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著者	INOUE　Katsuhiro, SAITO　Makoto
journal or publication title	Nichibunken Japan review : bulletin of the International Research Center for Japanese Studies
volume	8
page range	147-165
year	1997-01-01
その他の言語のタイトル	湖底堆積物の理化学的，鉱物学的および地球科学的特性より推定されるトルコ共和国コンヤ盆地の気候変動
URL	http://doi.org/10.15055/00000336

Japan Review, 1997, **8**: 147-165

CLIMATIC CHANGES IN THE KONYA BASIN, TURKEY, ESTIMATED FROM PHYSICOCHEMICAL, MINERALOGICAL, AND GEOCHEMICAL CHARACTERISTICS OF ITS LACUSTRINE SEDIMENTS

INOUE, Katsuhiro and SAITO, Makoto
Faculty of Agriculture Iwate University, Iwate, Japan

Physicochemical, mineralogical, and geochemical characteristics of 279 highly calcareous lacustrine sediment samples obtained from the upper 30 m of a 60.85 m drilling core in the western part of the Great Konya Basin, Turkey, were studied. The sediments have a predominance of silt and clay fractions with a median diameter of 3-5 μm. Vertical changes of the amounts of water soluble components, such as gypsum, carbonates, and non-salt minerals such as quartz, feldspars, and layer silicates in the sediments, suggest that there were climatic changes in the Konya Basin. The dominant clay mineral is smectite followed by kaolinite, illite, and palygorskite. The oxygen isotopic ($\delta^{18}O$) ratios of six quartz samples from the Konya sediments, a terra rossa soil beside Lake Beyşehir Gölü and paleosols at the foot of Mt. Erciyes Dağ ranged from +18.1 to +20.6‰. The dominant clay minerals and $\delta^{18}O$ ratios suggest that part of the quartz and coexisting layer silicates is of long-range transported and/or local aeolian dust origin from arid and semi-arid regions such as North Africa, Israel, and surrounding regions. The relatively high deposition rate might be due to aeolian dust input and/or the sediment input introduced by rivers such as the Çarşamba River from the Toros (Taurus) Mountains. The vertical distributions of electroconductivity, amounts of water soluble and non-salt components, and the gypsum content of the sediments suggest that gypsum-rich layers were formed under shallow, saline waters, possibly associated with warm to hot and dry environments such as the Last Interglacial epoch and the Early Holocene. The sediments characterized by relatively high amounts of non-salt sediments, in which gypsum did not accumulate, could be deeper water phases formed under the cold and/or wet environments such as the Glacial epochs. Our data suggest that climatic changes in the Mediterranean area can be partly estimated from physicochemical, mineralogical, and geochemical characteristics of the lacustrine sediments of the Konya Basin.

Key words: AEOLIAN DUST, CLIMATIC CHANGE, GYPSUM, KONYA BASIN, OXYGEN ISOTOPIC RATIO, QUARTZ.

INTRODUCTION

The Great Konya Basin in the Konya Province, Turkey, is located in the Central Anatolian Plateau at latitude 37-38°N and longitude 32-35°E and at an altitude of about 1,000 m. The Konya Basin is located in the west of the Great Konya Basin of 10,000 km^2 and it is surrounded by the Toros Mountains in the south, the Anatolides in the west and north and other high plateaus in the north. Several rivers flow into the Great Konya Basin, mainly from the south and from the west. The most important lacustrine sub-basins are the Konya, Hotamiş Karap'nar, Ereğli, and Karaman Plains.

The Quaternary history of the lake basins of central and southern Anatolia was reviewed by

Erol (1978). The physicochemical and mineralogical properties of soils and sediments and the formation and diagenesis of carbonates under the lacustrine environment in the Great Konya Basin were extensively studied by de Ridder (1965), Driessen and de Meester (1969), Driessen (1970), de Meester (1970a, 1970b, 1971), Müller *et al.* (1972), and Vergouwen (1981). Radiocarbon chronological studies of Late Pleistocene Konya Basin were also conducted by Roberts *et al.* (1979) and Roberts (1983) in relation to palaeoenvironments and palaeoclimates. However, less information is available on the vertical distributions of these properties in the lacustrine sediments from the Konya Basin in relation to climatic changes. The objectives of this study are to 1) investigate the physicochemical, mineralogical, and geochemical properties of the calcareous lacustrine sediments; 2) determine the origin of non-salt components such as quartz, layer silicates, and palygorskite, and the formation of salt minerals such as gypsum, calcite, and dolomite in the sediments; and 3) estimate climatic changes in the Konya Basin on the basis of the physicochemical, mineralogical, and geochemical characteristics of the Konya sediments.

GEOLOGY AND GEOMORPHOLOGY OF THE GREAT KONYA BASIN

The geomorphological and geological maps of the Konya Basin (Yasuda *et al.*, 1992) are shown in Figs 1 and 2, respectively. The Toros Mountains, which are located in the southern part of Turkey, consist mainly of pre-Miocene marine sediments. Alkaline intrusions of peridotite and serpentine occurred during the Upper Cretaceous. During the Oligocene epoch, the strata have been folded and in the Miocene the massif rose to its present level. The northern mountains consist of Palaeozoic limestone and schists. Andesitic and basaltic volcanoes, of various ages since the Miocene, are scattered on the edges of the Great Konya Basin, from the south-west to Niğde and Bor in the far east of the area. Numerous sulphur-rich mineral springs still occur on

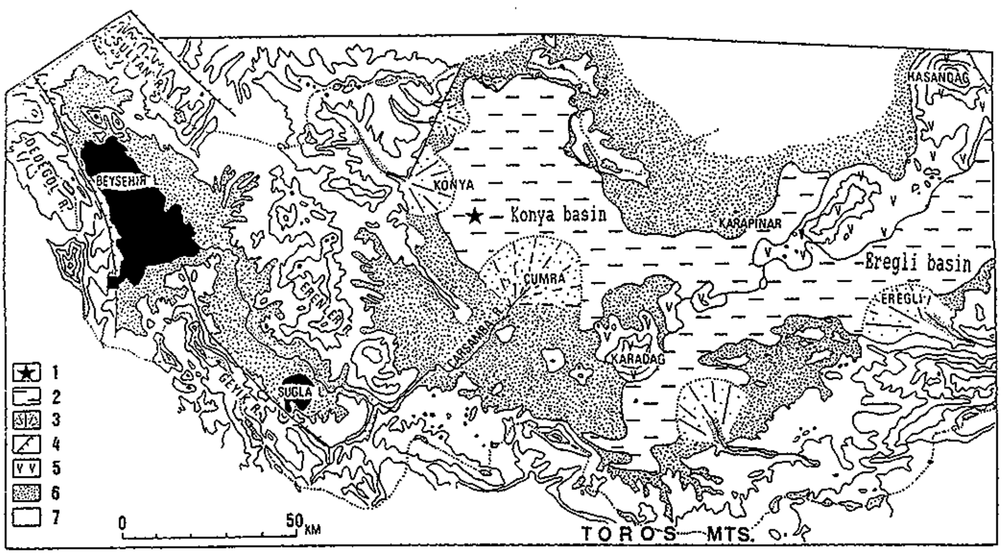

Fig. 1. Geomorphological map of the Konya Basin (Yasuda *et al.*, 1992).
1: drilling site, 2: pluvial lake surface, 3: alluvial fan, 4: fault, 5: volcano, 6: Anatolia surface, 7: mountains. A terra rossa soil was collected beside Lake Beyşehir Gölü (■).

