Invited review

Chronostratigraphy of the 600,000 year old continental record of Lake Van (Turkey)

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A B S T R A C T

Lake Van sediment cores from the Ahlat Ridge and Northern Basin drill sites of the ICDP project PALEOVAN contain a wealth of information about past environmental processes. The sedimentary sequence was dated using climatostratigraphic alignment, varve chronology, tephrostratigraphy, argon–argon single-crystal dating, radiocarbon dating, magnetostratigraphy, and cosmogenic nuclides. Based on the lithostratigraphic framework, the different age constraints are compiled and a robust and precise chronology of the 600,000 year-old Lake Van record is constructed. Proxy records of total organic carbon content and sediment color, together with the calcium/potassium-ratios and arboreal pollen percentages of the 166-m-long event-corrected Ahlat Ridge record, mimic the Greenland isotope stratotype (NGRIP). Therefore, the proxy records are systematically aligned to the onsets of interstadials reflected in the NGRIP and synthesized Greenland ice-core stratigraphy. The chronology is constructed using 49 age control points derived from visual synchronisation with the Greenland ice-core stratigraphy using the GICC05 timescale, an absolutely-dated speleothem timescale (e.g., Hulu, Sanbao, Linzhu cave) and the Epica Dome C timescale. In addition, the uppermost part of the sequence is complemented with four ages from Holocene varve chronology and three calibrated radiocarbon ages. Furthermore, nine argon–argon ages and a comparison of the relative paleointensity record of the magnetic field with reference curve PISO-1500 confirm the accuracy of the age model. Also the identification of the Laschamp event via measurements of 10Be in the sediment confirms the presented age model. The chronology of the Ahlat Ridge record is transferred to the 79-m-long event-corrected composite record from the Northern Basin and supplemented by additional radiocarbon dating on organic macro-remains. The basal age of the Northern Basin record is estimated at ~90 ka. The variations of the time series of total organic carbon content, the Ca/K ratio, and the arboreal pollen percentages illustrate that the presented chronology links ice-marine-terrestrial stratigraphies and that the paleoclimate data are suited for reconstructions and modeling of the Quaternary and Pleistocene climate evolution in the Near East at millennial timescales. Furthermore, the chronology of the last 250 ka can be used to test other dating techniques.

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1. Introduction

Lake sediments constitute valuable terrestrial archives of past environmental conditions. They are potentially continuous over several Interglacial/Glacial cycles and, ideally, varved, providing annually-resolved to seasonally-resolved records at sub-millennial timescales. An excellent example is the sedimentary sequence recovered from two sites in Lake Van (Turkey) by the PALEOVAN project of the International Continental Drilling Program (ICDP). The two drill sites, Northern Basin (NB) and Ahlat Ridge (AR) are located in the north western part of Lake Van at water depths of 245 m and 360 m (relative to present lake level at sea level), respectively. AR — the primary site — is a morphological ridge at the northern edge of the 440 m-deep Tatvan Basin. This special volume presents several multidisciplinary contributions of the PALEOVAN scientific team. The rationale for this study is to deliver and discuss a common chronology for paleoenvironmental investigations. General information about the pre-site survey are given in Litt et al. 2009 and about the project, the drilling operations and sampling party are given in Litt et al. (2012).

A robust age model is mandatory for a comprehensive temporal understanding of the environmental information in sedimentary archives. Terrestrial archives, and in particular the sediment of Lake Van, are also influenced by non-climate driven changes. Tectonic and volcanic activity causes post-depositional deformation, and results in mass-movement deposits and volcaniclastic layers (Stockhecke et al., 2014). Two major gaps occur in the composite AR record (at ~125 and ~170 mcbf, meters composite depth below lake floor) and the lowermost part of the NB record shows several unconformities. The lithostratigraphic framework (Stockhecke et al., 2014) takes all these processes into account in order to extract an event-corrected succession reflecting solely background sedimentation, and thus providing the backbone for the age model. Another characteristic lithological feature is the frequent intercalation of event deposits coinciding with each glacial termination and with the well expressed interstadials (Stockhecke et al., 2014).

