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# Mediterranean Quaternary River Environments

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# Glaciation, river behaviour and Palaeolithic settlement in upland northwest Greece

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ABSTRACT: Despite long-standing recognition of the widespread occurrence of glacial features and sediments in the headwaters of many Mediterranean river basins, the downstream impact of former glacial activity upon Mediterranean Quaternary river environments is poorly known. The Voidomatis River basin of northwest Greece, however, provides a notable exception as a substantial body of geomorphological data has recently been assembled. A large headwater basin of this river system lies in the high karst terrain of the Pindus Mountains and was glaciated during the Pleistocene on at least two occasions. Evidence is presented from Pleistocene river sediments preserved in the lower reaches of the Voidomatis basin which suggests that the cold stage river maintained a braided planform with a sediment load dominated by glacially-derived material. During the full-glacial period, riverine sediment fluxes were very high and meltwater discharges accelerated sediment delivery from headwater basins to bedrock-confined downstream reaches. At this time extensive spreads of predominantly coarse-grained glacio-fluvial materials built up across the valley floor. During phases of incision following the last glacial maximum, these sediments were terraced and now form prominent landscape features. Glacial activity was a *major* agent of landscape modification in parts of the Mediterranean region and this influence extended well beyond glacier margins by effecting wholesale changes in river regime and depositional environments. In addition, there is also a growing body of geoarchaeological evidence to suggest that, in marginal upland environments, glacial activity may have also influenced the timing of Palaeolithic settlement.

KEYWORDS: Greece, glaciation, Quaternary river environment, sediment sources, aggradation, Palaeolithic settlement, Klithi rockshelter.

## 1 INTRODUCTION

Wherever European uplands lay above the snowline during glacial stages of the Pleistocene, ice formed upon them and valley and cirque glaciers developed (Flint 1971). This was also the case in many of the high mountains of the Mediterranean lands as evidence for Pleistocene glacial activity is widespread in each of the countries which share the northshore coastline of the Mediterranean Sea (Fig. 1). Glacial landforms and sediments have been identified in northern and central Spain and southern France, along the length of both the Italian and Balkan peninsulas as well as in the uplands of Corsica (Conchon 1986) and Turkey (Messerli 1967). More recently some workers have also reported the presence of glacial sediments from as far south as Crete (e.g. Stewart 1993). The review by Messerli (1967) also documents several locations in Mediterranean northwest Africa where evidence for Late Pleistocene valley glaciation has been found (Fig. 1). To date, however, apart from the Alps themselves, detailed information about the nature, extent and age of the glacial sediments of southern and Mediterranean Europe is not yet available for many areas. Indeed, in comparison to our understanding of the glacial sedimentary sequences in northern and northwest Europe (see Ehlers 1983; Ehlers et al. 1991), the chronology and geomorphological significance of Pleistocene glacial activity in the Mediterranean region is poorly known and recent major reviews have highlighted the scarcity of basic field data (see Denton and Hughes 1981; Sibrava et al. 1986). Existing information is largely restricted to small scale maps which were compiled simply to illustrate the location of ancient glacial deposits in the mountain chains of Europe (cf. Messerli 1967; Flint 1971) (Fig. 1).

Despite long-standing recognition of the widespread occurrence of such glacial features in the headwaters of many river basins, the impact of former glacial activity upon Mediterranean Quaternary river environments is similarly poorly known. One notable exception, however, is provided by the Voidomatis River basin of northwest Greece where a substantial body of geological and geomorphological data has recently been assembled (Woodward 1990; Lewin et al. 1991; Woodward et al. 1992; Woodward et al. 1994). A large headwater basin of this river system lies in the high karst terrain of the Pindus Range and was glaciated during the Pleistocene on at least two occasions.

Using the example of the Voidomatis River this chapter aims to illustrate how glacial activity constituted a *major* agent of landscape change in certain parts of the Mediterranean region and to show that this influence

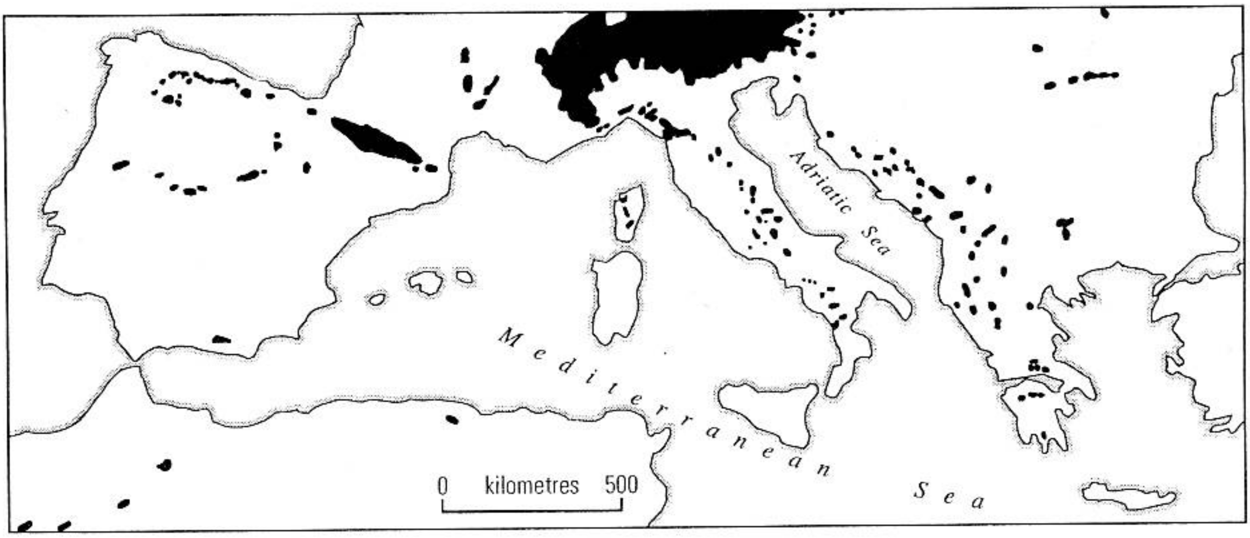


Figure 1. The distribution of Pleistocene glacial sediments and landforms in the Mediterranean region (after Messerli 1967 and Denton & Hughes 1981).

extended far beyond the glacial margins of the upland zone by forcing major changes in river regime and downstream depositional environments. These changes included large increases in both suspended and bed sediment loads, shifts in channel planform and sedimentation style, and substantial increases in rates of valley floor accretion. In addition, there is also a growing body of geoarchaeological evidence to suggest that, in marginal upland environments, glacial activity may have also influenced the timing of Palaeolithic settlement (cf. Bailey et al. 1990). Palaeolithic investigations in the Voidomatis basin began in 1983 and interest has mainly been focused upon the rockshelter site of Klithi located in the lower reaches of the Voidomatis River (see Bailey et al. 1984; Bailey and Gamble, 1990). Two principal archaeological research goals have been identified: (1) to provide a detailed definition of the Palaeolithic sequence at Klithi and the surrounding area and (2) to establish the relationship of this sequence to the environmental changes associated with the last glacial cycle (cf. Bailey et al. 1984).

