The Sedimentary Records in Mediterranean Rockshelters and Caves: Archives of Environmental Change

Jamie C. Woodward¹ and Paul Goldberg²

¹School of Geography, University of Leeds, LS2 9JT, United Kingdom
²Department of Archaeology, Boston University, Boston, Massachusetts 02215

It is important to develop rigorous methods and robust conceptual models for the interpretation of rockshelter and cave sediment records so that the cultural sequences they contain can be considered in their proper environmental context. Much of what we know about the prehistory of the Mediterranean region and adjacent areas has largely been pieced together from materials excavated from sedimentary sequences in those environments. The rockshelters and caves of the region form important environmental and sedimentary archives. Recent work has begun to consider if the remarkable climatic variability evident in the high-resolution lacustrine and ice core records is manifest in the rockshelter and cave sediment records of the area. In this context, the two main characteristics of a rockshelter or cave site which control its usefulness as an archive of environmental change are the temporal resolution of the sedimentary record and the environmental sensitivity of the site. Many rockshelters and caves can be described as either Active Karst Settings (AKS) or Passive Karst Settings (PKS) and site type is an important influence on climatic sensitivity with a direct influence upon the usefulness of the sedimentary sequence as a proxy record of climate change. It is now clear that some sites may preserve detailed paleoclimatic records and the climatic signal may be represented by distinctive suites of micromorphological features, by variations in the input of allogenic sediment, or by fluctuations in the mineral magnetic properties of the fine sediment fraction. It can be argued that data derived from the analysis of bulk coarse-grained samples often lacks the stratigraphic resolution and environmental sensitivity that can be obtained from other approaches. The most favorable sites for detailed paleoclimatic reconstruction appear to be in active karst settings such as Theopetra Cave (Greece) and Pigeon Cave (Morocco) where micromorphological analyses offer insights into the stratigraphic record that are not otherwise obtainable. The temporal resolution of a site can only be established through a rigorous stratigraphic analysis and a comprehensive dating program. These are fundamental considerations in the study of rockshelter sediment records, especially when attempting to correlate between sites and draw comparisons with other proxy records of environmental change derived from sedimentary environments with rather different characteristics. Rockshelters and caves are part of a wider sediment system, and their investigation must be accompanied by detailed geomorphological, sedimentological, palaeoenvironmental, and geochronological studies of the off-site Quaternary record.

INTRODUCTION

Sediments, in short, constitute the one common denominator of rockshelter archaeology and are therefore the necessary starting point for all attempts to construct a comprehensive regional scheme for Stone Age times (Laville et al., 1980:12).
Much of what we know about the Paleolithic, Mesolithic, and Neolithic cultures of the Mediterranean region and adjacent areas is derived from cultural remains preserved in rockshelter and cave sediment records (see Gamble, 1986; Strauss et al., 1996; Bailey et al., 1999). The archaeological record of the last glacial period is set against a backdrop of marked and often rapid environmental changes, including the maximum cooling of Oxygen Isotope Stage 2 when glaciers were present in many of the high mountains across the Mediterranean basin (Woodward et al., 1995). Recently acquired high resolution lake sediment records from southern Europe show rapid environmental fluctuations that correlate well with the Heinrich events recorded in the deep sea sediments of the North Atlantic and with the ice core records from Greenland. These records demonstrate that the closely coupled ocean-atmosphere system of the Northern Hemisphere during the last glacial extended its influence at least as far as the central Mediterranean (Allen et al., 1999; Galanidou et al., 2000). The significance of this connection has also been highlighted for fluvial systems in the Mediterranean region, with widespread evidence for increased hillslope and channel sediment fluxes associated with increases in flood magnitude during cold phases of the Pleistocene (see Lewin et al., 1991; Macklin et al., 1997; Fuller et al., 1998; Rose and Meng, 1999; Hamlin et al., 2000). The rapidity of the vegetation and geomorphological changes evident in these records has important implications for local and regional biome and landscape dynamics and poses new challenges for our understanding of the archaeological record of Paleolithic hunter gatherers. The cultural history of the Late Pleistocene in this region records the demise of the Neanderthals, the emergence of anatomically modern humans in Europe, and the beginnings of domestication and agriculture at the end of the last cold stage (see Gamble, 1994; Mellars, 1994; Bar-Yosef and Belfer-Cohen, 1992). Our knowledge of these pivotal stages in human history has largely been pieced together from materials excavated from sedimentary sequences in rockshelter and cave sites. It is, therefore, important to develop rigorous methods and robust conceptual models for the interpretation of rockshelter sediment records so that these cultural sequences can be considered in their proper environmental context.

Rockshelter and cave sediment records offer advantages over many open sites because they can provide both stratigraphic control and environmental context for the archaeological record. However, the paleoclimatic significance of the sedimentary records in these specialized depositional zones has been widely debated (Callcott, 1979; Farrand, 1985, 1988; Bailey and Woodward, 1997; Goldberg, 1992, Goldberg and Bar-Yosef, 1998; Macphail and Goldberg, 2000; Courty and Vallverdu, 2001), and the methods employed for intersite correlation have also proved controversial (see Turner and Hannon, 1988).

Recent work in the Mediterranean basin and adjacent regions has begun to consider if the remarkable climatic variability evident in the high resolution lacustrine and ice core records is manifest in the rockshelter and cave sediment records of the area. In this context, perhaps the two main characteristics of a rockshelter or cave site that control its usefulness as an archive of environmental change are the...
temporal resolution of the sedimentary record and the environmental sensitivity of the site. These are critical issues in the study of rockshelter sediment records, especially when attempting to correlate between sites or make comparisons with other proxy records of environmental change. These themes generated much discussion at the Philadelphia (SAA) Symposium on Rockshelter Sediment Records and Environmental Change in the Mediterranean Region (April 2000), and they are explored further below and in the articles that follow in these two special issues.