The stratigraphic correlation between the PALEOVAN drill sites is used for extrapolating the AMS-14C ages of terrestrial macro-remains from the NB record to the AR record. This enables the transfer of the AR chronology to the NB record. The stratigraphic correlation with previously recovered sediment cores (Landmann et al., 1996; Lemcke, 1996; Lemcke and Sturm, 1997) offers the advantage of transposing a varve chronology for the Holocene.

The lithostratigraphic framework of both drill sites documents that: i) lake-level variations expressed by abruptly changing lithologies and total organic carbon content were controlled by global climate changes, ii) climate-sensitive proxy records can be aligned with Greenland Stadials (GS) and Interstadials (GIS) and Marine Isotope Stages (MIS) and iii) volcanic events and associated tephras frequently intercalating the background sediments are datable (\(^{40}\text{Ar/}^{39}\text{Ar single-crystal dating}\) at least back to ~330 ka (Stockhecke et al., 2014). Consequently, the terrestrial archive of Lake Van provides a unique opportunity to apply both absolute and relative dating methods to records from both drill sites. To align ice-core and terrestrial records, several proxies reflecting independent processes, such as lake productivity and catchment processes, are used in combination to enhance the fidelity of the correlations.

The marine isotope stack LR04 (Lisiecki and Raymo, 2005) covering several millions of years, provides a recognized reference for correlating marine and terrestrial records at Glacial/Interglacial timescales (Melles et al., 2012), but is of inappropriate resolution for centennial/millennial-scale comparison. The overall good agreement of Glacial/Interglacial and stadial/interstadial variability expressed in the Lake Van sedimentary proxies invites comparison with other high-resolution archives. Millennial-scale reference templates include: i) the uppermost 60 ka of the NGRIP ice cores on the GICC05 timescale (NGRIP, 2004; Steffensen et al., 2008; Svensson et al., 2008; Wolff et al., 2010) and ii) the 400 kyr-old Chinese speleothem records (Wang et al., 2008; Cheng et al., 2009). Moreover, Barker et al. (2011) constructed a 800 kyr-old synthetic record of Greenland climate variability based on the thermal bipolar seesaw model (Broecker et al., 1990). They showed that millennial-timescale variability occurred in Greenland throughout the last 800 kyr and, by tying their model to the Chinese speleothem chronology, they provide a refined absolute age scale back to ~400 ka. By choosing absolutely dated speleothems, Barker et al. (2011) set their model free from dependence on orbital cycles underlying the Epica Dome C timescales (EDC; Jouzel et al., 2007). The expressions of interstadials/stadials in the Lake Van record, combined with a reference record resolving millennial-scale variability, provide the opportunity to use climatostratigraphic alignment to date the complete ~600 kyr-old record of Lake Van. Additionally, the comprehensive catalog of dated volcanic events in eastern Anatolia back to 400 ka (~40 recognized fallout and pyroclastic flows; Sumita and Schmincke, 2013a,b,c) hold the promise of the Lake Van record becoming one of the most precise tephrostratigraphic chronologies, cross-validated using geochemical fingerprinting.

Another method to date the Lake Van sediment is based on the paleomagnetic record of relative paleointensity (RPI) variations (Vigliotti et al., this issue). Matching these data with reference templates (i.e. stacked PISO-1500 record; Channell et al., 2009) provides robust stratigraphic tie-points, especially considering that the RPI is a global geophysical (geomagnetic) signal devoid of environmental influences. A prominent RPI minimum associated with the Laschamp geomagnetic excursion, accompanied by natural remanent magnetization (NRM) directions with negative inclinations representing the directional expression of the excursion, provides an especially useful chronostratigraphic marker. The Laschamp geomagnetic excursion is well-dated radiometrically (41.3 ± 0.6 ka BP, Laj et al., 2014; 40.70 ± 0.95 ka BP, Singer et al., 2009), by astrochronology (~41 ka BP, Laj and Channell, 2007) and consistent with the pronounced peak in \(^{10}\text{Be}\) flux associated with the Laschamp event found in the NGRIP (GICC05 age of Laschamp magnetic event: 41.2 ± 1.6 ka BP, Svensson et al., 2008). It demarcates the center of Dansgaard–Oeschger event 10 (GIS-10) in Greenland isotope record (NGRIP), which is also identified in terrestrial counterparts (e.g. Hulu Cave in China, Wang et al., 2001), so that the identification of the Laschamp event provides a relative time marker, which links to ice-core stratigraphies (from Greenland and Antarctica), speleothem and paleomagnetostratigraphic records (e.g., Austin and Hibbert, 2010).

