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Impacts of abrupt climate changes in the Levant from Last Glacial Dead Sea levels

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ABSTRACT

A new, detailed lake level curve for Lake Lisan (the Last Glacial Dead Sea) reveals a high frequency of abrupt fluctuations during Marine Isotope Stage 3 (MIS3) compared to the relatively high stand characterizing MIS2, and the significantly lower Holocene lake. The lake level fluctuations reflect the hydrological conditions in the large watershed of the lake, which in turn reflects the hydro-climatic conditions in the central Levant region. The new curve shows that the fluctuations coincide on millennial timescales with temperature variations recorded in Greenland. Four patterns of correlation are observed through the last ice age: (1) maximum lake elevations were reached during MIS2, the coldest interval; (2) abrupt lake level drops to the lowest elevations coincided with the occurrence of Heinrich (H) events; (3) the lake returned to higher-stand conditions along with warming in Greenland that followed H-events; (4) significant lake level fluctuations coincided with virtually every Greenland stadial–interstadial cycle.

Over glacial–interglacial time-scales, Northern Hemisphere glacial cooling induces extreme wetness in the Levant, with high lake levels reaching ∼160 m below mean sea level (mbmsl), approximately 240 m above typical Holocene levels of ∼400 mbmsl. These orbital time-scale shifts are driven by expansions of the European ice sheet, which deflect westerly storm tracks southward to the Eastern Mediterranean, resulting in increased sea-air temperature gradients that invoke increased cyclogenesis, and enhanced moisture delivery to the Levant. The millennial-scale lake level drops associated with Greenland stadials are most extreme during Heinrich stadials and reflect abrupt cooling of the Eastern Mediterranean atmosphere and sea-surface, which weaken the cyclogenic rain engine and cause extreme Levant droughts. During the recovery from the effect of Heinrich stadials, the regional climate configuration resumed typical glacial conditions, with enhanced Levant precipitation and a rise in Lake Lisan levels. Similar cyclicity in the transfer of moisture to the Levant affected lake levels during all of the non-Heinrich stadial–interstadial cycles.

1. Introduction

The last ice age was characterized by expansion of continental ice sheets and changes in ocean and atmosphere circulation patterns and strength relative to the present day, which are well documented in polar ice and marine records, including millennial-scale warmings and coolings (Dansgaard et al., 1993; Alley and Clark, 1999; Bard et al., 2000; Blunier and Brook, 2001; Wang et al., 2001; EPICA, 2006; Kawamura et al., 2007; Anderson et al., 2009). Middle- and low-latitude continental climate archives such as lake deposits, however, are more likely to be non-continuous compared to polar ice and marine sediments, and are usually more difficult to date and interpret (Quade and Broecker, 2009 and references therein).

The composition, structure and lake level history of the hypersaline terminal lakes that filled the tectonic depression of the Dead Sea basin (***DSB***; Fig. 1), the lowest elevation on Earth's surface, are sensitive to latitudinal shifts in the location of the boundary between the low-latitude Sahara-Arabia desert belt and the more temperate European-Mediterranean climate belt. Hence, the volumes of the lakes, as well as the geochemical and sedimentological properties of sediments deposited in them, reflect regional shifts of the climate zones, rendering the lake sediments as exceptional recorders of regional precipitation history (Begin et al., 1974; Katz et al., 1977; Stein, 2001; Bartov et al., 2003; Enzel et al., 2003; Kushnir and Stein, 2010; Waldmann et al., 2010). Climate changes

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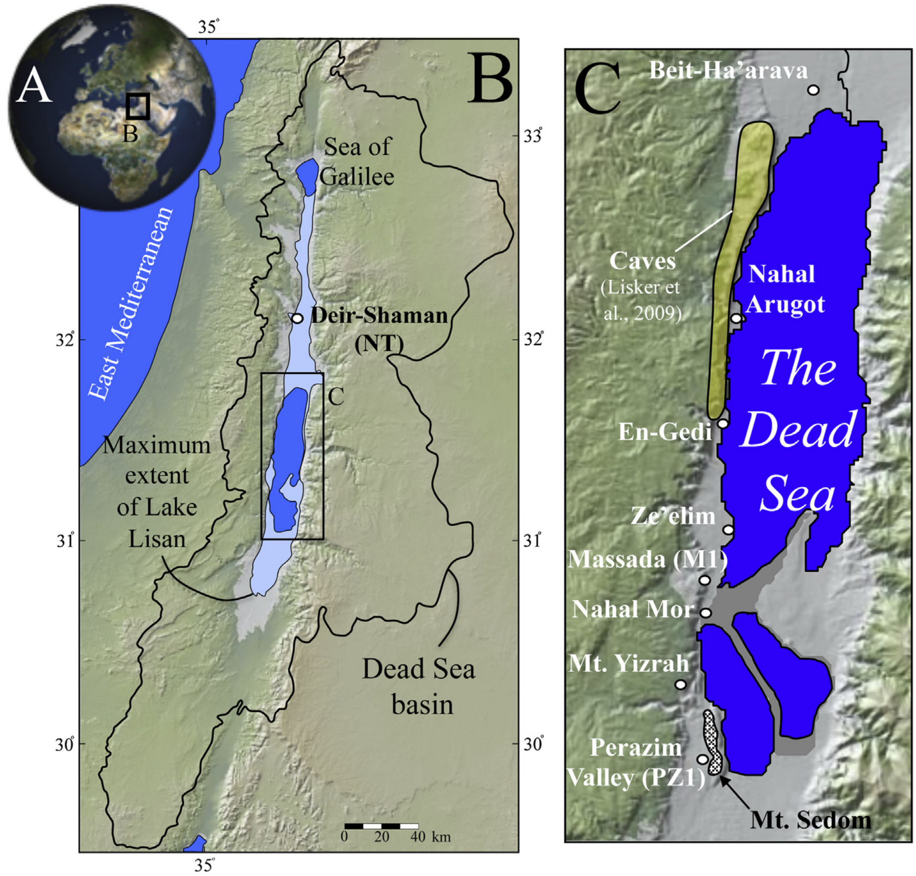

