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Reconstruction of climatic changes during the Late Pleistocene, based on sediment records from the Konya Basin (Central Anatolia, Turkey)

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Climatic changes during the last climatic cycle have been studied using three sediment cores from the Konya plain, a now dry, closed and semi-arid lacustrine basin at 1000 m altitude in central Anatolia, Turkey. The reconstruction of regional climatic characteristics and evolution is based on mineral, diatom, pollen and molluscan content of sediments. Correlations are made between cores using ^{14}C and U-Th ages, stratigraphy and drought levels shown by changes in mineral contents. Environmental responses to local and regional climatic changes are traced by trends in authigenic carbonates, evaporites, detrital mineral content and by diatom-inferred salinity levels.

Our data have shown that, during the period covering the end of the previous Glacial (Termination II) and the last Interglacial (between *c.* 150 and 117 ka), peat and freshwater shallow lakes expanded. From 117 to 66 ka, the plain was occupied by lakes, the salinity and existence of which varied in time and space. Specific events are marked by mineralogic and stratigraphic signals at (i) *c.* 101 ka and (ii) 66 ka. From 66 ka to 30 ka, desiccation of the lake is marked by a hiatus. At *c.* 27 ka, milder climatic conditions led to the extension of freshwater marshes and lakes in the central depressions while palaeosols developed on the emerged parts of the plain. From 25 to 20·5 ka ^{14}C cal., the sediments of a freshwater to brackish lake are present in one core only. From 20·5 ka ^{14}C cal. onwards, strong evaporitic conditions occurred, the lake edges being transformed into playas. Upper parts of the sequences registered other lacustrine short phases, both before the Younger Dryas and during the Holocene.

KEY WORDS Late Pleistocene; Central Anatolia; sediment record; carbonates; palaeoenvironment; palaeoclimate

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1. INTRODUCTION

Lake level changes of closed lacustrine systems are good indicators of climatic changes because of their quick response to the variations of the water input/output terms of the hydrological balance (Eugster and Hardie 1978). Such closed drainage basins with saline lakes occupying the hydrographically lowest areas are common throughout the arid regions of the world today. In the environmental setting of such saline lakes, annual evaporation exceeds annual inflow plus precipitation, so that their characteristic features are primarily controlled by the climate of the basins (Hardie *et al.* 1978). In these closed lakes, evaporation leads to element supersaturation in water and to consequent mineral precipitation. These precipitated minerals strongly reflect the lake water chemistry at the time of their deposition. Oscillations of lake level and variations of water chemistry usually result in the deposition of a wide assortment of carbonate minerals, with calcite precipitating when the water is fresh, while magnesian calcite, protodolomite and dolomite are deposited when the water is brackish to saline, i.e. when the salt lake is either shallow or of the sabkha type (Hsü and Kelts 1978). Thus, calcite and low Mg-calcite precipitation is usually attributed to periods of high water level and low rates of evaporation, whereas high Mg-calcite, protodolomite and perhaps dolomite precipitation occurs during periods of low water level and high evaporation (Landmann *et al.* 1996). Such brines enriched in Ca^{2+} and SO_4^{2-} and impoverished in bicarbonate will, with continued evaporative concentration, reach saturation with respect to gypsum. Consequently, the mineralogical composition and sedimentological characteristics of lacustrine deposits in closed, semi-arid, lacustrine depressions reflect climatic changes through lake level and lake chemistry changes (Müller and Wagner 1978).

Such sensitive lakes are found in the closed basins of central Anatolia (Irion 1973), where the semi-aridity is accentuated by the Taurus range acting as a precipitation orographic barrier and river-water trap (karstic losses). Previous sedimentological and geomorphological studies in the lacustrine systems of the Anatolian plateaus have evidenced alternating extention, shrinkage and drying periods during the Pleistocene, related to variations in the water balance of the lakes, supposing a time correspondence between high lake level periods, called 'Pluvials', and the 'Glacials' in temperate regions (Klaer 1965; Erinç 1970, 1978; Erol 1970, 1978). Recent studies have shown that one high lake stand occurred in the mid-Pleniglacial throughout Anatolia (Degens *et al.* 1984; Kis *et al.* 1989; Kazancı *et al.* 1994, 1997; Landmann *et al.* 1996; Naruse *et al.* 1997; Kuzucuoğlu and Roberts 1998; Fontugne *et al.* 1999; Roberts *et al.* 1999), although pollen studies (Bottema and van Zeist 1981; van Zeist and Bottema 1982) show the Pleniglacial to be dry as well as cold.

Using the above assessments and in order to understand the significance of this Pleniglacial high stand of Anatolian lakes, the study of the evolution of the mineralogical and biotic contents of the lime-rich lacustrine deposits in the closed palaeolake Konya have been used for the reconstruction of palaeoclimates during the Last Glacial.

1a. Background to the Konya Basin

Mountain ranges rising up to >3000 m isolate the inner Anatolian plateaus, located at an altitude of 1000 to 1300 m, from the Mediterranean cyclonic depressions and the cool and humid air from the north. These plateaus have a semi-arid climate, classified as continental, with cold winters and dry summers. In Konya, maximum temperature in July is 30°C (with a minimum of 15°C) and the minimum temperature in January is −5°C (with a maximum of 4°C). Mean evaporation rate is 1722 mm/year (data supplied by the State Water Works in Konya); monthly evaporation rate figures are greater than rainfall over most of the years (de Meester 1970a). Average rainfall is *c.* 300 mm/year. Main precipitation occurs in spring while snow occurs in winter. In spring, storms cause heavy wind erosion of the lacustrine marls and fossil dune fields (Kuzucuoğlu *et al.* 1998a).

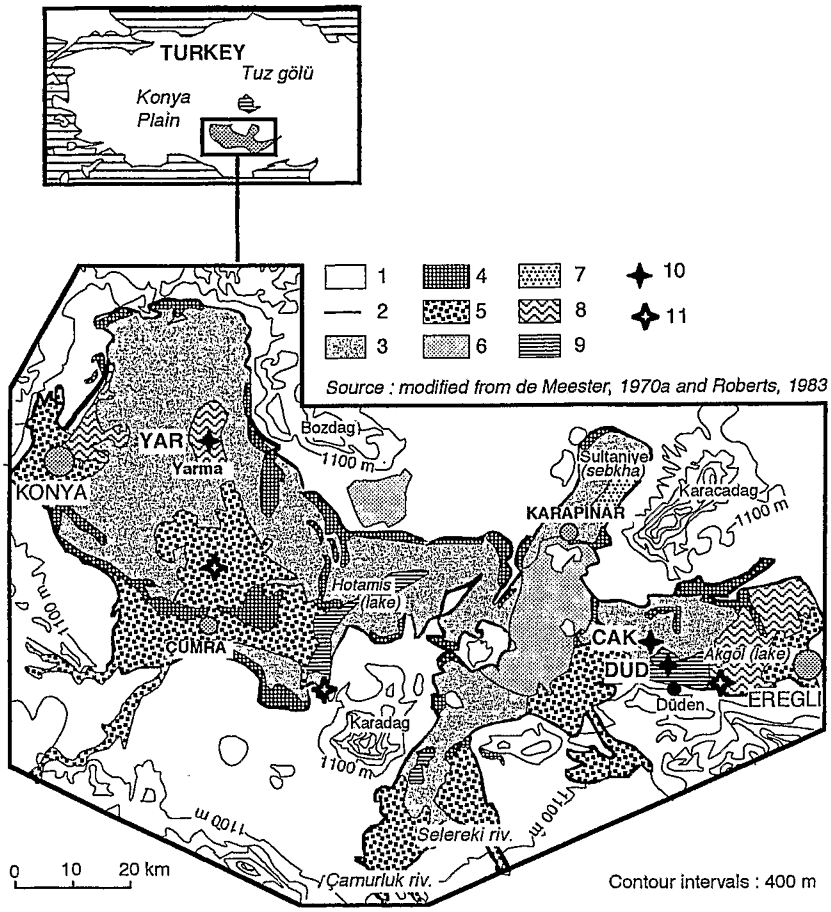
The Konya basin is mostly surrounded by limestone bedrock, either metamorphosed when Palaeozoic in age or soft lacustrine when Mio-Pliocene in age. In the Taurus mountains, which form the southern drainage area of the basin, pre-Miocene marine sediments are intruded by Upper Cretaceous peridotite and serpentine outcrops. Around the edges of the basin, volcanoes disrupt the limestone bedrock. Border faults may give rise to sulphur-rich springs constructing travertines. The sediment fill of the Konya basin is composed of 100 to 400 m thick lime-rich marls, containing up to 90% magnesium and calcium carbonates (de Meester 1970b) enriched in clastic material imported by rivers from the Taurus mountains, and by slope processes from the limestone and volcanic reliefs. Most rivers disappear before reaching the centre of the basin. Marshes and lakes, either seasonal or perennial, still occur in the lowest parts of the plain at the foot of alluvial fans. Deep seepage mainly supplies groundwater, reaching the impermeable marls of the lacustrine plain where it emerges as springs. In the lowest parts of the plain which collect most of the inflow (either surficial or underground), large areas are salt-affected and poorly drained.

In general, the hydrological balance in the plain is naturally characterized by large losses, mainly by evaporation, and partly by soak-away contributing to groundwater and by karstic losses to deeper strata. According to the calculation by Driessen (1970), the mean annual inflow into the whole Konya basin was, before irrigation started at the beginning of the 20th century, 1800×10^6 m^3 consisting of 632×10^6 m^3 river discharge, 368×10^6 m^3 local surface runoff and around 800×10^6 m^3 groundwater inflow (i.e. 44% of the inflow to the basin). An unknown amount of water outflows from the basin through karstic losses to the south and to the north towards the Tuz Gölü Basin. De Meester (1970a) estimates the impact of this underground outflow on the overall hydrological balance of the basin to remain very low. However, the State Water Works (1975) considers the confined and unconfined aquifers in the Neogene limestones covered by the Pleistocene fill and surrounding the plain, to produce *c.* 65×10^6 m^3 water discharge.

