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Dead Sea drawdown and monsoonal impacts in the Levant during the last interglacial

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ABSTRACT

Sediment cores recovered by the Dead Sea Deep Drilling Project (*DSDDP*) from the deepest basin of the hypersaline, terminal Dead Sea (lake floor at ∼725 m below mean sea level) reveal the detailed climate history of the lake's watershed during the last interglacial period (Marine Isotope Stage 5; MIS5). The results document both a more intense aridity during MIS5 than during the Holocene, and the moderating impacts derived from the intense MIS5e African Monsoon. Early MIS5e (∼133–128 ka) was dominated by hyperarid conditions in the Eastern Mediterranean–Levant, indicated by thick halite deposition triggered by a lake-level drop. Halite deposition was interrupted however, during the MIS5e peak (∼128–122 ka) by sequences of flood deposits, which are coeval with the timing of the intense precession-forced African monsoon that generated Mediterranean sapropel S5. A subsequent weakening of this humidity source triggered extreme aridity in the Dead Sea watershed and resulting in the biggest known lake level drawdown in its history, reflected by the deposition of thick salt layers, and a capping pebble layer corresponding to a hiatus at ∼116–110 ka. The *DSDDP* core provides the first evidence for a direct association of the African monsoon with mid subtropical latitude climate systems effecting the Dead Sea watershed. Combined with coeval deposition of Arabia and southern Negev speleothems, Arava travertines, and calcification of Red Sea corals, the evidence points to a climatically wet corridor that could have facilitated *homo sapiens* migration "out of Africa" during the MIS5e peak. The hyperaridity documented during MIS5e may provide an important analogue for future warming of arid regions of the Eastern Mediterranean–Levant.

1. Introduction

The Dead Sea is a hypersaline, terminal lake occupying the lowest surface on Earth's continents, whose water surface is currently at ∼428 m below mean sea level (mbsl), and whose large (∼40 000 km^2) watershed spans the Mediterranean and the Saharo–Arabian climate zones (Fig. 1). Its volume increases during glacials and declines during interglacials, with amplified positive and negative responses of its levels, respectively. The mineralogy, grain sizes, and chemical and isotope compositions of the lake deposits reflect the regional climate during past glacial-interglacial cycles (Enzel et al., 2008; Stein, 2001). Studies of the Holocene Dead Sea, the last glacial Lake Lisan, and earlier Pleistocene lake cycles (i.e., Lake Amora), based mainly on exposed deposits along the lake margins, show close connections between Northern Hemisphere (NH) climate changes and water levels, water chemistry, and sediment lithology on glacial-interglacial to millennial time-scales (Bartov et al., 2003; Haase-Schramm et al., 2004; Kushnir and Stein, 2010; Prasad et al., 2004; Torfstein et al., 2013b). For example, since the Last Glacial Maximum and during the last deglaciation (∼24–11 ka), lake level dropped from its glacial high-stand of ∼160 mbsl to below 460 mbsl at the Bølling–Allerød (Stein et al., 2010), stabilizing at a Holocene (average) level of ∼400 mbsl. However, margin exposures cover limited time-intervals and mainly sediments deposited during the last glacial Lake Lisan (e.g., Bartov et al., 2002); continuous sedimentation

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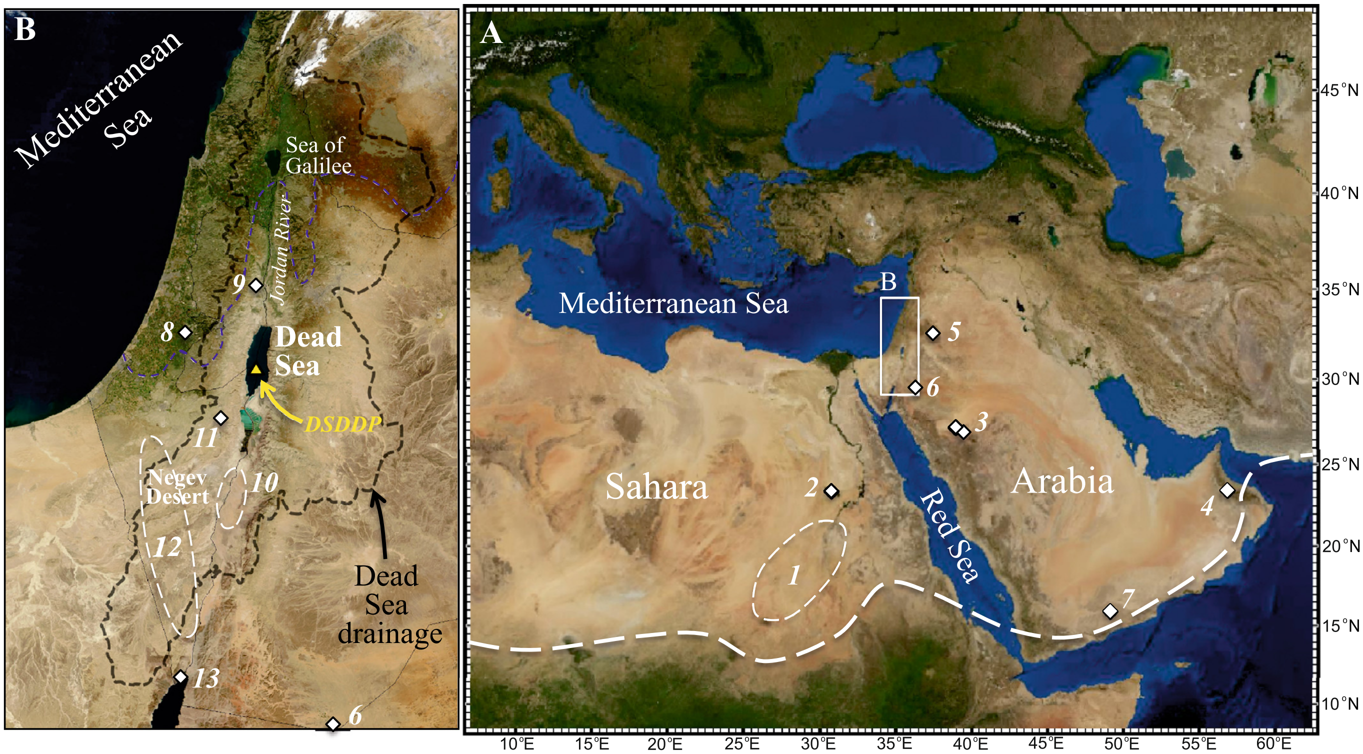