## 2 THE GLACIAL DEPOSITS OF GREECE

In the Pindus Mountains, as in most of the world's major mountain ranges, glaciers under average Quaternary conditions extended well beyond cirques at valley heads and during times of glacial maxima, equilibrium-line altitudes (ELAs) fell about 1000 m (Porter 1989). Between Mount Gramos (2520 m) on the Albanian border and Mount Taygetos (2407 m) southwest of Sparta, many peaks in the Pindus Range exceed 2000 m and glacial deposits have been reported from several locations (Figs 1 and 2). One of the earliest accounts reporting evidence for former glacial activity in Greece was published by Niculescu in 1915. This paper describes the glacial features around Mount Smolikas (2637 m), the second highest peak in Greece, which lies within the extensive ophiolite terrain of northern Epirus in the middle reaches of the Aoos River basin. Two decades later Sestini (1933) published his '*Tracce glaciali nel Pindo epirota*' which described glacial landforms at a number of sites and included an estimate of the position of ice age snowlines across Greece. More recently Pechoux (1970) has reported the occurrence of several small cirques and glacial sediments in the uplands of central Greece in the vicinity of Mount Parnassus (2450 m), Mount Ghiona (2510 m) and Mount Vardhousua (2495 m). In a brief discussion of the Quaternary geology in the Metsovitikos area of central Epirus, Lorsong (1979) has reported the occurrence of debris flow deposits and glacial moraines in the catchment of the Metsovitikos River.

The distribution of glacial features in Greece closely matches the present distribution of average annual rainfall which itself is closely related to topography (Fig. 2). Figure 2 also serves to further emphasise the marked contrasts in river regime which exist across Greece and the rest of the Balkan Peninsula. There is a tenfold increase in annual rainfall moving northwest from southeast Greece (< 400 mm) to parts of upland Epirus and Albania (2000-4000 mm). With such pronounced differences in present and probably past river regime and annual runoff it not surprising that inter-regional correlations between episodes of Quaternary alluviation within Greece have so far proved elusive (see Lewin et al. 1991). In addition, inter-basin comparisons are hampered by the overall paucity and often poor quality of dating control for Quaternary river deposits.

## 3 THE VOIDOMATIS RIVER BASIN

### 3.1 *Geological and geomorphological setting*

The Voidomatis basin (384 km$^2$) is located in the Epirus region of northwest Greece and drains part of the high-

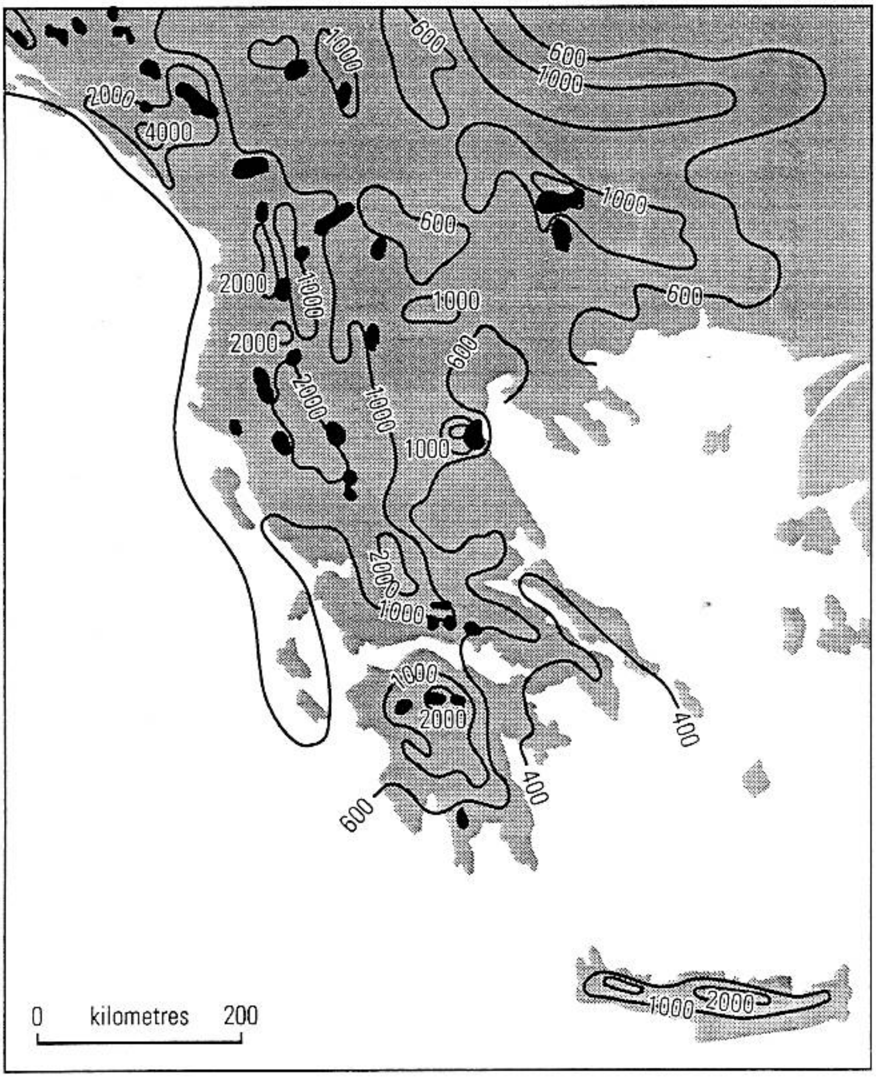


Figure 2. Average annual rainfall (after Osborne 1987) and the distribution of Pleistocene glacial features and sediments in Greece (after Denton & Hughes 1981).

relief, block-faulted karst of the Pindus Mountain Range (Figs 3 and 4). Elevations within the catchment range from c. 450 m on the Konitsa Plain to over 2400 m along the watershed of the Voidomatis and Aoos Rivers. The Voidomatis River is a 4th order, gravel-bed stream of steep average gradient (0.016 m $m^{-1}$) whose catchment is developed in resistant Jurassic and Eocene limestones which are capped in places by thick flysch beds of Late Eocene to Miocene age. The hard limestone rocks support the development of deep gorges and steep-sided tributary ravines (Vikos Gorge and Lower Vikos Gorge, Figs 3 and 4) whilst, in marked contrast, the erodible flysch terrains are characterised by sub-catchments of lower relief with greater drainage densities and higher present day suspended sediment yields (see Lewin et al. 1991).

### 3.2 *Climatic regime*

Epirus forms a zone of transitional climate between the Mediterranean region and central Europe and the heavy snowfalls and freezing temperatures of the Epirus winter are well documented (see Hammond 1967; Furlan 1977). The study area falls within the 'Mountain climate' zone of Walter and Lieth (1960) and mean annual rainfall frequently exceeds 2000 mm (Furlan 1977) (Fig. 2). The summer months are generally hot and dry although heavy thunderstorms are not uncommon in July and August.

## 4 THE GLACIATED HEADWATERS OF THE VOIDOMATIS BASIN

The limestone massif in the central and eastern part of the basin forms the highest part of the catchment where elevations locally exceed 2400 m. In the district surrounding the village of Tsepelovon the topography is dominated by an extensive range of morphological and sedimentological features indicating recent Pleistocene glaciation (Figs 4 and 5). Large-scale erosional features (glacial troughs and cirques) are carved into the hard limestone bedrock and the widespread deposition of glacially-modified sediments has produced a series of morainic lobes with associated glacio-fluvial landforms. These moraine ridges are capped by boulder-strewn surfaces and form a highly distinctive landform assemblage which blankets almost the entire area north of the modern stream channel (Figs 3 and 4). Large-scale ice-scoured troughs are present in the high limestone plateau and these features can be seen in the SPOT satellite image shown in Figure 5. All these features serve to demonstrate that ice accumulation in the high Pindus Mountains was *not* merely confined to a few isolated cirque hollows. The major centre of ice accumulation in the Voidomatis basin lay due north of Tsepelovon in the high plateau of the Gamilla Massif.