The reduced impact of inflow from the catchment area, and the water removal by evaporation, induce water and soil salinization. Most salts contained in the groundwater are sodium chloride (NaCl) and calcium sulphate ($CaSO_4$). These salts may be delivered by the deep and surrounding salt-containing sediments of Upper Eocene, Oligocene and Miocene ages (de Meester 1970a; State Water Works 1975). Gypsum is also found in the basin, within the Mio-Pliocene deposits. Inflowing water shows high Ca^{2+} and Mg^{2+} concentration, produced by dissolution of the surrounding limestones but also by volcanic material near Karapınar (Karacadağ) and near Karaman (Karadağ) (Figure 1) where streams and springs also deliver K and Na. Salts are common near the base of alluvial fans, as near the Zanopa fan where some gypsum crusts are still forming. Saline spring water deriving from seepage and run-off generates strongly salt-affected areas which bear hardly any plant cover (de Meester 1970a).

1b. Background to the Ereğli plain

The Konya plain is composed of two main parts: in the west the proper Konya plain, in the east the Ereğli plain, the southern part of which is occupied by reed-rich Akgöl Lake where the discussed cores have been obtained (Figure 2). The Ereğli plain is fed by the rivers from the Taurus, by springs along the southern carbonatic hills, and by the seasonal rise of the underground water table. It consists of three separate freshwater to brackish shallow open water bodies, linked by narrow channels opened in sand ridges (Figure 2). To the north, a series of closed and shallow depressions were under water until recent years, according to satellite images; they are now dry and salt-crusted. To the south, the lake used to be connected through a swallow-hole (the 'Düden') to the southern karstic limestone; this outflow explains the maintenance precisely here of a freshwater system. Surficial water input to the Ereğli plain consists mainly (Figure 2) of the Zanopa river and of more minor streams such as the Ayrancı river, the Ayran river (dried for irrigation purposes) and, exceptionally, by the Selereki and Çamurluk rivers when floods pass the western limits of the Ereğli plain. Annual river discharges (in m$^3 \times 10^6$) measured above dam sites are as follows: 168 for the Zanopa river, 50 for the Selereki river, 8 for the Ayrancı river (Driessen and van der Linden 1970). The Ereğli plain is also fed by underground water discharges from its southern and easternmost end (de Meester 1970a).



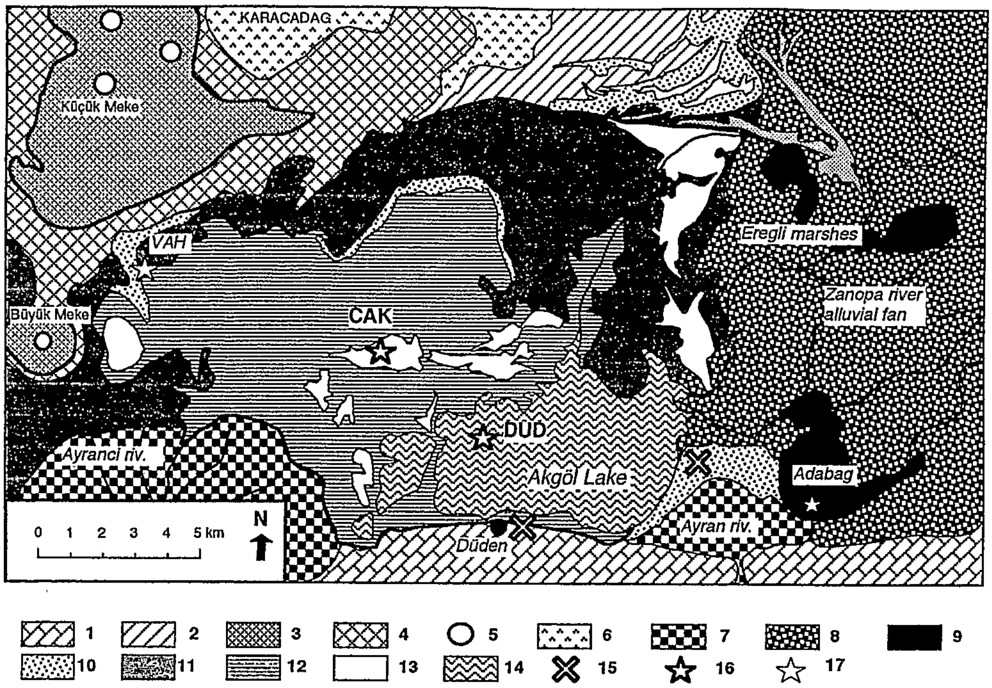
Legend : **1.** Pre-Quaternary limestones and volcanics; **2.** Limits of the Konya palaeolake; **3.** Pleistocene lacustrine marls; **4.** Sand and gravel shore deposits; **5.** Alluvial fans; **6.** Dune systems; **7.** Sebkha; **8.** Marshes; **9.** Lakes; **10.** Core sites studied; **11.** Other core sites cited in the text (Bottema and Woldring 1984; Inoue and Saito 1997; Roberts *et al.* 1999)

Figure 1. Geology of Konya basin and location of cores

2. METHODS

Three 25 m long, 64 mm diameter cores were extracted using a rotary and hydraulic Craelius XC-80H truck-mounted drill. Sub-cores of 1 m length were packed and sent to the laboratory in France. The cores were sub-sampled according to the stratigraphy in order to have samples representing each stratigraphic unit identified during the sampling process. Maximum intervals were of 25 cm except for the top 1 m part of the cores and of the deep peat layer (called Unit A in Figures 3 to 5) which were compressed during coring and not sub-sampled.

The CAK core was taken from the centre of a round and shallow playa north of the main Akgöl Lake at the altitude of 1000 m (Figure 2); the present water level varies according to seasonal river discharges to the Akgöl Lake. At the time of coring, it had been dry for four years and its bottom was covered by a thin (*c.* 5 cm thick) salty and silty clay crust. The DUD core was extracted from the centre of the main Akgöl Lake, 3 km southeast of the CAK station, in the vicinity of the 'Düden' (Figure 2). The altitude of the floor cored is *c.* 1·5 m lower than that of CAK (Orth 1996). The YAR core was drilled in the former marshes of Yarma, located in the northwestern part of the Konya plain, *c.* 5 km west of the Göçü palaeocoastline (Figure 1) (Mouralis 1996). Its altitude is *c.* 999 m.



Legend : **1.** Taurus dolomitic limestones; **2.** Mio-Pliocene soft limestones; **3.** Karapınar Pleistocene basalts; **4.** Windblown ash-covered plateau; **5.** Upper Pleistocene strombolian cones; **6.** Pliocene volcanic down-slopes of the Karacadağ; **7.** Small southern alluvial fans; **8.** Zanopa river alluvial fan; **9.** Peat areas in the Ereğli marshes; **10.** Coastal sand beaches and ridges; **11.** Dried Upper Pleistocene lake bottom; **12.** Ereğli plain bottom (deflated); **13.** "Peripheric" sabkhas; **14.** "Perennial" lake, today drying; **15.** ^{14}C dated beach ridges (Roberts, 1980; Fontugne *et al.* 1999); **16.** CAK and DUD cores location; **17.** Adabag cores (Bottema and Woldring 1984; Reed *et al.* 1999 and Roberts *et al.* 1999) and VAH well location (Kuzucuoglu *et al.* 1998b)

Figure 2. Location of CAK and DUD cores in the Ereğli plain (eastern part of the Konya plain)

Samples were wet sieved through a 50 μm sieve, in order to separate sand and silt–clay fractions. Petrographic and mineralogic counting and observation of grains were performed on the sand fraction under the binocular microscope. The detrital/authigenic origin of the carbonate minerals is based on a three-step approach: (i) binocular observation of grains $>50\ \mu$m; (ii) microscope observation of smear slides made from whole-sediment samples (mainly marls), in order to observe the shape and measure the size of particles (crystals, needles, micrite etc.); and (iii) the IR analysis results.

The overall mineralogic content of the sediments studied was identified by X-ray diffractometry performed at IRD and UMR 8591, by infrared spectroscopy on a Perkin-Elmer IR-TF/16 PC spectrometer at IRD, and by the microscope observation of smear slides. Minerals chosen for the study were quantified using FTIR (Fourier Transform Infrared absorbance spectroscopy) (Bertaux *et al.* 1998). Samples were prepared using the KBr disc method. A quantitative determination of calcite, aragonite, dolomite, gypsum, quartz and kaolinite was performed by making a multicomponent analysis of the sampled sediment spectra using the spectra of standard minerals. In order to check the validity of the results, the contribution of each of six minerals was also computed by measuring one of their specific absorption bands, easily identified in this type of sediment. For carbonates, out-of-plane bending mode of vibration (υ_2 absorption band) (White 1974) was used, with wave number 876 cm^{-1} for calcite, 857 cm^{-1} for aragonite, 881 cm^{-1} for dolomite (Chester and Elderfield 1967). For quartz, we used the 780 cm^{-1} absorption band, assigned to the pulsation of the bridging oxygen atom in the place of the Si–O–Si bonds between two adjacent tetrahedra (Fröhlich 1989). For kaolinite, we used the stretching vibration band at 3698 cm^{-1} of the inner-surface and outer OH (Ledoux and White 1964).

Diatom-inferred salinity (DIS) zones have been defined according to the composition of the diatom assemblages (Kashima *et al.* 1997) in samples where diatom frustules were sufficiently present and preserved.