THE GEOMORPHOLOGICAL SETTING OF ROCKSHELTER AND CAVE SITES IN THE MEDITERRANEAN REGION

The limestone rockshelters and caves of the Mediterranean region are found in a wide range of geomorphological settings. The local environment and the geometry and aspect of these sites are important controls on the nature and variety of the sediments deposited in the site and their rate of accumulation. The sites discussed in these special issues are located in 10 countries that lie within or close to the Mediterranean Sea basin (Figure 1). These range in elevation from ca. 750 m above sea level (Pigeon Cave, Morocco) to ca. 11 m above sea level (Franchthi Cave, Greece) and include sites in coastal locations, inland basins, deep mountain gorges, lowland floodplains, and lake shore environments (Table I). While the Mediterranean region is not easy to define (see Macklin et al., 1995), Figure 1 includes several sites that lie outside of the Mediterranean drainage basin and whose climates are strongly influenced by their proximity to the North Atlantic seaboard. In fact, the 26 sites shown encompass a wide range of terrains and climatic regimes from coastal Portugal and the Dordogne in the west, to the Levantine sites in the Eastern Mediterranean basin. These sites, and the environmental gradients and varied geomorphological settings associated with them, might be expected to provide an opportunity to examine the influence of large-scale climatic controls on the nature of rockshelter sedimentation during the Late Pleistocene and Holocene periods.

Active and Passive Karst Settings

In considering the geomorphological setting, it is helpful to consider the extent to which a site and the internal karst drainage network are interconnected in terms of water, solute, and sediment inputs through conduits in the bedrock walls and ceiling. The degree of interaction or coupling with the internal karst system can exert an important control on sediment transport pathways (Figure 2), on the ratio of allogetic to autogenic fine sediment delivery, and on the sensitivity of a given site to climatic changes and how these are manifest in the sedimentary record (Woodward, 1997b; Courty and Vallverdu, 2001). Rockshelters and caves have been classified in several ways (see Ford and Williams, 1989), but in this context, most sites can be described as either Active Karst Settings (AKS) or Passive Karst Settings (PKS), and some of the characteristics of such sites are listed in Table II.
Figure 1. Map of the Mediterranean basin and adjacent regions showing the principal rockshelter and cave sites discussed in the papers in these special issues (April and June 2001).
<table>
<thead>
<tr>
<th>Site Name and Country</th>
<th>Elevation</th>
<th>Geomorphological Setting</th>
<th>Maximum Observed Depth of Sequence</th>
<th>Earliest Evidence of Human Occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theopetra Cave (northern Greece)</td>
<td>280 m</td>
<td>On the northwestern edge and 100 m above the broad alluvial basin of the Peneios River east of the Pindus Mountains</td>
<td>&gt;6 m</td>
<td>Middle Paleolithic</td>
</tr>
<tr>
<td>Franchthi Cave (southern Greece)</td>
<td>11 m</td>
<td>Large cave on the northwest end of a narrow and rocky limestone headland at the southern end of the Angiol Peninsula overlooking Kilada Bay</td>
<td>&gt;12 m</td>
<td>Middle Paleolithic</td>
</tr>
<tr>
<td>El Miron Cave (northern Spain)</td>
<td>280 m</td>
<td>Set in the west-facing cliff of Monte Pando about 100 m above the Ero Calera. A steep rocky slope and talus cones lie in front of the cave mouth</td>
<td>&gt;5 m</td>
<td>Middle Paleolithic</td>
</tr>
<tr>
<td>Konispol Cave (southwest Albania)</td>
<td>400 m</td>
<td>Elevated south-facing hillside location in a rocky karstic terrain within the Pafos River basin</td>
<td>c. 5 m</td>
<td>Late Upper Paleolithic</td>
</tr>
<tr>
<td>Klithi Rockshelter (northwest Greece)</td>
<td>&gt;430 m</td>
<td>Set in near vertical cliffs in a deep mountain gorge</td>
<td>ca. 7 m</td>
<td>Late Upper Paleolithic</td>
</tr>
<tr>
<td>Kastritsa Rockshelter (northwest Greece)</td>
<td>470 m</td>
<td>Small cave in a narrow limestone ridge looking out across a flat lake marginal setting in the Ioannina basin</td>
<td>&gt;9 m</td>
<td>Upper Paleolithic</td>
</tr>
<tr>
<td>Aetokremnos Rockshelter (southwest Cyprus)</td>
<td>40 m</td>
<td>Collapsed shelter in the rocky coastal cliffs of the Alorotini Peninsula with talus slopes down to the present shore to the south and east</td>
<td>ca. 1 m</td>
<td>Final Paleolithic</td>
</tr>
<tr>
<td>Tabun Cave (Israel)</td>
<td>50 m</td>
<td>Large cave in the western cliff of Mount Carmel facing the Mediterranean coastal plain on the southern bank of Wadi Magbara</td>
<td>&gt;20 m</td>
<td>Lower Paleolithic</td>
</tr>
</tbody>
</table>

*It is important to appreciate that the geomorphological setting of many sites was rather different during the last glacial period due to, for example, changes in sea level such as at Franchthi in southern Greece.*
This simple classification of rockshelter and cave-mouth environments may be viewed as a continuum from a highly active to a fully passive karst setting (Table II), but it is important to remember that present conditions do not necessarily indicate those existing in the past. The position of a particular site along this continuum will influence sediment and solute sources, depositional mechanisms, and the nature and extent of any post-depositional modifications (including biological activity) (see Tsatskin et al., 1995). The rate of host rock breakdown may also be affected by the hydrogeological and geochemical setting. Some of the larger sites shown in Figure 1 will show characteristics of an AKS and a PKS because many of these features can be spatially and temporally variable, and intermediate groupings may, therefore, be appropriate.