### 4.1 *Sedimentology of the Tsepelovon glacial sediments*

When exposed in section, the most striking feature of

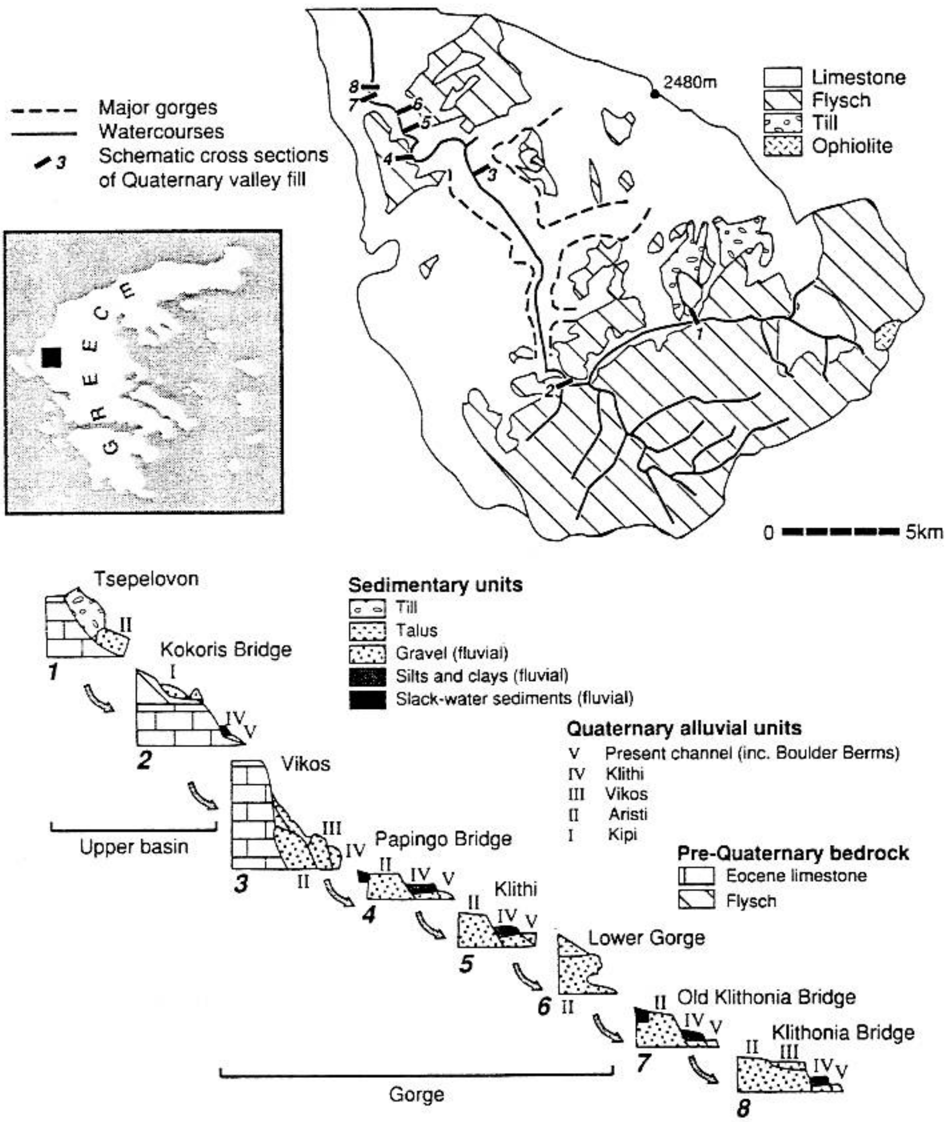


Figure 3. The geology and surface drainage network of the Voidomatis River basin. The lower part of the diagram shows schematic sections of the alluvial valley-fill sequence and the river terrace surfaces at each of these sites. Site 1 is located approximately 1.5 km south of the village of Tsepelovon in the glaciated part of the catchment. The main Vikos Gorge lies between Kokoris Bridge (2) and Vikos (3), and the Lower Vikos Gorge lies between Vikos (3) and the Old Klithonia Bridge (7). The Late Upper Palaeolithic rockshelter site of Klithi is located in the middle reaches of the Lower Vikos Gorge approximately 100 m upstream of site 5. The Voidomatis River joins the Aoos River approximately 5 km north of site 7 in the centre of the Konitsa Plain.

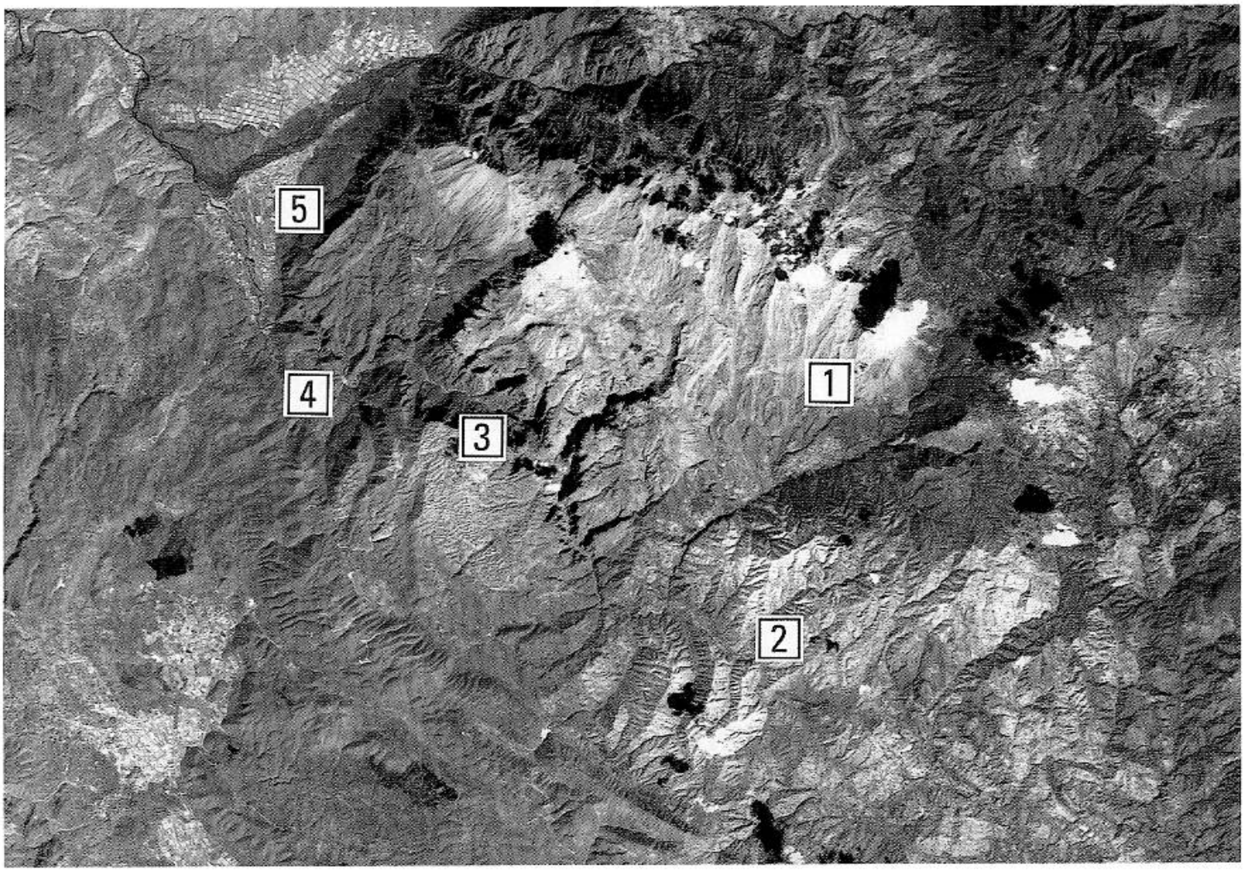


Figure 4. SPOT satellite image of the Voidomatis River basin highlighting the five major physiographic units described by Lewin et al. (1991). This scene provides a graphic illustration of the high-relief, block-faulted terrain of the study region. The scene incorporates all the area shown in Figure 1 and further highlights the distinctive, comparatively high-density pinnate drainage network of the flysch terrain upstream of Kokoris Bridge (site 2). This scene covers an area of approximately 40 × 28.5 km. Both the Voidomatis and Aoos River systems drain sub-catchments containing Pleistocene glacial sediments and both streams exit fault-bounded limestone gorges onto the Konitsa Plain. The Voidomatis-Aoos confluence is approximately 10 km from the Albanian border. Physiographic units: (1) Glaciated Tsepelovon district; (2) Headwater flysch terrain; (3) Vikos Gorge; (4) Lower Vikos Gorge; (5) Konitsa Plain.