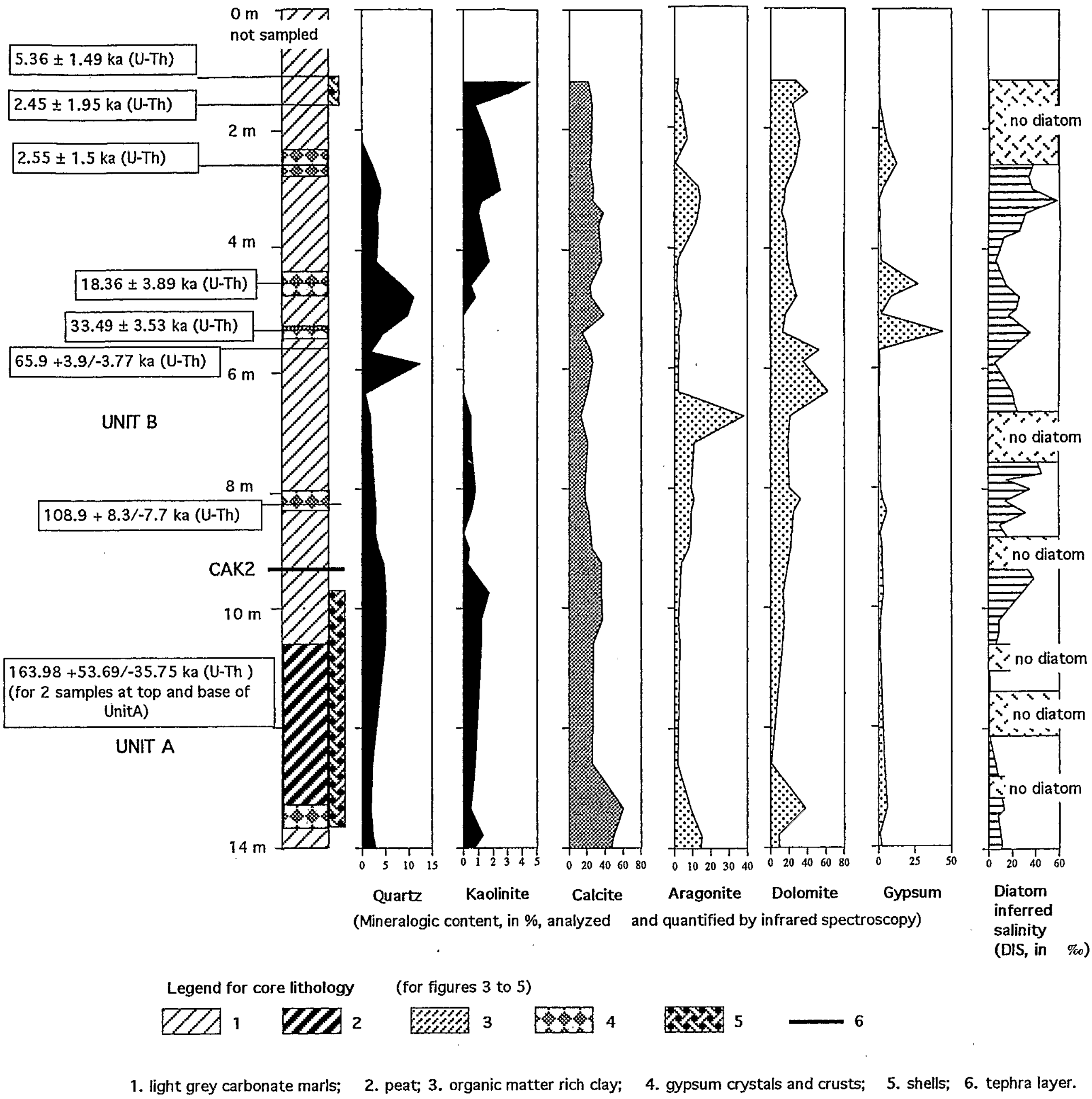


Figure 3. Mineralogic content of the CAK sequence

DIS results presented (Figure 6) use Fritz *et al.* (1991) diatom-based transfer function for the reconstruction of past changes in lake salinity. The function uses predictive models based on today's measured lake salinities and analysed diatom assemblages from Anatolia, computed in relation to the diatom assemblages identified in the core samples. Pollen was studied in the deep peat-like unit (Unit A) from the CAK core, with a total of 74 samples treated by the conventional HF method (Faegri and Iversen 1975). Out of these 74 samples, 26 pollen spectra were obtained. Results are illustrated with a palynologic diagram (Figure 7).

Mollusca were particularly abundant in organic matter-rich layers (Unit A and organic thin layer at 7·55 m in DUD). When sufficiently present, mollusca were picked up under the binocular microscope out of

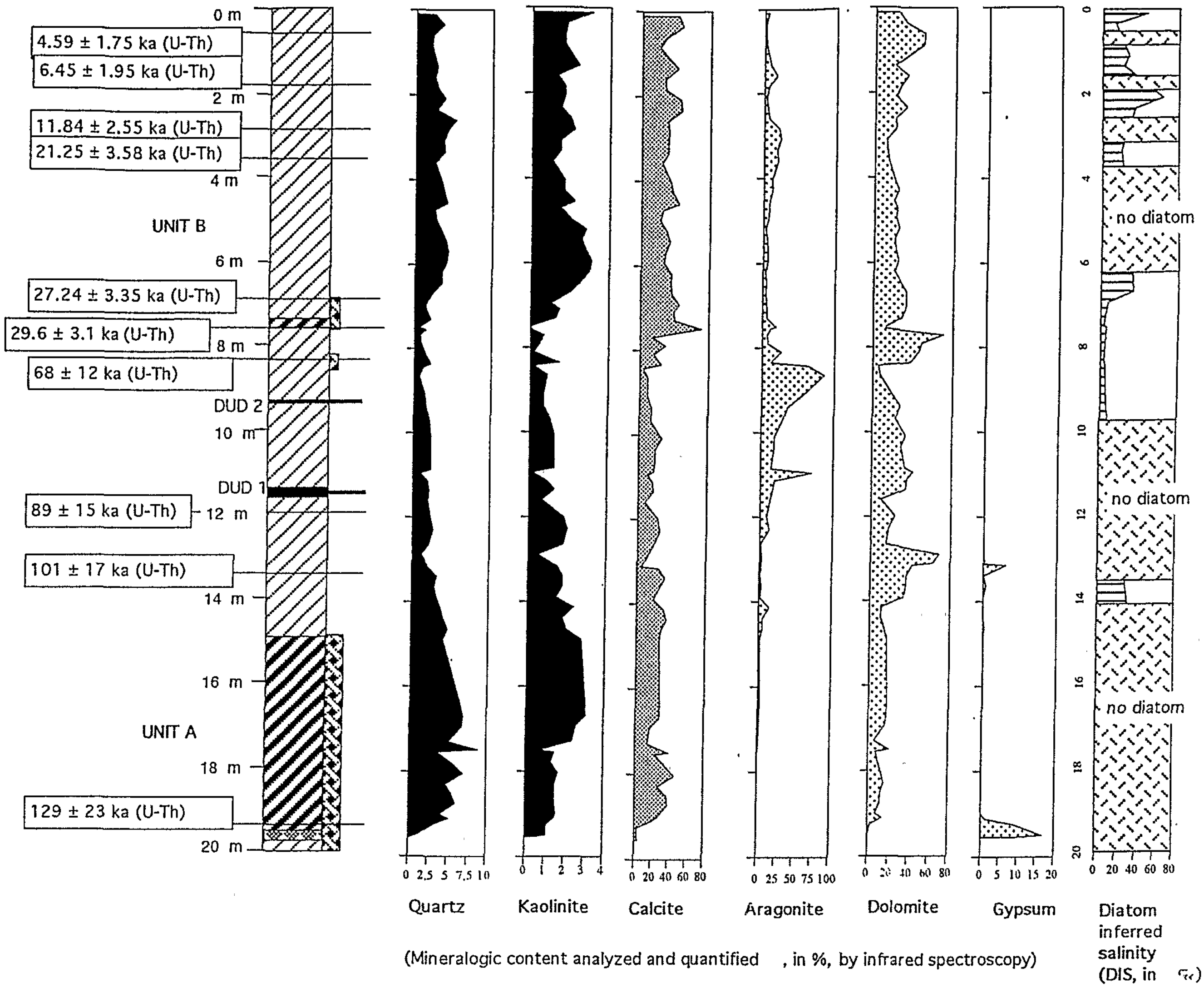


Figure 4. Mineralogic content of the DUD sequence (for legend of core lithology, see Figure 3)

the sand fraction (> 50 μm) for identification purposes. In some samples, the 'sand' fraction was mostly composed of shells (entire and broken).

The dating is based on ^{14}C β-counting of organic matter and U-Th analyses on gypsum and carbonates. ^{14}C dating was performed on the uppermost organic layers at the Laboratoire des Sciences du Climat et de l'Environnement (LSCE, Gif-sur-Yvette) and at the Underground Laboratory at Modane (French Alps), using an established method with a proportional counter. In the text, dates are given as ^{14}C calibrated dates (Stuiver and Reimer 1993) in order to allow comparisons with U-Th ages. However, the ^{14}C ages have to be considered as maximum ages since they could be affected by the hard water effect (uptake of 'old' carbon by biogenic carbonate) due to the limestone and karstic environment. This effect may lead to ageing, calculated to be 400 years in the Akgöl-Adabağ (Figure 2) site where sub-modern mollusc samples were ^{14}C dated by Roberts (1980). However, in the layers dated in this programme, the hard water effect may be minimal because of the low depth of the lake and of important mixing of lake water by persistent strong winds maintaining a good equilibrium between atmospheric and dissolved CO_2.