To sum up, this contribution compiles a range of relative and absolute age constraints produced by several independent methods in order to overcome the limitations and shortcomings of each single method and to establish one common chronology for the ~600 kyr-old Lake Van record. A robust and precise age model is an essential prerequisite for understanding the climate response to external forcing, for comparison of different records and data synthesis, and for resolving the successions and consequences of climate changes. Moreover, its outcome might help to improve calibration standards for other dating techniques (e.g., AMS-14C, \(^{40}\text{Ar/}^{39}\text{Ar\, dating}\), Uranium–Thorium dating of authochthonous carbonate, optical stimulated luminescence and thermoluminescence).
2. Dating methods

2.1. Event-corrected composite records and stratigraphic correlation

The lithostratigraphy of the Lake Van records distinguishes three main sediment groups: i) lacustrine clayey silt, ii) volcanioclastics and iii) coarse grained fluvial deposits. The lacustrine clayey silt group consists of eight lithologies, each reflecting different lake states along with one group (graded beds, Lg) reflecting regional events (Stockhecke et al., 2014). The event-corrected composite records of 166 m from AR, and 79 m from NB, represent only the lacustrine clayey silt without the event layers. The event-corrected records of both sites are used to construct the age model. Marker layers from the correlation of the two drill sites (Stockhecke et al., 2014) are taken to transpose ages between the drill sites.

2.2. Proxy data

Proxy records of total organic carbon content (TOC; details in Stockhecke et al., 2014, Fig. 1) also reflected in the sediment color (reflectance b*), calcium and potassium elemental ratios (Ca/K) measured by X-ray fluorescence (XRF; details in Kwiecien et al., this issue) and arboreal pollen (details in Litt et al., this issue), were used for age model construction. The TOC samples were taken at 2.5-cm increments over most of the AR composite record and at 20-cm increments over the NB composite record. Continuous 0.3-mm-resolved color reflectance data were exported from high-resolution core photographs taken with a Color Line Scan camera. XRF Core Scanner data were collected every 2 cm downcore over the whole composite profile of the AR. Arboreal pollen percentages (AP; ratio between tree and herbs) from palaeontological analysis were carried out on discrete samples collected at the same levels as those used for geochemical analysis at 20-cm increments from 0 to 60 mcblf of the AR composite record and at 1-m increments for 60–220 mcblf.

2.3. Reference timescales to align climate-sensitive proxy records

The proxy records were visually aligned to the GICC05/GICC05modeltext-based NGRIP isotopic record (0–116 ka BP; NGRIP, 2004; Steffensen et al., 2008; Svensson et al., 2008; Wolff et al., 2010) and the speleothem-based (116–400 ka BP) and
EDC3-based (400–650 ka BP) synthetic Greenland record (GLT-syn; Barker et al., 2011, Fig. 1). Instead of using one continuous but orbital-dependent EDC-timescale of lower resolution over the ~600 ka, we integrated three reference records, each with a resolution matching that of the Lake Van profile in the respective interval. This procedure involves two discontinuities at 116 ka and at 400 ka in order to link to the Lake Van record to the highest-resolved and absolutely-dated time reference templates. The absolute ages facilitate comparison with, for instance, discontinuous speleothem records from other regional archives such as Sofular cave (Fleitmann et al., 2009) or Soreq cave (Bar-Matthews et al., 1999).