Fig. 1. Location map. Light blue area in (B) marks maximum extent of Lake Lisan at ∼26 ka. Exact locations of caves northwest of the Dead Sea (bright yellow patch in C) are detailed in Lisker et al. (2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

have been invoked as a primary control on the rise and collapse of early human cultures (e.g., DeMenocal, 2001) and projections of more arid future climate (e.g., Held and Soden, 2006) are expected to have significant effect on this region with potentially critical geopolitical implications (e.g., Allan, 2001).

Here, we present a new, high-resolution Lake Lisan level curve through the Last Glacial period. While generating high-resolution chronologies is a major challenge in lacustrine environments, because they generally have limited well-dated exposed shoreline indicators, the steep boundaries along the modern Dead Sea expose well-preserved Lake Lisan stratigraphic sections that contain pristine primary aragonite, offering the possibility to obtain a high-resolution calendar chronology through U–Th and radiocarbon dating (Fig. S1; Haase-Schramm et al., 2004; Torfstein et al., 2013). Integration of such chronologies with dated beach terraces and buried beach deposits, and ages of cave deposits preserved at high elevations in the DSB, that constrain the timing of some high-stands (Lisker et al., 2009), uniquely allows for the reconstruction of the high-resolution lake level curve reported here (a detailed description of the integration between lacustrine and cave chronologies, and lake level indicators is included in the Supplementary material).

2. The Lisan Formation

The Lisan Formation comprises sediment sequences that were deposited in Lake Lisan, which occupied the tectonic depressions of the Dead Sea basin and Jordan Valley during the Last Glacial period (Zak, 1967; Begin et al., 1974). High-stand stages in Lake Lisan are characterized by the precipitation of annual couplets of alternating aragonite-detritus (***aad***) laminae, whereby the aragonite laminae are primary lake precipitates and the detritus laminae represent fine clastic input during winter storms (Begin et al., 1974; Stein et al., 1997) (Fig. S1). Additional gypsum and clastic layers, and in extreme cases halite units, reflect increasingly arid climate and lake low-stand conditions. The Lisan Formation type section in the Perazim Valley (the "***PZ1***" section; Marco, 1996; Machlus et al., 2000; Figs. 1, 2A and S1) is divided into three stratigraphic units (Machlus et al., 2000). The Lower and Upper Members (70–58.5 and 31–14.5 ka, respectively) are dominated by thick *aad* sequences, whereas the Middle Member (58.5–31 ka) is characterized by repeated alternations between gypsum, laminated silty detritus, sands and *aad* sequences, and is disrupted by a hiatus, all of which reflect significant lake level oscillations.

3. Lake Lisan water level curve

The ages of the boundaries between the three stratigraphic units are consistent with the transitions between Marine Isotope Stages (***MIS***) 4, 3 and 2 (Fig. 2), highlighting the responsiveness of the DSB watershed hydrology to global climate changes. The changes in the watershed hydrology are reflected in the lake level curve (Figs. 2B and S2), whereby interglacials are characterized by lower levels (e.g., the Holocene Dead Sea at ∼430–370 mbmsl), and ice ages by higher levels. In Lake Lisan, the highest stand of ∼160 mbmsl was reached ca 26 ka, during the coldest stage of the Last Glacial cycle, MIS2. Following the MIS2 high-stand, the lake level commenced its final retreat, which was punctuated by several short-term lake level drops at ∼24, 17.1–15.5 and ∼14.5–14 ka. Compared with the relatively stable high-stand conditions of ∼180 ± 20 mbmsl