In order to provide an extended dated chronology, U-Th dating was used to date carbonate- and gypsum-rich samples. U-series radionuclides were measured by high-resolution alpha spectrometry and ICP-MS at

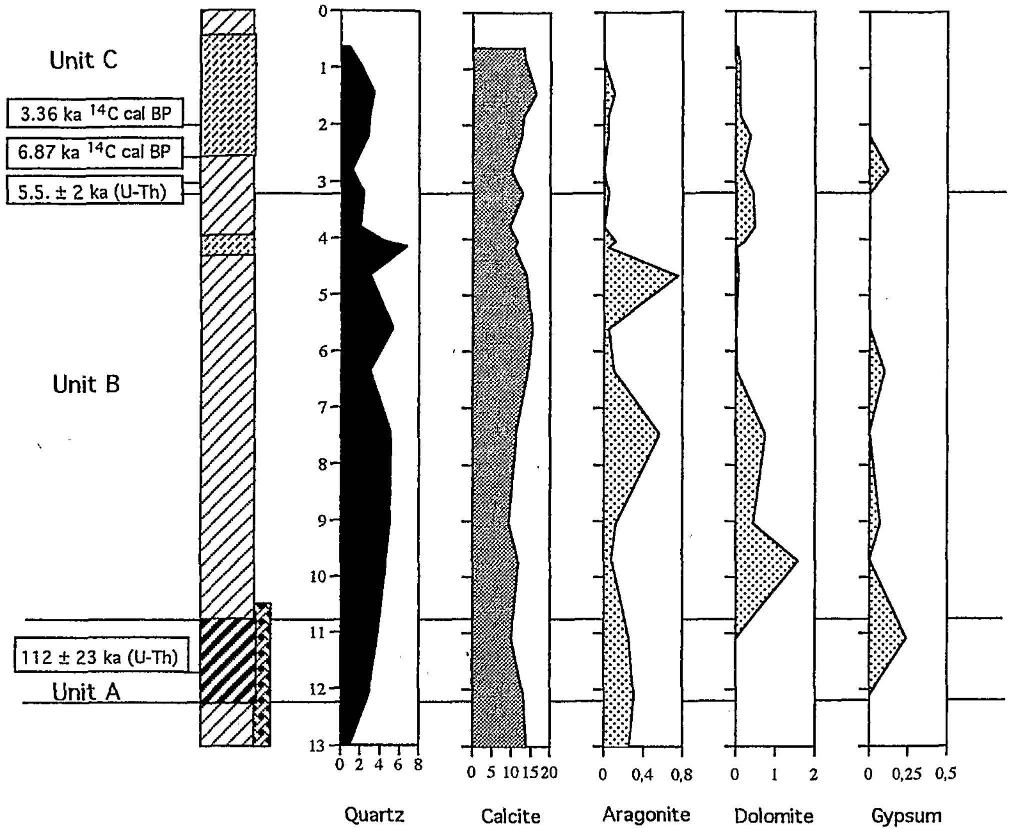


Figure 5. Mineralogic content of the YAR sequence. Analyses are X-ray diffractometry. X-scale units are calculated peak areas (for legend of core lithology, see Figure 3)

Lancaster University (Black *et al.* 1997). Corrections were made for decay of excess ^{234}U and detrital ^{230}Th, on the assumption that these were present at precipitation of the deposits. The correction for the detrital component was made from isochron plots after successive total dissolutions were performed following the preparation, firing and digestion outlined in Luo and Ku (1991) and Bischoff and Fitzpatrick (1991). In all cases the slopes of the isochrons are best determinations by a method of least-squares fitting which takes account of the errors in both variables (after York 1969; see Roberts *et al.* 1999 for more details).

3. RESULTS

The presentation of results will focus on the upper part of the cores, down to the plurimetrical deep peat used as a marker layer, which lies below the upper light grey marls. Accordingly, the length of the cores presented in the paper is 19·55 m for DUD, 13·35 m for CAK and 12 m for YAR. A first step will present the stratigraphy on the basis of lithology, chronology and mineralogy. This reference scheme will next be confronted with complementary proxy data.

3a. Lithology (Figures 3 to 5)

The three cores present a similar lithologic arrangement in two parts: a deep peat (Unit A) overlain by carbonated light grey marls (Unit B). Unit A consists of a thick (4·55 m in DUD; 2·35 m in CAK; 1·50 m in YAR) humic layer composed of a red to black peat, rich in macro remains overlying a black organic clay.

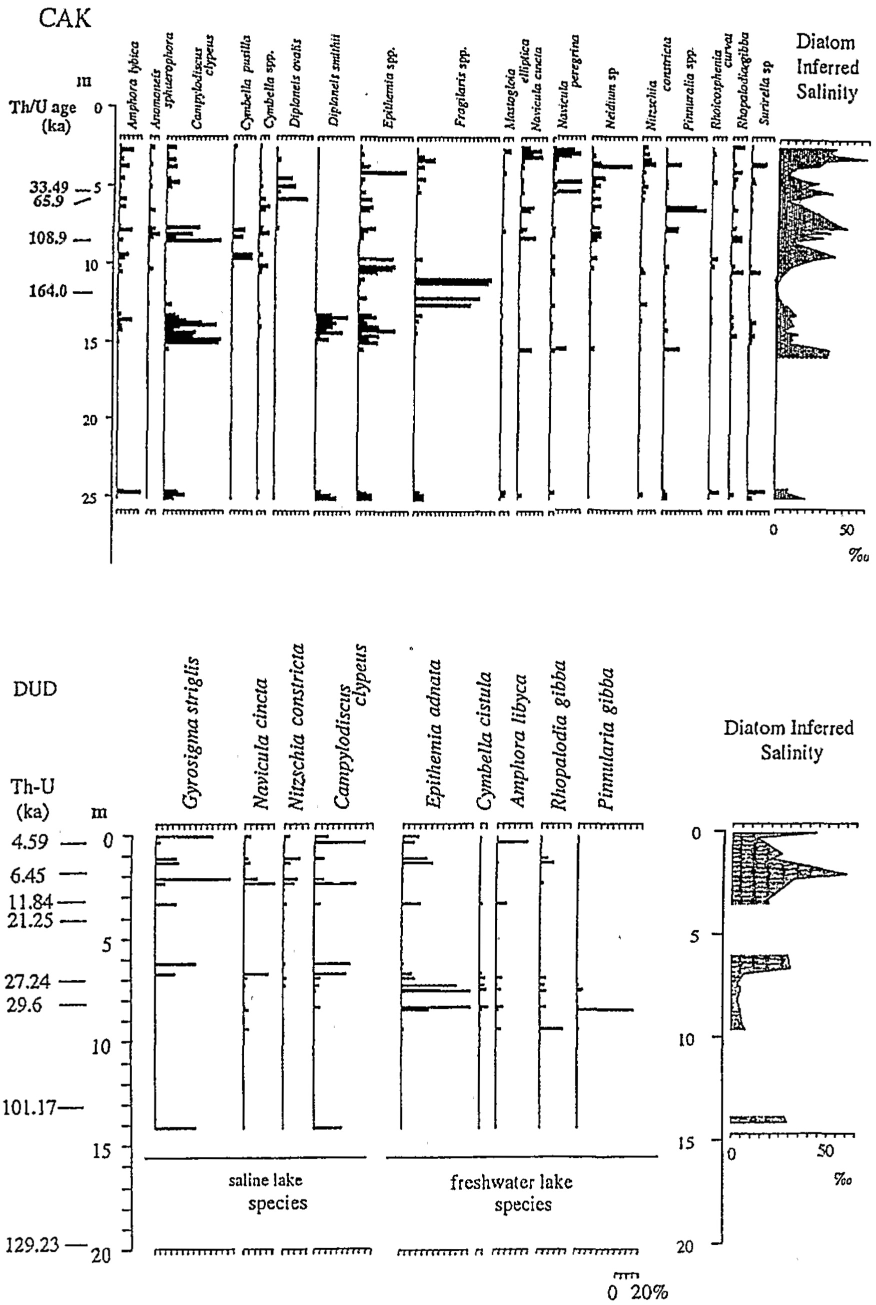


Figure 6. Diatom data from the CAK and DUD cores

Mollusc shells are present in the upper and lower layers situated below and above the peat. Unit B (top) consists of several metres of light grey carbonate deposits in which fragmented molluscan shells can occur. Unit B is 15 m thick in DUD, 11 m in CAK and 8·2 m in YAR. This unit presents some particularities in each core. In CAK, the marls contain four macroscopic gypsum-rich parts (including crusts occurring at 2·60 m and 8·10 m depth) and one tephra layer (CAK2 at 9·25 m; Figure 3). In DUD, a 12 cm thick organic peat-like layer, marked by root traces, shell and quartz accumulation, occurs at 7·43–7·55 m; two tephra layers were recognized at 11·65 m (DUD1) and 8·68 m (DUD2; Figure 4). In YAR, the marls are overlain by a 2·3 m thick, mollusca-rich, brown organic clay called 'Unit C' in Figure 5.

