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THESPROTIA EXPEDITION II ENVIRONMENT AND SETTLEMENT PATTERNS

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Cover: Megalo Karvounari seen from the northeast. Courtesy of the 32nd Ephorate for Prehistoric and Classical Antiquities

Layout: Esko Tikkala

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Multi-Proxy Analysis of Lake Sediments in Thesprotia and Its Implications for the Palaeoclimatic History

Sjoerd J. Kluiving, Myrsini Gkouma, Jan Graven and Inge De Kort

Introduction

This chapter describes the geo-archaeological research of three (former) lake areas in Thesprotia (Fig. 1). The three lakes have been subjected to sedimentological, palaeobotanical, and palaeoclimatic research in order to reconstruct landscape history.[1] Lake sediments have been shown to be excellent archives of regional climatic and environmental history, as their sedimentary record is related to a variety of factors: bedrock composition, tectonics, vegetation and climate.[2] Furthermore, we intended with our geo-archaeological research in the lakes to find evidence for presence and absence of human occupation.

Our work aimed at obtaining a long undisturbed core from the lake sediments for detailed laboratory analysis in order to: (a) reconstruct the environmental setting of the lakes on a sedimentological basis, (b) reconstruct the palaeobotanical record of the lakes based on pollen analysis, (c) give a palaeoclimatic signal of the diverse lake settings based on the stable isotope analysis, (d) assess the correlation of the above proxies (stable isotopes, sediments, pollen) in the framework of a multi-proxy palaeolandscape analysis, and (e) give an insight into the landscape variations, in conjunction with the regional archaeological record.

The three lakes to be studied were selected in the neighbourhood of the main study area of the Thesprotia Expedition, that is, the Kokytos valley. Initially Lake Limnoula and Lake Prontani were selected for coring (Fig. 1). These two lakes, however, have been occasionally subject to remarkable water level changes and drought periods in the past, and these environmental conditions have caused oxidation of pollen, making the sediments unsuitable for analysis. Therefore, a third lake, Lake Kalodiki, although located somewhat further away from the Kokytos valley (Fig. 1), was selected for analysis as it was considered more suitable for pollen preservation.

Landscape reconstruction studies in Thesprotia have previously been sparse, with the exception of work done in Lake Kalodiki[3] and the lower Acheron river.[4] In the

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[1] The results described in this chapter are a synthesis of a research project of students of the Institute for Geo- and Bioarchaeology and the Department of Palaeoclimatology and Geomorphology, VU University, Amsterdam, the Netherlands, which is published as Graven *et al*. 2009. We thank Sjoerd Bohncke for his advice in the pollen analysis, and Hubert Vonhof for interpreting the stable isotope data. Geert Jan Vis assisted constructively in the field and helped out with the magnetic susceptibility data. Finally we thank Martin Konert and Martine Hagen from the Sediment Analysis Laboratory at the VU University Amsterdam for their assistance with the TGA and grain size analysis. All illustrations are by the authors, Figs. 1-3 and 7-8 were redrawn for publication by Esko Tikkala. We also thank Björn Forsén for a thorough review process that helped to improve the chapter.

[2] Talbot and Allen 1996, 101.

[3] Botis *et al*. 1993; Ioakim and Christanis 1997.

[4] Besonen 1997; Besonen *et al*. 2003.

extended Epirus area on the other hand, extensive research has been conducted in Lake Ioannina,[5] in the Gramousti lake[6] and the Rezina marsh.[7]

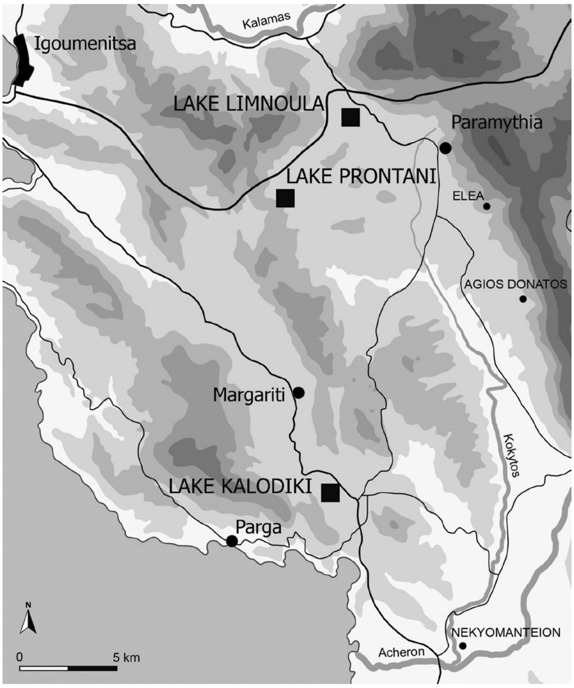

Fig. 1. Study area in Thesprotia indicating the location of the three lakes Limnoula, Prontani, and Kalodiki.

Methods

In order to answer the proposed research questions, a suite of geological methods was employed. Cores were taken in the field with a hand-operated sediment drill and auger. Two types of auger were used: a manual auger corer of 10 cm and a 2.5 cm diameter gouge. From the 55 cores taken during the survey, 41 were regarded suitable for construction of cross sections, as they were considered representative of the sedimentological setting studied, in terms of their location, depth and lithology. Two long cores from Lakes Limnoula and Kalodiki were used for detailed sampling and laboratory analysis. These cores were selected based on the potential for good preservation of organic matter content. From Lake Prontani no long core was retrieved.

The grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition. Grain size analysis therefore provides important clues to the sediment provenance, transport history and depositional conditions. Thermogravimetric analysis (TGA) is an analytical technique used to determine a material's thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a specimen is heated.[8] In this study it is used to measure the total organic matter and $CaCO_3$ content.

In this research project 211 samples have been analysed, usually simultaneously, for grain size and TGA. Analyses were conducted in 70 samples from Lake Kalodiki. At core KAL04 grain size analysis was performed every 10 cm only in the upper 3.25 meters, due to the high organic content in the lower samples, while TGA analysis was conducted for the entire core, sampled every 5 cm for 3.40-9.30 m. For Lake Limnoula, core LIM11 was sampled every 10 cm and additionally samples were analyzed in core LIM06 for each of the layers described in the field. In total, 122 samples were analyzed

5 Hughes *et al*. 2006; Lawson *et al*. 2004; Tzedakis *et al*. 2003.
6 Willis 1992a.
7 Willis 1992b; Willis 1992c.
8 Heiri *et al*. 2001.

for Lake Limnoula. For Lake Prontani, only 19 grain size measurements were analysed for cores PRO01 and PRO06.