The important point here is that site type exerts a crucial influence upon environmental or climatic sensitivity and will have a direct influence upon the usefulness of the sedimentary sequence as a proxy record of climate change. Thus, not all of the approaches currently employed in the study of rockshelter and cave sediment records will yield unequivocal paleoclimatic signals in all contexts. Theopetra Cave in Thessaly (Karkanas, this issue) and Pigeon Cave in Morocco (Courty and Vallverdu, 2001) may be described as Active Karst Settings, and these sites and

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Figure 2. The movement of silts and clays through conduits in the limestone bedrock is typical of many active karst settings in the Mediterranean region (see Table III).
Table II. Some of the characteristics of active karst settings and passive karst settings for rockshelter and cave mouth environments in limestone terrains.a

<table>
<thead>
<tr>
<th>Active (Humid) Karst Setting</th>
<th>Passive (Dry) Karst Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Linked to an internal cavern or conduit system</td>
<td>* No significant links with an internal conduit system</td>
</tr>
<tr>
<td>* Dripping vadose waters</td>
<td>* Dry site without flowing or dripping water</td>
</tr>
<tr>
<td>* Seasonal water flows and ponding</td>
<td>* Limited or no inwashing of sediments via karstic cavities</td>
</tr>
<tr>
<td>* Range of hydrological pathways</td>
<td>* Highly localized or no chemical precipitation</td>
</tr>
<tr>
<td>* Precipitation of calcite and other minerals</td>
<td></td>
</tr>
<tr>
<td>* Inwashing of fine sediments via conduits in the host bedrock</td>
<td></td>
</tr>
<tr>
<td>* Development of vegetation within the site</td>
<td>* Desiccation of macroscopic plant remains</td>
</tr>
<tr>
<td>* Mineralization of macroscopic plant remains</td>
<td></td>
</tr>
<tr>
<td>* Strong chemical diagenesis and mineral alteration</td>
<td>* Limited chemical diagenesis and mineral alteration</td>
</tr>
<tr>
<td>* Humidity may encourage host rock breakdown by frost action</td>
<td></td>
</tr>
<tr>
<td>* Evidence of erosion and sediment removal by invasive karst waters</td>
<td>* Limited host rock weathering by solution</td>
</tr>
</tbody>
</table>

a Note that these examples are hypothetical and not all the features listed will be present in all sites. Environments may shift between these two end-members and intermediate categories may be appropriate.

their sedimentary records display many of the characteristics listed for this group in Table II. Indeed, it is interesting to note that both sites contain important paleoclimatic records that have been pieced together from detailed micromorphological analysis of a range of primary and secondary microstratigraphic features. Many of these diagnostic features are the result of post-depositional alterations and mineral transformations related to subtle but significant changes in vadose water chemistry. In each case, the sedimentary and diagenetic processes within the cave appear to be well coupled with the dynamics of the external environment, and major climate changes have left distinctive and consistent signatures in the sedimentary record. It is also important to appreciate that the hydrological and geochemical setting may change over time as the site fills up with sediments. Conduits for both surface and subsurface water and sediment transfer may change in direction and amount, resulting in shifting pathways for solutes and sediments. At the same time, the zones of post-depositional modification may shift to other parts of the site (see Tsatskin et al., 1995).

A rockshelter with a permanently dry bedrock wall and ceiling that does not receive seepage or dripping vadose waters from the internal karst system will have...
a rather different depositional, geochemical, and biological history from a cave mouth with continuous dripping waters and extensive travertine development. The hydrogeological context will also influence the type of samples available for the application of geochronological dating methods (see Schwarzc and Rink, this issue). A rockshelter site such as Klithi, in the Voidomatis gorge of northwest Greece (Figure 3 and Table I), may be considered a passive karst setting because this is essentially a dry site with very limited vadose seepage at the present time (Woodward, 1997a). The fine sediments at this site are dominated by allochthonic materials introduced by various processes via the shelter opening and not directly from the internal karst system. Rockshelter sites in passive karst settings may be expected to provide good locations for the application of quantitative sediment sourcing methods because natural post-depositional modifications may be minimal in much of the sequence (Woodward et al., 2001). In such cases, it is especially important to study the wider Quaternary record to establish which sediment sources were important at different stages in the site’s history.

The hydrology of a site and the nature of the sediment-water interactions over time can be an important influence on the preservation of archaeological materials. For example, Weiner et al. (1993) have shown that extensive areas of the southern part of Kebara Cave in Israel (Figure 1) have been depleted in bone by diagenetic processes. In contrast, Klithi displays many of the features of a passive karst setting (Table II), and the bone remains are well preserved with little or no post-depositional weathering and clearly preserved cut marks (Gamble, 1997). In the case of macro-organic plant remains in Mediterranean caves and rockshelters, Hansen (this issue) points out that “dry sites” (passive karst settings) commonly contain a wide range of plant foods because the desiccation process helps preserve even very delicate structures, thus aiding identification. In contrast, preservation due to mineralization takes place in sites in more active karst settings where plant structures are replaced by calcium carbonate, for example, derived from groundwaters.

THE PALEOClimATIC SIGNIFICANCE OF ROCKSHELTER AND CAVE SEDIMENT RECORDS IN THE MEDITERRANEAN REGION

The Coarse Sediment Fraction

The formative work of Henri Laville and others in the rockshelters and caves of the Dordogne region of southwest France has been highly influential in the development of ideas for the paleoclimatic interpretation of rockshelter sediment records. Many of the classic French Paleolithic sites are characterized by accumulations of coarse angular limestone debris (eboulls) that have been attributed to the work of frost action. For example, Laville et al. (1980:52) stated:

We have seen that cryoelastism or frost action was the principal agent involved in the formation of rock shelters in the Perigord and was necessarily therefore responsible for the eboulls that volumetrically dominates their fill deposits.
Figure 3. Klithi rockshelter in the Lower Vikos Gorge (Voudomatis River) of northwest Greece. This is a dry site or passive karst setting with limited inputs of water and sediment from the internal karst system. Fine sediment has been washed down the cliff face above the site, but the rear of the shelter is dry.
Coarse-grained rockshelter deposits with comparable clast morphologies and geomorphological contexts have been recorded in sites throughout the northern Mediterranean region where frost action is still evident today. Interestingly, at 750 m above sea level in the mountains of eastern Morocco, Courty and Vallverdu (2001) report evidence for intensive cryoclastic cave wall fragmentation during the Pleistocene that produced deposits that are rather similar to the cryoclastic deposits found in rockshelters of western Europe. Laville (1976) presents his definition of "macrothermoclastism," which is a process associated with an annual freeze–thaw cycle (where an extended period of freezing produces large, angular rock fragments) and "microthermoclastism" associated with less extreme diurnal freeze–thaw cycles and the production of smaller rock fragments. While these process–response models may be appropriate in certain sites at certain times, the multifarious variables involved in host rock weakening and breakdown mean that these ideas cannot be applied as universal rules for paleoenvironmental reconstruction and are not supported by experimental research on rock disintegration (see Bailey and Woodward, 1997, for a full discussion). Indeed, as Vita-Finzi (1978:99) argued, more than two decades ago, in his book *Archaeological Sites in Their Setting*, "...attempts to infer freeze–thaw frequency and other climatic values from
the rock record call for an unacceptable level of conjecture.” As Collcutt (1979) pointed out, the simple equation of a sediment parameter with a geological process appears to be an affliction to which cave sedimentologists are particularly prone. In his review of the study of rockshelter and cave sediments, he went on to state:

In all areas of analysis it is difficult to find examples of adequate and consistent appraisal of the effects of non-climatic factors, such as local soil mantles, varying overburden lithology or even geomorphological setting (Collcutt, 1979:294).

