Northward intrusions of low- and mid-latitude storms across the Saharo-Arabian belt during past interglacials

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ABSTRACT

The rain regime of the Levant during the late Quaternary was controlled primarily by Mediterranean cyclonic systems associated with North Atlantic climate shifts. Lake levels in the Dead Sea basin have been robust recorders of the regional hydrology and generally indicate highstand (wet) conditions throughout glacial intervals and lowstands (dry) during interglacials. However, sporadic deposition of travertines and speleothems occurred in the Negev Desert and Arava Valley during past interglacials, suggesting intrusions of humidity from southern sources probably in association with enhanced activity of mid-latitude Red Sea synoptic troughs and/or low-latitude tropical plumes. The southerly incursions of wetness were superimposed on the long-term interglacial Levantine arid conditions, as reflected by the current prevailing hyperaridity, and could have had an important impact on human migration through the Red Sea–Dead Sea corridor.

INTRODUCTION

With less than 50 mm/yr of precipitation, the Saharo-Arabian desert belt is presently one of the most arid environments on Earth. During winters, the northern sector of this belt receives moisture carried by the subtropical jet stream in association with mid- to high-latitude cyclones. The source of humidity to the southern sector, however, is from northern shifts of the Intertropical Convergence Zone (ITCZ) (Nicholson, 2000). Considerable latitudinal shifts of these wind belts took place during the Quaternary in response to orbitally induced insolation changes over the tropics (Braconnot et al., 2008). The ITCZ position is closely linked to high-latitude temperatures, interhemispheric temperature asymmetry, and land- and sea-ice extent (Broccoli et al., 2006). Latitudinal expansion of monsoon precipitation is, thus, enhanced during both maximum obliquity and minimum precession, transporting moisture from both the Atlantic and Indian Oceans farther northward into the Saharo-Arabian region (Tuenter et al., 2003). Extensive pluvial conditions in the Saharo-Arabian belt are recorded mostly during past interglacials, indicating enhanced wetness in relation to northward migration of the ITCZ (Rohling et al., 2002).

In this paper, we present evidence of enhanced hydrological activity during past dry interglacial intervals in the presently hyperarid Dead Sea–Red Sea corridor (Fig. 1). We discuss our findings in light of previous suggestions referring to the northward migration of low-latitude monsoon systems. We further hypothesize that wet episodes during interglacial stages in the Levant (at the northeastern margin of the Saharo-Arabian desert belt) were related to enhanced activity of mid-latitude rains intruding the northern part of the African Rift Valley, in a manner similar to the present-day Red Sea troughs, defined as a complex elongated low-pressure synoptic system occasionally associated with increased spring moisture (Tsvieli and Zangvil, 2005). An alternative mechanism of rain delivery is enhanced activity of tropical plumes, associated with pronounced disturbances in the subtropical jet stream (in winters) (Ziv, 2001; Rubin et al., 2007).