### 2.4. Alignment of proxy data

The climate-sensitivity of the proxy records is reflected in their resemblance to Greenland temperature variability (Fig. 1). The NGRIP δ18O stratotype is apparently replicated in records from Lake Van. The temperature variations over Greenland are probably transmitted to Lake Van by atmospheric circulation changes controlling precipitation and the net water budget. High lake levels are apparent in warm interstadials/interglacials and low lake levels for the cold stadials/glacials (Stockhecke et al., 2014). This pattern is reflected in TOC-rich brown laminated (TOC-poor gray bioturbated or banded) sediment (Stockhecke et al., 2014) containing high (low) Ca/K intensities (Stockhecke et al., 2014; Kwicien et al., this issue; Çağatay et al., this issue). Because the interstadial onsets are reported as a consistent universal pattern (Wang et al., 2008; Cheng et al., 2009; Deplazes et al., 2013) and can be clearly identified as increases in TOC/b* and Ca/K, only the onsets were aligned to the interstadial onsets of the NGRIP δ18O record. The number of events identified is comparable to the peaks of the lower-resolution AP record, supporting synchronicity between internal lake responses and the vegetation dynamics and providing a mechanistic link for decreased input of detrital material (Ca/K) during warmer intervals when vegetation was thriving. Lead/lags between the proxy records are difficult to assess due to their differing resolutions, but the AP increase generally seems to lag behind the TOC increase. The minimal tuning approach incorporates the assumption of regular sediment accumulation rates between the age control points. For the intervals showing increased frequency of event deposits...
(terminations and pronounced interstadials), additional tie points were set. The resultant 62 age control points constitute: 56 ‘real’ tuning points, two tie points set to mark the sediment–water interface, and lacustrine sediment-fluvial deposits at the base, and four tie points to set the gaps by extrapolation.

### 2.5. Varve counting

Four marker layers allow for reliable use of four varve ages for dating of the uppermost meters of the PALEOVAN records (varve chronology by Landmann et al., 1996; Lemcke, 1996, 1997).

<table>
<thead>
<tr>
<th>Depth (mclbf)</th>
<th>Depth (mclbf-nE)</th>
<th>Age (ka BP)</th>
<th>Label</th>
<th>Age (ka BP)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>Bottom</td>
<td>Top</td>
<td>Bottom</td>
<td>From</td>
<td>To</td>
</tr>
<tr>
<td>20.06</td>
<td>21.60</td>
<td>16.28</td>
<td>17.64</td>
<td>38.8</td>
<td>43.0</td>
</tr>
<tr>
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<td>20.16</td>
<td>16.31</td>
<td>16.38</td>
<td>38.8</td>
<td>39.0</td>
</tr>
<tr>
<td>29.94</td>
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<td>24.32</td>
<td>24.53</td>
<td>63.9</td>
<td>64.6</td>
</tr>
<tr>
<td>46.41</td>
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<td>36.72</td>
<td>38.46</td>
<td>96.9</td>
<td>103.1</td>
</tr>
<tr>
<td>52.89</td>
<td>55.36</td>
<td>42.35</td>
<td>44.49</td>
<td>114.7</td>
<td>122.6</td>
</tr>
<tr>
<td>103.46</td>
<td>104.45</td>
<td>82.07</td>
<td>82.98</td>
<td>214.1</td>
<td>216.7</td>
</tr>
<tr>
<td>111.81</td>
<td>112.58</td>
<td>89.07</td>
<td>89.82</td>
<td>237.3</td>
<td>240.1</td>
</tr>
<tr>
<td>119.51</td>
<td>120.33</td>
<td>94.82</td>
<td>95.64</td>
<td>256.9</td>
<td>259.4</td>
</tr>
<tr>
<td>19.8</td>
<td>20.7</td>
<td>16.02</td>
<td>16.87</td>
<td>38.1</td>
<td>40.3</td>
</tr>
</tbody>
</table>