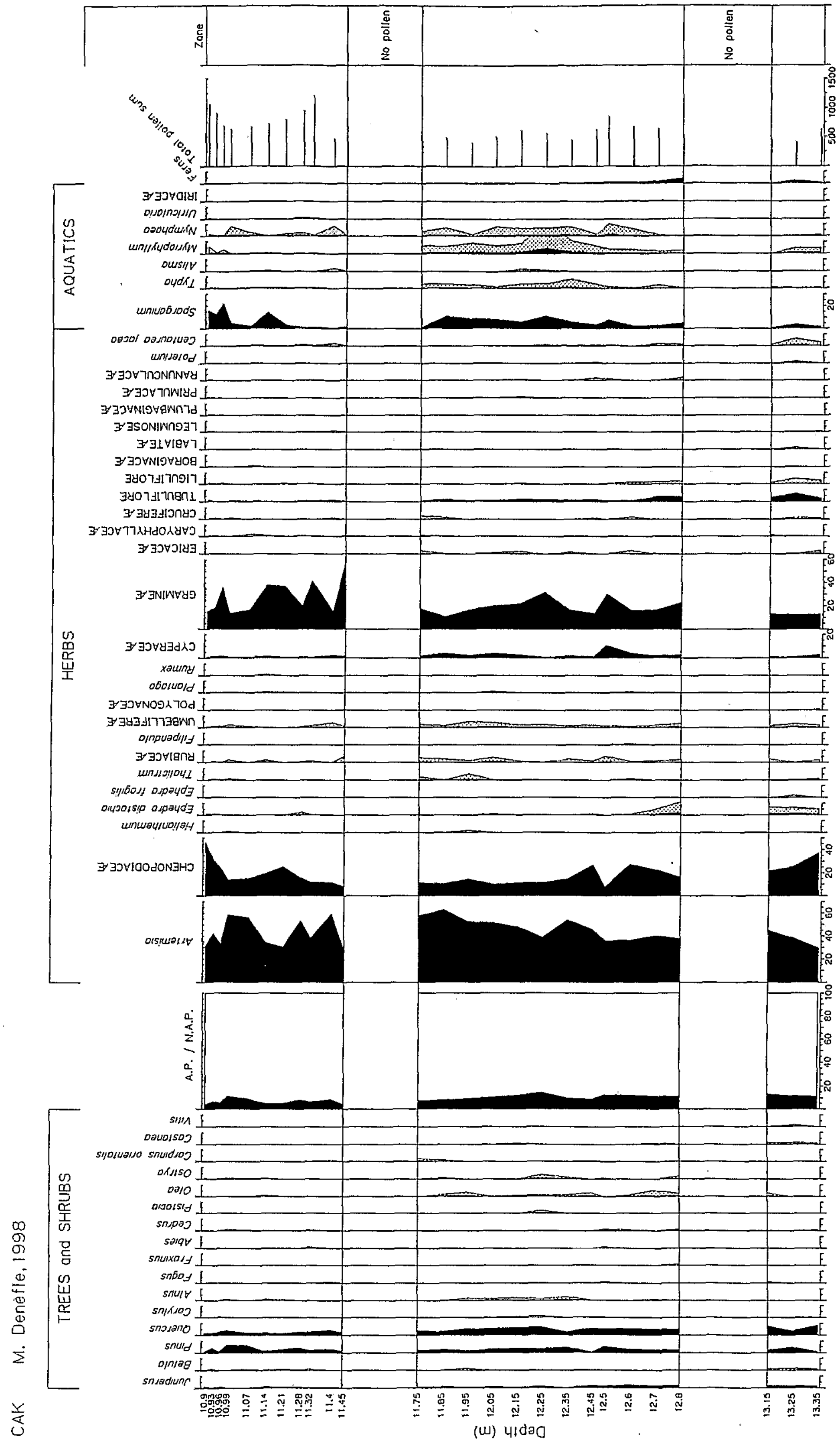


Figure 7. Pollen diagram of Unit A in the CAK core

3b. Dating (Table 1)

In spite of their large confidence intervals, the U-Th dates are used as a basis for the stratigraphic correlations between cores.

The base of Unit A (peat) is U-Th dated 129 $\pm$ 23 ka in DUD at 19·50 m, and 112 $\pm$ 23 ka in YAR at 11·90 m. In CAK the 163·98 $\pm$ 35·75 ka U-Th date from Unit A corresponds to a composite result from two samples: one from the top of the unit (11 m), mixed with one from its base (13·35 m). According to this set of dates, the age of this peat is centred on marine $\partial^{18}O$ isotopic stage 5e. Stage 5e is the Last Interglacial and is called Eemian in western Europe; it is dated 130–117 ka (Imbrie *et al.* 1984). However, the large confidence intervals of the dates obtained point to an age fitting in a time period spanning from the end of the previous Glacial (Termination II of marine $\partial^{18}O$ isotopic stage 6) to the following Interglacial (stage 5e).

Regarding Unit B (upper marls), available dates show that (i) the 115–60 ka period is equally recorded in CAK and DUD; (ii) a hiatus is noted between 60 and 30 ka; and (iii) after 30 ka, the record appears to be more discontinuous, also showing fewer similarities between CAK and DUD cores; however, it seems more complete in DUD.

Regarding the Holocene period, two U-Th dates from the upper metres of CAK may be rejected because of large uncertainties in the result (2·55 $\pm$ 1·54 ka at 2·6 m) and of stratigraphic inversion (5·36 $\pm$ 1·49 at 0·6 m). At the top of the YAR core, the 5·5 $\pm$ 2·2 ka U-Th date from the base (2·8 m) of the organic clay (Unit C) is confirmed by a similar ^{14}C date at 2·5 m (6·86 $\pm$ 0·4 ka ^{14}C cal. BP).

3c. Tephra layers

Three tephra layers have been identified in the parts of the DUD and CAK cores which are presented here. All three are composed mainly of trachytic glass associated with clinopyroxenes, amphiboles and biotites and were probably emitted by the Hasandağ, a stratovolcano located 70 km to the north of the Akgöl Lake (Kuzucuoğlu *et al.* 1998b).

The mineral composition and chemical characteristics of the glass (SiO_2 norm. = 64·5%) are very similar between the CAK2 and DUD1 tephra layers and are thought to point to possible identification of both layers and thus to determine their stratigraphic correlation in both cores (Kuzucuoğlu *et al.* 1998b). However, the stratigraphic interpretation of the U-Th dates when compared to the mineralogic content of the marls in Unit B (see Figure 9) prevents us from using CAK2 and DUD1 as certain stratigraphic tie-lines. The presence of apatite in DUD1 and its absence in CAK2 possibly confirms an age difference between the two tephra layers.

3d. Mineralogy

Apart from gypsum and aragonite (minerals characteristic of increasing aridity and evaporation impact; see Discussion) appearing at specific levels of Unit B, the mineral phases in the three cores are the same in both the peat and marl layers. The silicates present are quartz, plagioclase and mica (biotite, muscovite); the clay minerals are illite, kaolinite, chlorite and smectite; the carbonates are calcite and dolomite.

In all cases (Figures 3 and 4), quartz, kaolinite and calcite contents remain parallel along cores, in contrast to the evolution of the aragonite content. The dolomite content shows an intermediate behaviour, with fluctuations either parallel to or independent of the quartz–kaolinite–calcite content.

The content of analysed silicates remains low (5% maximum for quartz; 2% for kaolinite), in contrast to the carbonates which reach, in some levels, 40% (calcite), >50% (aragonite) and almost 60% (dolomite) of the mineralogic content.

The shape of the aragonite crystals is acicular; their length is 2 to 20 μm when precipitated. Calcite is the constituent element of both shells and lithics and, when detrital, calcite grains are several millimetres in size. At some levels calcite also appears as micritic muds, the elements of which are of a few micrometres in size.

Table 1. Results of ^{14}C and U-Th dating in YAR, CAK and DUD Cores from the Konya plain

Yarma marshes YAR Core				Akgöl lake							
				CAK Core				DUD Core			
Depth m	Age	Method of dating	Material dated	Depth m	Age	Method of dating	Material dated	Depth m	Age	Method of dating	Material dated
1·0	3·2 ka	^{14}C cal* (Gif 10318)	Organic clay	1·3	5·36 ± 2·49 ka (inversion)	U-Th	Carbonates	0·6	5·59 ± 1·75 ka	U-Th	Carbonates
2·0	3·36 ka	^{14}C cal* (Gif 10319)	Organic clay	1·6	2·45 ± 1·95 ka	U-Th	Carbonates	1·85	6·45 ± 1·95 ka	U-Th	Carbonates
2·5	6·87 ka	^{14}C cal* (Gif 10342)	Organic clay	2·6	2·55 ± 1·5 ka (polluted)	U-Th	Gypsum	2·55	11·84 ± 2·55 ka	U-Th	Carbonates
2·8	5·5 ± 2 ka	U-Th	Organic clay	4·6	18·36 ± 3·89 ka	U-Th	Gypsum	3·60	21·25 ± 3·58 ka	U-Th	Carbonates
								7·10	27·24 ± 3·35 ka	U-Th	Carbonates
								7·55	⩾33·6 ka (Gif/LSM 10314)	(out of range)	Organic clay
				5·7	33·49 ± 3·53 ka	U-Th	Gypsum	8·35	29·62 ± 12 ka	U-Th	Carbonates
				6·6	65·9 ka + 3·9/ − 3·77 ka	U-Th	Gypsum	8·35	68 ± 12 ka	U-Th	Carbonates
				8·2	108·9 ka + 8·3/ − 7·7 ka	U-Th	Gypsum	12·0	89 ± 15 ka	U-Th	Carbonates
								13·50	101 ± 17 ka	U-Th	Gypsum
11·8	112 ± 23 ka	U-Th	Carbonates (base of Unit A)	10·7	⩾50 ka (Gif/LSM10080)	^{14}C conv. (out of range)					
					163·98 ka + 53·59/ − 35·75 ka	U-Th†	Carbonates in peat (whole Unit A)	19·5	129 ± 23 ka	U-Th	Gypsum in peat (top of Unit A)

*^{14}C calibrated dates obtained from ^{14}C conventional dates using calculations from Stuiver and Reimer (1993)
†Date refers to two samples mixed from the top (11 m) and the base (13·35 m) of Unit A

When the main constituent of the carbonate marls, dolomite occurs as micritic muds, with some variations in size according to its origin. Sizes of the precipitated elements are usually a few micrometres (*c.* 1 to 4 μm) while, in the levels where dolomite is suspected to be imported from the watershed, the size of the grains is >20 μm.

3e. Diatoms

Diatom stratigraphy of lake sediments provides sensitive records of salinity changes. The diatom assemblages have been studied in all samples from CAK and DUD cores when they were present. They indicate several alternations between fresh and saline conditions, defined according to DIS (Figure 6). These DIS values must be treated with caution as probably only species with strongly structured valves like *Epitnemia* and *Campylodiscus* were preserved in the sediment, while diatom species with fine structures were probably broken or dissolved.

In nearly half the CAK core, diatoms are well preserved with entire frustules. In the remainder of the samples, diatoms are severely fractured or strongly dissolved with only the most heavily silicified parts of the valve remaining. The gaps with barren or rare diatom frustules are about 1 m thick between diatom-rich zones. The DIS curve allows us to distinguish two main zones. The first is a freshwater episode from 14 m to 10 m corresponding to Unit A (peat), expanding 40 cm above the top of the peat layer. In the second, above 10 m, the whole of the marl unit corresponds to brackish to saline lakes, with a very low salinity episode at 5·90 m.