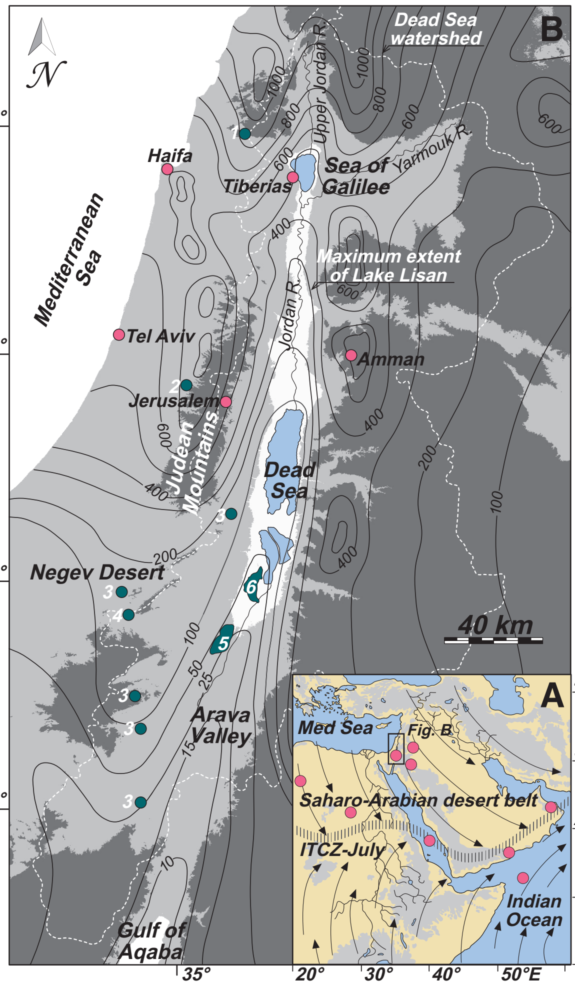

Figure 1. A: Location map of eastern Sahara and the Arabian Peninsula. Indicated in gray are areas above 1000 m. Dashed line marks location of the Intertropical Convergence Zone (ITCZ) in the present Northern Hemisphere summer, and the arrows stand for dominant wind directions (Nicholson, 2000). Red circles represent both continental and marine archives cited in this work. B: Location map of the Dead Sea and Arava Valley. Marked in dark gray are areas higher than 600 masl, and in light gray are areas between 600 masl and 180 mbsl. The latter contour corresponds to the highest level of Lake Lisan (marked by the white boundary) (Bartov et al., 2003). Dark gray contour lines indicate current precipitation in mm/yr; dashed white line stands for the Dead Sea watershed. Green dots and areas stand for the locations cited in this paper: 1—speleothems in the Peqiin cave (Bar-Matthews et al., 2003); 2—speleothems in the Soreq cave (Bar-Matthews et al., 2003); 3—speleothems in the Negev Desert (Vaks et al., 2007); 4—travertines in the Negev Desert (Schwarcz et al., 1979); 5—the areas covered by travertine deposits in the Arava Valley following Enmar (1999); 6—travertine deposits mapped and dated during this study.

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THE DEAD SEA–ARAVA VALLEY PALEOHYDROLOGICAL ARCHIVES

The Red Sea, Arava Valley, and Dead Sea region is a biogeographic transition zone between Africa and Eurasia that has witnessed significant climatic fluctuations since the early Neogene. This natural corridor has served both northward and southward dispersals of biota (Tchernov, 1992), providing a natural passage for hominid migrations out of Africa (Bar-Yosef, 2003; Vaks et al., 2007). Several paleohydrological archives developed within this corridor and are catalogued into (1) lake sediments deposited in the endorheic Dead Sea basin during the mid-Pleistocene (Lake Amora), the late Pleistocene (lakes Samra and Lisan), and the Holocene (Dead Sea) (Fig. 2A), (2) travertines in the Arava Valley (Fig. 2C), (3) speleothems in the Negev Desert (Fig. 2D), and (4) corals from elevated reefs along the northern Gulf of Aqaba margins.

The Dead Sea basin lacustrine bodies serve as robust tracers of hydrological conditions over the Dead Sea watershed (Fig. 1B) and thus efficiently gauge past precipitation-evaporation balance (Bartov et al., 2003). Their water levels have been controlled by rainfall originating in the East Mediterranean mid-latitude cyclones. Documented highstand stages correlate well with glacial (cooler) episodes in the Northern Hemisphere, while lowstands correspond to interglacial (warmer) intervals (Bartov et al., 2003) (Fig. 2J). Yet, several regional archives (Figs. 2D and 2E) record short episodes of significant increases in humidity superimposed on the general arid interglacial trends.

Deposition of travertines occurred in several localities in the Arava Valley and Negev Desert during past interglacials (Schwarcz et al., 1979; Livnat and Kronfeld, 1985; Enmar, 1999), with discrete U/Th ages at ca. 230, 174, 128, 105, and 84 ka (Fig. 2C; see Table DR1

