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Ahmet Evren ERGINAL [1*], M. Namik ÇAĞATAY [2], H. Haluk SELIM [3], Mustafa KARABIYIKOĞLU [4], Çağlar ÇAKIR [5], Nurettin YAKUPOĞLU [2], Dursun ACAR [2], Abdullah AKBAŞ [4] & Hakan KAYA [6]

MULTI-PROXY SEDIMENTARY RECORDS OF DRY-WET CLIMATE CYCLES DURING THE LAST 2 KA FROM LAKE ÇILDIR, EAST ANATOLIAN PLATEAU, TURKEY

Abstract: Erginal A.E., Çağatay M.N., Selim H.H., Karabiyikoğlu M., Çakir C., Yakupoğlu N., Acar D., Akbaş A. & Kaya H., *Multi-proxy sedimentary records of dry-wet climate cycles during the last 2 ka from lake Çildir, east Anatolian Plateau, Turkey.* (IT ISSN 0391-9838, 2019).

Multi-proxy analyses together with AMS radiocarbon dating of sedimentary organic carbon of a sediment core from Lake Çıldır, NE Turkey was carried out to study temporal changes in climate over the last two millennia. The lake is characterized by very fine to coarse silt-sized, carbonate-free sediments deposited at a relatively low sedimentation rate of less than 0.31 mm/yr. Results from element geochemistry, total organic carbon (C_{org}), and physical properties (gamma density and magnetic susceptibility results testified the occurrence of alternating cycles of drier and wetter climatic periods since about 2.2 ka cal BP. The period from 2166 ± 112 cal BP to the onset of Little Ice Age, including the Medieval Climatic Anomaly, is represented by alternation of warm and wet conditions with intervening relatively low-magnitude dry periods. The cold Little Ice Age period, on the other hand, was dry, with upward decreasing trends of Zr and Ti and C_{org} as well as relatively low values of Rb/Sr, indicating decreasing chemical weathering intensity in the drainage basin and low organic productivity in the lake. (IT ISSN 0391-9838, 2019).

Key words: Multi-proxy records, Chemical weathering intensity, Climate change, Core sediments, Lake Çıldır, NE Turkey

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INTRODUCTION

In the last two decades, several case studies concerning paleo-environmental reconstruction from lake sediments in various parts of Anatolia have provided substantial insight on the Holocene history of lake basins. Use of high resolution multi-proxy-based records from downcore analysis of lake sediments has made a prominent contribution to understanding of Holocene climatic and lake level changes. By virtue of the existence of closed-basin lakes with shallow water depth, much interest has been paid to central Anatolian lakes of various origin (Roberts & *alii*, 2001; Kashima, 2002; Jones & *alii*, 2006; Jones & *alii*, 2007; Jones & Roberts, 2008; England & *alii*,2008; Kuzucuoğlu & *alii*, 2011) in contrast to those located in northwestern (Akçer Ön & *alii*, 2011; Roeser & *alii*, 2012; Ülgen & *alii*, 2012; Ocakoğlu & *alii*, 2013, 2016) and southwestern Anatolia (Eastwood & *alii*, 2007). Recently, fairly comprehensive multi-proxy-based records have been obtained, especially from the varved sediments of Lake Van in eastern Anatolia, within the context of the ICDP drilling project "PaleoVan" (see papers in special issue of Quaternary Science Reviews, Litt & Anselmetti, 2014).

These studies based on the use of geochemical, biotic and physical proxies reconstructed the environmental and climate changes for the period spanning the last glacial-interglacial transition to the present. Stable isotope and pollen-based data, for instance, denoted relatively dry climatic conditions during early Holocene with alternating arid and humid periods in Lake Gölhisar in southwest Turkey (Eastwood & *alii*, 2007). Lithostratigraphic and biostratigraphic or diatom-based analyses of Lake Tuz revealed the onset of lake level drops at 10 ka BP, as evidenced by the presence of alluvial fan deposits that had prograded lakeward and toward the archaeological remains (Kashima, 2002). A 4700-year record of core sediments from Lake İznik in NW Turkey testified to abrupt changes towards an increase in drought frequency at 4.2 and 3.3 ka cal BP

(Ülgen & *alii*, 2012). Similar records for aridity between 6 ka and 4 ka BP were reported from Lake Tecer in Central Anatolia (Kuzucuoğlu & *alii*, 2011). High-resolution proxy records from the varved deposits of Lake Nar in central Turkey were obtained for the past 1700 years, clarifying repeated dry and wet periods in connection with North Atlantic and monsoon climate oscillations (Jones & *alii*, 2006). The paleo-ecological implications of the well-laminated sediments of this lake were recently documented by England & *alii* (2008), who presented comprehensive data for landscape changes in the period from Late Roman to the present day.

Despite the existence of several high-altitude lakes in the north-eastern part of the East Anatolian Plateau, no attempt has been made to investigate paleo-climatic records and lake level changes in the area. Since the pioneering work of Lahn (1949) concerning the origin of Lake Çıldır in this volcanic terrain, this area of high-altitude lakes has not drawn much interest with the exception of a recent study related to the heavy metal-induced ecological risks in Lake Çıldır (Kükrer & *alii*, 2014). This paper aims to discuss the temporal shifts in climate during the Late Holocene as recorded in a 68-cm long sediment core from Lake Çıldır (NE Anatolia, Turkey), using a multi-proxy approach based on geochemical (major-minor element geochemistry, Corg, $CaCO3$, petrophysical (magnetic susceptibility, gamma ray density), and sedimentological (grain-size) parameters. The core was dated using accelerator mass spectrometry (AMS) radiocarbon analysis of C_{org} in four samples, and the age model of the core was established using Bayesian statistics. Although earlier Atalay (1978) and Atalay & Koçman (1979) furnished data concerning the geomorphological characteristics and origin of the lake, the lake sediments are first addressed here with regard to climatic indicators in this volcanic highland, where the most severe winter conditions occur in all of Turkey. Since the surface waters of the lake freeze up to three months every year, sedimentation under a thick (about 70 cm) ice layer takes place at a slow rate.

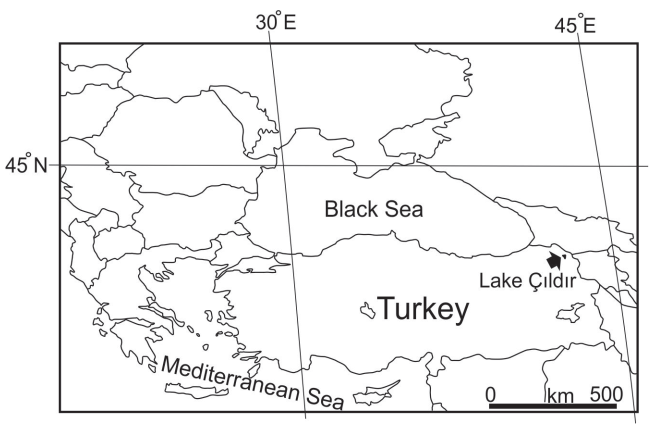

FIG. 1 - Location of study area.

MATERIALS AND METHODS

Study area

Lake Çıldır is the second largest lake in eastern Anatolia Plateau with a total surface area of 115 km^2 (fig. 1). The lake surface is 1959 m above sea level. It has an inverted triangle shape with longest and shortest dimensions of 18.3 km and 16.2 km, respectively. The lake bathymetry is barely known. Different suggestions have been made regarding its depth. Lahn (1949) was the first to study the origin of Lake Çıldır and suggested a maximum water depth up to 130 m. Atalay (1978), on the other hand, specified a maximum depth of about 42 m.

