that the proportions of non-carbonate silt and coarse silt material, which markedly increase immediately preceding the period of human occupation, show a systematic decrease in the upper 1 m of the deposit. As the increase signals a reduced glacial influence and possibly also a significant climatic amelioration between c. 20 ka and 16 ka, then it is tempting to relate the later decrease to renewed cooling. Some support for this interpretation is the coeval increase in clay content, which reaches levels comparable to those in the full-glacial pre-occupation sediments. This suggests a wider, perhaps regional, increase in aridity which promoted the entrainment and transport of aeolian dust. This deterioration may not have been sufficiently prolonged or intense for renewed glacier expansion, and is thus not recorded in the Voiolomatis alluvial sequence, nor do the CaCO₃ values in the Klithi sediments show any significant change throughout this period. It is tempting to relate these trends to the Younger Dryas cooling which took place between c. 11 ka and 10 ka, but poor dating resolution at the top of the Klithi sequence does not allow this point to be pursued.

A more detailed insight into local environment-tal changes during this crucial episode between 16 ka and 10 ka is offered by the more finely resolved and accessible sedimentary sequence at the neighbouring site of Megalakkos, where there are sharp alterations in sediment style over this period and a relatively small human impact on the sedimentary record (Woodward, Chapter 19).

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