Fig. 3. Chronostratigraphic framework of the AR record over the last ~600 kyr. A. Lithostratigraphy (key in Fig. 4) and age/depth model for Lake Van AR event corrected composite record (mclbf-nE) with the tie points of AMS-^{14}C calibrated ages, tephrostratigraphic ages (Sumita and Schmincke, 2013c), ^40^Ar/^39^Ar ages (Stockhecke et al., 2014) and age control points derived from the correlation of Lake Van paleoclimate records to ice core ^8^18O record of NGRIP/GLT-syn (see text for references) and Lake Van paleomagnetic to PISO-1500 stack (Channell et al., 2009). The bars of the paleomagnetic points represent duration of each event as given in Table 1. Linearly regressed tie points are in red. B. Age/depth model for Lake AR composite record (mclbf). C. Mass-accumulation rates (MAR) and linear sedimentation rates (LSR) of the AR record.

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2.6. Tephrostratigraphy

Three volcaniclastic layers (V-18, V-51 and V-60; Stockhecke et al., 2014) correspond to the onshore dated ~30 ka Nemrut Formation (NF), ~60 ka Halepkalesi Pumice-10 (HP-1) and ~80 ka Incekaya-Dibeli Tephra (Sumita and Schmincke, 2013a).

2.7. $^{40}$Ar/$^{39}$Ar ages

Reliable ages of six $^{40}$Ar/$^{39}$Ar single crystal dated tephra layer from ~162 ka BP to ~531 ka BP are available for cross-evaluation (Stockhecke et al., 2014).

2.8. C14 ages

Six calibrated AMS radiocarbon ages from 0.6 to 34 ka BP derived from terrestrial macro-remains from turbidite deposits from the NB sediment cores are available ( Çağatay et al., this issue). Three of these six calibrated $^{14}$C ages are transferred to the AR record. The three lowermost ages could not be transferred unambiguously to the AR record because event deposits are intercalated with banded sediments, which are difficult to correlate between cores. The three uppermost ages were used for dating the AR record. Five calibrated $^{14}$C ages were used to date the NB record as the lithological unit II provides no other age constraints (Fig. 2). The lowermost available $^{14}$C age (for NB) are in the interval where we tune our record to the NGRIP $\delta^{18}$O record. Although it agrees well with the tuned ages, we do not use these dates in the age model for consistency.

2.9. Magnetostratigraphy

The uppermost 110 m of the event-corrected composite record of the AR core has yielded normalized NRM intensity records, by using anhysteretic remanence (ARM), after 20 and 30 mT (mT) of AF peak field demagnetization, to normalize the NRM intensity for changes in concentration of remanence carrying grains down-core. To a first approximation, the normalized NRM record represents an estimate of the relative paleointensity (RPI) of the Earth’s magnetic field (Vigliotti et al., this issue). A case can be made that the RPI record is a global signal at millennial (but probably not at centennial) timescales, and therefore provides a valuable means of correlation using the calibrated RPI template known as PISO-1500 (Channell et al., 2009). RPI minima were identified in the AR record and a comparison with PISO-1500 reference template (Table 1). Some of the RPI minima in the AR

![Fig. 4. Marine- and ice-core and synthetic isotope chronologies aligned to the Lake Van paleo-climate records. A. LR04 isotopic record (in $\delta^{18}$O VPDB) and the difference between June and December insolation at 39° N, which reflects changes in seasonality (Laskar et al., 2004) documenting the Glacial/Interglacial cycles. B. Ice-core records (NGRIP/GLT-syn, in $\delta^{18}$O VSMOW). C. Lake Van proxy time series of TOC, AP and XRF-Ca/K and the lithology. The DU (Deformed Unit) with the mass-movement deposit (MMD) on top reflects in-situ replaced sediments, which are stratigraphically disturbed but its lithological signature allows identification of the sediments at the onset of MIS11 and the TV (details see Stockhecke et al., 2014). D. Natural remanent magnetization (NRM) normalized by anhysteretic remanence (ARM) after 20 and 30 mT (mT) of AF represents an estimation of the relative paleointensity (RPI) of the earth’s magnetic field. Identified minima (a–g) are in agreement with the reference record of the PISO-1500 stack (Channell et al., 2009). The minima at ~41 ka correspond to the Laschamp excursion. Diamonds indicate the age control points given in Table 3. LL: laminated, LF: faint laminated, Lmo: mottled, Lb: banded, Lm: massive, Lg: graded beds, the combinations reflect intercalations of two or more different lithotypes.](http://dx.doi.org/10.1016/j.quascirev.2014.04.008)
record (label a in Fig. 4) correspond to the geomagnetic excursions within the Brunhes chron (Laj and Channell, 2007). Apart from the apparent identification of the Laschamp (Table 1; Vigliotti et al., this issue), the directional excursions associated with the RPI minima are not identified at Lake Van. Directional excursions are known to be brief (often <1 ka) events that are short relative to the RPI minima in which they are found. For this reason, the directional excursions are often not recorded in sedimentary sections in which the RPI fluctuations are well defined. This is apparently the case in the sediments of Lake Van where the fidelity and resolution of the paleomagnetic directional record is insufficient to record the excursions, but sufficient to yield acceptable RPI records.