In the DUD core, diatoms are well preserved in some parts of Unit B. The main gaps with barren or rare diatom frustules occur below 9·35 m except for one sample at 14·20 m, and from 6·20 to 3·35 m. No diatoms were found in Unit A (peat). In Unit B (marls), one freshwater zone is clearly identified from 9·10 to 7·35 m (the 9·35 m level below and the 6·95 m level above being slightly brackish). The one diatom-rich sample at 14·15 m marks a possible saline episode (DIS = 30·6‰). Diatoms in the marls above 6·95 m indicate a brackish to saline lake, the record being non-continuous due to absence of data from 6·20 to 3·35 m. Within this zone, peaks in salinity are reached at 6·70–6·20 m (after 27 ka) and at 2·10 m (possibly Holocene).

In summary, Unit A appears to be a freshwater ecosystem, according to diatom assemblages in CAK, although there is none in DUD; Unit B shows brackish to saline lake environments.

3f. Pollen

Pollen is present in the peat (Unit A) and absent from the marl (Unit B) sections. A diagram is produced for Unit A in CAK (Figure 7) based on 26 pollen spectra; 53 taxa were identified, with 413 (minimum) to 3819 (maximum) pollen counted per sample. Calculations of percentages of taxa are based on sums excluding aquatic plant pollen and fern spores. Arboreal pollen (AP) groups are weakly represented ($\leqslant$15%) and are dominated by *Quercus* ranging from 1·4 to 8·2%, and *Pinus* (ranging from 0·8 to 6·7%); *Juniperus* remains modest (0·2 to 2·8%). Temperate or Mediterranean tree species are present, although scarce. Non-arboreal pollen (NAP) is dominant, with prevailing *Artemisia* ranging from 26·5 to 63·1% of all pollen, Chenopodiaceae from 7·9 to 46% and Graminaea from 3·9 to 41·52%. The dominance of these three taxa indicates a steppe vegetation with scarce trees, possibly concentrated in, some areas such as mountain slopes or river edges. High levels of Chenopodiaceae point towards arid climatic conditions (Rossignol-Strick 1995) with low water availability to plants and possibly salinity patches in parts of the plain. Wetland plants, especially *Sparganium*, indicate that marshes and shallow lakes occupied the lowest parts of the plain.

3g. Mollusca

Abundant freshwater mollusca are associated with organic layers (Unit A in the three cores + the thin peat layer at 7·55 m in DUD + the uppermost 2·3 m of YAR). All species (Figure 8), except *Oxyloma elegans*,

CORES	CAK core										DUD core							DUD, organic layer (7.43/55 m in Unit B)	
Depth (m)	9.50	10.40	10.80	12.80	12.90	13.15	13.45	13.70	15.10	15.30	16.70	16.95	18.30	19.55	19.80	20.00	22.45	7.55	8.43
Units				Unit A (11-13.50 m)							Unit A (15.00-19.55 m)								
Theodoxus fluviatilis					x			x											
Valvata cristata				x	x	x	x					x		x	x				
Valvata saulcyi	x	x	x	ab	ab	x	ab	x		ab	x	x	x	ab	ab	ab	ab	ab	ab
Bithynia tentaculata				x	x	x	x			x		x		x	x	x	x	x	
Lymnaea truncatula ?														x					
Lymnaea glabra ?										x									
Lymnaea palustris																			
Lymnaea peregra														x	x			x	
Lymnaea stagnalis						x								x			x		
Lymnaea sp.	x										x	x							x
Planorbis planorbis				x	x	x			x	x	x			x	x	x		x	
Gyraulus argaeicus		x												x	x		x		x
Armiger crista				x	x					x	x			x	x	x	x	x	
Hippeutis complanatus				x	x		x												
Planorbarius corneus					x														
Pisidium sp.				x						x		x	x				x	x	
Micromelaniidae				x	x		ab	ab	ab										
Kirelia sp.																	x		
Oxyloma elegans				x						x									

x = present
ab = abundant

Figure 8. Molluscan species from the CAK and DUD cores

belong to aquatic fauna living in a freshwater lacustrine environment. Mollusca generally appear for 1 to 2 m below Unit A and remain present for 0·30 to 0·60 m above it, associated then with a reduction in species number. This impoverishment shows lake level variations. Results illustrate a shallow lacustrine environment, possibly marshy in patches, in some ways similar to the present Akgöl Lake.

4. INTERPRETATION

4a. Establishing the stratigraphy

Lithology and chronology are the criteria used for establishing the stratigraphy of the three cores.

The most obvious fact with regard to the lithology is the presence in the three cores of a peak unit, several metres thick, at the base. Considering the confidence intervals of the U-Th dates obtained, this unit belongs to the last stage of the previous Glacial (Pleniglacial or Termination II, i.e. end of isotopic stage 6) and to the last Interglacial (isotopic stage 5e). Exhaustive IR analyses together with U-Th dating and investigation of precipitated carbonate contents (Figure 9) allow the identification, in the DUD and CAK cores, of a stratigraphic correlation in Unit B, between the spans 10·60–6·0 m in CAK and 15–7·50 m in DUD. This part of the record is clearly dated *c.* 115 ka to 60 ka: U-Th ages in both cores date a gypsum precipitation event at *c.* 110 ka. Similarly, the top of this part of the record belongs to the 66 $\pm$ 4 and 68 $\pm$ 12 ka time period. Between these two dated levels, the precipitated carbonate record from both cores (namely aragonite and dolomite) show strong similarities.

This observation allows the distinction between a lower sub-unit (B1), after the peat and before the gypsum peak at 13·15 m in DUD and 8 m in CAK, and an upper sub-unit (B2) the top of which seems to correspond to a hiatus. This hiatus is illustrated by (i) date-related and (ii) mineralogy-related arguments. (i) Sediments dated *c.* 66 ka are closely overlain by sediments dated *c.* 30 ka. Such low sedimentation rates are likely to indicate a hiatus. (ii) In both cores, aragonite increases towards the summit of Unit B and points to increasing aridity. However, in DUD this increase is capped with a thin peat-like layer indicating a humid, and freshwater environment. Accordingly, the succession represents a drought, followed by a hiatus without any sedimentation over a long time period; afterwards, the record registers a sudden, more humid event at *c.* 27 ka. Therefore, in both cores, three sub-units can be distinguished within Unit B. Two basal sequences show increasing aridity trends: B1 which ends with a gypsum layer; and B2 which ends with a hiatus lasting from *c.* 66 to 30 ka. After this hiatus, i.e. after *c.* 30 ka, the CAK and DUD records become contrasted, sub-unit B3 deposits being characterized by opposite sedimentation rates, higher in DUD and lower in CAK, where gypsum crusts occur several times while they are absent during sedimentation within the period after *c.* 30 ka in DUD.

4b. Origin and significance of the mineral phases

As observed in many perennial lakes in semi-arid regions, the Konya palaeolake sediments show abundant chemical precipitation. Indeed, the sediments contain the various components of evaporitic sequences usually described in continental environments (Collinson 1978), including freshwater organisms, alkaline earth carbonates and gypsum. The time succession (i.e. their stratigraphical succession) indicates an increasingly arid climate in a non-alkaline lake.

In such a context, the major sources of carbonate deposited in lake sediments are (Dean and Fouch 1983): (i) inorganically precipitated carbonate; (ii) photosynthesis-induced, inorganically precipitated carbonate (bio-induced carbonate); (iii) biogenic carbonate consisting of debris from calcareous plants and animals; and (iv) allochthonous (detrital) material derived from carbonate rocks in the drainage basin. These primary carbonates may be subsequently affected by diagenetic processes eventually leading to mineralogical changes.