Stable isotope geochemistry has been used as an indicator of palaeoclimate since the 1950s,[9] when the potential for oxygen isotope compositions to be used for palaeotemperature reconstruction was highlighted. The technique has been applied to marine and non-marine sediments and fossils. In lacustrine environments, stratigraphic changes in $\delta^{18}O$ values are commonly attributed to changes in temperature or precipitation/evaporation ratio, whereas those of carbon are used to demonstrate (often climatically induced) changes in carbon, cycling and productivity within the lake and its catchment. For this study forty samples were measured for $\delta^{18}O$ values after being ground to fine material. This analysis is done for the long core from Lake Kalodiki (KAL04).

Magnetic susceptibility is a method of measuring how susceptible is the sediment to be magnetized is. The signal originates primarily from *in situ* pedogenic production of fine-grained minerals, so a magnetic susceptibility curve will show the changes in composition of the intact sediment core.[10] The principle of measuring is that a loop generates a magnetic field, which magnetizes the susceptible substances in the sediment. A point sensor, placed directly after the loop, measures the changes in magnetic susceptibility. This is done with the GEOTEK Multi-Sensor Core Logger (MSCL) system. This analysis is done for the long cores from Lakes Kalodiki (KAL04) and Limnoula (LIM11).

The pollen record from lake sediments is an important proxy in the climate reconstruction.[11] The distribution of species through the samples will give an indication of the climatic conditions during sediment deposition. Not all sediments were considered suitable for pollen analysis. The clays in Lakes Prontani and Limnoula showed signs of periods of wetting and drying during the sedimentological history. These conditions lead to oxidation of the pollen, making them unsuitable for counting. Only Lake Kalodiki was considered to be most suitable for pollen analysis, although the same problem of oxidation appears for the top three metres of clay found in KAL04.

Results of multi-proxy analysis

Lake Prontani

Lake Prontani is a temporary lake situated to the north of the village Ambelia and south of Psaka at an altitude of ca. 240 masl. The surface of the lake is estimated to be 333 m^2, with a maximum length of 1.4 and maximum width of 0.4 km; however, the extent of the lake may vary, as the water level fluctuates remarkably seasonally and, according to local people, even dries out completely in periods of intensive aridity. The southwestern border of the lake is a steeply rising slope. On all other sides, the lake is surrounded by flat land shaped by alluvial fans. This area is used for sheep herding, while there are several plots of land with small orchards. The valley walls are composed for the most part of Paleocene and Eocene limestones, while the basin is filled with recent Holocene alluvial and lacustrine deposits. To the west, east and north, the walls of the valley consist of limestone formations, mainly crystalline massive dolomites, with narrow laminations

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[9] Leng and Marshall 2004.
[10] Thompson *et al*. 1975.
[11] Bradley 1999.

of gravel. At the south, limestone is present with fossils and flint in large banks and gravelly limestone, with generally solid fragments of algae dated to the lower and middle Triassic.[12]

This study indicates that the main infilling of Lake Prontani is of alluvial origin from the surrounding hills. The lake has experienced several erosion and infilling phases, which can be determined from the heterogeneous sedimentary infill. The difference in grain sizes encountered in the cores indicates different types of sedimentary environments – ranging from fine clay, representing a low-energetic setting, to coarse material with large limestone inclusions, which indicates a setting with higher energy. A translocation of the deepest part of the lake through time is observed, as indicated by the spatial pattern of the finest sediments. The coarse material suggests a mass movement from the surrounding hills, which formed the recent topography features, like the terrace in the centre of the east lake shore and the depressions on either side. In this type of sediments it is unlikely that pollen will be preserved, and therefore this lake was considered unsuitable for climate reconstruction. In Lake Prontani the entire sedimentary record can be subdivided in four sedimentary stages.[13]

Stage 1 corresponds to the deepest part of the cross section. It consists of clay to silty clay sediments with abundant gravel inclusions. The presence of fine and coarse material within the same sedimentary unit is indicative of two depositional processes. The fine material, clay and silt, is characteristic of a low-energy depositional process. This type of sediment is deposited on the bottom of deep-water lakes, assumed to originate from settling out of suspension, and indicates that the source of inflow is not close. The transitions within the unit between silt and clay layers signify alterations from deep to shallower water levels, and are related to the fluctuations of the lake water level in the past. On the other hand, the coarse material indicates a high-energy depositional process. This process is mainly related to the processes of mass movement on the steep hillsides, and is also responsible for the formation of the large fans that surround the lake.

Stage 2 consists of clay, silty clay and silty clay loam. The lithology indicates that during this stage the lake was gradually filled with sediment. This fine material is indicative of a standing water lacustrine environment, settling from suspension and filled by a low-energy source that is not proximal to the lake. It is possible that during this phase, the shore extended further than the present shoreline, and that therefore the lake level was considerably higher.

Stage 3 is found throughout the lake filling and is representative for the formation of the present topography around the lake. It consists of a relatively thick layer of loam (clay, sandy silty), loamy sand and sand as well as finer matrix sediments with limestone inclusions. The lacustrine fine sediments deposited during suspension phases are interrupted and eroded by coarser sediments indicating fluvial events. The coarse material can be attributed to more than one stream flowing into the lake with different degrees of flowing energy and capacity. Thickness and texture vary, depending upon distance from the source. The fact that the sediments include many plant remains is an indication of a shallow lake water level; the fact that they are highly oxidized suggests a long-time exposure, suggesting temporary dry conditions.

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[12] See the geological map IGME 1969.
[13] Graven *et al*. 2009.

Stage 4 consists of silty clay to silty clay loam. The sediments are relatively fine, but the bi-modal distribution of the grain size fraction indicates a double depositional origin. Most likely, the deposits are derived from different streams of relatively low energy, which flow into the lake at a continuous influx rate, as is suggested by the well to moderate sorting of the samples.[14] It is suggested that at this stage the water level was relatively low. During a drier stage with lower lake-levels, associated extensive run-off processes, caused by heavy rain, have produced the erosion and deposition of coarse material.