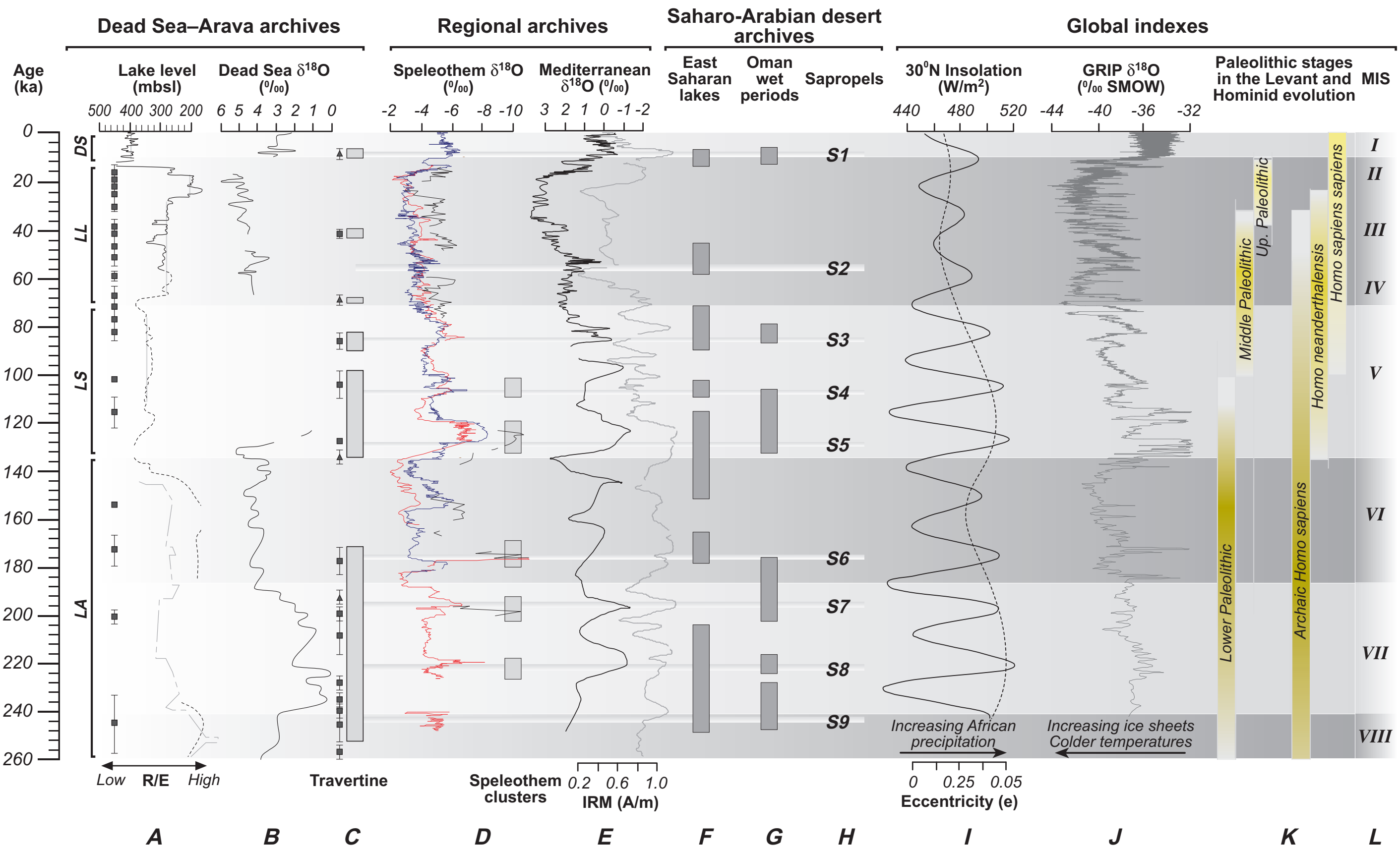

Figure 2. Compilation of lacustrine and travertine records from the Dead Sea basin and Arava Valley compared with regional and global records. A: Dead Sea basin lake-level fluctuations and timing of each lacustrine episode. DS—Dead Sea; LL—Lake Lisan; LS—Lake Samra; LA—Lake Amora. Small black squares are absolute TIMS and α-counting U/Th ages, as well as ^{14}C dating considered in this paper (Bartov et al., 2003; Waldmann et al., 2009). The continuous and dashed black curves represent the compiled lake-level curve between 180 ka and the present (Bartov et al., 2003; Waldmann et al., 2009); dashed discontinuous gray curve stands for the reconstructed runoff/evaporation ratio (R/E) between 260 and 140 ka (Torfstein et al., 2009). B: Oxygen isotope record of the Dead Sea basin lakes (Torfstein et al., 2009). C: Timing of Arava Valley travertine deposition. Black squares and their corresponding error bars stand for ages considered in this paper (Livnat and Kronfeld, 1985; Enmar, 1999); black triangles with their corresponding error bars represent new age data from this study. D: Oxygen isotope record from the Peqiin cave (in red), the Soreq cave (in blue) (Bar-Matthews et al., 2003), and the northern Negev caves (in black) (Vaks et al., 2007). Gray rectangles stand for growing speleothem clusters in the Negev Desert. E: Black curve stands for planktic foraminifera (*Globigerinoides ruber*) oxygen isotope record from the East Mediterranean (ca. 260–90 ka), following Kroon et al. (1998), and 90 ka to present from Almogi-Labin et al. (2009). Gray curve represents the eolian hematite content of East Mediterranean cores in isothermal remanent magnetization (IRM) values. The magnetic parameter is a proxy for the concentration of airborne Saharan hematite delivered into the East Mediterranean, reflecting oscillations in dust flux (Larrasoaña et al., 2003). F: Timing of lake resurgence in northeastern Sahara (McKenzie, 1993; Gasse, 2000; Geyh and Thiedig, 2008; Kharga Oasis, western Fezzan, and Murzuq basin, respectively). G: Timing of Oman wet periods (Burns et al., 2001). H: Timing of sapropel deposition in the East Mediterranean (Rossignol-Strick and Paterne, 1999). I: Summer insolation at 30°N (continuous black curve) and orbital eccentricity (dashed curve) (Berger and Loutre, 1991). J: Oxygen isotope record from Greenland Ice Core Project (GRIP) ice core (in ‰ with respect to SMOW) (Johnsen et al., 1997). K: Paleolithic stages in the Levant and hominid evolution (Bar-Yosef, 2003). L: Timing of Marine Isotope Stages (MISs).