these glacial sediments is their brilliant creamy-white colour which reflects their almost exclusively limestone origin (Fig. 6). These sediments are massive diamictons containing boulders in excess of 1 m in diameter and all size grades finer. The coarse fraction is dominated by limestone clasts (> 95%) with a minor flint and flysch gravel component. Most clasts are sub-angular to sub-rounded in form, unweathered, and frequently have scratched and striated surfaces. The glacial sediments are compact, unsorted and largely unstratified with a closed matrix-supported fabric.

Processes of glacial crushing and grinding have reduced the hard limestone source rock into a chemically-fresh rock flour. This fine matrix is composed largely of calcium carbonate (up to 95%) with quartz and plagioclase accounting for most of the acid insoluble residue – part of which can be accounted for by the presence of a minor flysch component. The mineralogical composition of the two main rock types in the catchment and the till sediments is shown in Figure 7. These peak-height data from X-Ray Diffraction (XRD) traces indicate a limestone source for the rock flour component of the glacial sediments. The coarse and fine elements of the glacial sediments also contain a very minor flysch component.

In Figure 8 the particle size characteristics of the silt and clay fraction (< 63 μm) of samples of till sediment (taken from the sections in Figure 6) are shown. This component is dominated by silt-grade $CaCO_3$ with a clay content of approximately 20% and median grain size ($D_{50}$) ranging from 12 to 15 microns. The resistant limestone rocks of the Voidomatis basin can only liberate significant amounts of material of this calibre when subjected to physical comminution processes in a glacial environment (cf. Woodward et al. 1992; Lautridou, 1988).

The glacial sediments are not strongly weathered and soil profiles on moraine crests are generally less than 50 cm thick. This probably reflects the fact that much of the winter precipitation at this altitude (> 1500 m) falls as

Figure 5. SPOT satellite image of the glaciated headwaters of the Voidomatis basin and the distinctive flysch terrain south of the contemporary river channel. This image highlights the marked contrast in slope form and drainage pattern and density in the headwater area. The Voidomatis River flows from right to left in the centre of this image. This image covers an area of approximately 18 × 11.5 km. The glacially-scoured limestone troughs of the Gamilla Massif are clearly visible at the top of this scene.

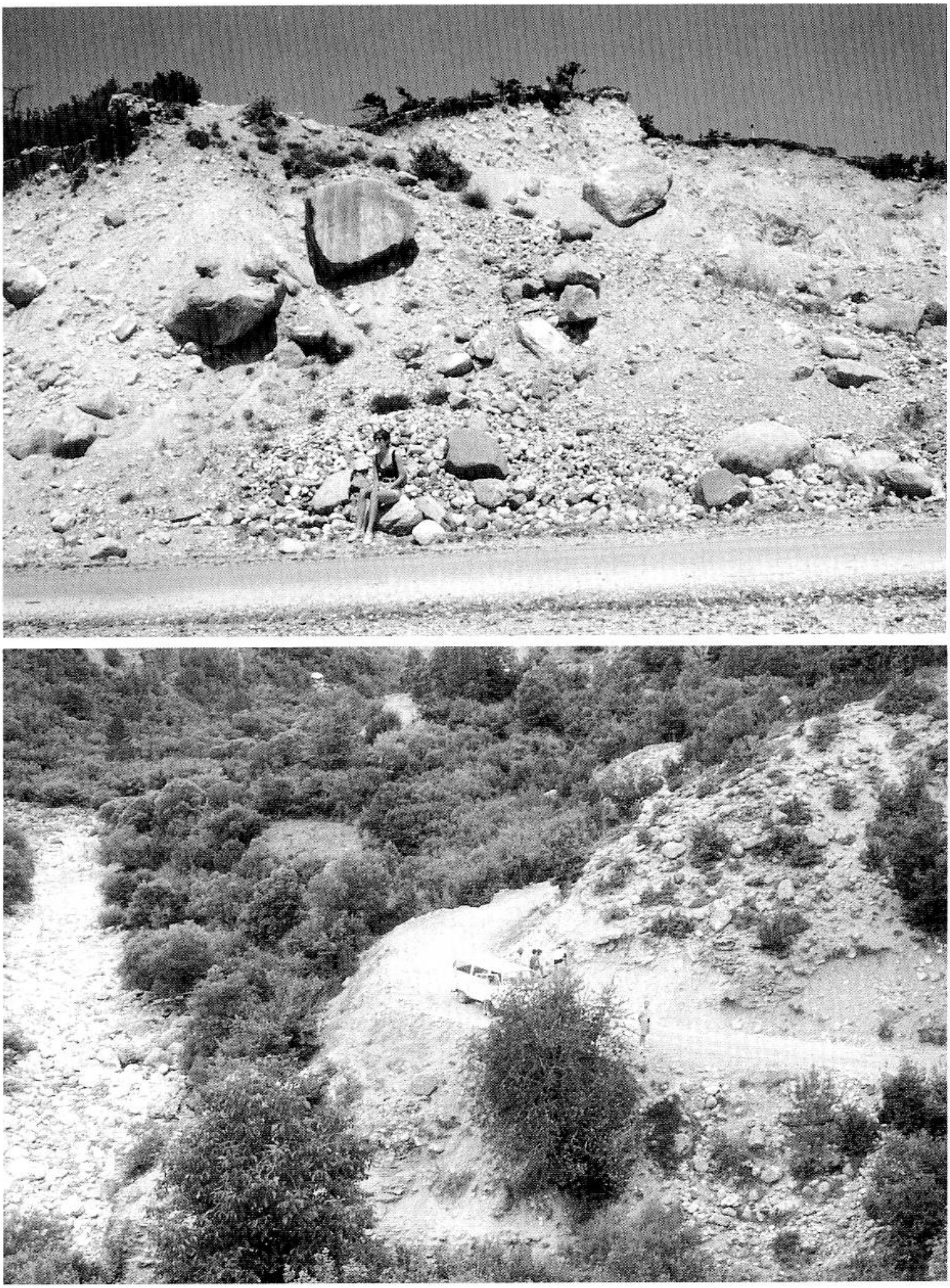

Figure 6. Top- A section in the Tsepelovon moraine complex exposing limestone-derived till sediments. Bottom- The terminus of a large moraine of Late Würm age adjacent to the bed of the modern Voidomatis River (view looking downstream) due south of the village of Tsepelovon.