The central Mediterranean basin is one of the most seismically active regions of the world (see King et al., 1997). Because of long-term tectonic instability, the limestone rocks of the Mediterranean region are commonly strongly folded and fractured with highly variable bedding thicknesses and joint spacings (Figure 4). This situation has created brittle bedrock walls in many locations that are especially susceptible to a range of rock reduction and particle detachment processes including seismic activity (Bailey and Woodward, 1997). It is likely that frost action is an important process in the production of coarse angular limestone clasts in many sites, especially in upland locations in the northern Mediterranean region (Figure 4 and Table I). However, such particles can be produced by a wide range of geomorphological processes (e.g., dissolution, seismic activity, hydration shattering; see Collcutt, 1977; Farrand, 1985), and, in the absence of other information, such deposits do not constitute a reliable basis for detailed paleoenvironmental reconstruction. In the case of the deposits at the Late Upper Paleolithic Klithi rockshelter in northwest Greece (Figure 1 and Table I), Bailey and Woodward (1997) have argued that in such a setting the caliber and form of the coarse limestone particles in the sequence could be conditioned more by tectonic preparation of the host rock than by the influence of exogenic detachment mechanisms (Figure 4).

Coarse sediments are clearly an important and often the dominant component of rockshelter sediment records. In conjunction with other information, the bulk particle size characteristics of the coarse sediment fraction and the shape, roundness, and weathering characteristics of the limestone clasts can provide useful information on site formation processes (see Woodward, 1997b; Farrand, 2000). However, it is important to consider the full range of potential rock reduction mechanisms at a given site, and it can be argued that data derived from the analysis of bulk coarse-grained samples often lack the resolution and environmental sensitivity that can be obtained from other approaches (see Goldberg, 1992).

Micromorphology and the Source of the Fine Sediment Fraction

Since the adoption of micromorphological techniques in the study of rockshelter sediment records (see Courty et al., 1988; Goldberg, 1992), greater emphasis has been placed on the paleoenvironmental significance of the fine sediment fraction. Many of the early approaches mentioned above relied heavily on the significance of the coarse sediment particles, and Laville’s (1975) definition of “frost slabs” is a good example. More recently, Woodward (1997a) and Woodward and Bailey (2000)
have argued that the fine particulate (silt and clay) fraction in many sites is dominated by allogenic materials because the host limestone bedrock in many Middle and Upper Paleolithic sites is typically extremely pure (< 1% insoluble residue), and the potential for fine sediment production on site is limited. Many of the sites listed in Table 1 are formed in hard pure limestones where the acid insoluble residue forms only a very small part of the total mass. Thus an understanding of fine sediment sources (including bedrock composition) and related off-site processes is important for the reconstruction of site formation. Woodward and Bailey (2000) provide a detailed discussion of the sources of fine sediments deposited in rockshelter environments, and Table III lists examples from a range of geomorphological settings in the Mediterranean region. Woodward et al. (2001) describe a new approach for the analysis of rockshelter sediment records, which involves the use of a multiparameter sediment fingerprinting method to provide quantitative estimates of the contribution of potential source materials to the sediments accumulating in a rockshelter site. A good deal of research (e.g., micromorphology, magnetic susceptibility analyses, and quantitative sediment sourcing) now largely focuses on the properties and significance of the fine sediment fraction, and some of the reasons for this shift in emphasis by many workers are listed in Table IV.

Goldberg (1992) has carried out micromorphological investigations of two of the reddened fine-grained units within the rockshelter of Pech-de-l’Azé II (Dordogne, France) that were previously described as paleosols representing weathering during interstadial or interglacial conditions (Laville et al., 1980). These reddened layers commonly lie between units dominated by coarse angular limestone rock fragments that represent host rock breakdown by frost action during the harsh climatic conditions of the last cold stage. Micromorphological analysis revealed an absence of illuvial clay and an assemblage of features more indicative of reworked Tertiary weathering products transported into the site by solifluxion processes (Goldberg, 1992). The new insights provided by a micromorphological approach revealed that the previous interpretation of these features as paleosols was no longer sustainable. Many of the rockshelters and caves of the Mediterranean region contain reddened sediments that often represent reworked soil materials derived from terra rossa that have been washed, slumped, or blown from their place of origin (Table III; see Bar-Yosef, 1993; Schuldenrein, 2001; Ellwood et al., this issue). Strongly weathered and decalcified soils that are rich in iron oxides with distinctive red hues are a characteristic feature of Mediterranean limestone terrains (Macleod, 1980; Woodward et al., 1994). In the absence of micromorphological information, it is often difficult to establish the genesis and paleoenvironmental significance of reddened sediments within a rockshelter sequence, although the mineral magnetic properties can be informative (see Ellwood et al., this issue).

In concluding this brief discussion of the paleoenvironmental significance of rockshelter sediment records and the wide range of approaches now employed to characterize sediment composition and microstratigraphic features, it is worth revisiting an article by Brain (1967:296) who stated [his italics]:

"short standard"
Table III. Examples of geomorphological and anthropogenic processes and the fine sediment deposition associated with them that have been reported for rockshelter and cave-mouth sites in various settings in the Mediterranean region (modified from Woodward and Bailey, 2000).