The lake is surrounded by high volcanic mountains of Mt Akbaba (3026 m) to the east and Mt Kısır (3197 m) to the west. Notwithstanding the lake occupying a tectonic corridor, an E-W-trending lava flow lying at between 2000 and 2150 m altitude separates the lake from Çıldır Plain to the north, implying that the lake could also be of volcanic origin due to the presence of a solidified lava barrier (Lahn, 1949). Excess waters of the lake are discharged along a deep (100 m) gorge to the south by a tributary of Arpaçay River that merges with the Aras River, which drains into the Caspian Sea.

Regarding climatic characteristics, the continental climate pattern of the northeast Anatolian highland of Turkey prevails in the lake area. According to data from Arpaçay Meteorological Station close to the lake area, the annual average temperature is 5.5 °C while winter temperatures may fall to below -40 °C due to the effects of the Siberian High. The area receives a total annual precipitation of 492.1 mm. Most precipitation falls during summer in consequence of convective air currents. Winter precipitation falls as snow with the duration of snow cover being at least 4 months. The lake basin is located in the Iran-Turan phytogeographic region (Atalay, 1994). Lower and upper levels of forest land are 1800 m and 2600 m, respectively. Anthropogenic steppe has a broad distribution. Although *Pinus sylvestris* is predominant, other species such as *Picea orientalis*, *Abies nordmanniana* and *Betula pendula* are also found in the forests. The grass and steppe comprise various species, such as *Achillea biebersteinii*, *Alyssum* sp., *Anthemis montana*, *Bromus japanicus*, *Campanula glomerata*, and *Centaurea depressa* (Koçman, 1990).

Bedrock geology in the environs of Lake Çıldır is made up almost completely of Plio-Quaternary volcanic rocks composed of andesite and basalt, except for marl and conglomerates of Pliocene age to the south (Lahn, 1949, Demirsu, 1954). Several previous studies were undertaken for Lake Çıldır and its surroundings (Lahn, 1949; Aktimur & *alii*, 1991; Yılmaz & Demircioğlu Yıldız, 2005). Bedrock geology in the vicinity of Lake Çıldır mainly consists of Plio-Quaternary andesitic and basaltic volcanic rocks except for Pliocene marl and conglomerates to the south (Demirsu, 1954). The Upper Miocene-Quaternary rocks are also present around Lake Çıldır (fig. 2). A volcano-sedimentary formation containing Upper Miocene-Lower Pliocene fluvial clastic rocks and andesitic lavas intercalated with the clayey, sandy, gravelly layers deposited on the Pre-Neogene basement in the north and south of the lake. Age of fluvio-lacustrine deposits with basaltic lava intercalations out cropping locally on the volcano-sedimentary formation is probably Plio-Quaternary. Thick basalt lavas of early Quaternary age cover the volcano-sedimentary formation in the west and east of lake. Geochemical analyses carried out on the volcanic rocks of the study area indicated that andesitic lavas are calc-alkaline and basaltic lavas are alkali character (Innocenti & *alii*, 1982). Structurally, as a result of increase in compression and uplifting towards the end of Late Pliocene, numerous right and left lateral strike-slip faults occurred in the region. A fast erosional period prevailed and erosional sediments were deposited in the basins. Alluvial deposits extending NE-SW consist of fine to coarse grained sediments with polygenic gravels. The gravels were derived from a rather large catchment area, mainly belonging to the Artvin-Bolnisi unit of the Eastern Pontides and Lesser Caucasus (Yılmaz & *alii*, 2000) and the local volcanic and pyroclastic rocks of Upper Miocene to Pliocene age.

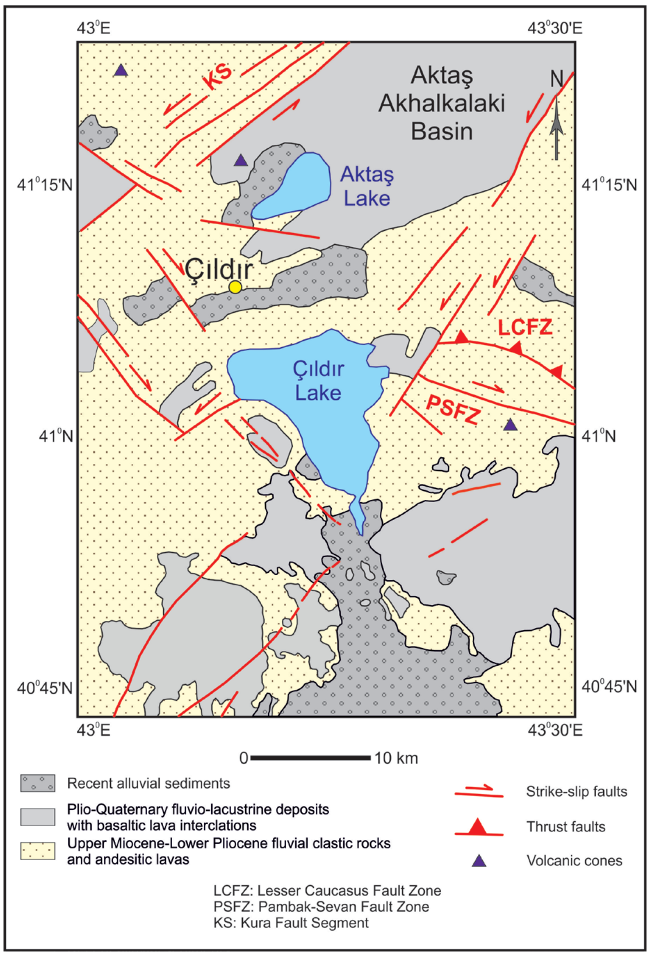

FIG. 2 - Simplified geological map of study area map (modified from Koçyiğit & *alii*, 2001).

Sampling and analyses

For the paleo-environmental study, a 68 cm-long sediment core was recovered in June 2015 from a water depth of 14 m in the central part of the lake using a Kajak Sediment Core Sampler with a 6 cm-diameter tube (fig. 1c). The core was split lengthwise into two parts. Sediment samples for dating were extracted from four different depths of 5, 10, 25 and 68 cm from one core half. The working half of the core was sampled at a continuous 1 cm spacing for $CaCO_3$, total organic carbon (C_{org}) and Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) analysis. For the analysis, samples weighing about 2 g were dried at 70 °C and then pulverized. $CaCO_3$ content was measured using a Scheibler calcimeter (Schlichting & Blume, 1996) and C_{org} by the modified Walkley-Black Titration Method (Gaudette & *alii*, 1974).

The other (archive) half of the core was used for the measurement of physical properties using a Geotek Multi Sensor Core Logger (MSCL) at EMCOL Laboratories in Istanbul Technical University, Turkey. Magnetic Susceptibility (MS) and Gamma Density (GD) on split cores were measured. For these analyses, the surface of the split sediment was cleaned, smoothed and covered by a thin plastic film (cling film) to avoid contamination. MS and GD measurements were carried out at 0.5 cm resolution.

The grain size distribution (GSD) of 18 samples was determined to evaluate possible relationships between grain-size and sediment transport and depositional dynamics. The samples were collected from different intervals. Depths of the intervals are shown in fig. 3a and b. Water treatment was performed as a dispersant agent to provide an evenly-dispersed suspension of silts and clays. All samples were measured (volume versus particle size) using a MASTER SIZER 2000 grain-size analyzer with measurement range of 0.02-2000 µm.