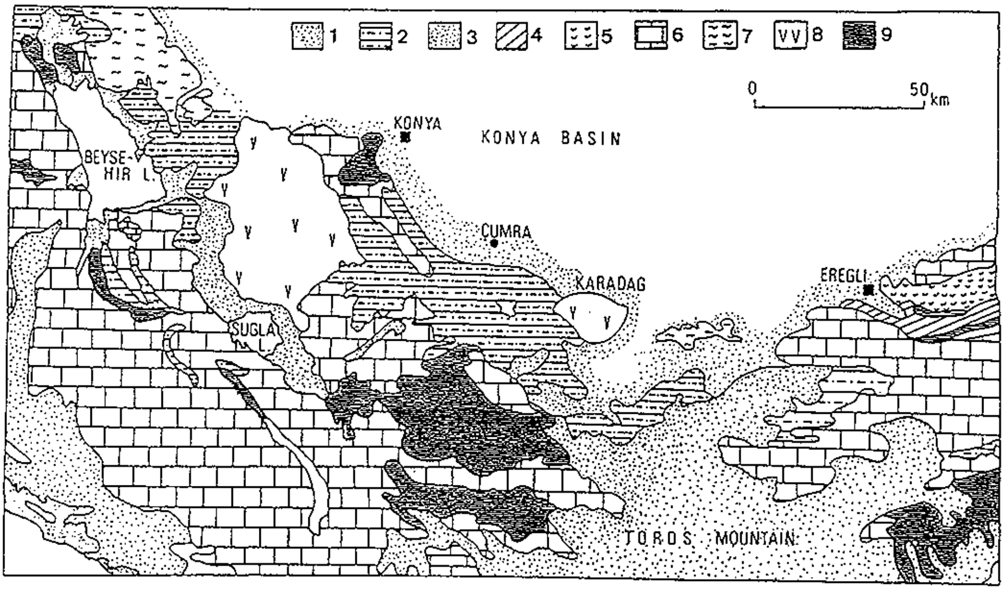

Fig. 2. Geological map of the Konya Basin (Yasuda *et al.*, 1992).
1: alluvium, 2: limestone (Neogene), 3: limestone, marly sandstone (Miocene), 4: flysch, 5: gypsum, marly limestone (Oligocene), 6: limestone (Mesozoic), 7: schist (Paleozoic), 8: andesitic basalt, 9: ultrabasic mass.

some faults. Along the fringes of the plain, Mio-Pliocene freshwater limestones are faulted with terraces on the slopes. The Great Konya Basin itself is filled by Quaternary sediments (de Meester, 1970b).

During some periods of the Late Pleistocene epoch, most of the Great Konya Basin was covered by a shallow lake with a fairly constant water level (12 to 20 m), leaving a number of sandy beach ridges and sand plains located roughly at the 1,010 m contour. On top of the soft-lime lake bottom a large variety of other sediments were deposited, resulting in various physiographic units.

De Meester (1970a, 1971b) studied the soils and produced a soil association map of the area. He divided the Great Konya Basin Plain into uplands, colluvial slopes, piedmont plains (bajadas), terraces, alluvial plains, and lacustrine plains. The uplands include part of the mountain surrounding the basin and a number of volcanoes. The colluvial slopes are the taluses of limestone or tephric material from the mountains, consisting of an unconsolidated mixture of soil materials and rock fragments accumulated at the base of the mountain slopes primarily by gravity. The terraces of flat Neogene limestone are located along the fringes of the Konya Basin. They slope gently towards the center and are locally dissected by erosion gullies. The piedmont plains found at the base of the uplands consist of the finest material carried from the uplands towards the basin by the combined action of gravity and water. This fine material is transported through small gullies dissecting the piedmont plains radially towards the center of the basin. The alluvial plains and fans comprise the sediments of some rivers debouching into the southern part of the basin. Depending on the geological and climatic conditions of their catchment areas, these rivers differ greatly in seasonal flow and in the nature of their deposits. The alluvial fans or inland deltas consist of sediments ranging from coarse sand to heavy clay texture. The lacustrine plains are flat and contain up to 900 gkg^{-1} carbonates. Deposited under water, they cover vast areas in the center of the Konya Basin. They are bordered by sandy beach ridges and shores at 1,010-1,020 m altitude formed by continual washing by the former Pleistocene lake dated from 23 to 17 ka (Roberts *et al.*, 1979; Roberts, 1983).

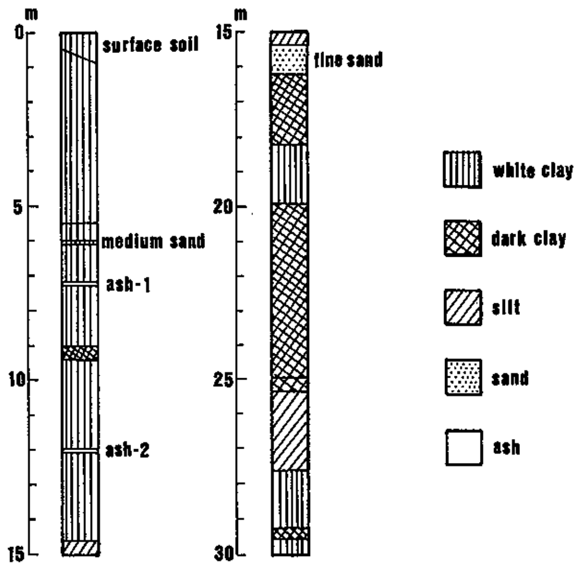

Fig. 3. A stratigraphy of the drilling core of lacustrine sediments obtained in the western part of the Konya Basin.

Rivers descending into the Konya Basin from the surrounding mountains usually disappear before reaching the center of the basin, where a perennial or annual lake is sometimes present. The groundwater level is close to the surface of the sediments. Most clastic debris is deposited in alluvial fans at the foot of the mountains. A drilling core with a thickness of 60.85 m was obtained from the lacustrine plain in the western part (37° 45' 13.3" N, 32° 43' 05.4" E) of the Konya Basin, located 18 km southeast of Konya City (Fig. 1), on October 1-10, 1991. Fig. 3 shows the stratigraphy of the upper 30 m of the drilling core. Dacitic to rhyolitic tephric materials were found in the sediments.

MATERIALS AND METHODS

1. Sediments and soils: The drilling core was cut approximately every 10 cm. Fluvial sandy sediments at 12.0-13.1 m and 15.4-16.2 m and the lower part of the core, more than 30 m in depth, were not analyzed. In total 279 samples were analyzed. First, a selection of gypsum crystals >2 mm were removed by hand. Then air-dried samples were sieved using a 2 mm screen. The gravel fractions (>2 mm) remaining on the screen were predominantly gypsum with lesser amounts of shell fragments. Soil samples were also collected from a terra rossa soil formed on Mesozoic limestone beside Lake Beyşehir Gölü (Fig. 1) and from three paleosols buried in the tephric deposits at the northern foot (1,729 m above sea-level) of Mt. Erciyes Dağ in Central Anatolia.