Lake Limnoula

Lake Limnopoula, Chotkova or Limnoula is a temporary (winter) freshwater lake situated 0.7 km southwest of the villages Krystallopigi and Kephalovryso near Paramythia at an elevation of ca. 190 masl. The lake covers an area of 1.33 km^2, but it floods nearly every winter, giving a maximum water depth of 10 m and a total additional flooded area of around 1 km^2. In the dry season, half of the lake bed is used for rice cultivation; the other half is used for pasture.

Lake Limnoula is surrounded by recent alluvial deposits formed by the seasonal fluctuations of the lake. The valley walls are composed for the most part of Paleocene and to a lesser extent of Eocene limestones, while the basin is infilled by recent Holocene alluvial and lacustrine deposits. To the south and southwest the limestone formations are dolomitic, while on the north, east and west limestones are cherty, range from fine-grained to sub-lithographic, and are usually fossiliferous. Oligocene flysch outcrops are formed at the base of the northeastern valley wall. The flysch is composed for the most part of alternating soft micaceous sandstones and shales with intercalated thinly-bedded biogenic limestones and marls near the top. Recent talus and scree slopes cover the contact of the basin with the flysch unit. Quaternary siliceous deposits are located at the base of the west valley wall.[15]

Five main multi-proxy stages of formation constitute the sedimentary record in Lake Limnoula. The lowest and oldest part of the lake infill is represented by stage 1, which consists mostly of a black-coloured clay substrate with an increasing organic content towards the top boundary. Immediately above the organic matter increase, an abrupt coarsening of the matrix occurs. Some charcoal macro remains were found at the top of this stage. Magnetic susceptibility measurements show a pronounced peak at the same level of the sudden coarsening and the black coloured sediment, suggesting the presence of a palaeosol (Fig. 2). The depositional environment at the time would be a relatively dry period of the lake, leading to low water level, subaërial sediment exposure, and soil formation.

Stage 2 appears to be characterized by frequent water level fluctuations, indicated by small-scale changes in grain size and organic matter content and by larger-scale changes in the carbonate content. Carbonate content correlates inversely with organic matter content, which can be explained by the occurrence of two alternating environments. One environmental setting has a high clastic influx and a high carbonate content that has a grey, bluish grey colour and consists of fine material with some shells. In this environment there was occasionally a more intense inflow, preserved as thin layers of

[14] Talbot and Allen 1996, 101.
[15] See the geological map of IGME 1969.

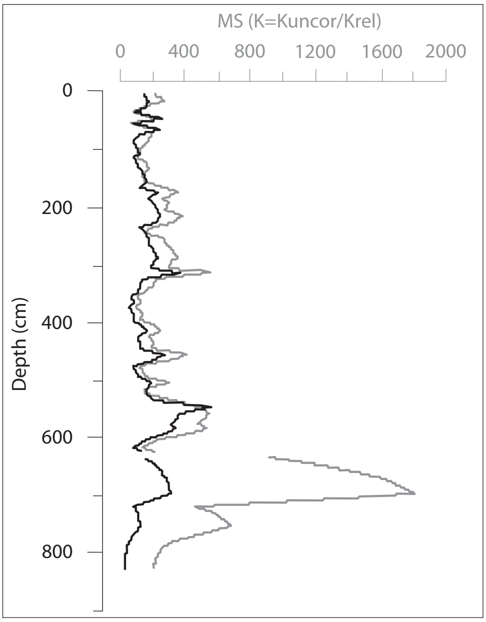

Fig. 2. Lake Limnoula: Magnetic susceptibility results from core LIM11, depth 0-830 cm. The black line shows the measured data; the gray line shows the volume-corrected data.

relatively coarse material (silt clay to silty loam). The other environmental setting has a limited influx, leading to conditions favourable for organic matter accumulation; this is shown in the TGA results and the dark grayish brown and black colour. The phases with high organic matter are probably linked to low water level conditions and coincide with high magnetic susceptibility values represented as two peaks at the same depth (Fig. 2).

The latter data support the hypothesis for the start of pedogenesis (soil formation). Additionally to the high clastic inflow, high carbonate content might be explained as a result of pedogenic processes. During this process, the carbonate in the top layer is leached to the lower layers. This would also be an explanation for the low carbonate values between 150 and 300 cm. The same process might also explain the low carbonate percentages in stage 1, and would account for the absence of correlation between the carbonate and organic matter content.

Stage 3 consists of fluvial deposits from slope washes or seasonal streams that flow into the lake. This top sediment is dried out as a result of a seasonal fluctuating water level. This conclusion fits with the historical information about the lake before being drained. The top stage contains, at a depth of 60 cm, a black soil layer with a higher amount of organic matter and low carbonate content. There are also some small fluctuations in grain size and magnetic susceptibility, which would indicate the presence of seasonal streams, coming from different parts of the lake.

Stage 4 is only found in small parts at the edges of the lake. This stage consists of sandy loam with gravel and is similar to stage 3, but is differentiated from it in terms of stratigraphic position. Stage 4 is interpreted as an extensive erosional event, successive of stage 2 and preceding stage 5. The diffuse boundary with stage 2 indicates, however, a gradual and slow depositional process, originating from the sedimentary process, alleviation, that formed the fans surrounding the lake basin. Further to the edge of the basin, so more proximal to the fans, the boundary between stage 4 and 2 becomes sharper. Fe/Mn nodules are found and prove that the sediments in this stage originated from the dissolution of the surrounding limestone bedrock.

Stage 5 constitutes the more recent rising stage of the lake, covering in parts the alluvial deposits described above. The sediment that is found in this stage is silty clay and silty clay loam with few thin layers of clay and silt loam. This stage indicates the final rising and shallowing phase of the lake before its final drying out. The sediments are indicative of a fluctuating water level, which is already shallower than at the former stages

(1 and 2). These gradual fluctuations are indicative of a seasonal lacustrine environment, with a succession of episodes of deepening and shallowing in a seasonal time-scale. This suggestion correlates with the oral information for the recent history of the lake (before it has been drained out) that the water level would fluctuate significantly on an annual basis. Reduced to oxidized sediment, the presence of snails, shells, plant remains and plant roots are indicative of soil formation processes. Supporting characteristics are the presence of charcoal nodules and concretions and more abundant organic matter content. The magnetic susceptibility results confirm the gradual infilling and shallowing of the water level, with a decreasing trend to the lower part followed by a sharp rise in the upper part suggesting distinctive changing from wet to drier climatic conditions.