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. Rewashed loess and *terrarossa* may be introduced into rockshelters by this process (see Bar-Yosef, 1993). This mechanism has been recognised in numerous rockshelter and cave sites in the Mediterranean region including Franchthi (Farrand, 1988), Megalakissi (Woodward, 1997b), Koniasi (Schindler et al., 2001), and Astrakremenos (Mandel and Simmons, 1997).

2. Colluvial Processes: This may involve a range of sediment transfer mechanisms including periglacial processes, mass movements, and slope wash processes. The latter may include fines washed down gorges walls during storm events which may have exited the karst drainage system via flood-filled conduits (Woodward, 1997a). 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. Eolian 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 and local deflation zones can be important (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). Mandel and Simmons (1997) have identified fine and very fine-grained beach sands that form an important component of the fine matrix within the sedimentary record of the Astrakremenos rockshelter in southwest Cyprus. These sediments were blown into the site around 10,500–10,000 yr B.P. from an extensive early Holocene beach during a lowered sea level.

4. Fluvial Processes: Fluvial processes can deposit suspended load and bed load sediments within rockshelter sites, and the caliber of the sediments will depend on the magnitude of the flood events and the local geomorphological setting. Rockshelter environments may form important slackwater sedimentation zones and such deposits have been reported at Erika in the Voidomatis basin (Hamlin et al., 2000; Woodward et al., 2001). Fine sediments are commonly deposited by fluvial processes in active karst settings (see Table II) when sediment-laden flows from the internal karstic drainage deposit their loads in cave passages and shelter openings (see Radov and Valverde, 2001).

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 deposits may interdigitate with aeolian or colluvial sediments. The sequence at Kantritza 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; Galanidou et al., 2000). At Yarimburgaz Cave in Turkey the upper cave encloses Chalcolithic to Upper Paleolithic occupations above beach sands attributed to the Last Interglacial (Farrand and McMahon, 1997).

6. Human Activity: Fine sediments resulting from human activities take a range of forms and are present in many sites. These deposits may include fine alluvial sediments dragged into a site on wet carcases and the waste products of flint tool manufacture (microdebitage). The latter may also be considered as allochthonous 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%. Between ca. 11,500 and 9500 yr B.P. at Franchthi Cave, human imports and debris markedly increased the sedimentation rate. 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).

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Physical and chemical weathering of the host bedrock will also produce fine sediments but the significance of this source will vary from site to site. This list is not exhaustive, and coarse sediments (>2 mm), organic materials and chemical precipitates, for example, are not considered here. It is also important to appreciate that many rockshelters do not contain sedimentary records because of limited sediment supply or removal by erosion.
Table IV. Properties of the fine sediment fraction in rockshelter and cave sediment records in terms of its utility as a record of environmental change (modified from Woodward and Bailey, 2000).

- 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 allogenetic 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 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 (Woodward et al., 2001).
- In contrast to the poorly sorted coarse-grained products of host bedrock breakdown, many primary fine sediment properties display limited lateral variation within coeval sedimentary units although this characteristic can be blurred by human activity.
- Analysis of the microstratigraphic features within the fine sediment component can provide greater temporal resolution for a given sequence. In active karst settings, the primary and secondary characteristics of the fine sediment fraction may form a high resolution record of external climatic changes.
- Micromorphological observations may allow the nature, extent, and sequence of any post-depositional alterations (including those caused by anthropogenic and other biological activity) to be identified.
- Micromorphology is commonly focused on features associated with the fine sediment fraction, and it can provide refinements or avenues of interpretation that are not achievable using other methodologies (Goldberg, 1992).

Each particular cave site must be treated individually, special notice being taken of its topographical situation and its relation to other geological formations. This is important since a method of climatic deduction appropriate to one site may be quite unsuitable for another.

Many workers have stressed the idiosyncratic nature of rockshelter sediment records but have questioned their value as records of regional paleoclimate either because the intensity of human occupation has blurred the stratigraphic record, or because local or site-specific processes that are not diagnostic in palaeoclimatic terms have dominated the processes of sedimentation for all or part of the site’s history. The sedimentary records in rockshelter and cave sites are commonly the product of multiple variables, and each site must be examined in terms of its particular geomorphological and hydrogeological context. The sedimentary records in many sites appear to be strongly influenced by human activity or local environmental factors (or both), and the analytical approach employed needs to be tailored to suit the environmental context encountered at a given site (Woodward, 1997a, 1997b). Thus, Courty and Vallverdu (2001) have applied micromorphological techniques at three sites and developed criteria for the palaeoclimatic interpretation of each of them as they are located in contrasting geomorphological and hydrogeological settings in the western Mediterranean region. The articles in these two special issues encompass a range of passive and active karst settings and show clearly that the rate of sedimentation, the range of fine sediment sources, the intensity of human interaction, the frequency and magnitude of gaps in the stratigraphic record,
and the degree of post-depositional change will all vary from site to site and over time.

**THE LAST GLACIAL MAXIMUM IN THE MEDITERRANEAN REGION**

Over the last few decades, there has been considerable debate surrounding the nature of the environment across the Mediterranean region during the Last Glacial Maximum (LGM). The presence of glacial sediments and landforms in the uplands across the region attests to the harshness of the glacial climate (see Palmentola et al., 1990; Woodward et al., 1995) (Figure 5). This period forms part of Oxygen Isotope Stage 2 in the deep sea record, and the apparently conflicting signals from continental pollen and lake level records have generated much of the controversy (see Bailey et al., 1983; Prentice et al., 1992; Harrison and Diegerfeldt, 1993). The issues will not be reviewed in detail here, but it is instructive to briefly examine two examples since it can be shown that contrasting interpretations of sedimentological and palynological data from rockshelter and cave sites in the eastern and western Mediterranean regions have played a key role in the development of this debate.