2. Particle size distribution: The sediments were repeatedly washed with a large amount of deionized water and sonicated. After passing through 0.2 and 0.063 mm sieves, coarse and fine sand fractions were separated and weighed. The suspensions containing the fraction <0.063 mm were adjusted to pH10 with 0.2 M NaOH and dispersed. Particle size distribution analysis was conducted using a Shimadzu Particle Analyzer SA-CP3L. The fractions of coarse sand (2-0.2 mm), fine sand (0.2-0.02 mm), silt (0.02-0.002 mm), and clay (<0.002 mm) were calculated on the basis of these data. The median diameter of the <0.063 mm fraction was also obtained by the

Shimadzu Particle Analyzer.

3. pH, electroconductivity (EC) and water-soluble components: The pH and EC were determined in the soil:water ratio of 1:2.5 with a TOA glass electrode pH meter and a TOA electroconductometer, respectively. For determination of water-soluble components, 0.50 g of each sediment was shaken with 100 mL of deionized water at 30°C for 2 h. After centrifuging at x 5,000 *g* for 10 min, the supernatants obtained were ultrafiltered by passing through 0.2 μm membrane-filter. Water-soluble bases (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were determined using a Perkin-Elmer Atomic Absorption Spectrometer 3,300. Water-soluble anions (SO_4^{2-}, Cl^-, and NO_3^-) in the supernatants were determined using a Shimadzu Ion-Chromatograph HIC-6A. Amounts of water-soluble components are given on an oven-dry basis.

4. Non-salt components: Sub-samples (2.0g) of all sediment samples except two that were rich in tephric material were treated three times with 100 mL of 1 M CH_3COONa buffer solution (pH5). After washing with copious deionized water, non-salt components of the sediments were determined gravimetrically.

5. Gypsum contents: The >2 mm fraction of the sediments was characterized by a predominance of gypsum crystals. The gypsum content in the <2 mm sediments was determined on the basis of the Ca^{2+} dissolved with deionized water. The total gypsum contents of the sediments were determined from the amounts of >2 mm gypsum crystals in the sediments and the gypsum contents in the <2 mm sediments.

6. X-ray diffraction (XRD) analyses: Sub-samples of sediments were ground in an agate mortar. The minerals were identified by XRD analysis (powder method). On the basis of the intensity of diffraction peaks, the relative amounts of quartz, feldspars, calcite, dolomite, and gypsum were determined. For clay mineral analysis, the sediments were successively treated with H_2O_2, deionized water and CH_3COONa buffer (Kunze and Dixon, 1986) and were dispersed at pH10. The clay fractions (<2 μm) collected by sedimentation and siphoning were washed with 0.5 M $MgCl_2$ or 1 M KCl solution. Mg- or K-saturated clay suspensions were mounted on glass slides and air-dried. X-ray diffractograms were obtained for parallel-oriented specimens. In order to investigate more precisely the mineralogical characteristics of the clays, Mg-clay specimens were solvated with glycerol and K-clay specimens were heated at 300 and 550°C for 1 hr. The clay mineral composition was isolated with a Rigaku X-ray Diffractometer RAD-1A using Fe-filtered Co $K\alpha$ radiation generated at 30 kV and 10 mA. Amounts of clay minerals were determined on the basis of peak areas.

7. Oxygen isotopic ratio ($\delta^{18}O$) determinations: After treatment with H_2O_2 and 6 M HCl to remove organic matter, carbonate, and iron oxides, the sediment residues were sonicated (20 kHz, 300 W, 5 min) and dispersed in alkaline medium (pH10). Size-fractionation at 1, 10, and 20 μm was done by conventional centrifugation and sedimentation techniques. The size-separates were dried and weighed. Quartz fractions of the size-separates were isolated by sodium pyrosulfate fusion, hexafluorosilicic acid and boric acid treatments (Sridhar *et al.*,1975). The oxygen of quartz samples was liberated by reaction with bromine pentafluoride and converted into CO_2 on which $^{18}O/^{16}O$ ratios are expressed as $\delta^{18}O$ notation in parts per thousand (‰) relative to Standard Mean Ocean Water (SMOW). The analytical error is less than ±0.1‰. The mean $\delta^{18}O$ value of the reference quartz sample NBS #28 was +9.65‰ during the present work.

8. Electron microscopy: Selected clay samples were treated with Na-citrate-dithionite-bicarbonate (Mehra and Jackson, 1960). For transmission electron microscopic examination, a drop of deferrated, Mg-saturated, and diluted clay suspensions was deposited on a Cu grid covered with a collodion film. The transmission electron micrographs were taken at 100 kVwith a Hitachi H-800 instrument.

RESULTS

1. Particle size distribution and median diameter

Fig. 4 shows the vertical changes of particle size distribution and median diameter of the lacustrine sediments. Except for tephra and fluvial sand layers, the non-salt sediments in the Konya Basin are characterized by a predominance of silt and clay fractions. The median diameter of the <0.063 mm fraction ranges from 3 to 5 μm for almost all of the sediments, suggesting that the non-salt sediments consist of long-range aeolian dust and/or river clays. The median diameter of the tephra from Quaternary volcanoes such as Kara Dağ, Karap'nar cone, and Hasan Dağ and

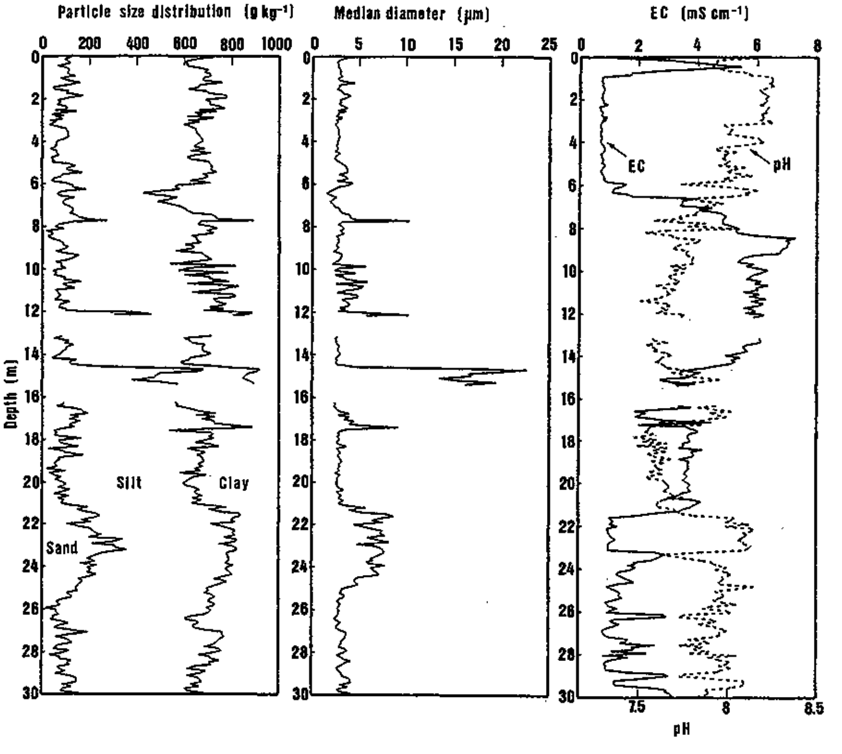

Fig. 4. Vertical changes of particle size distribution of the sediments, median diameter of <0.063 mm fraction of the sediments, pH and electroconductivity (EC) of the Konya sediments.

the fluvial sands ranged from 10 to 25 μm.