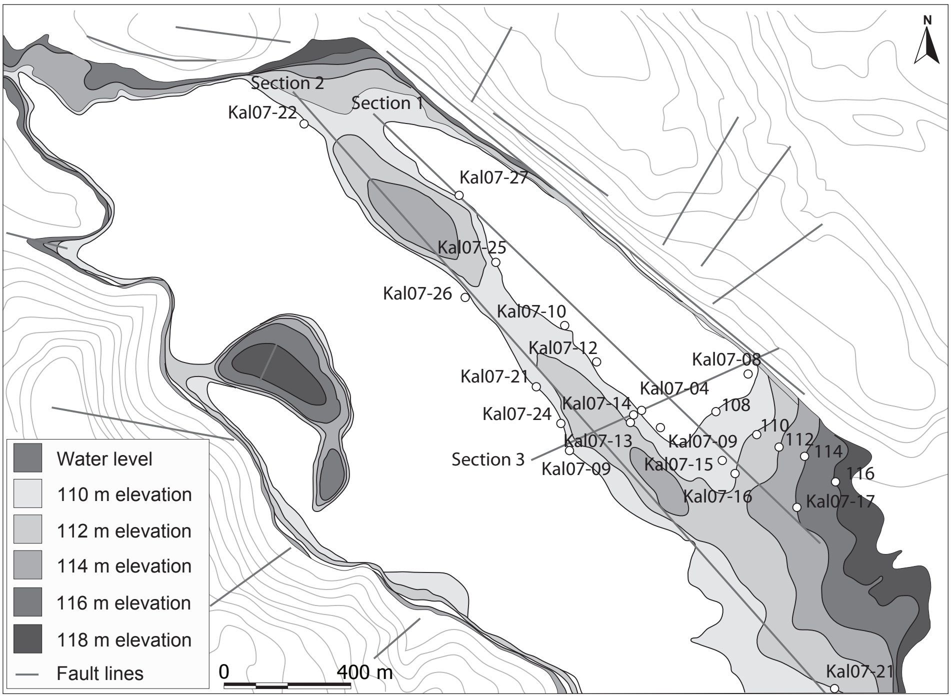

Fig. 3. Lake Kalodiki with the location of the boreholes. Three cross sections are indicated with lines. For the elevation cf. the legend. Fault lines are drawn after Botis *et al*. 1993.

Lake Kalodiki

Lake Kalodiki is situated in an extended basin with the longest axis running northwest-southeast at ca. 108 masl (Fig. 3). The maximum length is about 3.7 km and the width about 0.7 km. The basin actually consists of two fens, separated by a ridge running along the length of the basin. The ridge is believed to have carried the main road in earlier times. Nowadays only a dead-end dirt road runs along the ridge and the modern road is situated to the west. The area is partly in use as pasture for flocks of sheep.

The basin is filled with alluvial and fluvial sediments, whereas the surrounding hillsides mostly consist of crystalline massive dolomite, with narrow laminations of gravel. Dolomite is nearly absent to the east of the basin, where it is replaced by schists of late Triassic to late Jurassic age. The northeastern edge consists of limestone with fossils and flint in large banks and gravelly limestone, with generally solid fragments of algae dating from the lower and middle Triassic. The southeastern edge of the basin is formed by Triassic breccias consisting of cemented limestones and dolomites.[16]

To the northwest and east of Lake Kalodiki, there used to be two further lakes that were drained in the last ten or twenty years. Lake Kalodiki was preserved because of its importance as a nature reserve. Even though the lake was chosen by us because of its ability to hold water, it does dry out in periods of severe aridity, once in several years.[17]

Sample no.	Date		
1. KAL 04 432.5-435	40230 +/- 1100 BP	-20.8 o/oo	40300 +/- 1100 BP
2. KAL 04 670-674.5	39900 +/- 1100 BP	-21.6 o/oo	39960 +/- 1100 BP
3. KAL 04 905-910	40230 +/- 1100 BP	-18.1 o/oo	40340 +/- 1100 BP

Fig. 4. Radiocarbon (AMS) dating results.

Absolute and relative dating of the Lake Kalodiki core (KAL04)

Three radiocarbon samples were taken of the calcareous mud in the Lake Kalodiki core KAL04 from peaks in the $CaCO_3$ content. They all resulted in dates around 40,000 years BP (Fig. 4.). This is most likely caused by the fact that the samples are beyond the range of ^{14}C dating, and therefore they can only be used as a minimum age for deposition at the sampled depth of core.

Relative dating means fitting the pollen record into a record of known age. The rate of accumulation of the calcareous sediment can be estimated at between 0.8 and 1 mm per year. The 610 cm calcareous rich sediment (from 320 to 930 cm depth) would have taken between 6,100 and 7,625 years to accumulate. The sequence is characterized by a high *Quercus* component, and one major cold period near the top.

In Lake Ioannina four main interglacials are defined with a complete vegetation development, based on the Ioannina 249 core. These are the Dodoni I (390-410 ka), Pamvotis (326-338 ka), Zitsa (208-221 ka) and Metsovon (117-129 ka) periods (Tzedakis and Bennett 1995). All these periods have a high dominance of *Quercus* and a tree-pollen percentage of around 80%, just as the KAL04 pollen record shows (Fig. 5). Because of regional differences, a precise match between pollen curves of diverse environmental settings at Kalodiki and Ioannina is not possible, even though the warmer-colder periods should be visible.

Between the minimum radiocarbon date at KAL04 and the Metsovon period there are several other forested periods, the Thyamis, Perama, and Vikos periods. These three periods of potential dates are of the early Weichselian age; Thyamis and Perama are often dated together (91-100 ka), Vikos is slightly younger (76-85 ka). All have about 70 to 75% of tree pollen, and all show a roughly equal number for *Quercus* and *Pinus*. The Kalodiki pollen record shows more *Quercus* than *Pinus*, but this could easily have been caused by the higher elevation of Lake Ioannina (470 masl as compared to 108 masl for Lake Kalodiki), favouring *Pinus* over *Quercus*. Since our pollen sequence spans only about 6,000 to 7,000 years, and because of the difficulties of correlating individual pollen curves, relative dating also using lithostratigraphic criteria indicates that the most recent period (early Weichselian) does seem the most probable date for the interpreted pollen sequence at core KAL04 (Fig. 5).