Fe, Ca, K, Ti, Sr, Rb and Zr concentrations were determined through the digested phase by an Inductively coupled plasma mass spectrometer (ICP-MS) in ACME Analytical Labs, Vancouver BC, Canada. The prepared samples were digested with a modified Aqua Regia solution concentrated with the mixture of HCl, HNO3 and deiyonized H_2O. Duplicate sample, method blank and internal standard reference material (STD DS10) provided by ACME Analytical Labs were considered for quality control. The results obtained from the reference sample analysis and the detection limits of the analysis are presented in tab. 1.

TABLE 1 - Reference material analyses results and detection limits of the elements.

Elements	Observed values	Expected values	Detection limits
Fe	2.81%	2.55%	0.01%
Ca	1.11%	0.98%	0,01%
K	0.34%	0.33%	0,01%
Ti	0.064%	0.070%	0.001%
Sr	68.8 ppm	58 ppm	0.5 ppm
Rb	27.4 ppm	27.4 ppm	0.1 ppm
Zr	2.3 ppm	2.4 ppm	0.1 ppm

In the absence of datable plant materials in the core, AMS radiocarbon dating of five subsamples in the sediment's bulk organic carbon fraction was performed at Beta Analytic facility, Miami, USA. All samples were washed in distilled water and dried (at 40 °C) before analysis. In order to measure the reservoir effect, we used uncalibrated ages on LC gravity core and created a penultimate model to evaluate the reservoir effect by testing top of the core which is supposedly correspond to most recent sediments. However, penultimate model calculated the top of the core as 490 yrs. Therefore, we interpreted 490 years to be the reservoir age. Four ^{14}C dates were calibrated by using the Calib v7.1 software (Stuiver & Reimer, 1993) with IntCal13.^{14}C calibration curve (Reimer & *alii*, 2004) and a reservoir age correction of 490 yr. Based on the "clam" script (Blaauw, 2010), non-bayesian statistics model, operated by R. studio was used on calibrated ages to obtain age-depth profile on the sediment core. The script generated a cubic spline age-depth model with 95% Gaussian confidence interval.

RESULTS

Lithology and grain size characteristics

Grain-size variations in lake sediments, based on recognition of sub-populations of tractive load, saltation load and suspension load within the individual arithmetic, geometric or log-normal grain size distribution, can be regarded as an effective sediment proxy in enabling important clues to evaluate changes in the processes and energy level of sediment transport and environment of deposition trough time and space, since they are sensitive to the changes of the past environmental conditions in the surrounding area (Folk & Ward, 1957; Visher, 1969; Friedman, 1979; Bui & *alii*, 1990; Pye, 1994; Shrivastava & *alii*, 2012; An & *alii*, 2012; Xiao & *alii*, 2012; Kazancı & *alii*, 2016). Coarsening-upward and/or fining upward grain-size changes recorded in lake sediments also provide important insight on the climatic and/or tectonic controls on sedimentation and lake level changes: coarse–grained sequences may represent low stands related to periods of dryer and warmer climate or tectonic activity, whereas fine-grained sequences may indicate high stands associated with periods of wet and cold climates or tectonic stability or both combinations.

This study, which is the first grain size analysis of sediments from Lake Çıldır, provided a preliminary basis for allowing a general assesment of grain size variations through 68-cm long sediment core, recovered from the shallow, open (offshore) lake bottom, and investigate sediment transport and depositional processes in relation to specific environmental changes in the study area.

The primary lithologic component of the sediments in the core was made up of homogeneous structureless dark-grey mud, predominantly consisting of fine-to coarse silt with small proportions of clay and sand. The X-ray radiography of the sedimets, however, show that the sediments are faintly laminated and have banded structure (fig. 3a), as indicated by light and dark density variations. Low-angle laminations are also noted below 20 cm core depth.

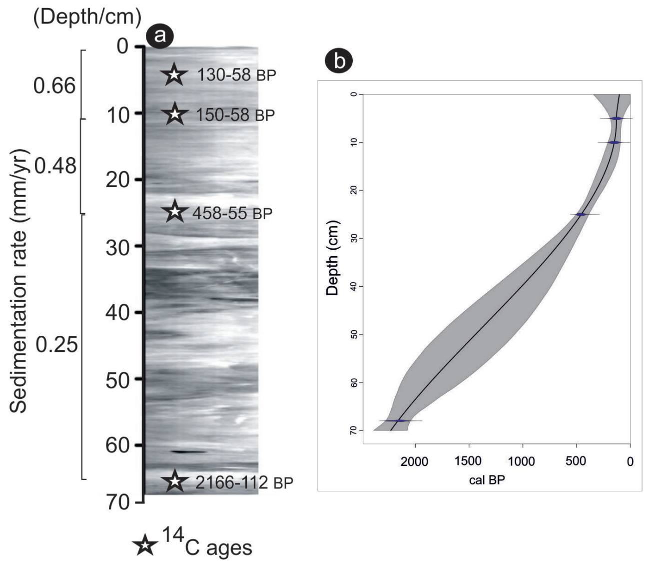

FIG. 3 - a) X-ray radiography and AMS radiocarbon ages and (b) age-depth curve obtained from LC core.

The frequency distribution curves of the 18 samples retrived from the different levels of Lake Çıldır core are shown in fig. 4(a). It is clear from the figure that the grain size distribution of the representative samples are represented by symmetric and asymmetric curves. The symmetric ones (11 samples) are characterized by narrow and fairly smooth to slightly irregular curves with moderately to sharply defined peaks, representing positive kurtosis (mesokurtic to leptokurtic) and unimodal distribution, whereas the asymmetric curves (7 samples) are characterized with minor secondary peaks and negatively- and positively-skewed (samples Ç30, Ç31. Ç38, Ç39 and Ç9, Ç,24, Ç25) curves respectively, with small volumes of finer and coarser components in the tails, indicating bimodal distribution.

In general, the range of the grain sizes in the Lake Çıldır sediments span between *ca.* 0.3 (medium clay) and 700 µm (coarse sand) and reaches maximum value with the primary modes, d (0.5), at 9 to 14 µm (medium silt). Negative- and positive-skewed bimodal samples reveal secondary modes at around fine silt and coarse silt (21 to 30 µm). However, the overall clustering of the primary modes are at 9 to 14 µm and indicates moderately- to well-sorted medium silt with minor volumes of medium clay and very fine sand representing finer and coarser tails respectively.

To compare grain size curves further in order to find similar patterns of distribution or groups, a Ward's cluster analysis, based on squared Euclidean, was employed, which enabled recognition of five sub-groups (fig. 4b). Samples from depths of 59 and 57 cm are particularly characterized by unimodal (normal) distributions with steep curves representing better-sorted central portions than the tails, whereas the samples in the other sub-groups are represented by bimodal distributions with sub-equal amounts of the two modes characterized by relatively fine to coarse-skewed curves.