**Kastritsa Rockshelter and the Lake Ioannina Record**

The rockshelter site of Kastritsa is located in the Ioannina basin in northwest Greece at an altitude of ca. 470 m above sea level (Figure 1 and Table 1). This site was first excavated by Eric Higgs in 1966 and 1967, and this work found evidence of Paleolithic occupation dating from ca. 20,000 to 12,000 yr B.P. The stratigraphic record has been divided into 32 layers, and the oldest part of the sequence (layers 16–26) is mainly lake beach deposits consisting of densely packed water-worn pebbles interspersed with fine-grained lake sediments (Figure 6). The pebbles are well-rounded, indicating intensive abrasion, and their distribution is consistent with wave action at the lake edge (Bailey et al., 1983:26). These littoral zone sediments lie more than 3 m above the mean water level in the modern lake, and they were associated with radiocarbon ages of 20,800 ± 810 and 20,200 ± 480 yr B.P. They were, therefore, interpreted as representing high lake levels at the LGM (Figure 6).

The evidence for high lake levels and a humid climate at Kastritsa during the LGM was problematic since the pollen record from Lake Ioannina shows the presence of an artemisia steppe with few trees, indicating cold and dry conditions (Bottema, 1974; Tzedakis, 1993). While the possibility of tectonic uplift of the Kastritsa ridge cannot be discounted (see King and Bailey, 1985), alternative climatic models have been proposed. Prentice et al. (1992) attempted to reconcile this problem by proposing that the climate at the LGM was characterised by an increase in seasonality with more intense winter storms and more runoff (producing the high lake levels) but with a more prolonged summer drought which restricted tree growth and gave rise to the steppe-like pollen assemblages. In common with other locations and periods in the Mediterranean region, accurate paleoclimatic inter-
Figure 5. The distribution of glacial sediments and landforms in the mountains of the Mediterranean basin (after Messerli, 1967). Many of these areas have not been mapped in detail and have not been accurately dated. However, the widespread occurrence of these features attests to the harshness of the climate (at least in the uplands) during cold stages and the potential importance of frost action in rock breakdown. It is interesting to note that glacial features have been identified in northwest Africa where Courty and Vallverdu (2001) report evidence of intense frost action in the sequence at Pigeon Cave (750 m above sea level).
Figure 6. Schematic section of the stratigraphy at Kastritsa rockshelter and the radiocarbon ages from the littoral sediments as described by Eric Higgs and his team in the 1960s. The location of Kastritsa and the postulated Last Glacial Maximum shoreline are also shown (based on a diagram in Vita-Finzi, 1978). The locations of the long sediment cores I-249 and I-284 analysed by Tzedakis (1993) and Frogley (1997) are also shown (see Galanidou et al., 2000).

The archaeological sequence at Kastritsa and its relationship to the pollen record from Lake Ioannina has recently been re-evaluated by Galanidou et al. (2000). New AMS radiocarbon ages have been obtained from charcoal from the cultural layers, and these authors argue that human occupation of the site began earlier than previously thought at sometime before 23,880 yr B.P. towards the end of an interstadial. The new chronology for the site shows that the beach sediments actually...
Woodward and Goldberg

prodate the LGM as defined by the global marine oxygen isotope record. New high resolution data from the local lacustrine record at Ioannina have also been used to establish the paleoenvironmental context of Paleolithic occupation at the site. Significantly, ostracod and mollusc data indicating a low lake level between 20,000 and 22,000 yr B.P. are in good agreement with the pollen spectra of this time (Frogley, 1997). Galanidou et al. (2000) point out that conventional understanding of the LGM around 18,000–20,000 radiocarbon yr B.P. that correlates with the maximum extent of global ice as recorded in the deep sea oxygen isotope record (see Shackleton and Opdyke, 1973) does not correspond with the most severe climatic conditions in this part of the Mediterranean region. Indeed, the pollen record from Lake Ioannina shows that the most severe climatic deterioration was associated with Heinrich event 2 in the North Atlantic around 2000 years earlier. These new paleoenvironmental and chronological data from Lake Ioannina and Kastritsa rock shelter suggest that if the beach deposits do represent higher lake levels and are not purely an artefact of tectonic activity, the probable environment at the time was not one of high glacial conditions as assumed in the past. This effectively removes the need to invoke climatically complex scenarios (e.g., Prentice et al., 1992) and special pleading to reconcile the apparently conflicting evidence regarding the lake level stands (Galanidou et al., 2000:354).

Pollen from Rockshelter Sediments in Southwestern Europe

In a forceful critique of the paleoclimatic data from rockshelter, lake sediment, and marine sediment cores in southwestern France, northern Spain and the Bay of Biscay, Turner and Hannon (1988) question the existence of the Lascaux and Langerie interstadials that have been postulated on the basis of pollen spectra recovered from rockshelter sediment records in the region (Figure 7). Turner and Hannon (1988) have examined the continuous pollen records from lakes and bogs in these regions and find no evidence for these interstadials. The traditional interpretation of the pollen data recovered from the rockshelter records advocates a radically different interpretation of the sequence of climatic changes and vegetation patterns that took place in southwestern Europe between ca. 35 and 10 ka B.P. from those suggested by continuous records from lake sediments and peat bogs. Turner and Hannon (1988:42) have stated:

A careful consideration of pollen diagrams [derived from rockshelter sediments] covering the purported Lascaux and Langerie interstadials, said to occur between 16 and 20 ka B.P. (conventionally the maximum period of glacial advance of the last glacial stage), suggests that temperate pollen has percolated down through overlying [rockshelter] deposits and been preserved in certain sedimentologically favorable beds. Although widely accepted by archaeologists, these interstadials appear to have no reality and must be rejected.

While we need to improve our understanding of the taphonomy of pollen deposition in rockshelter and cave-mouth environments, this example shows that the typically very small concentrations of pollen preserved in rockshelter sediments (and the unusual fossil assemblages), and the many uncertainties surrounding the mecha-
Figure 7. The Upper Paleolithic cultures and climatic phases recognized for the period between 36,000 to 10,000 yr B.P. in southwest France and Spain (based on Renault-Miskovsky, 1986; Turner and Hannon, 1988). Note that the rockshelter sediment records are fragmentary and none of the sequences shown spans the entire period.
nisms of pollen delivery and preservation in a particular sedimentary unit, indicate that palynological data from caves and rockshelters do not provide a reliable indicator of past climatic conditions. Figure 7 also illustrates the fragmentary nature of the rockshelter sediment record with none of the sequences covering the entire period of interest. This serves to emphasize the importance of developing accurate chronologies based on multiple dating methods whenever possible.