2. pH and electroconductivity

Fig. 4 also indicates the vertical changes of pH and EC values of the sediments from the Konya Basin. The pH values range from 7.5 to 8.3. Such alkaline pH values are characteristic of saline or saline-sodic soils in arid and semiarid regions and also of many freshwater lakes. The EC values are not uniform. The sediments from the layers of 0.1-0.5 and 7-15 m gave EC values greater than 4 $mScm^{-1}$ and the EC values of the sediments of 6.5-7.0, 15.0-21.5, 23.0-24.0, 26.0-26.3, 28.8-29.0, and 29.5-30.0 m ranged from approximately 2-4 $mScm^{-1}$, indicating a significant negative correlation ($r = -0.78^{***}$, $P < 0.001$) between the EC and pH values of the sediments. The EC values of the sediments are possibly related to their gypsum content.

3. Water-soluble components

Fig. 5 shows the vertical distributions of the amounts of water-soluble bases and anions in the calcareous lacustrine sediments, respectively. The amounts of water-soluble bases vary with depth. The surface soils are characterized by an accumulation of Mg^{2+} and Na^{+}. In the sediments at 1-7 m, water-soluble bases are present in small amounts. At layers deeper than 7 m, water-soluble bases were identified in the sediments from 7-15, 17-21, and 23-30 m. The abundance of water-soluble bases decreased in the order: $Ca^{2+} >> Mg^{2+} > Na^{+} >> K^{+}$, indicating that water-

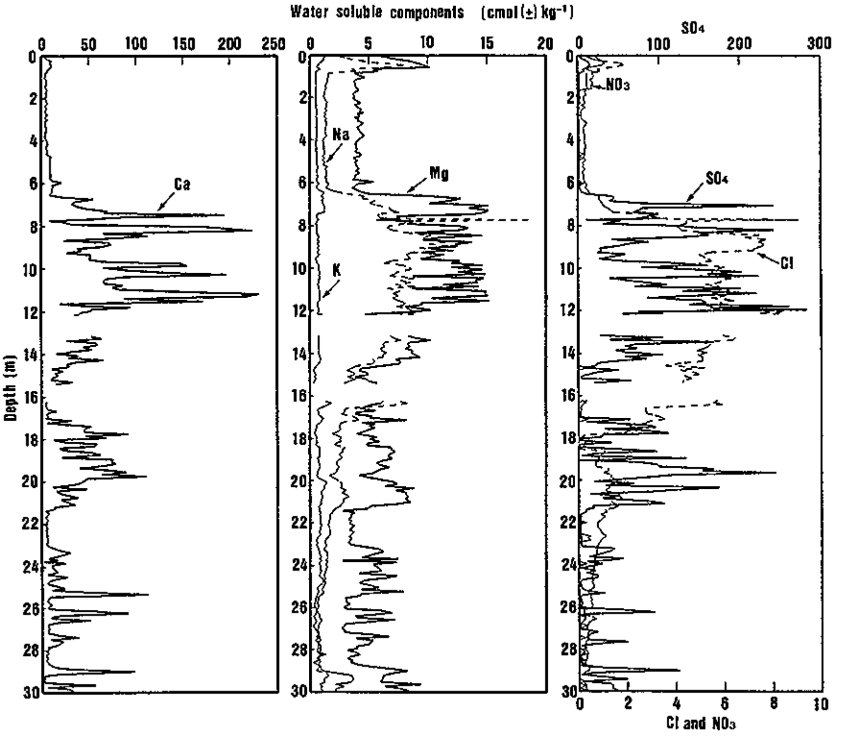

Fig. 5. Vertical changes of the amounts of water-soluble components of the Konya sediments.

soluble minerals are mainly Ca salts. Layers containing high amounts of water-soluble bases have relatively small amounts of non-salt sediments. Water-soluble anions are predominantly SO_4^{2-} followed by Cl^- and NO_3^-. Amounts of SO_4^{2-} are highly correlated with those of Ca^{2+} ($r = 0.76^{***}$, $P < 0.001$), suggesting that these ions are dissolved from gypsum.

The cations and anions that form soluble salts come from dissolved minerals as they weather. If precipitation is too low to provide leaching water (usually less than about 380 mm annually), most or all of the soluble salts remain in the soil. As water evaporates from the soil surface, the salts move towards the surface but remain within the soil. Incoming waters bring more dissolved salts. After many years of salt addition, sediments with high salt concentrations develop. Salts in other soils are currently increasing where seepage waters evaporate rather than run off.

4. Mineralogical characteristics

Fig. 6 indicates the X-ray diffractograms of two selected sediments (2.80-2.86 and 11.01-11.12 m). The X-ray diffractograms of almost all the sediments showed strong reflections of gypsum (7.67, 4.29, 3.81, 3.06, 2.87, 2.68, and 2.48 Å), calcite (3.84, 3.03, and 2.49 Å), dolomite (3.69,

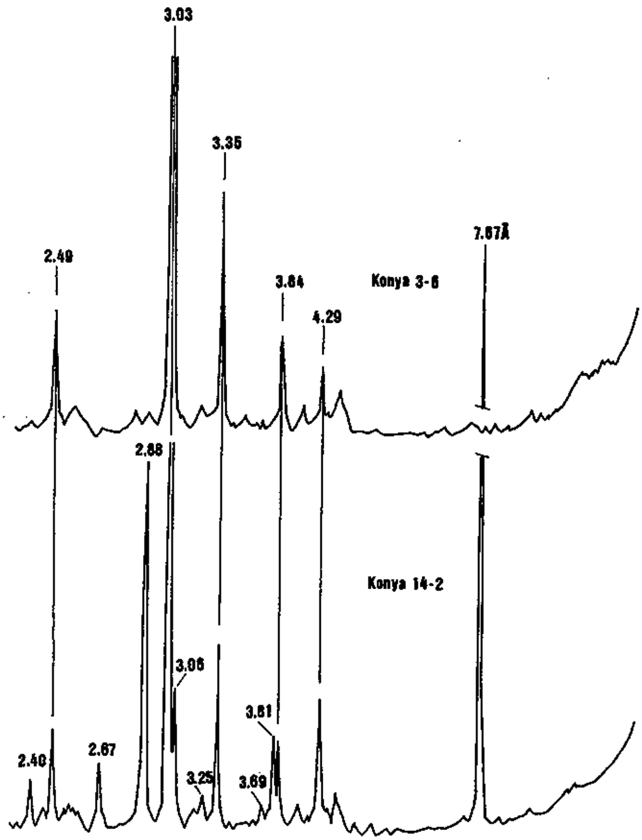

Fig. 6. X-ray diffractograms of selected lacustrine sediments (powder method). Konya 3-6 and 14-2 samples show the lacustrine sediments from 2.80-2.86 and 11.01-11.12 m, respectively.

2.88, 2.66, and 2.40 Å), quartz (4.25 and 3.35 Å) and feldspars (3.25 Å). On the basis of the intensities at 7.67 Å for gypsum, 3.03 Å for calcite, 2.88 Å for dolomite, 3.35 Å for quartz, and 3.25 Å for feldspars, the relative amounts of these minerals in the sediments are shown in Fig. 7.