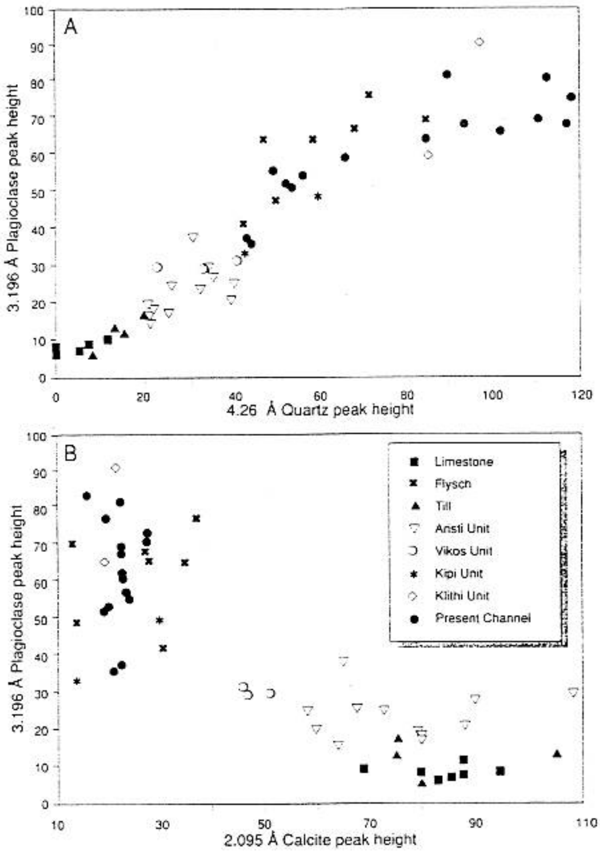


Figure 7. Peak height data from X-ray diffraction (XRD) traces showing the broad mineralogical composition of the < 63 µm component of the Voidomatis glacial and alluvial sediments. A) Plot showing the strong positive correlation between quartz and plagioclase in the basin sediments ($r^2 = 0.86$). B) Plot showing calcite and plagioclase relationships. The Aristi unit sediments are poor in plagioclase and quartz and rich in calcite reflecting their derivation from limestone-rich glacial sediments. In contrast, the Klithi unit sediments are rich in non-carbonate (flysch-derived) materials. The Vikos unit sediments are intermediate between these two groups (see Woodward et al. 1992).

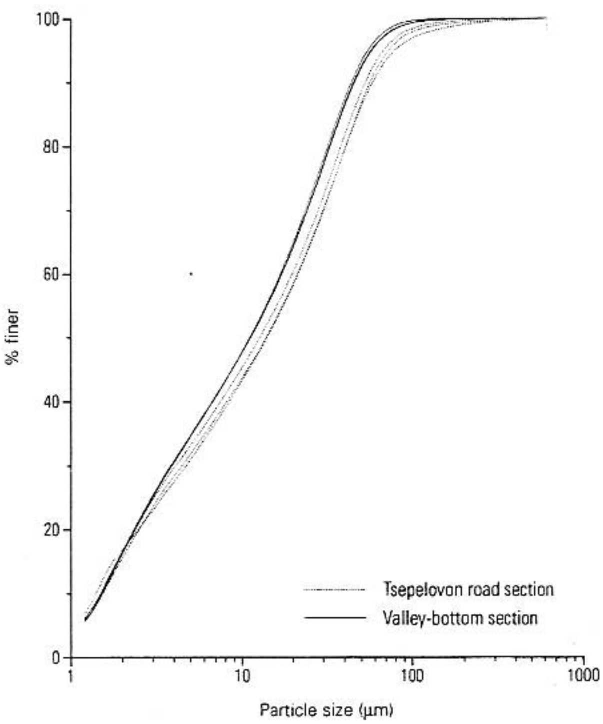


Figure 8. Particle size characteristics of the fine fraction of till sediments exposed in the Tsepelovon road section and the valley-bottom section shown in Figure 6. Sample preparation involved screening through a 63 µm sieve and chemical dispersion in sodium hexametaphosphate. Size distributions were determined using a Malvern Mastersizer Laser Diffraction Particle size analyzer (see Agrawal et al. 1991).

snow and infiltration rates (effective precipitation) are thus much reduced in comparison to conditions in the Lower Vikos Gorge and Konitsa Plain at lower altitude (< 500 m) where strongly leached soils are present on age-equivalent Pleistocene alluvial sediments (Woodward et al. 1994).

## 5 THE IMPACT OF GLACIAL ACTIVITY UPON THE RIVER ENVIRONMENT

This section discusses the impact of the headwater glaciers upon the Late Pleistocene Voidomatis River environment. Table 1 shows that two alluvial units (Aristi and Vikos) have been dated to this period. Most attention is directed to the properties and significance of the Aristi unit sediments as these are the most extensive and have the largest volume of all the Voidomatis river deposits.

### 5.1 *The Quaternary alluvial sequence in the Voidomatis basin*

The Quaternary alluvial succession has been investigated through a combination of detailed geomorphological survey and both field- and laboratory-based lithological analyses of valley fill deposits allied to a multi-method (ESR, TL and $^{14}C$) dating programme (see Lewin et al. 1991). This sequence embraces at least five major episodes of Quaternary alluvial sedimentation prior to the development of the modern floodplain system and each is followed by a period of incision and soil development. The lithological and sedimentary properties, altitudinal relationships, ages and depositional environments of these units are summarised in Table 1 (see also Lewin et al. 1991; Woodward et al. 1992).

Recent work based on terrace surface soil development in the Lower Vikos Gorge and Konitsa Plain has suggested that the Aristi unit may be subdivided into two distinct alluvial units which are difficult to differentiate using only primary lithological criteria (see Woodward et al. 1994). At present this pre-Late Würm episode of 'Aristi-type' sedimentation has only been identified with certainty at a single location in the catchment. While this chronosequence largely corroborates the model of alluvial history reported by Lewin et al. (1991), there is now some evidence to suggest that the northern Pindus Mountains were also glaciated before the last major (Late Würm) ice advance and that at least two phases of glacial activity can now be recognised in the Greek Pleistocene. Only isolated remnants of this earlier glacio-fluvial aggradation remain and it is the Aristi unit sediments of Late Würm age which dominate the Pleistocene fluvial geomorphology of the basin and provide the main focus for the following discussion.

### 5.2 *The Late Würm pro-glacial Voidomatis River*

The Aristi unit is believed to be the terraced remnant of a formerly extensive glacio-fluvial outwash train that was deposited by an aggrading, low-sinuosity proglacial stream which drained a series of valley glaciers in the Tsepelovon region (Lewin et al. 1991). This unit forms a striking alluvial terrace averaging 12.4 m above the level of the contemporary stream bed which can be traced almost continuously from the former glacier margins in the Tsepelovon district to the Aoos River junction on the Konitsa Plain more than 40 km downstream. During the Late Würm, channel morphology was influenced largely by meltwater discharges with high sediment loads (Lewin et al. 1991). The Aristi unit sediments consist almost exclusively of massive and flat-bedded, matrix-rich cobble gravels with occasional boulder-sized clasts. Clast imbrication is locally well developed where there is a lower proportion of creamy-white silty matrix.

Figure 6 shows the terminus of a large moraine in the bottom of the present valley system adjacent to the contemporary stream bed of the Voidomatis River. The basal sections of this moraine are being actively eroded by the modern stream where it is possible to observe in section the transition from fully-glacial to fully-fluvial sedimentary facies of the Aristi unit.

### 5.3 *Lithology of the Aristi unit sediments*

The lithological composition of both the coarse and fine elements of this alluvial unit are similar to the till sediments of the Tsepelovon district. The coarse (8-256 mm) component is dominated by limestone (95.4%) gravels with a significant minor proportion of flint (Table 1) and the fine matrix (< 63 µm) contains up to 85% $CaCO_3$. XRD analysis of the < 63 µm fraction of this unit shows these sediments to be characterised by a large proportion of limestone-derived (calcite-rich) sediment (Woodward et al. 1992).