A large suspension population in the samples suggests that heavily-loaded very fine to coarse silt-sized suspended sediments, along with minor amounts of clay and fine

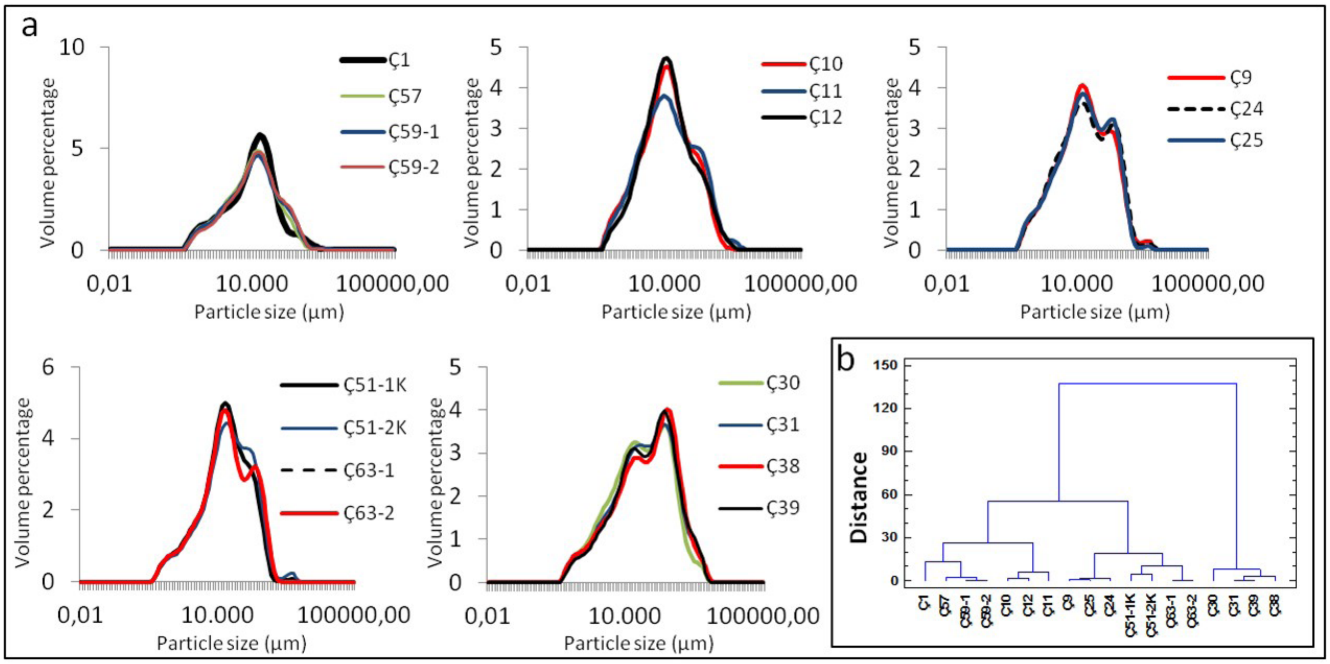

FIG. 4 - (a) The frequency distribution curves and (b) dendogram of the 18 analyzed samples based on cluster analysis. Numbers from 1 to 63 represent depths of samples in cm from top to bottom in LC core. Note that the sediment samples are represented by unimodal and bimodal grain size distributions.

sand, were carried in the transporting fluid and a rapid sedimentation rate of each bed or lamina was dominant at the depositional site. This interpretation is supported by the silt-dominated grain size distribution of the samples with unimodal to bimodal curves. The validity of this interpretation of rapid sedimentation could be challenged on the grounds that fine-grained sediments should represent a slow sedimentation in a standing, low energy lake environment. The cored sediment of the Lake Çıldır, however, is characterized by diffusely laminated to faintly cross-laminated (below 20 cm), silt-dominated sedimentation, as shown by X-ray radiography and grain size distribution, rather than pronounced rhythmic planar lamination or varved-like deposits consisting of alternating layers of fine to coarse sedimentation which are commonly regarded as characteristic features of slow, annual cycles of sedimentation in deep glacial lakes. Therefore, it seems reasonable to interpret the faintly laminated silt-dominated sediments of Lake Çıldır as having been deposited rapidly from homopycnal plumes resulting from heavily laden suspension loads transported by a small number of short headed streams, mainly fed by snow-meltwaters and rain fall during summer seasons, draining into the stagnant and relatively shallow lake environment from the small drainage basins in the suroundiing area. The presence of cross lamination below 20 cm depth may suggest current activity at the lake bottom, probably resulting from low density turbidity currents.

The bimodal grain-size distribution implies more than one transport and sedimentation process involved in deposition of the sediments. A number of alternative explanations could be advanced to explain the bimodality. The most likely reasons are: a) variation in the textural characteristics of the weathered material and/or soils in the catchment area, (b) alternating seasonal sedimentation during ice-covered winter and summer periods, c) storm originated wave reworking of the lakebottom sediments and d) deposition from wind-blown sediments.

The suspended load dominated grain size distribution of the unimodal and bimodal samples with minor grain size variation and the absence of coarsening and/or fining upward sequences in the core sediments of the Lake Çıldır may represent short term temporal variations rather than pronounced long term climatic changes in the study area. The bimodal grain-size frequency curves with secondary finer and coarser modes consisting of fine to coarse silt and sand components may imply aeolian signatures in the lake sediments.

AMS ^{14}C ages, age-depth model and sedimentation rates

AMS radiocarbon and calibrated ages measured from the sedimentary bulk organic carbon fractions are presented in tab. 2 and fig. 3. Considering that C3 terrestrial plants exhibit lower δ^{13}C values (-28 to -25‰) relative to temperate phytoplankton (-22 to -19‰) (Hedges & *alii*, 1984; Hedges & *alii*, 1997), the Lake Çıldır δ^{13}C values of bulk organic matter ranging from -24.5 to -23.5 suggest that the sedimentary bulk organic carbon is likely to be mainly of lacustrine phytoplankton origin, which is confirmed by a significantly high Pearson's correlation coefficient ($r = 0.65$, $p < 005$) between chlorophyll degradation products (CDP) and total organic carbon in core sediments (Kükrer & *alii*, 2015).

The topmost sample from 5 cm below the lake floor yields a calibrated date of 130 ± 58 yr BP (BP meaning be-

TABLE 2 - AMS radiocarbon ages obtained from bulk organic carbon fraction of LC core.

Sample no.	Lab no.	Depth (cm)	Uncalibrated age (BP)	$\delta^{13}C$ (‰PDB)	Reservoir effect	2 sigma Calibrated ages (cal BP*)
LC1	405710	5	620 ± 30	-24.2	490	130 ± 58
LC2	405711	10	740 ± 30	-24.5	490	150 ± 58
LC3	369394	25	1310 ± 30	-23.5	490	458 ± 55
LC4	369396	68	2980 ± 30	-23.9	490	2166 ± 112

fore the year 1950), suggesting a radiocarbon reservoir age for Lake Çıldır. Reservoir age effect in lakes can be due to several factor and in volcanic lake such as Cildir the most likely explanation is that volcanic CO^2 degassing from the lake floor results in a proportion of "dead" carbon incorporated in the organic fraction by photosynthetic activity, resulting in ages which are older than true. In order to calculate the reservoir effect, a penultimate age-model is made to interpolate of the topmost sediments. Even though the topmost section of the core represents the most recent sediments, penultimate model shows ~490 yr BP (BP meaning before the year 1950).