The lake level controversy at Kastritsa and the many problems associated with the detailed paleoclimatic scheme produced from discontinuous rockshelter sediment records in southwestern France and northern Spain highlights the importance of making detailed comparisons with well-dated off-site records (including paleoecological, stratigraphical, and geomorphological archives as appropriate) within robust dating frameworks.

DISCUSSION: SITE SENSITIVITY, TEMPORAL RESOLUTION AND OFF-SITE CORRELATION

It is clear from the papers in these two special issues (April and June 2001) that the sedimentary records in the rockshelters and caves of the Mediterranean region constitute important paleoenvironmental and sedimentological archives. This is especially apparent for the last 40,000 years, a period that incorporates the LGM and the Lateglacial and is well constrained by radiocarbon dating. In certain cases, such sequences can provide important proxy climate records that are in good agreement with other independent sources of data. At present, however, the paleoclimatic data derived from rockshelter and cave sediment records is essentially qualitative (see Woodward, 1997a, 1997b; Courty and Vallverdu, 2001; Karkanas, this issue), and more research is needed in order to evaluate whether appropriate criteria can be identified to allow the use of transfer functions or other modelling strategies to provide estimates of mean annual temperature and precipitation for key periods (see Allen et al., 1999). These sedimentary records are of most value when accompanied by robust dating frameworks based on the application of more than one method beyond the range of AMS radiocarbon dating (see Schwarcz and Rink, this issue). At the same time, it is important to appreciate that the sedimentary data are indispensable to evaluate and constrain the chronometric dates (e.g., Karkanas et al., 2000).

The development of new dating methods and the refinement and calibration of existing ones has allowed some rockshelter stratigraphies to be placed within impressive geochronological frameworks (see Schwarcz and Rink, this issue; Woodward et al., 2001). The correlation (albeit tentative in some cases) of sedimentary features in rockshelter sediment records in various parts of the Mediterranean basin (including Greece) with Heinrich events and the Younger Dryas cooling, further highlights the potential sensitivity of some sites, for these signatures are not always clearly identifiable in regional pollen records (Woodward, 1997a; Turner and Sánchez-Gotie, 1997; Tzedakis et al., 1997; Courty and Vallverdu, 2001; Karkanas, this issue). It must be borne in mind, however, that establishing correlations...
among rockshelter sites is often problematic because the temporal continuity of the stratigraphic record is highly variable from site to site and, in many cases, large portions of time are not represented by deposits (Campy and Chaline, 1993). Faurand (1993) has estimated that approximately 50% of the nominal time span of the stratigraphic sequence at Franchthi Cave in southern Greece (Figure 1 and Table I) is completely missing from the excavated portion of the site. Moreover, he has no doubt that the occurrence of substantial hiatuses in deeply stratified rockshelter sites is the rule, not the exception (see Figure 7).

Long pollen records from lake basins in southern Europe have provided perhaps the most detailed records of Quaternary environmental change in the Mediterranean region (e.g., Wijmstra, 1969; Pons and Reille, 1988; Perez-Obiol and Julia, 1994; Tzedakis, 1993; Allen et al., 1999). Many of these records are well dated, and, because of more or less continuous sedimentation and favorable conditions for pollen preservation, these records can be correlated over extensive areas (Tzedakis et al., 1997). Many lacustrine sites provide continuous and often high resolution records of environmental change that are superior in many aspects to rockshelter sediment records in terms of their suitability for paleoclimatic reconstruction (Allen et al., 1999). However, such records also require careful interpretation as many species are over- or underrepresented in pollen records because of differential pollen production, dispersal, and preservation and pollen from isolated refugial populations may not always be represented in regional pollen records (see Bennett et al., 1991). It is therefore important to point out that macro-organic remains from rockshelter sites can be usefully compared to the fossil record obtained from lakes and peat bogs (see Hansen, this issue). Data on carbonized plant remains preserved in rockshelter sedimentary records not only provide information on the use of local resources, but they also form an important source of information on past plant communities and on the location of refugia, because the species represented may not be recorded in pollen spectra retrieved from lake sediment records.

Because the high resolution proxy climate records currently emerging from lake sediment records in the Mediterranean region show evidence of rapid and high amplitude climate changes throughout much of the last cold stage (Allen et al., 1999), researchers must guard against using “curve-matching” techniques as the principal means of intersite correlation and paleoclimatic interpretation of the rockshelter sediment record. Isotopic analysis of speleothems from Soreq Cave in Israel by Bar-Matthews et al. (1999) has identified six distinctive cold peaks during the last 60,000 years, four of which correlate well with the ages of three Heinrich events (H1, H2, H5) and with the age of the Younger Dryas stadial. Bar-Matthews et al. (1999) conclude that many climate events recorded in the North Atlantic may have also occurred in the Eastern Mediterranean region. However, they also point out that the other two Heinrich events are not recorded in the Soreq speleothem record while other millennial-scale events are recorded only on a regional scale. The sedimentary records in lakes and rockshelters differ markedly in terms of temporal continuity, and the dating control is commonly much more robust in the former. No cave or rockshelter site in the region contains a complete sequence
through the Pleistocene (see Figure 7) and, while it is often reasonable to assume uniform rates and uninterrupted sedimentation in lacustrine environments, the rockshelter sediment record is fragmentary, and the temporal resolution of rockshelter deposits is typically much coarser.

Vita-Finzi (1978) argued that the matching of sequences of cooler and warmer, or wetter and drier episodes, may well be out of phase by one or more cycles. Furthermore, the chances of making erroneous correlations in this way will certainly increase if one or more of the records is fragmentary. With the empirical reality of the high resolution records from ice cores and lake sediments revealing rapid and high amplitude changes over time scales of less than a century, it would be unwise to “count from the top” (see Bowen, 1978) when attempting to correlate climatic signals from rockshelter and cave sediment records. Assumptions of uniform rates of sedimentation in rockshelter sites are rarely valid for extended periods, either within or between sites (see Gamble, 1986, p. 351). The elaborate paleoclimatic scheme constructed by Henri Laville for the rockshelter sediment records in the classic Paleolithic sites of southwest France was wedded to the Penck and Brückner model of Alpine glaciation, which is now known to be a gross oversimplification (see Bowen, 1978, Stringer and Gamble, 1993). Indeed, more than two decades ago, Vita-Finzi (1978:17) commented:

The use of certain well-established sequences or horizons as standards against which the local record can be matched appears an economical device for spreading the benefits of radiometric dating: many prehistoric caves are dated by correlating the cold episodes apparently represented in their infills with an accepted glacial chronology. The economy is a false one which leads at best to circular argument and at worst to misleading conclusions, and any procedure which divorces climatic interpretation from excavation is to be welcomed.