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[16] See the geological map of IGME 1969.
[17] Botis *et al*. 1993.

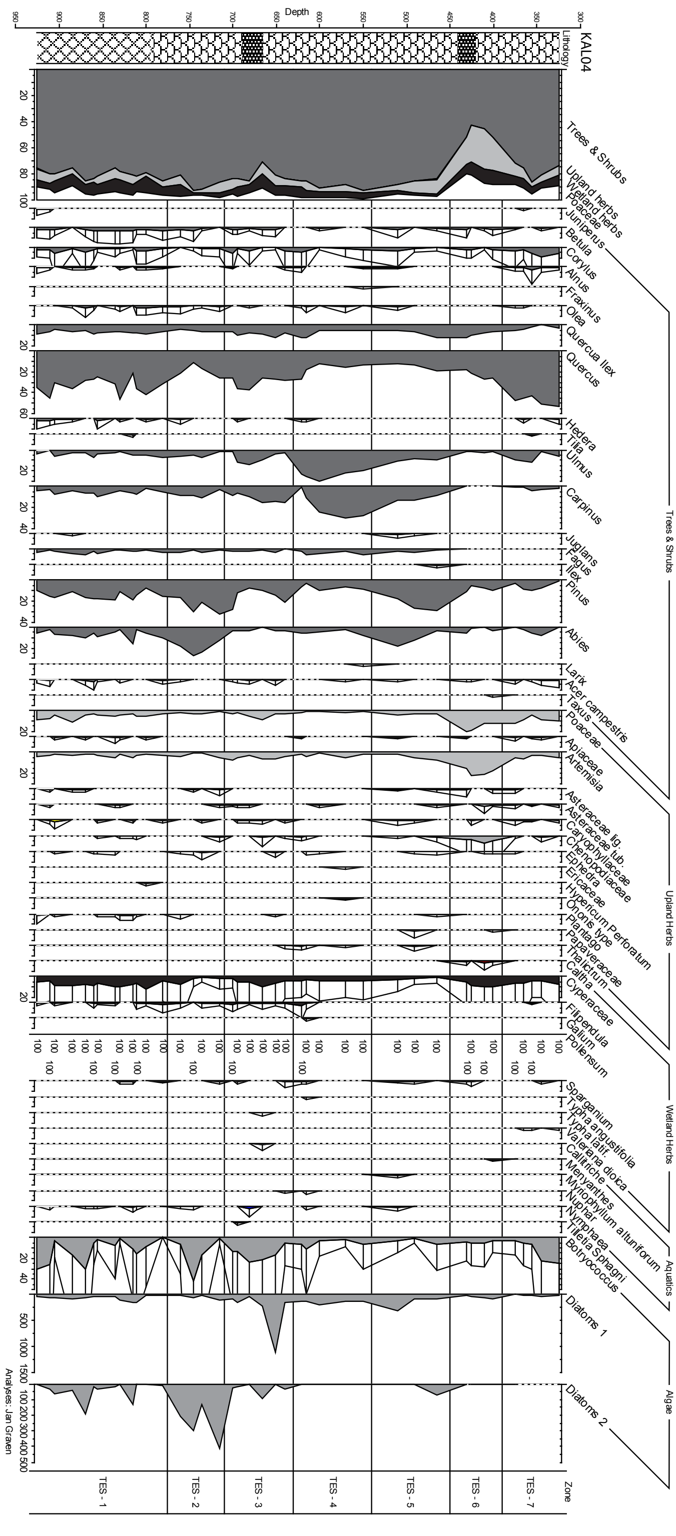

Fig. 5. Pollen diagram for core KAL04, Lake Kalodiki.

Stage	Lithology	Pollen	Stable isotopes	Interpretation
1	Interfingering layers of organic calcareous gyttja and calcareous gyttja	Quercus	Small-scale fluctuations	Fairly stable climatic conditions with short-period oscillations reflected in water level fluctuations
2.1	Calcareous gyttja	Pinus and Abies	Wet conditions	Wet and cold climatic conditions are slowly evolving into dry and warmer
2.2	Organic calcareous gyttja	Quercus	Dry conditions	
3	Clay			Tectonic event
4.1	Minerogenous calcareous gyttja	Quercus	Shift to wet climate	Long period of wet temperate climate and high water level followed by a short time of cold dry conditions with shallow water levels
4.2	Organic gyttja	Open vegetation, herbs	Dry conditions	
5	Minerogenous calcareous gyttja/ few organic layers	Quercus	Wet and dry conditions	Temperate wet conditions
6 & 7	Silty clay/clay			

Fig. 6. Summary of multi-proxy data (lithology, pollen, and stable isotopes) of sediments of Lake Kalodiki, and subdivision of environmental interpreted stages.

In Lake Kalodiki we distinguish seven multi-proxy stages of lake evolution (Fig. 6): Stage 1 consists of interfingering layers of organic calcareous gyttja and calcareous gyttja (Fig. 5). The pollen data show a *Quercus*-dominated dense forest, while the stable isotope values indicate small-scale fluctuations, which represent fairly stable climatic conditions (Figs. 5, 8). It is therefore suggested that the pollen record reacts with a time lag to rapid climate change (except for *Botryococcus*), being a less sensitive proxy in comparison to isotopes and lithology. Consequently, all proxies indicate the existence of stable climate conditions with small fluctuations in the water level, therefore a more temperate climate than the present.

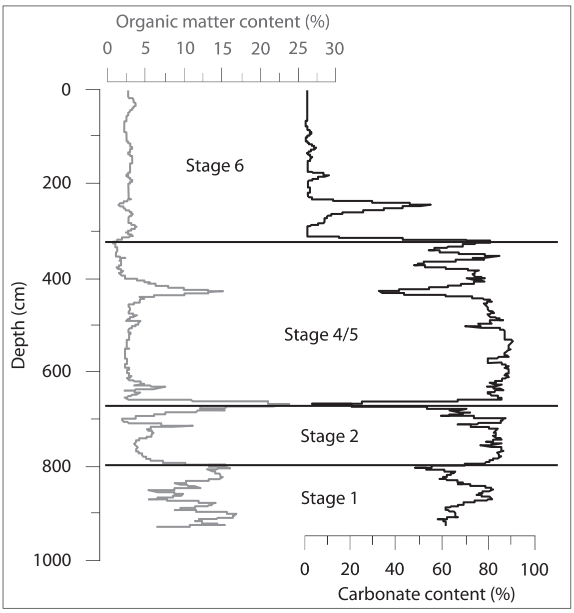

Fig. 7. Plot of the TGA results of core KAL-04, depth from 0-930 cm.