The topmost sample from 5 cm below the lake floor yields a calibrated date of 130 ± 58 yr BP. This radiocarbon reservoir age for Lake Çıldır is in conformity with the present-day through-flow nature of the lake, which has inflowing and outflowing streams. The radiocarbon age-depth curve suggests that the core bottom has an age of 2166 ± 112 yr BP (fig. 3b). The sedimentation rate averages 0.31 mm/yr and varies between 0.25 mm/yr and 0.66 mm/yr over this time span. The average sedimentation rate of 0.31 mm/yr is, for instance, lower than that in Lake Neor, which is located in a geologically and geographically similar setting in NW Iran (Kazancı & *alii*, 2016). The relatively higher sedimentation rates coincide well with wet periods, as confirmed also by the downcore distribution of MS, GD, and geochemical proxies (see discussion in section 3.3). The periods of enhanced chemical weathering marked by conspicuous peaks and alternating relatively short-term drier periods are shown in fig. 5.

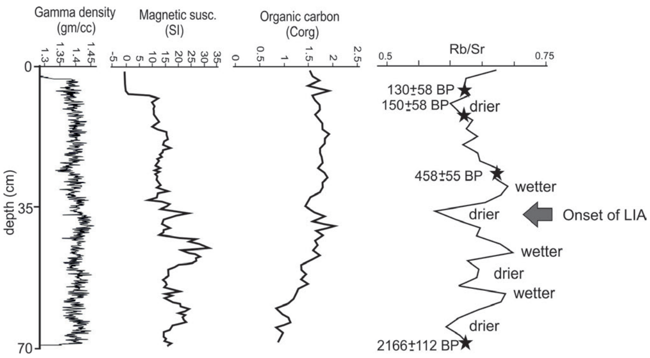

FIG. 5 - Downcore distribution of MS, GD, Corg and Rb/Sr in LC core.

Vertical distribution of paleoenvironmental proxies

Magnetic susceptibility (MS) values vary from 0 to 32.5 SI, with an average value of 15.33 SI and a high standard deviation of 7.2 SI (fig. 5). The highest values are observed between 48 and 42 cm (near 1354-1096 yr BP), corresponding to a light unit in the X-ray radiography. Other relatively high values occur between 62 and 58 cm (near 1941 and 1780 yr BP). The near zero values in the top 10 cm of the core are due to the watery, organic matter-rich nature of the mud. The maximum GD value is 1.42 g/cc, together with average and standard deviation values of 1.35 g/cc and 0.08 g/cc, respectively (fig. 5). The gamma density profile shows slightly upward decreasing values due to an increase in the porosity and water content of the mud because of the effect of compaction affecting sediments downcore. Four relatively local increases at depths of 68.5, 56, 42 and 34 cm in GD can be attributed to the higher content of coarser grains, as confirmed in lake sediments elsewhere (Chapron & *alii*, 2010).

Repeated total inorganic carbon (TIC) analyses of the lake samples show an absence of carbonate in the Lake Çıldır sediments. C_{org} content averages 1.69% and ranges between 0.82% and 2.3%, with a low standard deviation of 0.37. The downcore distribution of C_{org} shows an upward-rising tendency from the base of the core up to 43 cm core depth (near 1138 yr BP) (fig. 5). The C_{org} values remain relatively constant for the upper part of the core except for a decrease between 35 and 30 cm.

Distribution of Ca, K, Ti, Fe, Sr, Zr, K and Rb, and Rb/Sr along the Lake Çıldır core is presented in fig. 6. Ca, Sr, K, and to some extent Rb show similar trends, with relatively low values in the middle part between 36 and 16 cm (near 849-233 BP) and high values in the upper and lower parts of the core. The highest values of these elements occur at 53 cm (1570 yr BP) and 0.5 cm core depths. For statistical relationships between the studied elements, Pearson correlation coefficients were calculated (tab. 3). The strongest correlations exist between Ca and Fe, Sr and Fe, Ca and Sr, and K and Rb. A weaker but statistically significant correlation ($p < 0.05$) exists between elements Fe and K, Ca and K, and K and Sr. The dendogram obtained from cluster analysis also shows associations between Ca-Sr-Fe, K-Rb, Ti and Zr in the Lake Çıldır sediments (fig. 7).

Ti and Zr, as indicators of heavy mineral concentrations (i.e. rutile, titanomagnetite, zircon, usually in coarse silt fraction), show trends different from each other and from those of the other elements (fig. 6). Ti shows a general upward decreasing trend, whereas Zr increases from the base of the core to 43 cm (around 1138 yr BP) core depth, then decreases at 34 cm (raround 770 yr BP), followed by a general upward decrease towards the core top. A decrease in Zr at 34 cm is also observed for all the other element profiles.

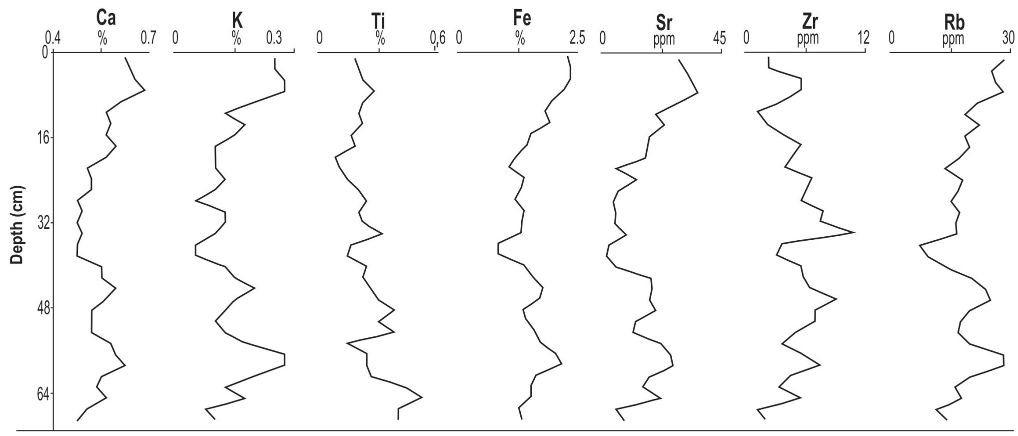

FIG. 6 - Downcore distribution of proxy elements in LC core.

DISCUSSION

Source and depositional processes of sediments

The Lake Çıldır sediments are devoid of any carbonate minerals. This, together with similar trends of carbonate-associated elements (i.e., Ca and Sr) and detrital input indicators (K, Rb and Fe), strongly suggest that Ca and Sr are associated mainly with plagioclase derived from volcanics widely exposed in the lake's drainage area. This conclusion is further supported by the high correlations of Ca and Sr with Fe (tab. 3) and cluster analyses (fig. 7). The cluster analysis also shows associations between Ca, Sr and Fe, K and Rb, and Ti and Zr in the sediments, which in turn correspond to plagioclase (Ca, Sr), mafic minerals (Fe, Ca), illite and alkali feldspar (Rb, Sr), and heavy minerals (Ti, Zr, Fe) inputs from the drainage area of the lake. The delivery of plagioclase and mafic minerals to the lake was relatively higher from 2200 yr BP until 1780 yr BP, followed by a tendency to decrease until 770 BP and of increase until the present, together with the intervening low-amplitude fluctuations. The tendency towards increase in Zr until 770 BP suggests an increased sediment input as well as slightly increased MS and Corg, followed by continual decrease until the present.

The downcore distributions of Ca, Fe, Ti, Sr, Zr, K, Rb and Rb/Sr are considered herein to infer paleoclimatic changes. Among geochemical proxies, the Rb/Sr ratio is used for providing useful information on the degree of chemical weathering in lake catchments (Jin & *alii*, 2001, 2006a, b). Since earlier studies (Dasch, 1969; Chen & *alii*, 1996), it is known that the rate of weathering of plagioclase (rich in Ca and Sr) is faster than that of alkali feldspars (rich in K and Rb), leading to a fractionation between Rb and Sr and increase in Rb-Sr ratio in the weathered detrital material (Minyuk & *alii*, 2014; Liu & *alii*, 2014) but decrease in authigenic carbonate and the bulk sediment. However, in lakes with carbonate-free sediments such as the Çıldır Lake Rb-Sr ratio increases with the weathering intensity in the catchment (see section 4.1).