The amounts of water-soluble Ca^{2+} in the <2 mm sediments (Fig. 5) were related to the amounts of gypsum crystals in the >2 mm sediments. There was a significant positive correlation between the amounts of water-soluble Ca^{2+} and the peak intensities (cps) of gypsum at 7.67 Å (r = 0.67***, P <0.001). Therefore, the water-soluble Ca^{2+} originates mainly from the <2 mm gypsum particles of the sediments. With the assumption that water-soluble Ca^{2+} is dissolved from gypsum crystals in the <2 mm sediments, the total amounts of gypsum in the sediments can be calculated (Fig. 7). Gypsum accumulation is observed in the sediments from 7-12, 13-15, 17-21, and 24-30 m and is especially evident at 7-12 m. The maximum is 288 gkg^{-1} from 8.15-8.25 m. Gypsum accumulation suggests that the sediments were deposited under shallow, saline-alkaline environments.

The peak intensities of calcite at 3.03 Å showed a significantly negative but relatively low correlation (r = -0.43***, P <0.001) to those of dolomite at 2.88 Å in the sediments. Dolomite could be formed by dolomitization from calcite under the influence of ground-water which is rich in Mg^{2+}.

Table 1 shows the amounts of quartz in nine selected samples. After treating with 6 M HCl, the 1-10 μm fractions were separated and determined by weight to lie in the range 63 to 233 gkg^{-1} of the total sediments. The 1-10 μm fractions contained 91 to 207 gkg^{-1} of quartz. The

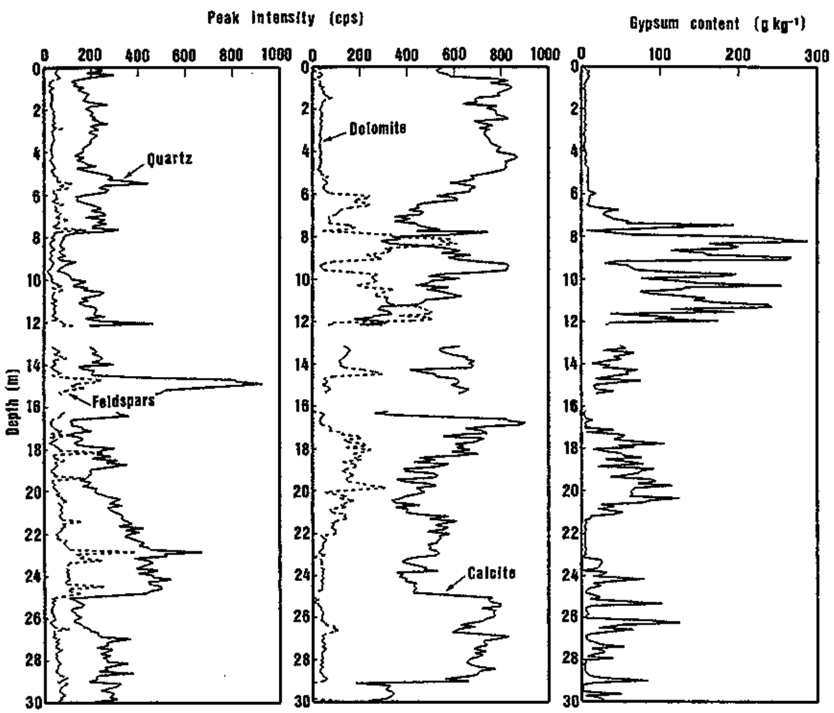

Fig. 7. Vertical changes of relative amounts of quartz, feldspars, calcite and dolomite, and the gypsum content of the Konya sediments.

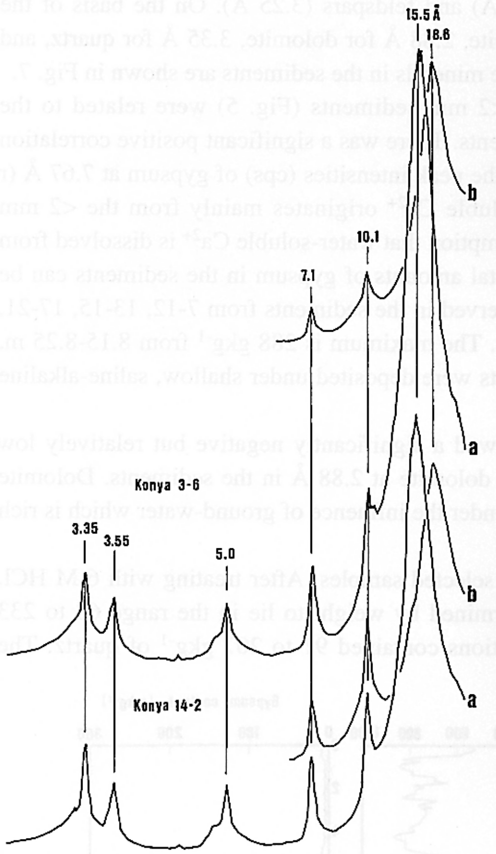

Fig. 8. X-ray diffractograms of parallel-oriented and Mg-saturated clays prepared from selected lacustrine sediments.
For sample descriptions see Figure 6. a: Mg-clay, b: glycerol-solvated Mg-clay.

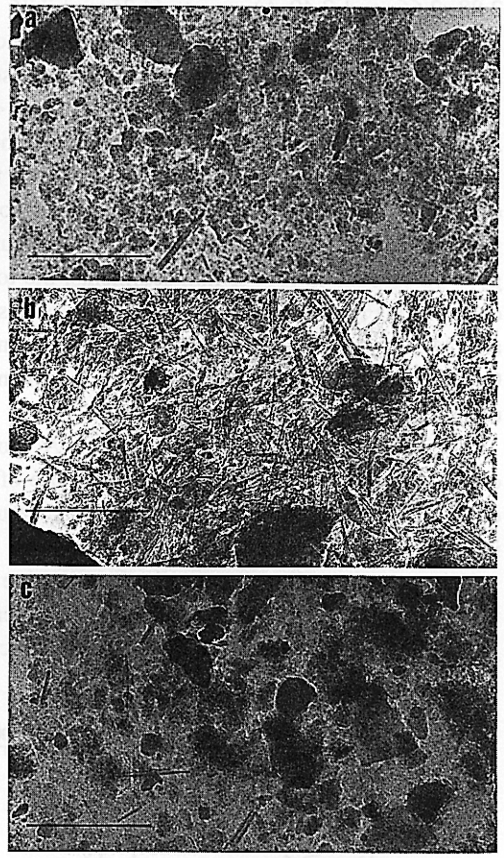

Plate 1. Transmission electron micrographs of the non-salt components of the clay fraction separated from the Konya lacustrine sediments.
a, the gypsum-poor sediment (0-0.10 m); b, the gypsum-rich sediment (8.49-8.59 m); c, the gypsum-poor sediment (22.67-22.77 m). Scale bar indicates 0.5 μm.

vertical distribution of the quartz XRD intensity was strongest in ranges 0-8, 11-17, 18-19, 20-25, and 27-30 m (Fig. 7). The significant amount of fine-grained quartz in the sediments suggests that it derives from the Çarşamba River which flows out of the Toros Mountains (de Ridder, 1965) and/or long-range aeolian dust transported from arid and semiarid regions.

After dissolution of salt-minerals with the CH_3COONa buffer solution and water, the clay mineral compositions of 60 samples, which were taken every 0.5 m from the drilling cores, were determined. X-ray diffractograms of two Mg-saturated and glycerol-solvated clay specimens showed a shift in reflection from 15.5 to 18.6 Å, indicating the predominance of smectite (Fig. 8). The clay fractions also contained significant amounts of illite (10.1 and 5.0 Å), kaolinite (7.1 and 3.55 Å), and quartz (3.35 Å). The relative amounts of these clay minerals were 800 to 880 gkg^{-1} for smectite, 50 to 110 gkg^{-1} for illite, 20 to 40 gkg^{-1} for kaolinite, and 40 to 80 gkg^{-1} for quartz. Palygorskite was also isolated by electron microscopy in the clay fractions of the

Table 1. Amounts of 1-10 μm fractions in sediment samples; quartz contents in 1-10 μm fractions; and oxygen isotopic ratios of quartz from selected Konya sediments, a terra rossa soil beside Lake Beyşehir Gölü, and paleosols buried in tephric deposits at the northern foot of Mt. Erciyes Dağ.