Stage 2 comprises of two lithological units, which correlate well with pollen and stable isotope data. The lowest one consists of pure calcareous gyttja, indicating a deeper lake level during a wetter period. At the same time pollen data show a slight cooling, seen from the decrease in *Quercus*, in favour

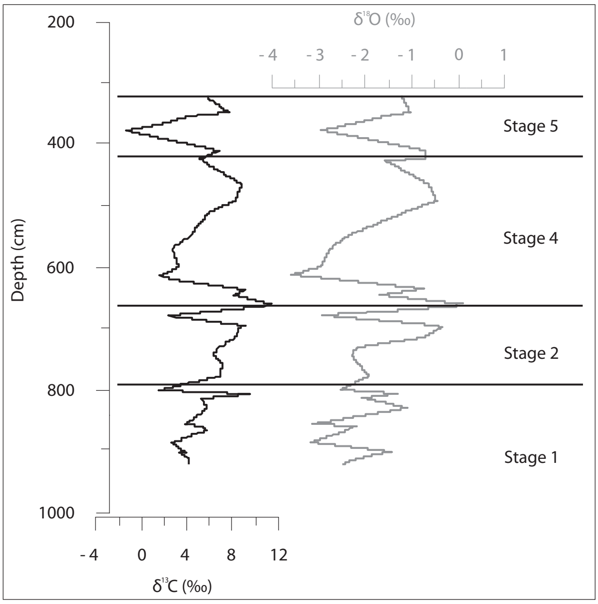

Fig. 8. Plot of the Stable Isotope results of KAL04, depth from 320-930 cm.

of *Pinus* and *Abies*, while stable isotope data suggest wet climatic conditions. The upper lithological unit of this stage, consisting of organic calcareous gyttja, indicates a drier period with a lower water level. Pollen shows this stage as a return to a warmer period, as seen in stage 1. Stable isotopes suggest the gradual changing from a wet to a drier climate. The extreme peak indicates a very short wet period; this precedes the explosive algae growth, shown as high organic matter content and low carbonate content (Fig. 7).

Stage 3 comprises the result of one or more tectonic events. During this time, a ridge is formed in the northwest part of the lake, as a result of the uplift of a former sedimentological setting, whose lithology (clay) is not recognized in any of the identified stages (1 or 2). It is therefore concluded that the sediment of the stage must have accumulated prior to stage 1 and been uplifted probably in a later stage.

Stage 4 consists of two lithological units. In the lowest part, minerogenous calcareous gyttja is present. At this stage, pollen suggests the existence of a temperate climate with a *Quercus*-dominated forest, while the isotope data show a quick shift to a wet climate. The upper unit consists of organic gyttja. In the upper part of this stage, pollen data indicate the transition to a cold period with open vegetation and abundant herbs, while stable isotopes show a slow increase to values suggesting drier climatic conditions.

Stage 5 consists mainly of minerogenous calcareous gyttja with a few very thin organic layers, indicating rising of the water table, whereas no shallowing of the water table was indicated. It is suggested, though, that the upper layers of this stage might have been eroded by alluvial sediments of stage 7; see below. The pollen record in stage 5 shows a marked increase in temperature displayed by a rapid rise in *Quercus*, while stable isotopes show wet conditions followed by a drier period.

Stages 6 and 7 comprise one period as indicated by the lithological data. No pollen or stable isotope data are available for this period. During this period the calcareous gyttja deposits are replaced by silty clays and clays (stage 6). These layers are interrupted by erosional events of coarse detritus input (stage 7). This change must be related to a different geomorphological environment and climate. The source of the lake water has changed from the inflow of non-clastic groundwater to a detritus input derived from the surrounding hills forming alluvial fans (most likely from the Holocene). These fans are now an important part of the basin topography.

Regional correlation

The research performed by Botis *et al*. in 1993 gives a good insight into the climatic conditions in the lower Thesprotia region. When comparing these results with the present data, the following can be concluded. (A) Calcareous mud was deposited during the Late Glacial, from early Weichselian (76-85 ka) to approximately late Weichselian (11,049±144 years BP), over the greatest part of the basin. (B) Peat accumulation started according to Botis *et al*. (1993) in the southern part of the big fen during the late Weichselian, whereas our research indicates the presence of peat layers in the northern and eastern part of the big fen as well. During the same timeframe, unstable climatic conditions resulted in the temporary extension and contraction of the lake shore. (C) During the Holocene, the ridge in between the big fens started forming as a result of tectonic activity, and has been further shaped by the influx of clastic material from the alluvial fans.

Lake Ioannina is the location nearest to our area where intensive palaeobotanical research has been carried out.[18] The lake has a continuous and stable sedimentation history and has been constantly filled with water. This gives a good chance for undisturbed pollen records reaching a depth of 319 meters.

A major problem when correlating the Kalodiki core with data from Ioannina is the distance between the two sites. While the lakes are only just over 50 km apart, they are located at different elevations in two different climatic settings and are separated by a high mountain range. Kalodiki therefore has a Mediterranean climate, while the climate in Ioannina is more moderate, with lower temperatures and more rainfall. These differences are clearly seen when comparing the Kalodiki pollen record with those of Ioannina. The Ioannina record shows a large amount of *Pinus* favoured by the colder climate, while the Kalodiki pollen record shows *Quercus*, which is more suited to the milder climate of Kalodiki. The assumption is made that large-scale climatic changes and trends will be visible in both records and will therefore be used as a basis for obtaining a relative date for the Kalodiki record, compared to records from Lake Ioannina, resulting in a possible date in early Weichselian for the calcareous mud at Lake Kalodiki.

As far as the Holocene record is concerned, there is little palaeoclimatic information available for Greece. A low-resolution record of interpreted lake-level fluctuations exists for Lake Ioannina, but the data from the last 5,000 years are too sparse to relate to geomorphic changes in our area. A record of lake-level fluctuations exists for Lake Xinias,[19] 160 km to the east, but the lake is located on the other side of the Pindos Mountains, a major orographic boundary, and thus a comparison to our area is not appropriate. Furthermore, the data from Lake Xinias – like those from Lake Ioannina – are very sparse for the middle and late Holocene.