During meltwater flood discharge events the Tsepelovon glaciers would have provided the major source of alluvial material for the cold stage river system, whereas today, the fine sediment load of the modern Voidomatis River is derived almost exclusively from erosion of local flysch rocks and soils. During the full-glacial period, however, limestone-rich rock flour provided the main source of fine alluvial sediment. Limestone material dominates the *gravel* fractions of the modern river (72.7%) and the late Holocene Klithi unit (69.3%), but the limestone rocks do not supply significant amounts of sediment in the < 63 µm range under modern climatic conditions. The fine matrix of the Late Pleistocene Aristi unit sediments is dominated by limestone-derived sediment as indicated by plagioclase-quartz and plagioclase-calcite relationships (Fig. 7). Solutional processes are important in the contemporary weathering environment and material < 63 µm is not a major constituent of recent (limestone) breakdown products. The limestones supply large amounts of rudaceous (> 2 mm) sediment while any limestone-derived material < 63 µm is largely removed in solution.

The marked contrast between the modern river system and the cold-stage glacial Voidomatis is shown in Figure 7. This simple mineralogical comparison serves to high-

Table 1. Altitudinal relationships, lithological properties, depositional environments and ages of the Quaternary alluvial units in the Voidomatis basin. The dates were obtained by the following methods: a) AMS $^{14}C$; b) ESR; and c) TL (see Lewin et al. 1991). Recent work reported by Woodward et al. (1994) – based upon terrace surface soil profile development – has shown that the Aristi unit sediments represent two distinct phases of glacio-fluvial sedimentation (see text).

| Alluvial unit | Height of terrace surface above river bed level (m) | Maximum observed thickness of unit | Clast lithological (bedload) composition (8-256 mm) | | | | | | Coarse (C)/ fine (F) sediment member ratio | Munsell colour of < 63 µm fraction | Fluvial sedimentation style and (in brackets) the dominant source of the suspended sediment load | Age of unit (years BP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Clasts N | Samples N | % Limestone | % Flysch | % Flint | % Ophiolite | | | | |
| Present channel | | | 8388 | 7 | 72.7 | 26.6 | 0.5 | 0.2 | C > F | Yellowish brown 10YR 5/8 | Incising, confined meandering gravel bed river. Low suspended sediment load. (Flysch sediments) | < 30 |
| Klithi unit | x = 3.2, s = 0.7, Range = 1.8–4.5 | 4.5 | 1139 | 2 | 69.3 | 29.6 | 1.0 | 0.1 | C ⋖ F | Yellowish brown 10YR 5/8 | Aggrading, high sinuosity gravel bed river. High suspended sediment load. (Flysch sediments) | 1000 (±50)[a] – 30 |
| Vikos unit | x = 6.8, s = 1.7, Range = 3.9–9.7 | 8.3 | 695 | 2 | 82.3 | 12.8 | 0.6 | 4.3 | C ⋗ F | Brownish yellow 10YR 6/8 | Incising wandering gravel bed river. Low suspended sediment load. (Flysch & Glacial sediments) | 24,300 (±2600)[b] – 19,600 (±3000)[c] |
| Aristi unit | x = 12.4, s = 3.9, Range = 6.7–25.9 | 25.9 | 5680 | 9 | 94.6 | 3.1 | 2.2 | 0.1 | C ⋗ F | Very pale brown 10YR 8/7-4 | Aggrading, low sinuosity, coarse sediment river system. High suspended sediment load. (Glacial sediments) | 28,200 (±7000)[c] – 24,300 (±2600)[b] |
| Kipi unit | 56 | 22.9 | 361 | 1 | 18.7 | 36.7 | 0.9 | 44.0 | C > F | Yellowish brown 10YR 5/8 | Aggrading (?) low sinuosity, coarse sediment river system. (Flysch sediments) | > 150,000[c] |

light the dramatic influence of glaciation upon this Mediterranean river system.

### 5.4 *Dating the glacio-fluvial sediments*

Below an exposure in Aristi unit gravels underlying slackwater sediments at Old Klithonia Bridge (Fig. 3 site 7), part of a red deer jaw bone and a number of Palaeolithic flint flakes were discovered in a small palaeochannel infilled with sandy silts. The sharp, unabraded edges of the lithic material and the fragile jaw bone (which still contained several teeth) indicated that this material was probably *in situ*. The jaw bone was submitted for $^{14}C$ dating but was devoid of collagen and therefore unsuitable. However, teeth from the mandible were submitted for enamel dating by ESR (using the linear, continuous U-uptake model; R. Grün, pers. comm. 1989) and yielded ages of 24,300 ±2600 (571c), 25,000 ±500 (571a), and 26,000±1900 (571b) years BP from three separate dating assays. These ages, together with a TL date of 28,000 ±7100 years BP (VOI23) also obtained from fine sediments at Old Klithonia Bridge, indicate that the Aristi unit, and the glaciation to which it relates, is of Late Würm age.

### 5.5 *Slackwater sedimentation*

The large proportion of silt- and sand-size matrix in the Aristi gravels indicate that suspended sediment loads were high during the full-glacial period. A closed clast-supported fabric in which all the voids are filled with fine materials is typical of the Aristi unit sediments and thin (up to 20 cm) lenses of exclusively fine-grained (sand- and silt-rich) sediment are occasionally present. The combination of high suspended sediment loads and the ponding of tributary ravines resulted in the development of thick sequences of fine-grained slackwater sediments (cf. Baker et al. 1983) at a number of tributary junctions in the Lower Vikos Gorge. These sediments were laid down in low-energy conditions and individual laminae may contain up to 40% clay and fine silt (Woodward 1990).

### 5.6 *River regime*

At present, from early summer to late autumn, stream flow is maintained only in the reaches downstream of a major exsurgence in the Vikos Gorge. In the central and upper reaches of the basin main channel flows are ephemeral and controlled by late autumn and winter precipita-