Sample No.	Depth (m)	Amount of 1-10 μm fraction (gkg^{-1})	Quartz content in 1-10 μm fraction (gkg^{-1})	$\delta^{18}O_{SMOW}$ (‰)
Lacustrine sediments, Konya Basin				
8-5	7.00-7.11	194	166	-
9-9	8.15-8.25	71	133	-
10-7	9.00-9.10	63	91	-
14-5	11.34-11.45	155	177	+19.8
19-3	14.40-14.50	86	207	-
25-3	18.37-18.47	179	173	-
29-1	20.30-20.40	233	143	+20.6
36-10	26.18-26.30	139	184	-
38-9	27.89-27.99	230	200	-
Terra rossa soil, Lake Beyşehir Gölü				
B-1	0-0.20	214	226	+18.7
Paleosols, Mt. Erciyes Dağ				
E-11	2.80-3.10	130	109	+18.1
E-17	4.40-4.70	101	122	+18.3
E-23	6.30-6.55	117	109	+18.3

gypsum-rich sediments. The clay fractions of the gypsum-poor sediments were, however, characterized by the predominance of smectite with a small amount of palygorskite (Plate 1).

5. Oxygen isotopic ratios

Table 1 shows the quartz contents and $\delta^{18}O$ ratios of 1-10 μm quartz fractions of two sediments from the Konya Basin, a terra rossa soil beside Lake Beyşehir Gölü, and three paleosols buried in tephric deposits in Mt. Erciyes Dağ. All samples were characterized by a significant amount of fine-grained quartz (about 90 to 230 gkg^{-1} in the 1-10 μm fractions). The $\delta^{18}O$ ratios of quartz purified from selected sediments were +19.8 and +20.6‰. Similar $\delta^{18}O$ ratios were obtained from a terra rossa soil (+18.7‰) and from paleosols (+18.1 to +18.3‰) in

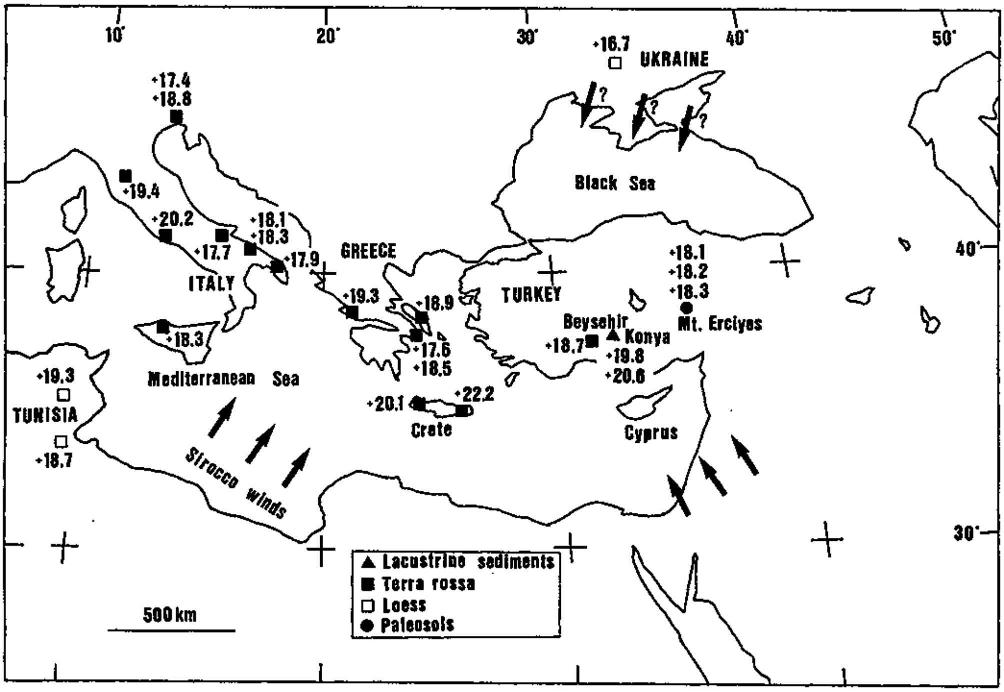

Fig. 9. Quartz oxygen isotopic ratios in the Mediterranean area.
The $\delta^{18}O$ ratios of quartz samples from terra rossa soils in Italy, Greece, and Crete and loess in Tunisia and Ukraine are cited from Jackson et al. (1982), Mizota et al. (1988; unpublished data), and Rapp and Nihlén (1991).

Turkey. These $\delta^{18}O$ ratios are near the upper critical levels of quartz of sedimentary and metamorphic rocks and are different from those of quartz in volcanic rocks.

These $\delta^{18}O$ ratios of 1-10 μm quartz are quite similar to those (+17.4 to +20.2‰) from terra rossa soils developed in Cretaceous limestones in Italy (Jackson *et al.*, 1982), Greece (Mizota *et al.*, 1988), and Crete, and in loess in Tunisia (Rapp and Nihlén, 1991). On the other hand, $\delta^{18}O$ ratios of quartz from two loess samples in the Ukraine were +16.7‰ (Mizota, unpublished data) (Fig. 9). These $\delta^{18}O$ ratios are similar to those of quartz isolated from loess in China and from loess-derived soils, sediments, and aeolian dust deposits in East Asia (Inoue and Mizota, 1988; Inoue and Naruse, 1991; Inoue *et al.*, 1993). The $\delta^{18}O$ data reveal that part of the quartz in the sediments of the Konya Basin came from long-range aeolian dust transported predominantly from arid and semiarid regions such as North Africa, Israel, and surrounding areas, rather than from the Ukraine or the South Russian plain.

DISCUSSION

1. Formation of salt-minerals

The occurrence of salt-affected sediments is dependent both on geological and climatic factors. Salt-affected sediments form easily in arid and semiarid regions where evaporation is high and exceeds rainfall. Natural salt-affected sediments preferentially occur in hydrographic closed basins.

Vergouwen (1981) proposed the genesis of salt-affected soils in closed basins such as the Great Konya Basin. Materials dissolved from the sediments and rocks are introduced by rivers, ground-waters, and springs into the Konya Basin. He also analyzed the water quality of ground-waters from the western parts of the Konya lacustrine plain. Ground-waters were characterized by high EC values and high amounts of Mg^{2+}, Na^{+}, Cl^{-}, and SO_4^{2-} followed by Ca^{2+} and HCO_3^{-}. During evaporation, the remaining solution becomes more and more concentrated until it becomes saturated with respect to some minerals, which then precipitate. Salt will accumulate where water evaporates as surface-water. For example, in the water of a temporary or permanent lake in the center of the basin, white salt rims form around the lake. Evaporation also occurs below the ground surface and minerals precipitate at different positions in the sediments depending on the Mg/Ca ratio of the water (Müller *et al.*, 1972) and the solubility of the minerals. The less soluble minerals will usually precipitate at a lower depth in the sediments than will the more soluble minerals which often accumulate in the surface layers.