While middle and late Holocene palaeoclimatic information from Greece may not be significant, there does appear to be increasingly robust evidence for a significant, abrupt aridification event around 4200 BP over the eastern half of the Mediterranean and West Asia.[20] Presumably this event would have affected Greece as well, and may have led to a reduction in vegetation cover, thus increasing the impact of erosion. However,

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[18] E.g. Frogley *et al*. 1999; Lawson *et al*. 2004; Tzedakis 1994; Tzedakis *et al*. 2002.
[19] Digerfeldt *et al*. 2007.
[20] Besonen, 1997; Besonen *et al*. 2003.

this issue cannot be adequately addressed with the present body of Greek palaeoclimatic information. Furthermore, this event may be impossible to recognize with a proxy like pollen because of the strong overprint of anthropogenic influence that begins at this time. To resolve the issue, development of multi-proxy records including moisture balance measurements that are unaffected by human activity (e.g., an oxygen stable isotope record) would be more suitable.

Multi-proxy data from two sites located ca. 80 km to the north of Kalodiki recognized several erosive events during the middle to late Holocene. More specifically, using pollen data from the Gramousti lake and the Rezina marsh, Willis recognized erosive events from ca. 6300-5000 BP, 4300-3500 BP, and finally at 2500 and 2000 BP following vegetation contraction.[21] Climatic shifts, anthropogenic influence, tectonic activity and karstic hydrology were cited as possible causes for these periods of increased erosion, whilst anthropogenic influence was the more favoured explanation, especially for the event dating to 4300-3500 BP, correlating to the Early Bronze Age. The 6300-5000 BP erosive event correlates to the Final Neolithic Period.

The study of Besonen highlights the locality of these events and the existence of diverse micro-climates within short distances in the lower Acheron valley, where none of the above erosive events were identified.[22] According to Besonen, an extensive erosive event took place around AD 1500, which is roughly contemporaneous with the start of the Little Ice Age.[23] The cooler and wetter climate of this time would have resulted in an increased delivery of sediment to the fluvial system. Alternatively, anthropogenic activities such as deforestation and land use for agriculture would have led to an increased delivery of sediment. This later interpretation is supported by the fact that the area was intensively cultivated during the Early Modern period. According to Besonen no other correlation between periods of increased or decreased valley infilling due to climatic or anthropogenic factors could be positively or negatively deduced.

Conclusion

An undisturbed palaeoenvironmental, palaeoclimatic and palaeobotanical record was obtained from Lake Kalodiki, while at the same time insight was gained into the palaeogeographic evolution of Lakes Prontani and Limnoula. There seems to exist a pronounced variability between the environmental settings of the three lakes and the factors that have influenced their formation. These factors are related to the intensive tectonic activity, the diverse karst hydrology and the complex topography, which creates various climatic shifts within a limited study area.

More specifically, Lake Prontani is a part of an open basin covered with alluvial fan deposits, while the lake itself is filled with water originating from the fans. This means that there are short periods of erosion and sudden infilling, which interrupt the slow and continuous sedimentation – conditions that render this lake unsuitable for climate reconstruction. Lake Limnoula is also prone to erosional streams flowing into the basin, while at the same time the continuous sedimentation is interrupted by pedogenetic

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[21] Willis 1992a; Willis 1992b; Willis 1992c.

[22] Besonen 1997; Besonen *et al*. 2003.

[23] Grove 1988.

processes due to extensive drought periods coinciding in time with equivalent stable landscape conditions. While the several cycles of rising and falling of the water level in Lake Limnoula can be further related to climatic oscillations of wetting and drying, the sediments of the lake can be highly bioturbated and disturbed, due to the soil formation processes mentioned above. These pedogenetic processes, even though destructive for the palaeobotanical reconstruction study, can be used as chronostratigraphic evidence of climatic stability and stable landscape conditions, and combined with radiocarbon dating could be correlated with archaeological periods in the Kokytos valley.

Lake Kalodiki was the most promising lake for palaeoclimatic, palaeobotanical and palaeogeographic reconstruction. Using the multiple laboratory analysis, we assessed the correlation of the three environmental proxies: lithology, pollen, and stable isotopes. From the combined data discussed in the stages described above, it is suggested that lithology results are in accordance with the stable isotopes' values, whereas there is a time lag to the results of the pollen record. This relatively strong correlation gave the study evidence for interpreting the palaeoenvironmental, climatic and botanical data.

The most challenging part of this research is related to the question of linking the landscape variability to the archaeological evidence of the region, as this is studied by the Thesprotia Expedition. Two important factors render this part particularly complex and need to be taken into account.

- In terms of landscape variability, the complex topography and hydrology of the area favour the existence of several microclimatic environs within short distances. In this region, the location of Lake Kalodiki, outside the Kokytos river basin, at a lower elevation and more proximate to the sea, makes the palaeoclimatic correlation of the lake with the study area of the Thesprotia Expedition questionable.
- The second factor is related to the chronological framework of the study. Even though this study is informative in terms of the palaeogeographic evolution of the region, there is a lack of chronostratigraphic data, which renders the correlation between the palaeolandscape changes and the archaeological data problematic. As mentioned above, the dating of the soil layers identified in Lake Limnoula could have constituted evidence for climatic and environmental stability periods, potentially to be related to the existence of archaeological evidence in the surrounding area.

The Lake Kalodiki record is dated, according to the radiocarbon results, to a minimum of 40,000 ^{14}C yrs BP. At that time the basin of Kalodiki was enclosed and the surrounding hills were covered with dense vegetation of *Quercus*. These conditions prevented the occurrence of erosion and provided the ideal setting for the accumulation of an undisturbed sedimentological sequence, which delivered an ideal archive for regional climate and environmental reconstruction. This environmental setting changed with the activation of the alluvial fans and the subsequent erosion of the lacustrine deposits. It is suggested that this event either is related to the dramatic climatic change from Pleistocene to Holocene, or was due to a dramatic event followed by alteration in the hydrological conditions. At the shores of the lake, the Holocene sediments are most likely eroded, and therefore the Holocene palaeoclimatic reconstruction study should be focused on the deeper central part of the lake (see also Lelivelt, this volume).