Under relatively wet conditions, plagioclase would weather at a higher rate than alkali feldspar, releasing a higher amount of Sr from plagioclase than Rb released from K-feldspar. Hence, the Rb/Sr ratio of the weathered detrital matter delivered to the lake would be lower during wet (humid) periods relative to that delivered during dry periods. The dissolved Sr from the catchment is transported to the lake and commonly incorporated in the authigenic carbonate minerals (i.e., aragonite and calcite), thus resulting in a low Rb-Sr ratio of the bulk sediment. Hence, in such lakes with authigenic carbonate deposition, Rb-Sr ratio of bulk sediments is used as weathering intensity index of rocks in the drainage catchment area, with this ratio decreasing with increasing weathering intensity in the catchment under increasingly wet conditions.

The catchment area of Lake Çıldır is predominantly of Plio-Quaternary volcanic rocks (i.e., basalts and andesites) in which plagioclase is the most abundant rock-forming mineral. In the absence of carbonate minerals in Lake Çıldır sediments, however, dissolved Sr from plagioclase of the volcanic rocks is not deposited in the lake sediments but transported out of the lake with the discharge waters. Thus, the Rb-Sr ratio of the bulk sediments of Lake Çıldır depends mainly on the Rb-Sr ratio of the detrital material transported from the catchment, and should increase with increasing weathering intensity in the drainage basin. This interpretation of Rb/Sr ratio as a proxy of weathering intensity for authigenic carbonate-deficient lakes, such as Lake Çıldır, is therefore contrary to that for authigenic carbonate-bearing lakes. In Lake Çıldır sediments, the conclusion that Sr occurs mainly in the detrital mineral fraction is supported by the close similarity of its profile to those of other elements, such as K, Rb, Ti, and Zr, known to be the indicators of lithogenic detrital input (see Section 3.3).

TABLE 3 - Correlation coefficients between the specified proxy elements in LC core.

	Ca	Fe	K	Rb	Sr	Ti	Zr
Ca	1	1.00	0.40	0.23	1.00	-0.22	-0.28
Fe		1	0.40	0.23	1.00	-0.22	-0.2
K			1	0.90	0.40	0.01	0.02
Rb				1	0.23	-0.02	0.18
Sr					1	-0.22	-0.28
Ti						1	0.09
Zr							1

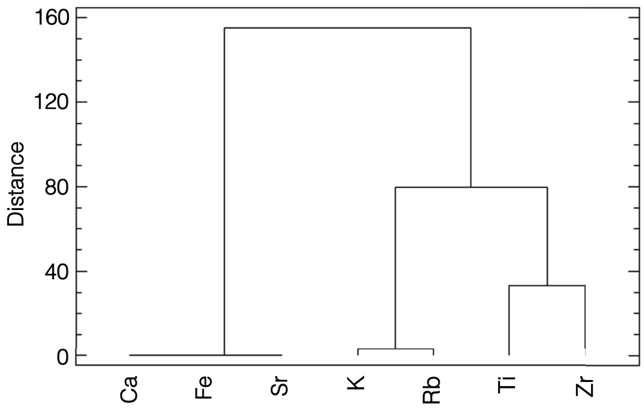

FIG. 7 - Dendogram of proxy elements in LC core based on cluster analysis.

Wet and dry climate cycles over the last 2200 years

The Rb/Sr profile of the Lake Çıldır core shows frequent variations within a range of 0.63 to 0.69, suggesting alternations of wetter and drier conditions during the dated time span (fig. 5). When the ages and Rb/Sr-defined stages are compared with previous lake archives in Anatolia, results are indicative of sequential stages of wetter and drier conditions.

It can be stated that the lowermost part of the section at 2166 ± 112 cal yr BP starts with a dry period while in general terms the region remained wet from 2000 cal yr BP to 850 cal yr BP (fig. 5), supported by the expansion of the Zelkova forests in western Georgia around 2000 yr BP (Kvavadze & Connor, 2005). This period includes alternating of two dry and three wet periods until the onset of LIA around 770 yr BP.

From bottom to top of the core, higher Rb/Sr ratios, each close to 0.7, correspond to wet intervals and are observed around 1655, 1224, and 622 yr BP, marked by relatively increased amounts of C_{org} and MS, indicating high organic productivity and detrital input (fig. 5). The wet stages are interrupted by dry periods, which are commonly characterized by low Rb/Sr values, equal to or lower than 0.6, along with a decrease in C_{org} and MS values. The first important dry period following a humid period occurred at about 2055 yr BP according to our age-depth model (fig. 3b). The second dry stage, found in the lower sections of Lake Çıldır, occurred at between 1527-1354 BP. The third drier stage took place between 1224 and 622 yr BP, including the onset of LIA. The period from 622 to 130 cal yr BP is represented by the tendency of increased drought. From 770 cal yr BP until present, the most conspicuous change occurs in the distributions of Zr and Ti, both of which displaying an upward decreasing tendency, suggesting decreasing sediment grain size. This period is represented by lower C_{org} and MS values and a decline in the Rb-Sr ratio, all of which suggesting a general increase in the aridity starting from 770 yr BP.

The relatively cold/dry period from about 650 to 130 cal yr BP coincides well with the cold/ dry Little Ice Age (LIA), with relatively low amplitude climate oscilations. This cold/ dry period is characterized by a relatively low Rb-Sr ratio in the Lake Çıldır sediments, and also previously recorded in Anatolian lakes such as Lake Nar (Jones & *alii*, 2006) and Lake Küçükçekmece (Akçer Ön & *alii*, 2011), as well as Lake Ioannina in Greece (Xoplakli & *alii*, 2001) coastal Syria (Kaniewski & *alii*, 2011) and the Aral Sea in central Asia (Sorrel & *alii*, 2007). During and after this stage, only the topmost 10 cm of the lake sediments was deposited, corresponding to a sedimentation rate of 0.66 mm/yr.

CONCLUSIONS

Multi-proxy sedimentary records, including total organic carbon (C_{org}), magnetic susceptibility (MS), gamma density (GD) and elemental composition of a core dating back to 2166 ± 112 cal BP from Lake Çıldır on the East Anatolian Plateau were obtained to reconstruct the paleoclimate of the region. The 68 cm long core includes laminated to cross laminated, very fine to coarse silt-sized sediments, deposited at a low average sedimentation rate of 0.31 mm/yr. Rb/Sr, as an indicator of differential chemical weathering of alkali and plagioclase feldspars in the lake catchment area, indicates alternation of centennial-scale wetter and drier phases with varied length of deposition times. The period spanning from about 2000 cal BP to the onset of Little Ice Age, including the Medieval Climatic Anomaly, is represented by relatively warmer and wetter conditions with low-magnitude alternations of drier periods. The LIA, which is manifested by an increasing trend aridity until about 130 cal yr BP with relatively low amplitude changes, indicated by a general upward decreasing Rb-Sr ratio, Corg, and the input of Zr and Ti, as well as a low rate of sedimentation, indicating lower inflow and reduced sediment transport.