The precipitation of calcite is the first step in the evolution of a brine (Eugster and Hardie, 1978). The solution becomes either carbonate-rich or carbonate-poor, depending on the ratio of Ca^{2+} to carbonate in the initial solution. The next cation which is usually removed from the solution is Mg^{2+}. In waters with intermediate $(Ca^{2+} + Mg^{2+})/(HCO_3^{-})$ ratios, more and more Mg will be incorporated in calcite as Mg^{2+} is enriched in the solution relative to Ca^{2+} as a result of calcite precipitation, until finally dolomite may be formed. Although the co-precipitation of Mg and Si finally leads to the formation of Mg-rich smectite, part of the smectite in the sediments could be derived from aeolian dust as discussed below. The second step in the evolution of brines may be the precipitation of sepiolite (Vergouwen, 1981). No sepiolite was, however, isolated in the 30 m sediments from the Konya Basin.

In such brines, the precipitation of gypsum is the third step (Vergouwen, 1981). The concentrations of Ca^{2+} and SO_4^{2-} will change in opposite directions as gypsum precipitates. Thus essentially different brines develop after the precipitation of calcite and gypsum. Subsequent evaporation and precipitation of gypsum will lower the sulphate concentration and the major constituents of the ground-water will be Na^{+}, Ca^{2+}, and Cl^{-}. The absolute Ca^{2+} concentration gradually increases during evaporation. The removal of Ca^{2+} is explained by the precipitation of calcite, which is consistent with a gradual decrease in alkalinity.

The calcite isolated through the 30 m drilling cores of the calcareous lacustrine sediments (Fig. 7) was possibly of precipitate origin. Gypsum is also present in considerable amounts in samples 7-12 and 17-21 m and small quantities were found in the surface layers (0-7 m, Fig. 6), where it is associated with the more soluble minerals. This evidence suggests that the sediments of 7-12 and 17-21 m formed in a shallow saline lake or playa and subsequent evaporation and precipitation of gypsum proceeded, possibly under hot and dry climatic conditions. As shown in Figure 10, the non-salt sediments such as the aeolian dust materials and/or the river clays were continuously deposited in the Konya Basin. Although calcite is dominant in the 0-7 m sediments, gypsum-precipitation did not occur, suggesting less saline waters and a smaller extent of evaporation.

2. Origin of quartz, palygorskite, and layer silicates

The $\delta^{18}O$ ratio of quartz is useful as a tracer to estimate the origin of the parent materials of soils and sediments (Jackson, 1981; Mizota and Inoue, 1988). The $\delta^{18}O$ ratios (Table 1) indicate that part of the quartz separated from the sediments in the Konya Basin might result from long-range aeolian dust transport, suggesting that layer silicates coexisting with quartz might also derive from aeolian dust. The prevailing north wind and the common south wind are dry; the latter comes from the arid areas of North Africa, Israel, and their surroundings and loses its burden of moisture in the Toros Mountains. The relative humidity in the Konya Basin is usually below 50%, and the basin is dusty in the dry season.

Dust plumes from Africa that move west over the Atlantic Ocean are usually more frequent and larger in size than those that move north over the Mediterranean Sea. Nevertheless, aerosol dust from Africa plays a large role in soil genesis in the Mediterranean area (Macleod, 1980; Nihlén and Solyom, 1986; Rapp and Nihlén, 1986; 1991). The major constituents isolated in continental dusts derived from soils and sediments are quartz, feldspars, calcite, dolomite, micas, kaolinite, illite, smectite, mixed-layer silicates, and palygorskite (Pye, 1987). Quartz, feldspars, and micas are virtually ubiquitous. Clay mica and quartz comprised 500 to 640 and 140 to 190 gkg^{-1}, respectively, of fine Saharan dust samples (Glaccum and Prospero, 1980). Palygorskite is the most diagnostic clay mineral in terms of the source area, since it forms mainly in alkaline arid conditions in the presence of salts and free silica, and is unstable in other diagenetic environments (Pye, 1987). The presence of palygorskite in dustfalls over Europe has been cited as partial evidence of a North African origin (Bain and Tait, 1977). North African dusts transported over the Mediterranean have a dominant kaolinite component in the clay fraction (Chester *et al.*, 1977), while those transported over the eastern Mediterranean and from Israel are rich in smectite (Yaalon and Ganor, 1973).

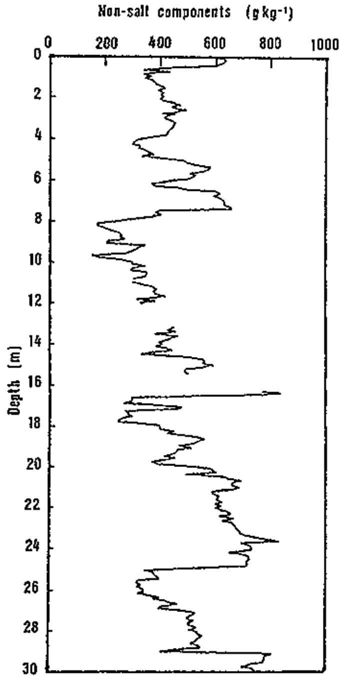

Fig. 10. Vertical distributions of the amount of non-salt components of the Konya lacustrine sediments.

The clay fractions of the sediments from the Konya Basin were characterized by the predominance of smectite followed by illite, kaolinite, and quartz. De Meester (1971) isolated palygorskite in the calcareous soils from the Great Konya Basin. Palygorskite was isolated in almost all the sediments (Plate 1). The clay mineral composition of the Konya sediments is similar to those of long-range aeolian dust in the Mediterranean and North Africa (Pye, 1987). Smectite may be formed from micas or illite under dry alkaline conditions.

The non-salt sediments, including the minerals and Palaeozoic schist fragments around the basin, might have been introduced by rivers such as the Çarşamba karstic river from the Toros Mountains. The dominant minerals of the Çarşamba River clays and the sediments near Çumra in the southern part of the basin are muscovite and illite with minor admixtures of kaolinite and traces of quartz (de Ridder, 1965). Volcanic quartz is characterized by the low $\delta^{18}O$ ratios of +5 to +10‰ (Mizota and Inoue, 1988). The particle size distribution and the median diameter of the sediments (Fig. 3) and $\delta^{18}O$ ratios of quartz in the sediments (Table 1) suggest that the non-salt components, such as quartz and layer silicates, in the Konya lacustrine sediments derive from aeolian dust transported from arid and semi-arid regions over a long distance and/or from

Çarşamba River sediments from Palaeozoic schists in the Toros Mountains.

Generally, the dust flux is higher in the last Glacial epoch than the Holocene. In the mid-latitude area of East Asia, it is estimated to be 1.4 to 2.3 cm kyr^{-1} in the Last Glacial epoch and 0.4 to 0.7 cm kyr^{-1} in the Holocene (Inoue and Naruse, 1991). On the other hand, dust fluxes are 2 to 8 cm kyr^{-1} for Israel (Yaalon and Dan, 1974) and 1.8 to 2.3 cm kyr^{-1} for the Pyrenees (Bücher and Lucas, 1975). Rapp and Nihlén (1991) estimated that the dust flux in Europe has been about 4 to 5 cm kyr^{-1} since the Last Glacial maximum.