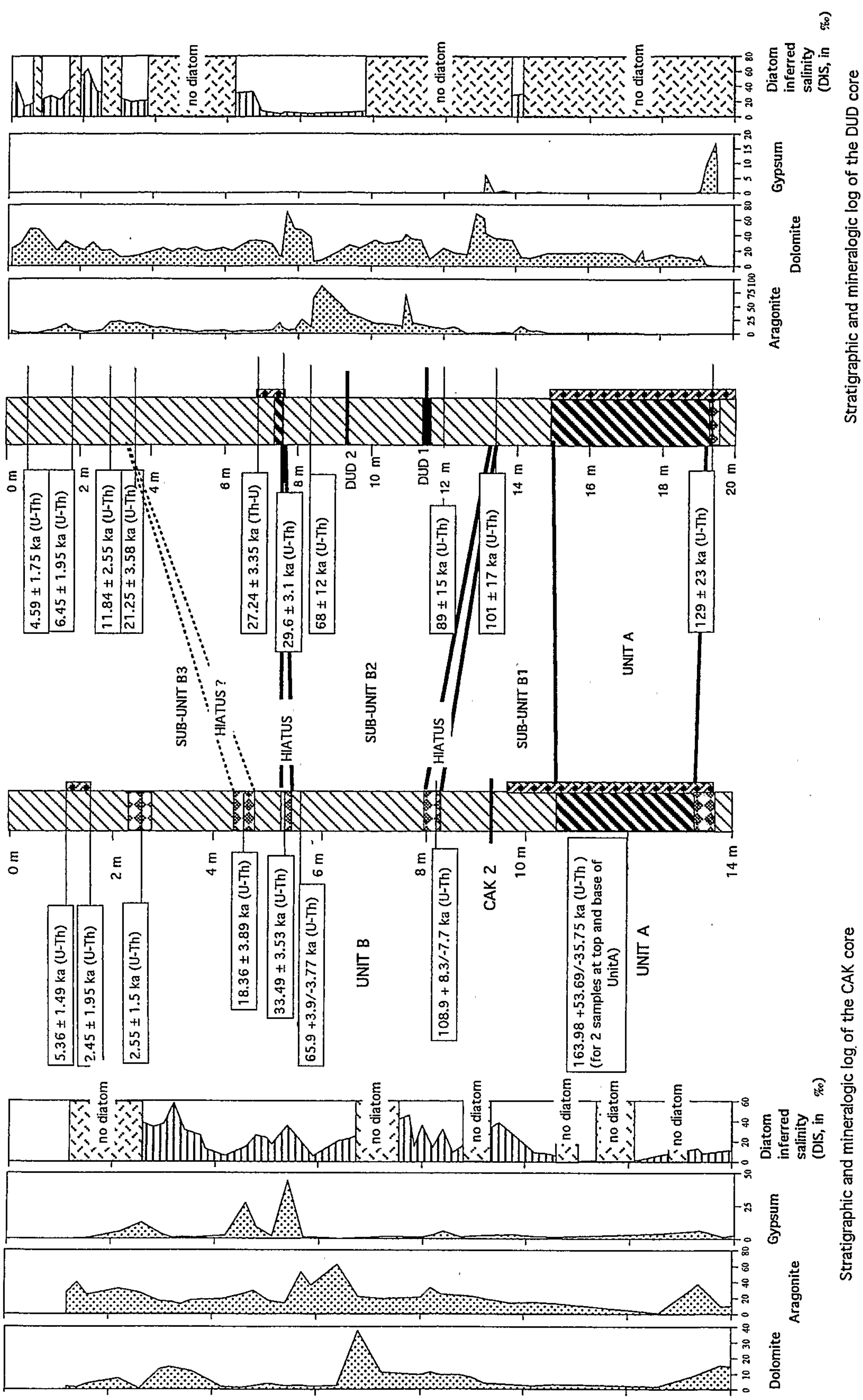


Figure 9. Stratigraphic and age correlations between CAK and DUD cores

Conventionally, the origin of carbonates (detritic, primary precipitation, diagenetic precipitation) is determined by use of mineralogic (texture, habitus) criteria. The quantitative analysis of the mineral content of carbonated sediments allows us to produce additional information in evidence of parallel or non-parallel time variations of the proportions of the sediment components, which may behave in-phase, out-of-phase or independently from one another.

Using this approach, we use kaolinite (K) and quartz (Q) as representatives of the silicates, also present in the sediments, where they cannot be of any other origin than detrital (aeolian or riverine). They will be used as a comparative base for the evaluation of the detrital character of the carbonates.

Results show that K and Q are present and show maximum values in the peat (at a time when aeolian input should be minimum) and that the lowest K and Q values are recorded during the most arid phases. This observation points to a transportation mode linked more to run-off than to wind action.

Calcite (C), in all cores, shows behaviour similar to that of K and Q (Figures 3 and 4), the stratigraphic zones identified corresponding to specific trends: at the base, K–Q–C content is high (Unit A); the first part of Unit B (sub-units B1 and B2) is characterized by K–Q–C minimum values when aragonite and dolomite values are maximum; in the upper part of Unit B (sub-unit B3) the K–Q–C curves again show maximum values, while aragonite content is at its minimum and dolomite values behave independently from the other curves. Accordingly, in the records studied, calcite is interpreted as a detrital mineral, mainly imported by run-off.

In contrast, the aragonite content is at a minimum when the Q–K–C content is maximum. Aragonite precipitation, being specific to a lacustrine environment in a semi-arid climate (Xiouzhu *et al.* 1996), is therefore interpreted as being syn-sedimentary and the high values indicate an aridity trend.

The behaviour of dolomite appears to be more ambiguous, its characterization being more difficult to establish in comparison to the other minerals, except for some peaks in the two lowest parts of Unit B (at 13·15–12·90 m and 7·9–7·7 m in DUD; at 6·4 m and 5·7 m in CAK) where maximum values are in contrast to aragonite minima. Such variations may have two explanations: (i) primary precipitation of dolomite within an aragonite–dolomite–gypsum sequence during a period of increasing aridity; and (ii) diagenetic formation of dolomite by replacement of aragonitic mud at sub-aerial exposure surfaces through processes of evaporation and capillary attraction (Wilson 1975). Whatever explanation is retained, the aragonite–dolomite–gypsum succession acquires the same climatic significance, i.e. an increasing aridity trend.

4c. Diatom data

The diatom-inferred salinity (DIS) data reflect a ratio, in a sediment, between saline and freshwater environment species, the simultaneous presence of which may have two different interpretations. (1) It may indicate a salinity gradient whose variations will be very sensitive to lake depth, when low lake level implies that peripheral areas can be seasonally exposed. If this hypothesis is correct, the diatom spectra indeed represent an instant in time of the environment salinity, and the evolution of the saline/non-saline population groups represents water salinity evolution. (2) In contrast, saline water diatoms found in the sediment may not be contemporaneous with the freshwater ones, and may have been introduced into the sediment during an elevation of the lake level which induced erosion of the lake banks containing salt water species deposited during previous low-level and more saline periods. The ratio then points to an elevation of the lake level and a deepening of the lake, and not a lake water salinity increase.

Taking into account this observation, it seems difficult to use DIS data as a reliable indicator either of lake water salinity or of lake depth. However, the salinity index produced by the diatom analyses confirms, in both cores, the opposition between: (i) a freshwater environment in Unit A and subsequent Unit brackish and salted Unit B; and (ii) a generally brackish environment in sub-units B1 and B2 as opposed to sub-unit B3 showing higher and variable DIS values.

The diatoms thus confirm the stratigraphic division of the marls based on mineralogical and chronological data; however, and possibly because of frequent lake level variations (as explained above), data are insufficient to determine either the salinity level of the lake water or its depth.

5. DISCUSSION

In spite of the presence of several hiatuses in the sedimentary records, the following discussion is a first attempt to reconstruct the environmental changes in central Anatolia during the last 150 000 years. Some literature references will be cited to complete the presentation of the terminal phases of the cycle.

The overall discussion will focus on the interpretation of the results presented earlier in the light of the last glacial cycle chronostratigraphy based on the isotopic signals from deep sea records (Imbrie *et al.* 1984), ice cores (GRIP members 1993), long pollen diagrams (Woillard 1978; Beaulieu and Reille 1984; Guiot *et al.* 1989) and synthetic geochronology (Martinson *et al.* 1987).

These global palaeoclimatic records show the following. (i) The $\partial^{18}O$ isotopic stage 6 (*c.* 190–130 ka) is the previous Glacial, corresponding to stages 4 to 2 (*c.* 74–12 ka) in the Last Glacial. It is characterized by an increasingly arid climate with landscapes increasingly dominated by herbaceous communities. Aridification culminates at the end of the Glacial stage (*c.* 150–130 ka), called Termination II (the end of stage 2, the driest and coldest part of the Last Glacial is similarly called Termination I). (ii) The $\partial^{18}O$ isotopic stage 5 (*c.* 130–74 ka) is divided into five sub-stages with the oldest, 5e (*c.* 130–117 ka, called Eemian in western Europe) corresponding to its warmest part. Sub-stages 5c (*c.* 104–98 ka) and 5a (*c.* 92–74 ka) are warmer periods within stage 5; sub-stages 5d (*c.* 117–104 ka) and 5b (*c.* 98–92 ka) are colder periods within stage 5. (iii) The proper Last Glacial starts at *c.* 74 ka with stage 4, a cold episode. The following stage 3 (*c.* 59–24 ka) is characterized by a varying climate ending with the glacial maximum called Pleniglacial (*c.* 24–18 ka ^{14}C cal. BP) followed by the late Glacial period (*c.* 18–12 ka ^{14}C cal. BP). and (iv) The present interglacial (called the Holocene) starts at *c.* 12 ka ^{14}C cal. BP.

5a. Termination II (end of stage 6) and Last Interglacial (stage 5e) (c. 150–117 ka)

When taking into account the confidence intervals of the U-Th dates from Unit A in the three cores (the U-Th date from the CAK peat remaining weakly reliable), it appears that the peat developed during a time range corresponding to the end of stage 6 and sub-stage 5e. Accordingly, one of the major results presented by this study of the three cores is the evidence of the development of a peat layer several metres thick in the Konya basin during this time period.

More precision is obtained by the pollen analyses from the CAK core showing that, while vegetation in the plain was steppe-like and treeless, high percentages of Chenopodiacea and *Artemisia*, as well as very low AP/NAP ratios (always lower than 15%), are indicative of a cold dry climate, especially in the bottom and middle parts of the pollen record in the peat. Towards the top of the diagram (Figure 7), increasing aquatic plants represent a still cold but wetter climate. As a matter of fact, mollusca also show, in the upper part of Unit A in the CAK and DUD cores, a shallow lake in the Akgöl depression. The mineral composition of sediments indicates increasing running water input. However, pollen indicates a quite cold climate, and the peat must correspond either to the end of stage 6 (Termination II) or to the second half of stage 5e that Guiot *et al.* (1989) also characterized as wet and cold in the Les Echets continental record. This succession calls for comparison with the end of the Last Glacial cycle, when the first half of stage 2 corresponded to a 12 m deep brackish lake and stage 1 (the Holocene, i.e. the present Interglacial) to an often dry environment with some local marshy to lacustrine areas. In contrast, the end of stages 6 and/or 5e were times of peat development all over the plain, with the mineralogy indicating high levels of detrital input into the marshy and lacustrine depressions, confirming revival of riverine inflow from the drainage area.

Such wet and cold climatic conditions during the last Interglacial have no present equivalent in today's Anatolian closed lacustrine depressions (except, as in the Ereğli plain, for some local peat developing in relation to alluvial fan growth and poor drainage). This may point to climatic differences between the present Interglacial and the last, possibly a wetter one (Guiot *et al.* 1993).

5b. The Last Glacial

In the basal half of both CAK and DUD cores (sub-units B1–B2), the sediments (mineralogy, diatoms) registered climatic changes during the period 115–66 ka, lake water chemistry and lake level changes being similar in both sites.

Sub-units B1 and B2 represent two successive periods of increasing aridity: one (B1) from *c.* 115 to *c.* 101 ka, ends with gypsum precipitation indicating a possible desiccation of the lake; a second lake period (B2) starts some time after this eventual hiatus, and ends at *c.* 66 ka (U-Th date of the gypsum crust at 6·6 m in CAK gives a time range of 69–62 ka for this event). The end of sub-unit B2 is marked, on both sites, by a clear evaporitic (aragonite–dolomite–gypsum; gypsum present only in CAK) sequence.