An additional problem that can hamper on-site and off-site correlation relates to those micromorphological data where, due to discontinuous sedimentation, the evidence for climatic cooling, for example, may be in the form of secondary features that have been superimposed on sediments deposited during interstadial conditions. In such cases, it can be difficult to establish good chronological control for the duration of these climatic phases (see Karkanas, this issue; Courty and Vallverdu, 2001). Furthermore, in contrast to many of the classic rockshelters in the Dordogne, for example, Mediterranean cave sequences are often characterized by complex sedimentary architectures with localized facies changes, both within and between individual stratigraphic units. These changes have resulted from processes such as localized dumping or trampling or severe diagenesis that has affected restricted horizons or zones (see Goldberg and Bar-Yosef, 1998; Weiner et al., 1993; Tsatskin et al., 1995). It is often difficult to differentiate between penecontemporaneous changes to cave sediments and those resulting from later groundwater effects (Tsatskin et al., 1995). Thus, in such contexts, it is not only difficult to demonstrate contemporaneity and to correlate strata, but it also hampers attempts to reconstruct a coherent geological history of the deposits and their reaction products.

It was pointed out earlier that the two main characteristics of a rockshelter or
cave site controlling its usefulness as an archive of environmental change are the temporal resolution of the sedimentary record and the environmental sensitivity of the site. While it is not easy to quantify these parameters, it is important to consider them in any discussion of intersite correlation. The high resolution pollen records from southern Europe contain evidence of rapid and high amplitude climatic changes that appear to agree well with the ice core records from Greenland (see Allen et al., 1999). From the evidence presented in the articles in these special issues, it is clear that we are now beginning to recognize such complexity in rockshelter and cave sediment records, but the available stratigraphic windows may be small in view of the fragmentary nature of the sequences. Recent work on the speleothems in Soreq Cave in Israel has shown that the changing composition of percolating groundwaters in a Mediterranean karst can be a sensitive indicator of the external climate. Thus, the most favorable rockshelter sites for detailed palaeoclimatic reconstruction appear to be in active karst settings such as Theopetra, Pigeon Cave, and El Miron, where micromorphological analyses offer insights into the stratigraphic record that are not obtainable using other approaches (Karkanas, this issue; Court and Valverde, 2001).

Sensitivity refers to the propensity of a system to respond to a minor external change (Schumm, 1991). The change occurs at a threshold, which when exceeded produces a significant adjustment. If the sedimentation processes in a rockshelter site are sensitive and close to a threshold, they will respond to an external influence (such as a change in precipitation and runoff), but if they are not sensitive to changes, they may not respond. Sensitivity may be difficult to define for a particular site, and buffering effects and lag times may be involved that result in the sedimentation processes in the cave or rockshelter being out of phase with the external environment (see Baker et al., 1997). In this context, it can be argued that data derived from the analysis of bulk coarse-grained samples often lacks the stratigraphic resolution and environmental sensitivity that can be obtained from other approaches such as micromorphology. The temporal resolution of a site can only be established through a rigorous stratigraphic analysis and a comprehensive dating program. These are fundamental considerations in the study of rockshelter sediment records, especially when attempting to correlate between sites and draw comparisons with other proxy records of environmental change derived from sedimentary environments with rather different characteristics.

CONCLUSIONS

The rockshelters and caves of the Mediterranean region and adjacent areas form important environmental and sedimentary archives. Important advances in our understanding of these systems have been made since the review of Collcutt (1979). An improved understanding of site formation processes and palaeoenvironmental context in the Mediterranean region cannot be achieved through the application of a single approach, whether this is micromorphology, quantitative sediment sourcing, the measurement of mineral magnetic parameters, or more traditional sedi-

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mentological analysis. There is still a need for increased dialogue between the various proponents of these methods, and collaboration should take place in the field and in the laboratory. These approaches should be regarded as complementary and synergistic (see Woodward et al., 2001), and they need to be integrated more fully across a range of environments and site types. For example, an understanding of fine sediment provenance and sediment delivery mechanisms is crucial for the interpretation of the magnetic susceptibility signal (Ellwood et al., 1997; Ellwood et al., this issue). At the same time, data from micromorphological analyses can help to decouple the natural (geogenic) and anthropogenic signals in the sedimentary record and can unravel these from the sequence of natural post-depositional alterations that have affected the primary sedimentary record (Karkanas et al., 1999; Courty and Vallverdu, 2001). All of these data may be important for the design of the most appropriate dating strategy (such as ESR dating of teeth or OSL dating of eolian sediments) for a rockshelter site (see Schwarz and Rink, this issue).

It is now clear that some sites may preserve remarkably detailed paleoclimatic records, and these signals may be represented by distinctive suites of micromorphological features, by variations in the input of allochthonous sediment, or by fluctuations in the mineral magnetic properties of the fine sediment fraction. However, the apparent sensitivity of a site may be due to a fortuitous combination of local factors, and we should not expect the same sedimentological or mineral magnetic parameters to represent the same local or regional paleoenvironment at each site. It is also important to point out that rockshelters and caves are just one part of wider proximal and distal sediment systems, and, as highlighted by the controversy surrounding the nature of the Last Glacial Maximum in southern Europe, their investigation must be accompanied by detailed geomorphological, sedimentological, paleoecological, and geochronological studies of the off-site Quaternary record (Woodward and Bailey, 2000).

We are grateful to Geoff Bailey, Mick Frogley, and Chronis Tzedakis for reviewing the manuscript and to David Appleyard of the Graphics Unit in the School of Geography for drawing the maps and figures.

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Received October 22, 2000
Accepted for publication November 25, 2000