2.10. \(^{10}\)Be during the Laschamp

About 60 \(^{10}\)Be samples were measured with AMS at the Laboratory of Ion Beam Physics, ETH Zürich (Lachner et al., in preparation) and reveal a Beryllium-10 flux peak in a depth range from 19.8 to 20.7 mcblf (Table 1). This interval is mostly included in the depth (20.06–21.6 mcblf) where the Laschamp event was identified as a low in the RPI record. Moreover the \(^{10}\)Be peaks are coincident with the paleomagnetic directions indicating an almost full directional change for the magnetic field. The \(^{10}\)Be signal shows the expected increase in the flux of this radioisotope to the sediment by about a factor of two. Thus both, width and dynamics of the \(^{10}\)Be signal support the proposed alignment to the NGRIP record.

2.11. Linear sedimentation and mass accumulation rates

Wet-bulk densities of the whole rounds were determined by using a Multi Sensor Core Logger (MSCL) in the field. The wet-bulk densities were used to calculate mass accumulation rates (MAR in g cm\(^{-2}\) a\(^{-1}\)) according to Niessen et al. (1992). Average TOC contents of 1.15% were used to derive the dry-bulk density (\(-0.047 \times TOC + 2.6\)) and porosity (Niessen et al., 1992).

3. Results

3.1. Chronology of the Northern Basin

The transferred tie points from the AR record and the additional \(^{14}\)C ages are shown against the event-corrected composite (mcblf-nE) and composite depth (mcblf) in Fig. 2. The age control points are given in Table 2. The constructed age model is comprised of a total of 59 tie points: two marking the top and bottom of the record, five calibrated \(^{14}\)C ages, 52 ages transposed from the AR chronology (six using varve correlation and 36 using volcaniclastic layers). The sequences covering MIS 1 and 3 are well-constrained. MIS 2 is dated by \(^{14}\)C ages, but the similarity between the banded sediment and the frequently intercalating event deposits limited the establishment of an event corrected depth scale and consequently led to overestimations of sedimentation rates (non-linearity; Stockhecke et al., 2014). The chronology of MIS 4 and 5 based on stratigraphic correlation is less robust. The linear depth/age relationship supports the constructed chronology.

3.2. Chronology of the Ahlat Ridge

The compiled ages from the different methods are shown against the event-corrected composite (mcblf-nE) and composite depth (mcblf) in Fig. 3. The age control points are given in Table 3. Ages are given in thousands of years before present (ka BP), where 0 BP is defined as 1950 AD. Marine isotope stage (MIS) boundaries follow Lisiecki and Raymo (2005) and the nomenclature of the substages follows Jouzel et al. (2007). Generally, the ages agree and reveal a linear sediment accumulation with time. The climatostatigraphic alignment between the proxy records and ice-core stratigraphy provided the best coverage on age control. The age model was constructed using the 49 tuning-based age control points, the four ages from varve chronology and three calibrated \(^{14}\)C ages (total 56, red line, Fig. 3A).