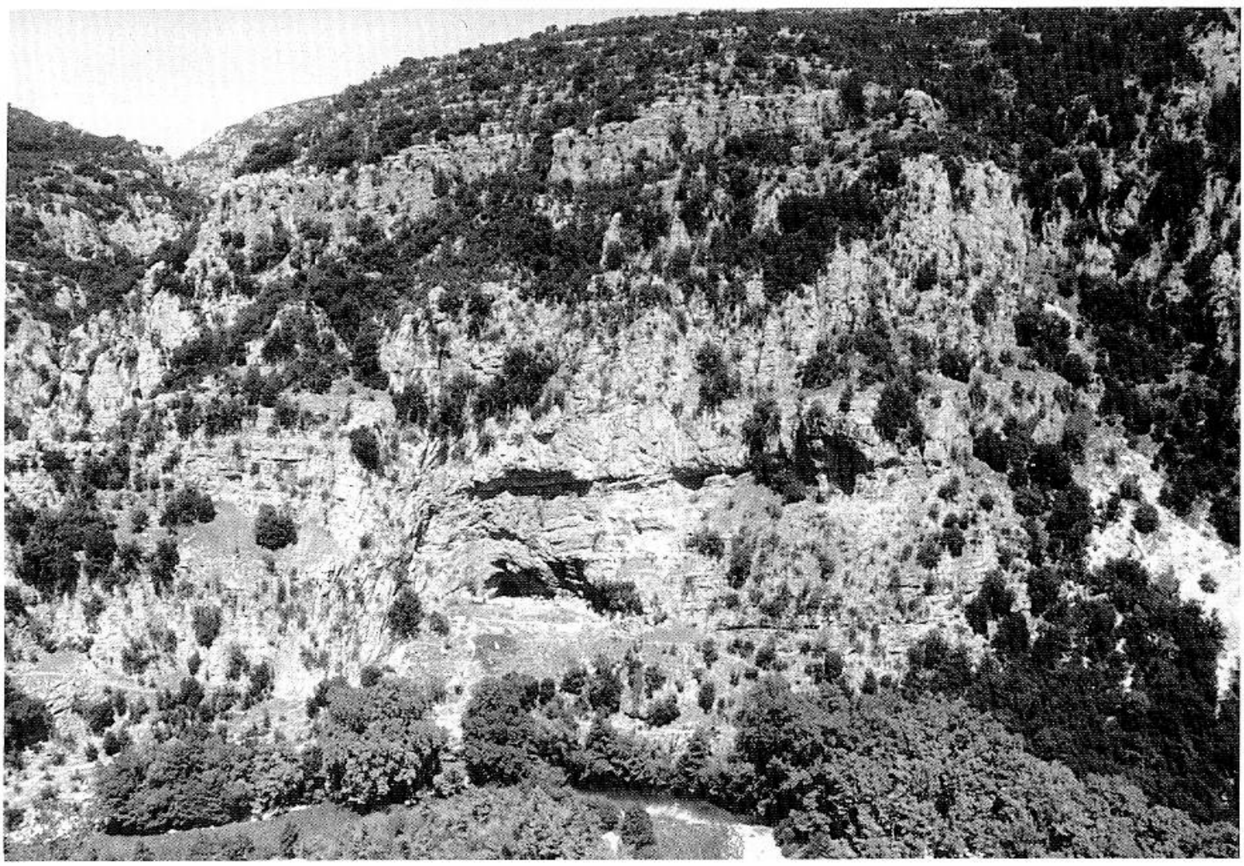

Figure 9. The Klithi rockshelter in the Lower Vikos Gorge. The site is approximately 30 m wide and 10 m deep. It is the largest rockshelter site known in Epirus and was discovered in 1979. Excavations commenced in 1983 led by Geoff Bailey and his co-workers. The site has proved to be immensely rich in both lithic and faunal material with a high density of artefacts in the upper part of the rockshelter sedimentary fill. The large faunal assemblage is dominated by ibex and chamois and the stone tools comprise a typical Late Upper Palaeolithic microlithic flint industry (see Bailey et al. 1986).

tion and snowmelt through the spring. During the Late Pleistocene, however, it is likely that peak flows would have been associated with spring and summer meltwater discharges.

## 6 PALAEOLITHIC SETTLEMENT AND ROCKSHELTER SEDIMENTATION AT KLITHI

### 6.1 *Geoarchaeological objectives*

The archaeological research objectives in the Voidomatis basin were broadly twofold: (1) to establish the nature of the Palaeolithic sequence at the Klithi rockshelter (Fig. 9) and (2) to determine the relationship of this sequence to the environmental changes associated with the last glacial cycle (see Bailey et al. 1986). At the beginning of the Klithi project in the early 1980s, it soon became apparent that the sedimentary fill at the Klithi rockshelter would play a central role in any attempt to correlate the environmental ('off-site') and archaeological ('on-site') records. The rockshelter sedimentary sequence thus provides an important bridge between the Palaeolithic record at Klithi and the climatically-driven changes recognised in the Pleistocene river environment (Woodward 1990).

### 6.2 *Excavation, coring and Palaeolithic occupation*

Since 1983 excavations have focused upon the rockshelter site of Klithi in the Lower Vikos Gorge (Figs 3 and 9). This site contains at least 7 m of Pleistocene sediments – the upper two metres of which are extremely rich in lithic and faunal material (Bailey et al. 1986; Bailey and Thomas 1987). This archaeological assemblage and a series of radiocarbon dates indicate that occupation of the site took place during the Late Upper Palaeolithic between c. 16,000 and 10,000 years BP, with no evidence of Palaeolithic occupation at this site before or after this period (Bailey et al. 1986; Bailey and Gamble 1990). Evidence for both earlier and later human activity has, however, been found on the Konitsa Plain but *not* in the rockshelter and cave sites of the Lower Vikos Gorge (see Figs 3 and 4).

In 1986, during an experimental drilling programme, a 7 m-long sediment core was recovered from Klithi which provided a valuable window into the nature of the pre-occupation sediments (below 2 m) in the rockshelter sequence (Bailey and Thomas 1987). A detailed study of this core was undertaken by the first author in order to place the rockshelter sediments within an appropriate local environmental context and to establish linkages with the climatically-driven changes recorded in the 'off-site' Pleistocene sedimentary records (Woodward 1995). A range of sediment analyses including detailed particle size analysis, $CaCO_3$ content, mineralogy, and magnetic susceptibility were performed on over 50 samples throughout this sequence and some of the results are shown in Figure 10 and Table 2. The rockshelter sedimentary sequence is described fully in Woodward (1995) and only the main features of the sequence are presented here.

### 6.3 *The Klithi rockshelter sediments*

The rockshelter deposits are composed largely of unconsolidated angular limestone clasts of various sizes within a predominantly silt-grade calcareous fine matrix. These materials are typically roughly stratified and very poorly sorted.

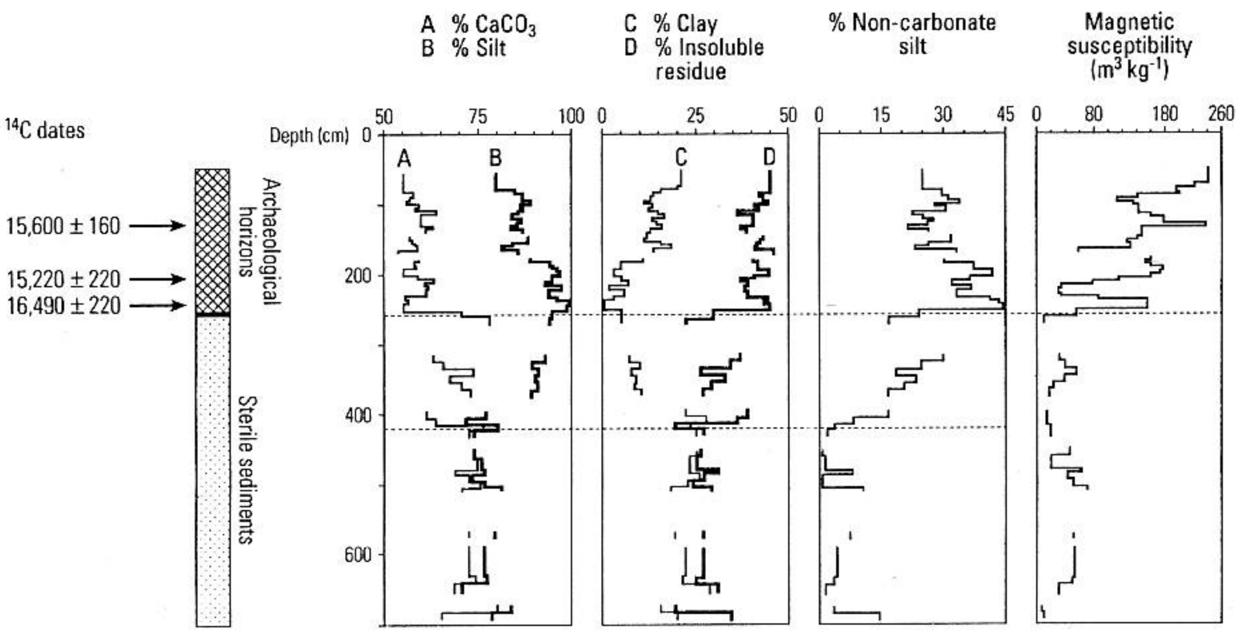


Figure 10. Downcore changes in the particle size characteristics, $CaCO_3$ content and magnetic susceptibility of the fine sediments of core Y25. Depth is in centimetres below the surface. Below the upper dashed line the sediments are archaeologically sterile. Laboratory numbers for radiocarbon dates (top to bottom): OxA - 1155, OxA – 1091, OxA – 1092.