REFERENCES

AKÇERÖN S., ÇAĞATAY M.N. & SAKINÇ M. (2011) - *Küçükçekmece lagünü çökellerinde "Küçük Buz Çağı" ve "Orta Çağ Ilık Dönemi" kayıtları [Sedimentary records of Little Ice Age and Medieval Warm Period in Küçükçekmece Lagoon]*. İTÜ Dergisi/d, 10 (4), 131-140.

AKTIMUR H.T., TEKIRLI M.E., YURDAKUL M.E., ERCAN T., KEÇER M., AKTIMUR S., ÜRGÜN B.M., GÜRBÜZ M., CAN B. & YAŞAR T. (1991) - Kars, Arpaçay ve Çıldır Dolayının Jeolojisi, MTA Rapor N. 9257 (yayımlanmamış). (Geology of Kars, Arpaçay and Çıldır, MTA Report, N. 9257, Unpublished)

AN F., MA H., WEI H. & LAI Z. (2012) - *Distinguishing Aeolian signature from lacustrine sediments of the Qaidam basin in northeastern Qinghai-Tibetan plateau and its palaeoclimatic implications*. Aeolian Research, 4, 17-30.

ATALAY İ. (1978) - Çıldı*r Gölü ve Çevresinin Jeomorfolojisi [Geomorphology of Lake Çıldır and It's Environs]*. Jeomorfoloji Dergisi, 7, 23-34.

ATALAY İ. (1994) - Türkiye Vejetasyon Coğrafyası. *[Vegetation Geography of Turkey]*. Ege Üniversitesi Yayınları, 352 s., İzmir.

ATALAY İ. & KOÇMAN A. (1979) - *Kuzeydoğu Anadolu'nun Jeotektonik ve Morfotektonik Evriminin Ana Çizgileri [Outlines of the Geotectonic and Morphotectonic Evolution of Northeast Anatolia]*. Jeomorfoloji Dergisi, 8, 41-76.

BLAAUW M. (2010) - *Methods and code for 'classical' age-modelling of radiocarbon sequences*. Quaternary Geochronology, 5, 512-518

Bui E.N., Mazullo J. & Wilding L.P. (1990) - Us*ing quartz grain size and shape analysis to distinguish between aeolian and fluvial deposits in the Dallol Bosso of Niger (West Africa).* Earth Surface Processes and Landforms, 14, 157-166.

Chapron E., Albéric P., Jézéque D., Versteeg W., Bourdier J.L. & Sitbon J. (2010) - *Multidisciplinary characterisation of sedimentary processes in a recent maar lake (Lake Pavin, French Massif Central) and implication for natural hazards*. Natural Hazards and Earth System Sciences, 10, 1815-1827.

Chen J., Wang H. & Lu H. (1996) - *Behaviours of REE and Other Trace Elements During Weathering–Evidence from Chemical Leaching of Loess and Paleosol from the Luochuan Section in Central China.* Acta Geologica Sinica, 9 (3), 290-302.

Dasch E.J. (1969) - *Strontium Isotopes in Weathering Profiles, Deep-Sea Sediments, and Sedimentary Rocks*. Geochimica Cosmochimica Acta. 33 (12), 1521-1552.

Demirsu A. (1954) - Çıldır-Posof-Şavşat-Kemalpaşa bölgesinin jeolojik etüdü hakkında mecmua. MTA Rapor No. 2377, Ankara.

Eastwood W.J., Leng M.J., Roberts N. & Davis B. (2007) - *Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey.* Journal of Quaternary Science, 22, 327-341.

England A., Eastwood W.J., Roberts C.N., Turner R. & Haldon J.F. (2008) - *Historical Landscape Change in Cappadocia (Central Turkey): A Palaeoecological Investigation of Annually-Laminated Sediments from Nar Lake.* The Holocene, 18 (8), 1229-1245.

Folk R. & Ward W.C. (1957) - *Brazos River bar: a study in the significance of grain size parameters.* Journal of Sedimentary Petrology, 27, 3-26.

Friedman G.M. (1979) - *Differences in size distributions of populations of particles among sands of various origins.* Sedimentology, 26, 3-32.

Gaudette H. E., Flight W.R., Toner L., Folger D.W. (1974) - *An inexpensive titration method for the determination of organic carbon in recent sediments*. Journal of Sedimentary Research, 44, 249-253.

Hedges J.I., Turin H.J. & Ertel J.R. (1984) - *Sources and Distributions of Sedimentary Organic Matter in the Columbia River Drainage Basin, Washington and Oregon*. Limnology and Oceanography, 29 (1), 35-36.

Hedges J.I., Keil R.G. & Benner R. (1997) - *What Happens to Terrestrial Organic Matter in the Ocean?* Organic Geochemistry, 27 (5-6), 195-212.

Innocenti F., Mazzuoli R., Pasquare G., Di Brozolo F.R. & Villari L. (1982) - *Tertiary and Quaternary Volcanism of the Erzurum–Kars Area (Eastern Turkey): Geochronological Data and Geodynamic Evolution*. Journal of Volcanology and Geothermal Research. 13 (3-4), 223-240.

Jin Z., Wang S., Shen J., Zhang E., Li F., Ji J. & Lu X. (2001) - *Chemical weathering since the Little Ice Age recorded in lake sediments: A high-resolution proxy of past climate.* Earth Surface Processes and Landforms, 26 (7), 775-782.

Jin Z., Li F., Cao J., Wang S. & Yu J. (2006a) - *Geochemistry of Daihai Lake sediments, Inner Mongolia, north China: Implications for provenance, sedimentary sorting, and catchment weathering.* Geomorphology, 80, 147-163.

Jin Z., Cao J., Wu J. & Wang S. (2006b) - *Rb/Sr Record of Catchment Weathering Response to Holocene Climate Change in Inner Mongolia.* Earth Surface Processes and Landforms, 31 (3), 285-291.

Jones M.D., Roberts C.N., Leng M.J. & Türkeş M. (2006) - *A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate.* Geology, 34, 361-364.

Jones M.D., Roberts C.N., & Leng, M.J. (2007) - *Quantifying Climatic Change Through the Last Glacial-Interglacial Transition Based on Lake Isotope Palaeohydrology from Central Turkey.* Quaternary Research, 67 (3), 463-473.

Jones M.D. & Roberts C.N. (2008) - *Interpreting Lake Isotope Records of Holocene Environmental Change in the Eastern Mediterranean*. Quaternary International, 181 (1), 32-38.

Kaniewski D., Van Campo E., Paulissen E., Weiss H., Bakker J., Rossignol I. & Van Lerberghe K. (2011) - *The medieval climate anomaly and the little Ice Age in coastal Syria inferred from pollen-derived palaeoclimatic patterns*. Global and Planetary Change, 78, 178-187.

Kashima K. (2002) - *Environmental and Climatic Changes during the Last 20,000 Years at Lake Tuz, Central Turkey.* Catena, 48 (1-2), 3-20.

Kazanci N., Gulbabazadeh T., Leroy S.A. G., Ataselim Z. & Gürbüz A. (2016) - *Aeolian Control on the Deposition of High Altitude Lacustrine Basins in the Middle East: The Case of Lake Neor, NW Iran*. Quaternary International. 408 (A), 65-77.

Koçman A. (1979) - *Physical Geography of the Upper Kura Basin, NE Anatolia.* [Dissertation]. Atatürk University, Erzurum. 1-280 (in Turkey).