The pollen sequence from this study suggests a possible early Weichselian dating of Kalodiki lake sediments, whereas the same sedimentological sequence continues until the late Weichselian. This period can be related to the Middle to Upper Palaeolithic archaeological framework and is represented by rich scattered finds and sites in Epirus. In the proximity of Kalodiki, Palaeolithic tools at the site of Morphi are relatively dated to the Middle and Upper Palaeolithic period.[24] At least during the Middle Palaeolithic period the basin of Kalodiki was enclosed and the surrounding hills were covered with dense vegetation of *Quercus*. Kalodiki formed one of the numerous basins (poljes) that are found in Epirus, which would have provided a favourable environment to the Palaeolithic populations, constituting a refuge for animals and plant species and providing a secure source of water within an inhospitable mountainous environment.

[24] For the finds from Morphi, see e.g. Runnels and van Andel 2003, 61, 72-74, 94, 105, 107-108, 129.

Bibliography

Besonen 1997 = M.R. Besonen, *The Middle and Late Holocene Geology and Landscape Evolution of the Lower Acheron River Valley, Epirus, Greece*. Unpubl. MSc Thesis, University of Minnesota 1997.

Besonen *et al*. 2003 = M.R. Besonen, G. Rapp and Z. Jing, 'The Lower Acheron River Valley: Ancient Accounts and the Changing Landscape', in J. Wiseman and K. Zachos (eds.), *Landscape Archaeology in Southern Epirus, Greece* I (Hesperia Suppl. 32), Princeton N.J. 2003, 199-263.

Botis *et al*. 1993 = A. Botis, A. Bouzinos and K. Christianis, 'The Geology and Palaeoecology of the Kalodiki peatland, Western Greece', *International Peat Journal* 5 (1993), 25-34.

Bradley 1999 = R.S. Bradley, *Paleoclimatology: Reconstructing Climates of the Quaternary*, San Diego 1999.

Digerfeldt *et al*. 2007 = G. Digerfeldt, P. Sandgren and S. Olsson, 'Reconstruction of Holocene Lake-Level Changes in Lake Xinias, Central Greece', *The Holocene* 17 (2007), 361-367.

Frogley *et al*. 1999 = M.R. Frogley, P.C. Tzedakis and T.H.E. Heaton, 'Climate Variability in Northwest Greece During the Last Interglacial', *Science* 285 (1999), 1886-1889.

Graven *et al*. 2009 = J. Graven, I. de Kort, M. Gkouma, *Palaeolandscape History in Northwest Greece: A Multi-Proxy Analysis of Lake Sediments* (IGBA report 2009/05), Amsterdam 2009.

Grove 1988 = J.M. Grove, *The Little Ice Age*, London 1988.

Heiri *et al*. 2001 = O. Heiri, A.F. Lotter and G. Lemcke, 'Loss on Ignition as a Method for Estimating Organic and Carbonate Content Insediments: Reproducibility and Comparability of Results', *Journal of Paleolimnology* 25 (2001), 101-110.

Hughes *et al*. 2006 = P.D. Hughes, J.C. Woodward, P.L. Gibbard, M.G. Macklin, M.A. Gilmour and G.R. Smith, 'The Glacial History of the Pindus Mountains, Greece', *The Journal of Geology* 114 (2006), 413-434.

Ioakim and Christianis 1997 = C. Ioakim and K. Christanis, 'Late Quaternary of a Peat Profile from the Kalodiki Peatland in Epirus, Western Greece: Sedimentary and Vegetational History', *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften* 148 (1997), 95-104.

Lawson *et al*. 2004 = I. Lawson, M. Frogley, C. Bryant, R. Preece and P. Tzedakis, 'The Lateglacial and Holocene Environmental History of the Ioannina Basin, North-West Greece', *Quaternary Science Reviews* 23(14-15) (2004), 1599-1625.

Leng and Marshall 2004 = M.J. Leng and J.D. Marshall, 'Palaeoclimate Interpretation of Stable Isotope Data from Lake Sediment Archives', *Quaternary Science Reviews* 23 (7-8) (2004), 811- 831.

Runnels and van Andel 2003 = C. Runnels and T.H. van Andel, 'The Early Stone Age of the Nomos of Preveza: Landscape and Settlement', in J. Wiseman and K. Zachos (eds.), *Landscape Archaeology in Southern Epirus, Greece* (Hesperia Suppl. 32), Princeton N.J. 2003, 47-134.

Talbot and Allen 1996 = M.R. Talbot and P.A. Allen, 'Lakes', in H.G. Reading (ed.), *Sedimentary Environments: Processes, Facies and Stratigraphy*, 3rd ed., Oxford 1996, 83-123.

Thompson *et al*. 1975 = R. Thompson, R.W. Battarbee, P.E. O'Sullivan and F. Oldfield, 'Magnetic Susceptibility of Lake Sediments', *Limnolology Oceanography* 20 (1975), 687-698.

Tzedakis 1994 = P.C. Tzedakis, 'Vegetation Change through Glacial-Interglacial Cycles: A Long Pollen Sequence Perspective', *Philosophical Transactions: Biological Sciences*, 345 (1994), 403-432.

Tzedakis *et al*. 2002 = P.C. Tzedakis, M.R. Frogley and T.H.E. Heaton, 'Duration of Last Interglacial Conditions in Northwestern Greece', *Quaternary Research* 58 (2002), 53-55.

Tzedakis *et al*. 2003 = P.C. Tzedakis, M.R. Frogley and T.H.E. Heaton, 'Last Interglacial Conditions in Southern Europe: Evidence from Ioannina, Northwest Greece', *Global and Planetary Change* 36 (2003), 157-170.

Willis 1992a = K.J. Willis, 'Late Quaternary Vegetational History of Northwest Greece. I. Lake Gramousti', *New Phytologist* 121 (1992a), 101-117.

Willis 1992b = K.J. Willis, 'The Late Quaternary Vegetational History of Northwest Greece. II. Rezina Marsh', *New Phytologist* 121 (1992b), 119-138.

Willis 1992c = K.J. Willis, 'The Late Quaternary Vegetational History of Northwest Greece. III. A Comparative Study of Two Contrasting Sites', *New Phytologist* 121 (1992c), 139-155.

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