Table 2. Summary of selected sediment property values for Klithi rockshelter core Y25. Ranges and mean values for each core section are shown. 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. All values refer to the sediment fraction < 63 μm. 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.

| Sediment property | Upper section (0-2.5 m) | Central section (2.5-4.2 m) | Lower section (4.2-7 m) | Whole core (0-7 m) |
|---|---|---|---|---|
| $CaCO_3$ (%) | 54.0-64.0 (58.5) | 61.4-78.1 (69.0) | 65.2-80.6 (72.9) | 54.0-80.6 (64.0) |
| Clay (%) | 0.28-20.5 (10.4) | 5.2-27.8 (11.4) | 15.7-28.7 (22.2) | 0.28-28.7 (13.5) |
| Non-carbonate silt (%) | 21.1-43.9 (31.1) | 8.2-29.4 (19.7) | 0.9-14.8 (4.9) | 0.9-43.9 (22.5) |
| 16-32 μm (%) | 26.3-37.9 (31.3) | 23.8-30.7 (27.3) | 13.3-25.9 (20.7) | 13.3-37.9 (27.9) |
| Magnetic susceptibility ($m^3 kg^{-1}$) | 28.1-239.6 (143.3) | 8.7-54.5 (27.3) | 5.5-68.7 (39.0) | 5.5-239.6 (95.7) |

Downcore changes in fine sediment lithology within the Klithi rockshelter sequence reflect the changing supply of three main fine sediment sources – namely materials ultimately derived from the limestone and flysch rocks of the catchment and aeolian dust of uncertain provenance. Sedimentological and geomorphological evidence suggests that the basal and archaeologically-sterile portion of the core sequence (below 4.2 m) correlates with the Late Würm Aristi unit of the Voidomatis alluvial sequence (Fig. 10) and thus represents full-glacial conditions in the Voidomatis basin before c. 24,000 years BP (Lewin et al. 1991). The fine matrix of the basal core material is lithologically similar to the fine matrix of the Aristi alluvial unit and is composed largely of silt-grade $CaCO_3$ (up to 80%). This fine material is not a by-product of *in situ* limestone breakdown. Much of this material was blown into the site during the full-glacial period and was locally derived. Fine-grained alluvial materials, deflated from the adjacent Voidomatis floodplain immediately below the rockshelter site, provided the dominant source.

The central and upper sections (above 4.2 m) of the rockshelter core sequence record a considerable change in fine sediment character (Fig. 10 and Table 2). This change in lithology was a response to a decrease in the availability and supply of limestone-derived fines from the floodplain surface of the pro-glacial Voidomatis River. During the Late Würm, as the supply of glacio-fluvial fine sediment waned, the delivery of flysch-derived (quartz-rich) silts increased in importance. A proportion of these quartz-rich silts was also locally derived from local riverine/aeolian sources. The fine fraction of the Vikos alluvial unit contains a significant flysch component (Fig. 7 and Table 1). In addition, a significant proportion of this latter (flysch-derived) non-carbonate fine silt material in the rockshelter deposits was washed down through fissures in the host limestone bedrock (Woodward 1990, 1995).

The Palaeolithic occupation horizons begin in the upper part of the Klithi rockshelter sedimentary record (post c. 16,000 years BP – above 2.2 m in core Y25: Fig. 10). The deposits in this part of the sequence contain a significant amount of non-carbonate silt (Fig. 10) and show evidence of modification by human activity. This human impact is reflected in the magnetic enhancement of the fine fraction due to burning (Fig. 10) and the abundance of human habitation debris and organic material (Bailey and Thomas 1987).

The Vikos alluvial unit was deposited following incision of Aristi unit sediments around 19,600 ±3000 years BP (Table 1). During the deposition of the Vikos alluvial unit and the subsequent phase of incision, the central and archaeologically-rich upper parts of the rockshelter fill were deposited (Fig. 10). It seems likely that rockshelter occupation at Klithi began during incision of the Vikos unit sediments during the climatic improvement which accompanied at least partial deglaciation of the headwater region. At this time the Vikos unit river was flowing at a level up to c. 7 m above present river level, but was probably reworking the extensive spread of Aristi unit sediments and incising into the alluvial valley floor. The presence of glaciers in the basin headwaters appears to have created conditions severe enough to deter any human use of the upland interior at the Last Glacial Maximum (cf. Bailey et al. 1993). Throughout this period attempts to access the Lower Vikos Gorge during the spring and summer may have been thwarted by peak stream flows associated with glacial meltwater discharges.

In summary, the lithological and environmental changes recorded in the Late Pleistocene rockshelter sequence broadly mirror the major changes recognised in the alluvial sedimentary record of the adjacent river environment. The sedimentary sequence at the Klithi rockshelter has provided an important link between the environmental and archaeological records.

## 7 CONCLUSIONS

The profound impact of glacial activity on Quaternary river behaviour has been well documented in many areas outside of the Mediterranean region (e.g. Rose et al. 1980; Baker 1983; Church and Ryder 1972; Macklin and Lewin 1986). However, despite long-standing recognition of the former presence of glaciers in the headwaters of many Mediterranean river basins, the impact of glacial activity upon Mediterranean Quaternary river environments has received relatively little attention. The example of the Voidomatis River presented in this chapter demonstrates that glacial activity was a *major* agent of landscape modification in parts of the Mediterranean region and that this influence extended well beyond glacier margins by effecting wholesale changes in river regime and depositional environments.

Evidence from Pleistocene river sediments preserved in the lower reaches of the Voidomatis basin suggests that the cold stage river maintained a braided planform with a sediment load dominated by glacially-derived material. Compared to present conditions, sediment fluxes were very high as large suspended and bed sediment loads caused shifts in channel planform and sedimentation style and substantial increases in rates of valley floor accretion. Meltwater discharges accelerated sediment delivery from the headwater basins to bedrock-confined downstream reaches and extensive spreads of predominantly coarse-grained, glacio-fluvial materials built up across the valley floor. During phases of incision following the Last Glacial Maximum, these sediments were terraced and now form prominent landscape features.

In comparison to present conditions, it is clear from the glacial geomorphological evidence that the headwaters of the Voidomatis basin were subjected to a more severe climatic regime for at least part of the last glacial period. In a recent paper Prentice et al. (1992) suggest that the ice age climate of the Mediterranean region was characterised by cold winters, intense winter precipitation and summer drought, and central to this hypothesis is an *increased seasonality* of precipitation as a key to the full-glacial Mediterranean palaeoclimate. Such a scenario is not incompatible with the glacial evidence from the Pindus Mountains. Summer temperatures were probably cooler allowing snowfields to persist and thicken and valley glaciers to develop. A plentiful precipitation supply must have been available to feed the snowfields of the Gamilla Massif.

As far as the archaeological record of the Late Würm is concerned, more information is needed from sites at intermediate altitude (500-1000 m) in the upland interior of the Mediterranean zone. The available geoarchaeological evidence from Epirus suggests that glacial activity not only effected major landscape changes, but may have also influenced the timing of Palaeolithic settlement in marginal upland locations such as the Lower Vikos Gorge of the Voidomatis basin (cf. Bailey et al. 1990). We await with interest the opportunity to compare these findings with data from other glaciated basins in the Mediterranean lands.

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