The dust flux in the eastern Mediterranean area including Turkey is not known. Non-salt sediments for the Konya Basin range from 153 to 839 gkg^{-1} (Fig. 10) and average 469 gkg^{-1}. The sediments at 12.0-13.1 and 15.4-16.2 m depth may be fluvial sands. The average amount of non-salt components in the top 12 m lacustrine sediments was 400 gkg^{-1}. The average amounts of non-salt sediments in the 0-0.5 and 4.9-7.7 m depth were 614 and 518 gkg^{-1}, respectively, suggesting that aeolian dust could be predominantly deposited under hot and dry conditions. Non-salt sediments in the 0.5-4.9 and 7.7-12.0 m depths were 397 and 294 gkg^{-1}, respectively. Those relatively low amounts suggest a low dust flux and high water input into the basin under a cool and wet climate.

3. Climatic changes in the Konya Basin

The climate of the Konya Plain is semi-arid with cold winters, wet springs, and hot and dry summers. Since both the prevailing north wind and the common south wind are dry, the Konya Basin usually has a relative humidity below 50%. Annual precipitation is less than 300 mm. Precipitation exceeds 1,000 mm in the catchments feeding the basin, but the low precipitation in the basin and the absence of internal drainage, clearly cause salinization in the lowest part of the basin.

With the exception of very wet and saline or alkaline soils, the original Holocene vegetation of the Great Konya Basin was probably grassland with forest adjacent to rivers. At present, heavy grazing by sheep prevents regrowth and only a poor cover of drought-resistant grasses and spiny weeds are found, both on saline or alkaline soils and elsewhere. For over 50 years, parts of the basin have been irrigated. Aridity will eventually be replaced by, perhaps, a greater problem; i.e. the accumulation of soluble salts in the soil. This has indeed happened to some extent already in recent decades in the basin.

Palaeoclimates and palaeovegetations can be directly estimated by palynology. Palynological and algal analyses of two soil samples from 1-2 m in the Konya depressions showed a predominance of *Chenopodiaceae* and *Tamaricaceae* as flora and *Pediastrum* and *Botryococcus* as algae (de Meester, 1971), indicating a sedimentation under water and the flora of a saline steppe. Based on palynological studies of the sediments from Lake Beyşehir Gölü and Lake Akgöl, Turkey, Bottema and Woldring (1984) suggested that there were vegetational and climatic changes during these 15 kyr. Yasuda (1988) estimated on the basis of the palynological studies of the Çivril Marsh that the southwestern part of Turkey had a wet climate and a high water level from about 2 to 4 ka and under a dry climate and a low water level from 5 to 6.5 ka. De Meester (1971) also reported that the ^{14}C ages of two shell *(Lymnaea)* samples from the soils and ridges of the Konya depressions were approximately 11 and 12 ka. In the present study, a ^{14}C dating of humic acid purified from the Konya sediments of 6.00-6.56 m gave >40 ka. Roberts *et al.* (1979) reported that the last major phase of high lake levels in the Konya Basin occurred between 23 and 17 ka. The exact ages of the sediments remain unclear.

The vertical distributions of EC values, the amounts of water-soluble components, especially Ca^{2+} and SO_4^{2-}, and the amounts of gypsum, carbonates, and non-salt sediments (Figs. 5, 7, and 10) seem to be related to climatic changes in the Konya Basin during the time period covered by the core described here (possibly >180 ka). Evidence has been obtained of climatic changes between the northern and southern parts of the Mediterranean area, depending on intertropical convergence zone (ITC) and polar front, during the last 32 kyr (Roberts *et al.*, 1979; Roberts, 1983; Bottema and Woldring, 1984; Yasuda, 1988).

The vertical distributions of the amounts of water-soluble and non-salt components in the top 12 m sediments (Figs. 5 and 10) suggest that there were climatic changes in the Konya Basin. Low EC values and small amounts of water-soluble components suggest that the sediments were formed in deep, relatively fresh water, probably in cold and/or wet environments. The long-range and/or local aeolian dusts may be transported from arid and semiarid regions such as North Africa, Israel, and surrounding regions into the Konya Basin. Sediments with high EC values, high amounts of water-soluble bases, and high gypsum contents are probably formed under a shallow, saline lake in a warm to hot and dry climate such as the Interglacial epoch. Erol (1978) expressed doubt at the interpretation proposed by de Meester (1971) that the lake had dried out completely at the beginning of post-Pluvial times (c. 16,000 B.C.) and proposed that the Konya Basin experienced a marked dry period during the Early Holocene. Roberts *et al.* (1979) proposed that the last major phase of high lake levels in the Konya Basin occurred between 23 and 17 ka and after 17 ka during the late Glacial epoch, the basin seemed to have been largely dry. Our data suggest that the Konya Basin was under a cold and wet climate in the Glacial epochs and under a dry and hot climate in the Last Interglacial epoch and the Early Holocene.

Acknowledgements: The authors are grateful to Dr. C. Mizota, Iwate Univ. and Prof. M. Kusakabe, Okayama Univ. for the determination of $\delta^{18}O$ ratios of quartz samples and to Dr. L.P. van Reeuwijk, International Soil Reference and Information Centre, Wageningen, the Netherlands, for providing valuable references. This study was partly supported by a 1991 Grant-in-Aid for International Scientific Research (Field Research) (Yasuda no. 03041092) of the Ministry of Education, Science, Sports, and Culture of Japan and the Grant of the Sumitomo Foundation (953305-Inoue).

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湖底堆積物の理化学的，鉱物学的および地球化学的特性より推定されるトルコ共和国コンヤ盆地の気候変動

井上克弘・斉藤　真

要旨：トルコ共和国コンヤ盆地西部の30mボーリングコアから得られた石灰質湖底堆積物279点について、理化学的、鉱物学的および地球化学的特性が研究された。湖底堆積物はシルト・粘土成分に富み、中央粒径値は３～５μmであった。堆積物中の水溶性成分含量、石膏含量および石英・長石・層状ケイ酸塩鉱物のような非塩類鉱物含量の垂直変化はコンヤ盆地で気候変動があったことを示している。

堆積物の主要な粘土鉱物はスメクタイトであり、カオリナイト、イライトおよびパリゴルスカイトを伴った。コンヤ盆地の堆積物、ベイシェヒール湖岸のテラロッサ土壌およびエルシエス火山北麓の古土壌から分離した６点の微細石英の酸素同位体比（$\delta^{18}O$）は＋18.1～＋20.6‰であった。主要粘土鉱物と酸素同位体比は、石英と共存する層状ケイ酸塩鉱物の一部が北アフリカ、イスラエルおよびその周辺地域など乾燥・半乾燥地域から長距離輸送された風成塵およびローカルな風成塵由来であることを示している。湖底堆積物の比較的高い堆積速度は風成塵の供給に加えてトロス山脈からチャシャンバ川のような河川からの堆積物の付加があるためと考えられる。

堆積物の電気伝導度、水溶性成分含量、非塩類成分含量および石膏含量の垂直分布から、石膏に富む層は、恐らく最終間氷期や完新世前期のような温暖／高温・乾燥環境下において浅い塩水のもとで形成されたものと考えられる。一方、石膏が集積していないやや非塩類堆積物含量が高い層は、氷期のような寒冷・湿潤環境において深水下で形成されたと思われる。本研究結果は、コンヤ盆地の湖底堆積物の理化学的、鉱物学的および地球化学的特性から地中海地域の気候変動を部分的に予測できることを示唆している。