Koçman A. (1990) - *Kura Nehri Yukarı Havzası'nda Doğal Bitki Toplulukları ve Yetişme Ortamı Özellikleri [Natural Plant Populations and Their Habitats in the Upper Kura Catchment Basin (NE Anatolia)].* Ege Coğrafya Dergisi, 5 (1), 46-47.

Koçyiğit A., Yilmaz A., Adamia S. & Kuloshvili S. (2001) - *Neotectonics of East Anatolian Plateau (Turkey) and Lesser Caucasus: Implication for Transition from Thrusting to Strike-Slip Faulting.* Geodinamica Acta. 14 (1-3), 177-195.

Kuzucuoğlu C., Dörfler W. & Kunesch S. (2011) - *Mid- to Late-Holocene Climate Change in Central Turkey: The Tecer Lake Record*. The Holocene, 21 (1), 173-188.

Kükrer S., Şeker S., Abaci Z.T. & Kutlu B. (2014) - *Ecological risk assessment of heavy metals in surface sediments of northern littoral zone of Lake Çıldır, Ardahan, Turkey.* Environmental Monitoring and Assessment, 186, 3847-3857.

Kükrer S., Erginal A.E., Şeker S. & Karabiyikolu M. (2015) - *Distribution and environmental risk evaluation of heavy metal in core sediments from Lake Çıldır.* Environmental Monitoring and Assessment, 187(7), 453.

Kvavadze E.V. & Connor S.E. (2005) - *Zelkova Carpinifolia (Pallas) K. Koch in Holocene Sediments of Georgia – an Indicator of Climatic Optima*. Review of Palaeobotany and Palynology, 133 (1-2), 69-89.

Lahn E. (1949) - *Çıldır Gölü ve Hazapin Gölü'nün Jeolojisi Hakkında (Kars İli) [Géologie du Çıldır Gölü et du Hazapin Gölü (Anatolie Nord)].* Türkiye Jeoloji Bülteni, 2 (1), 113-117.

Litt T. & Anselmetti F. (2014) - *Lake Van Deep Drilling Project PALEOVAN.* Quaternary Science Reviews, 104, 1-7.

Liu J., Chen J., Selvaraj K., Xu Q., Wang Z. & Chen F. (2014) - *Chemical Weathering Over the Last 1200 Years Recorded in the Sediments of Gonghai Lake, Lvliang Mountains, North China: A High-Resolution Proxy of Past Climate.* Boreas, 43 (4), 914-923.

Minyuk P.S., Borkhodoev V.Y. & Wennrich V. (2014) - *Inorganic Geochemistry Data From Lake El'gygytgyn Sediments: Marine Isotope Stages 6-11.* Climate of the Past, 10 (2), 467-485.

Ocakoğlu F., Kir O., Yilmaz I.O., Acikalin S., Erayik C., Tunoglu C. & Leroy S.A.G. (2013) - *Early to mid-Holocene lake level and temperature records from the terraces of Lake Sunnet in NW Turkey.* Palaeogeography Palaeoclimatology Palaeoecology, 369, 175-184.

Ocakoğlu F., Oybak Dönmez E. Akbulut A., Tunoğlu C., Kir O., Açikalin S., Erayik C., Yilmaz İ.Ö. & Leroy S.A.G. (2016) - *A 2800-year multi-proxy sedimentary record of climate change from Lake Çubuk (Göynük, Bolu, NW Anatolia).* The Holocene, 26 (2), 205-221.

Pye K. (1994) - *Properties of sediment particles*. In: Pye K. (Ed.) *Sediment Transport and Depositional Processes*, Blackwell, Oxford, 1-24.

Reimer P.J., Baillie M.G.L., Bard E., Bayliss A., Beck J.W., Bertrand C.J. H., Blackwell P.G., Buck Ce., Burr G.S., Cutler K.B., Damon P.E., Edwards R.L., Fairbanks R.G., Friedrich, M., Guilderson, T.P., Hogg A.G., Hughen K.A., Kromer B., Mccormac F.G., Manning S.W., Ramsey C.B., Reimer R.W., Remmele S., Southon J.R., Stuiver M., Talamo S., Taylor F.W., Van Der Plicht J. & Weyhenmeyer C.E. (2004) - *IntCal04 Terrestrial radiocarbon age calibration*, 26-0 ka BP. Radiocarbon, 46, 1029-1058.

Roberts N., Reed J.M., Leng M.J., Kuzucuoğlu C., Fontugne M., Bertaux J., Woldring H., Bottema S., Black S., Hunt E. & Karabiyikoğlu M. (2001) - *The tempo of Holocene climate change in the eastern Mediterranean region: New high-resolution crater-lake sediments data from central Turkey.* The Holocene, 11, 721-736.

Roeser P.A., Franz S.O., Litt T., Ulgen U.B., Hilgers A., Wulf S., Wennrich V., Ön S.A., Viehberg F.A., Çağatay M.N. & Melles M. (2012) - *Lithostratigraphic and geochronological framework for the paleoenvironmental reconstruction of the last 36 ka cal BP from a sediment record from Lake Iznik (NW Turkey).* Quaternary International, 274, 73-87.

Schlichting E. & Blume E. (1996) - *Bodenkundliches Practicum*. Verlag Paul Parey, Hamburg und Berlin, 209 pp.

Shrivastava P.K., Asthana R., Roy S.K., Swain A.K. & Dharwadkar A. (2012) - *Provenance and depositional environment of epi-shelf lake sediment from Schirmacher Oasis, East Antarctica, vis-a-vis scanning electron microscopy of quartz grain, size distribution and chemical parameters.* Polar Science, 6, 165-182.

Sorrel P., Popescu S.M., Klotz S., Suc J.P. & Oberhänsli H. (2007) - *Climate variability in the Aral Sea basin (Central Asia) during the Late Holocene based on vegetation changes.* Quaternary Research, 67, 357-370.

Stuiver M. & Reimer P.J. (1993) - E*xtended 14C database and revised CALIB radiocarbon calibration program*, Radiocarbon, 35, 215-230.

Ülgen U.B., Franz S.O., Biltekin D., Çağata M.N., Roeser P.A., Doner L. & Thein J. (2012) - *Climatic and environmental evolution of Lake Iznik (NW Turkey) over the last ~4700 years.* Quaternary International, 274, 88-101.

Visher G.S. (1969) - *Grain Size Distributions and Depositional Processes.* Journal of Sedimentary Petrology, 39 (3), 1074-1106.doi: 10.1306/74D71D9D-2B21-11D7-8648000102C1865D.

Xiao J., Chan Z., Fan J., Zhou L., Zhai D., Wen R. & Qin X. (2012) - *The link between grain-size components and depositional processes in a modern clastic lake.* Sedimentology, 59, 1050-1062.

Xoplakli E., Maheras P. & Luterbacher J. (2001) - *Variability of Climate in Meridional Balkans During the Periods 1675-1830 and Its Impact on Human Life.* Climatic Change, 48 (4), 581-615.

Yilmaz A., Adamia S., Chabukiani A., Chkhotua T., Erdoğan K., Tuzcu S. & Karabiyikoğlu M.F. (2000) - *Structural correlation of the southern Transcaucasus (Georgia)-eastern Pontides (Turkey).* In: Bozkurt E., Winchester J.A. & Piper J.D.A. (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society of London, Special Publications, 173, 171-182.

Yilmaz S. & Demircioğlu Yildiz N. (2005) - *Evaluation of Wetlands in the East Anatolia Region*. Journal of Applied Sciences, 5 (7), 1173-1177.

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