The B1–B2 sedimentation record seems to correspond to the whole time period from sub-stage 5d to stage 4. Within this period, the gypsum layer (and the possible associated desiccation event), dated in DUD (13·55 m) 101 $\pm$ 17 ka and in CAK (8·20 m) 109 $\pm$ 8 ka, could mark the warm sub-stage 5c. In contrast to the development of peat (Unit A) indicating humidity at the end of the warmest sub-stage 5e, the gypsum layer between sub-units B1 and B2 shows that the warm sub-stage 5c was drier, in this case.

From 66 to 30 ka, there was no lake in the Ereğli plain. This hiatus period fits into isotopic stage 3, which was slightly warmer than previous and subsequent stages 4 and 2. In Süleymanhacı Lake, located on the southernmost border of another part of the Konya plain, a very shallow evaporative saline lake stage was identified below a hiatus by Reed *et al.* (1999) and Roberts *et al.* (1999) and U-Th dated to 44·1 $\pm$ 3·1 ka on a gypsum crust. This highly evaporative period appears as a threshold in the functioning of the basin since, after 30 ka, the records of sub-unit B3 are contrasted between the cores. (i) A freshwater peat (marshes) development at the start of sub-unit B3 in DUD is not present in CAK. A similar thin peat layer was found in the VAH site (Figure 2) on the northern shores of the Ereğli plain (VAH) where it was ^{14}C dated 26 ka cal. BP (Kuzucuoğlu *et al.* 1998b). In Göçü, a palaeosol, also indicating vegetation growth on emerged parts of the plain, was similarly ^{14}C dated 28·3 $\pm$ 1·1 ka BP (Fontugne *et al.* 1999; Karabıyıkoğlu *et al.* 1999). (ii) The sedimentation record is marked by several hiatuses and gypsum deposition on the more peripheral site (CAK). (iii) The sedimentation rates are higher in DUD than in CAK. Thus, in contrast with B1–B2 period, the sedimentary environment of the cores shows a differentiation of the system with CAK located at the lake edges and DUD at the lake centre. According to U-Th dating, the sub-unit 3 marls were deposited after *c.* 27 ka; they may have registered some late Glacial and Holocene lacustrine events in the upper 2–3 m. However, the possible inversion in the age distribution, the lack of correspondence between the mineralogical records in CAK and DUD cores, and the absence of visible stratigraphic limits do not allow recognition of the location of the possible hiatus. However, two U-Th dated levels in Sub-unit B3 from DUD seem to indicate that the carbonate marls deposited from 7 to 3·50 m could correspond to the lake-bottom sediments contemporaneous with the coastal deposits of the 25–20·5 ka BP Upper Pleistocene high (12 to 20 m deep) lake.

The climatic trend during the Last Glacial cycle shows a 'regular' deterioration starting with a first period marked by two repetitive cycles (sub-units B1 and B2), followed by desiccation between *c.* 68 and 30 ka. A second period (sub-unit B3) shows disruption in the functioning of the basin, with sedimentation records interrupted by several hiatuses in some places. The global trend is lake contraction, which may be interrupted by re-extension phases. Several gypsum-rich layers in CAK show the strongest evaporitic phase of the whole series studied. In contrast, no gypsum was precipitated in the centre of the lake (DUD) possibly because the Düden prevented lake stratification.

5c. The Pleniglacial (24–18 ka cal. BP*)*

In the Konya basin (Figure 1), the whole surface of the plain is known to correspond to the dried base of an Upper Pleistocene lake >4000 km^2 in area, well ^{14}C dated 25–20·5 ka cal. BP on *Dreissena* sp. shells from coastal sand deposits (de Meester 1970a; Roberts *et al.* 1979; Roberts 1983; Kuzucuoğlu *et al.* 1997; Naruse *et al.* 1997; Fontugne *et al.* 1999; Roberts *et al.* 1999). During this period, several episodes of high lake levels (12 m to 20 m in depth) occurred in the Konya plain (Karabıyıkoğlu *et al.* 1999). Numerous freshwater to brackish mollusca fossilized in the sand beaches surrounding the bottom of the lake testify that it was a perennial lake. Such a lake should have left specific records in the lake-bottom sediment sequences, with expected calcitic deposits. Although it was not present in other cores from the southwestern part of the plain (Reed *et al.* 1999; Roberts *et al.* 1999), U-Th dating in DUD may allocate the *c.* 7·0 m to 3·6 m part of the core to a brackish deep lake system. The mineralogical and diatom data seem to show this record to be interrupted by a sudden change (i.e. a drought and a hiatus) at *c.* 3·6 m. According to U-Th dated gypsum levels, this episode does not seem to be recorded in CAK, as in other cores studied by Roberts *et al.* (1999).

5d. The late Glacial (18–12 ka cal. BP*)*

The sudden Pleniglacial desiccation is followed by a severe drought to which the gypsum crust at 4·5 m in CAK could be related. Desiccation was followed by a dune field formation OSL dated 14·3 ± 3·2 ka (Kuzucuoğlu *et al.* 1998a). Further information from CAK and DUD cores is insufficient due to different records and to a hiatus suggested by the U-Th dates. From research in other parts of the plain, we can state that there was a late Glacial lake phase between >14 and 12·8 ka ^{14}C cal. BP (Roberts 1980; Bottema and Woldring 1984; Fontugne *et al.* 1999).

5e. The Holocene (<12 ka cal. BP*)*

In the DUD core, a freshwater system is recorded by the diatom-inferred salinity data in the upper 1·50 m of the DUD core (U-Th dated 6·5 ± 1·9 and 4·6 ± 1·7 ka), by shells and marshy deposits in the upper 2·30 m of the YAR care, ^{14}C dated 4·9 ka cal. BP and U-Th dated 5·5 ± 2·2 ka. This episode also appears in the upper part of a core drilled near Çumra (Figure 1) in the western part of the Konya plain (Inoue and Saito 1997). In some sub-basins of the Konya plain, two phases of Holocene lake and marsh renewals have been identified and ^{14}C dated 6·9–6·4 ka and 5·4–4·7 ka cal. BP (Fontugne *et al.* 1999); these ages match with those obtained by U-Th dating on the Akgöl lacustrine carbonates.

The absence of a lacustrine record in the Konya Basin during the 9–6·8 ka ^{14}C cal. BP Holocene Climatic Optimum, which is marked in other parts of the Eastern Mediterranean region by a large vegetation expansion responding to the steady increase in temperature and precipitation, points to an increased effect of evaporation possibly due to the derivation of precipitation by the Taurus orographic barrier, as indicated by increased runoff recorded within the sapropel episode in the eastern Mediterranean marine cores (Fontugne *et al.* 1994; Kallel *et al.* 1997).

6. CONCLUSIONS

6a. Reconstructing past environments of inner Anatolia

During the Last Glacial cycle, Central Anatolia shows contrasting responses to climatic changes, especially: (i) during the Last Interglacial, which appears to be different from the present one; (ii) during the Pleniglacial; and (iii) during the Holocene climatic optimum. Also, it can be noted that, on the Anatolian plateaus, there is no strict correspondence between cold–dry and warm–humid periods, as usually indicated during glacial and interglacial periods. This may be due to the specific behaviour of a high-altitude, semi-arid lacustrine environment; it may also represent a regional response to specific climatic conditions integrating the role of the Anatolian orographic barriers, its continentality trends, and its position on the cross-roads between temperate, Mediterranean and sub-tropical climatic zones.

On the Konya plain, the time period corresponding to the end of the Previous Glacial (end of stage 6 and Termination II) and to parts of the Last Interglacial (stage 5e) appears to respond to a cold climate, with a treeless landscape; however, lakes were present on the plain and thick peat developed all over the plain, certainly responding to an increasingly positive water balance. Our results do not allow us, because of the uncertainties introduced by the confidence intervals of the U-Th dates, to characterize in more detail the warmest phase of the Last Interglacial.

Following this phase, the colder sub-stages of the Last Interglacial and the Last Glacial stage are known to be dry in the Eastern Mediterranean area, as shown by the results of pollen analyses in the marine cores in the Levantine Basin (Cheddadi and Rossignol-Strick 1995) where the Chenopodiaceae curve reflects the dryness of the climate, with two peaks during MIS 5 corresponding to two colder sub-stages in the last Interglacial, a slightly more humid MIS 4 when Chenopodiaceae content decreases, followed by a MIS 3 also characterized by two Chenopodiaceae peaks. During this period, on the Konya plain, carbonate marl deposition shows shallow, sometimes evaporitic, lake systems responding to semi-arid to arid conditions, with increasing salinity cycles ending in lake desiccation during stage 3.

During the Pleniglacial, the deep, freshwater to brackish lake ^{14}C dated 25–20·5 ka cal. BP in the Konya plain appears to have been a short-term and exceptional episode of higher water input, and/or decreasing evaporation. It is a specific regional response since lakes in other areas around the Mediterranean are dry or at their lowest level (Street and Grove 1979; Roberts 1983; Prentice *et al.* 1992; Roberts and Wright 1993; Kuzucuoğlu and Roberts 1998).

6b. The mineralogical content and indicators of environmental changes

The sequential deposition of carbonates and sulphates in the stratigraphic column illustrates trends in the water salinity. In the case of increasing evaporation, peaks of aragonite are followed by peaks in dolomite and, eventually, by peaks in gypsum content. The Konya plain sediment fill reflects the Late Pleistocene climatic changes. However, after 30 ka, the comparison between cores located in different parts of the basin also shows a sensitivity to local factors which can be explained by the shallowness of the lake and the variability of the water input.

During the evaporitic episodes of the Last Glacial, Ca-Mg carbonates accumulated in the lake mud flats while, at higher stages, Ca-Mg carbonates could be moved into the central lake, either as clastics or by dissolution and reprecipitation. When evaporites accumulated in the peripheral sabkhas, the central lake must have been relatively small and shallow and, in the area located next to the input/output of water (the 'Düden') which prevented stratification, no gypsum precipitation took place. During wetter periods, the carbonate mud flats surrounding the lake became flooded and the lake possibly expanded to the full size of the basin.

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