The age model of the 1st climate cycle (Fig. 1A) is based on tuning, varve chronology and \(^{14}\)C ages. It is very well constrained and broadly supported by three \(^{39}\)Ar/\(^{39}\)Ar ages (differences are between 0.4 and 1.4 kyr) and identified RPI minima, including the Laschamp excursion (Fig. 4D). The latter include an interval with reverse polarity constrained by the age model from 38.8 to 43.0 ka BP (Table 1, Vigliotti et al., this issue), within <1 ka of the generally accepted age for this magnetic excursion (41.3 ± 0.6 ka BP; Laj et al., 2014; 40.70 ± 0.95 ka BP; Singer et al., 2009). With the presented age model the \(^{10}\)Be during this excursion shows...
Table 3
Age model for ICDP PALEOVAN drill cores of the AR drill site (5034-2). Errors refer to the dating error of the original reference timescale and do not include the additional error related to climatostratigraphic alignment (n.s.: not specified).

<table>
<thead>
<tr>
<th>Depth (mcblf)</th>
<th>Depth (mcblf-nE)</th>
<th>Age (ka BP)</th>
<th>Error</th>
<th>Event</th>
<th>Timescale</th>
<th>References</th>
</tr>
</thead>
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<tr>
<td>210.7590</td>
<td>165.6867</td>
<td>595.213 n.s.</td>
<td>Extrapolation</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>206.7010</td>
<td>162.7903</td>
<td>579.000 n.s.</td>
<td>MIS15.1 GLT_syn GDC3Age Barker et al., 2011</td>
<td></td>
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</tr>
<tr>
<td>200.5660</td>
<td>156.7461</td>
<td>556.000 n.s.</td>
<td>MIS14.3 GLT_syn GDC3Age Barker et al., 2011</td>
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</tr>
<tr>
<td>195.0000</td>
<td>151.6882</td>
<td>528.000 n.s.</td>
<td>Onset MIS13.3 GLT_syn GDC3Age Barker et al., 2011</td>
<td></td>
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<tr>
<td>187.8170</td>
<td>146.1734</td>
<td>488.500 n.s.</td>
<td>Peak MIS13.1 GLT_syn GDC3Age Barker et al., 2011</td>
<td></td>
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</tr>
<tr>
<td>180.6070</td>
<td>143.0002</td>
<td>459.000 n.s.</td>
<td>Extrapolation</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>173.2130</td>
<td>139.0000</td>
<td>436.000 n.s.</td>
<td>Extrapolation</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>166.1050</td>
<td>132.0000</td>
<td>413.285 n.s.</td>
<td>Extrapolation</td>
<td>2010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Errors refer to the dating error of the original reference and do not include the additional error related to climatostratigraphic alignment (n.s.: not specified).

- a Differ from table as this tie point is more confident.
- b Mid-point.
- c Avg LSR, 0-158mcblf-nE, 0.3 mm/yr.
- d Avg LSR, 187-206mcblf-nE, 0.18 mm/yr.

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maximum fluxes for a time range between 38.1 and 40.3 ka (Table 1). An error of about 1.6 ka is given for the onset of DO 10 of the GICC05 age model (Table 2, Blockley et al., 2012). The tuned age model and independent dating are thus in good agreement. Sediment accumulation changes are documented by MAR variations and independent dating are thus in good agreement. Sediment accumulation changes are documented by MAR variations and independent dating are thus in good agreement. Note that the age model is less well constrained than the AR site and the record covers ~90 kyr. Geochemical fingerprinting of the volcanoclastic layers will allow the chronology to be improved by tephrostratigraphy. We conclude that the AR age model enables the investigation of annual- to centennial climate variability of the Holocene, centennial- to millennial scale of the Last Glacial/Interglacial cycle, and multi-millennial variability for the 2nd to 6th last climate cycles. The NB age model serves to date event deposits precisely and to establish an event catalog within a context of millennial scale climate change. The widely supported chronology of the AR record, based on a variety of independent methods, facilitates reconstructions and modeling of Quaternary climate evolution in the Near East over the past ~600 kyr. Moreover, the chronostratigraphy for the last 250 kyr provides a useful reference to test and improve other dating methods.

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