Fig. 1. (A) Regional location map. The Dead Sea basin is located between the Saharo–Arabia desert belt and the Mediterranean climate zone. The modern northern boundary of the boreal summer rains is marked by a thick-dashed white curve. (B) The Dead Sea watershed. The lake receives waters from a large watershed encompassing the two above mentioned climate zones, and its composition and sedimentary record reflect the climate-hydrological conditions over a very large geographical area. A dashed blue line marks the approximate locus of the 400 mm/y isohyet beyond which a steep climate gradient leads to an extreme desert environment. Currently, most of the precipitation in the northern Dead Sea watershed comes the Mediterranean during the winter. The Negev Desert and Arava valley in the southern part of the watershed receive minor amounts of localized rain primarily associated with active Red Sea trough systems and tropical plumes (Ziv et al., 2006). During the last interglacial the areas that currently receive rains from east Mediterranean sources were significantly drier. Locations of geological archives discussed in this paper: The *DSDDP* core location at the mid-Dead Sea; Then (by numbers): (1) Northern Sahara (Smith et al., 2007; Szabo et al., 1995); (2) Western Desert–Egypt (Crombie et al., 1997); (3) Nafud Desert (Rosenberg et al., 2013); (4) Oman Cave (Fleitmann et al., 2003); (5) Azraq Oasis–Jordan (Cordova et al., 2013); (6) South Jordan (Petit-Maire et al., 2010); (7) Yemen Cave (Fleitmann et al., 2011); (8) Soreq Cave (Bar-Matthews, 2014; Bar-Matthews et al., 2003); (9) Ma'ale Efrayim Cave (Vaks et al., 2003); (10) Arava valley travertines (Livnat and Kronfeld, 1985; Waldmann et al., 2010); (11) Tzavo'a Cave (Vaks et al., 2006); (12) Central and Southern Negev Caves (Vaks et al., 2007); (13) Gulf of Aqaba corals (Lazar and Stein, 2011).

has occurred only in the deepest part of the lake. The Dead Sea Deep Drilling Project (*DSDDP*) conducted in 2010–2011 under the auspices of the Intercontinental Scientific Drilling Program (*ICDP*), recovered a detailed sedimentary record going back to MIS7, from the deepest basin of the modern lake (Neugebauer et al., 2014). The drilling took place at a lake depth of 297 m, and the coring reached 456 m below the lake floor (mblf), recovering otherwise hidden sedimentary sections of the last interglacial low-stand lake.

This study presents a 200 kyr climate record from the DSDDP core and focuses on the climate history of the Levant during the last interglacial MIS5. This time interval has relevance in the context of climate models indicating a more arid Middle East with increasing global temperatures (e.g., Held and Soden, 2006), thus implying increased future fresh water scarcity in a water-starved and politically unstable region. Because the last interglacial peak (MIS5e, between ∼135–116 ka; Lisiecki and Raymo, 2005) was characterized by stronger insolation, warmer global temperatures, higher sea levels, and smaller continental ice sheets compared to the Holocene, the DSDDP core record provides a test of such predictions; thus, it serves as an analogue for a future warmer world. Our results show both extreme hyperaridity during MIS5e, including an unprecedented drawdown of Dead Sea water levels, as well as important impacts of a particularly strong precession-controlled African monsoon that generated a major sapropel (S5; Rohling et al., 2002; Rossignol-Strick, 1985) in the eastern Mediterranean.

2. Sedimentary records of the Dead Sea lakes and their hydroclimate connection

Previous studies on marginal terraces and short cores drilled along the Dead Sea shores have revealed that the lithology of the lacustrine sections directly reflects the watershed hydroclimatology (e.g., Begin et al., 1974; Bookman (Ken-Tor) et al., 2004; Haase-Schramm et al., 2004; Migowski et al., 2006; Stein et al., 1997; Yechieli et al., 1993). A wet hydrological regime is represented by summer deposition of primary (evaporitic) aragonitic laminae. These laminae alternate with detrital quartz and calcite silt grains from desert dust origin (Haliva-Cohen et al., 2012), that accumulated in the Dead Sea watershed and was washed into the lake during winters. The alternating aragonite and detritus couplets comprising the *aad facies* (Figs. 2, S1) reflect annual cycles of deposition (Begin et al., 1974; Prasad et al., 2004). The Ca-chloride Dead Sea brine is poor in bi-carbonate and sulfate, required for aragonite or gypsum precipitation. These ions are supplied by freshwaters entering the lake during wet periods in the watershed, and support the precipitation of aragonite and gypsum, which are characteristic of wet glacial intervals in the Dead Sea lacustrine deposits (Stein et al., 1997; Torfstein et al., 2008, 2005). During arid periods, smaller amounts of bi-carbonate and sulfate are supplied to the lake and the deposition is dominated the silty quartz and calcite grains comprising the laminated detritus (the *ld facies*; Haliva-Cohen et al., 2012). This sediment comprises significant portions of the interglacial sequences exposed along the margins of the modern lake (e.g.,