in the GSA Data Repository[1] for details). Brief depositional events occurred as well at ca. 70 ka, ca. 40 ka, and 8 ka, concurrent with sharp decrease in Dead Sea basin lake levels, potentially indicating episodic contribution of humidity from southern sources. Complementary palynological studies of the Arava travertines suggest a considerable rise in regional precipitation during their deposition (Weinstein-Evron, 1987), in agreement with short-term concurrent flooding events (Greenbaum et al., 2006) and speleothem deposition in the Negev Desert (at 130–120 ka and ca. 108 ka) (Vaks et al., 2007) (Fig. 2D).

The oxygen isotope record of the Dead Sea basin lakes ($\delta^{18}O_{lake}$) provides additional evidence for episodic wet events during past interglacial stages. Contrary to other comparable archives, the $\delta^{18}O_{lake}$ values were relatively heavy (~4‰–5‰) during wet, highstand intervals, while lighter values (~1‰–3‰) were attained during dry, lowstand stages (Kolodny et al., 2005; Torfstein et al., 2009) (Fig. 2B). The $\delta^{18}O_{lake}$ trend reflects corresponding changes in East Mediterranean surface water (Fig. 2E), reflecting the dominance of the source effect, compared to the relatively smaller impact of other factors such as precipitation, amount, and distance (Kolodny et al., 2005). However, during the twentieth century, several negative $\delta^{18}O_{lake}$ spikes of ~2‰ were recorded in the Dead Sea, and were recorded during exceptionally strong winter flooding (Gat, 1984). These spikes lasted 1–2 yr, after which the $\delta^{18}O_{lake}$ values returned to their long-term, steady-state value. Similar negative excursions have been identified in authigenic aragonites precipitating in the lake during past interglacial stages and were interpreted to reflect pronounced flooding events (Torfstein et al., 2009). Interestingly, the extremely negative $\delta^{18}O$ excursions were mainly recorded during intervals of lowstand conditions in the lakes (e.g., during MIS3 in Lake Lisan and MIS7 in Lake Amora). The floods were probably strong enough to temporarily shift the $\delta^{18}O_{lake}$, without influencing the long-term lake level and $\delta^{18}O_{lake}$.

A southward migration of East Mediterranean cyclones (known as Cyprus low depressions) during past interglacials has been proposed as the mechanism driving wet episodes in the Arava Valley, Negev Desert, and the Red Sea (Arz et al., 2003; Vaks et al., 2007). The magnitude and extension of East Mediterranean cyclones, however, is limited by the southeast Mediterranean physiography, resulting in a steep rainfall gradient at the northern Negev, even during the relatively wet late Pleistocene (Enzel et al., 2008). Moreover, lake levels were significantly lower during past interglacial intervals (Torfstein et al., 2009; Waldmann et al., 2009), as expected considering their close response to a Northern Hemisphere climatic regime. Indeed, well-studied cave deposits in central and northern Israel (Fig. 2D) do not provide any indication of anomalous rainfall regime (Bar-Matthews et al., 2003). Interpreting the growth periods of speleothems in the Negev Desert as indicators of southward shifts of East Mediterranean storm tracks does not coincide with synchronous lowstand conditions in the Dead Sea basin lakes. On the contrary, enhanced inland penetration of humidity originating from the northwest would most likely result in an overall increase of freshwater supply to the Dead Sea basin watershed, resulting in lake-level rise. We thus suggest an alternative scenario whereby a temporal northward migration of low-latitude rainstorms may have caused short humid episodes during past interglacials in the Red Sea–Arava Valley corridor.

A SOUTHERN SOURCE OF HUMIDITY?

The combined evidence obtained from the different archives in the East Mediterranean supports increased regional humidity originating from south of the Levant, mainly during MIS7 and MIS5, but possibly also during MIS3 and the early Holocene (ca. 8 ka). Yet, the typical climatic conditions during these interglacial stages are relatively arid compared to glacial intervals, with lowstands of the Dead Sea basin lakes indicating weaker East Mediterranean cyclone activity. Increased humid conditions during past interglacials are also recorded at a greater spatial scale by speleothem growth in the southern part of the Arabian Peninsula (Burns et al., 2001) (Fig. 2G; Oman wet periods), fresh groundwater recharge in Jordan (Frumkin et al., 2008), and the reappearance of many fluviolacustrine systems in the Sahara and Saudi Arabia (Gaven et al., 1981; McKenzie, 1993; Gasse, 2000; Geyh and Thiedig, 2008; among others) (Fig. 2F). Dust contribution from the Sahara to the East Mediterranean decreased during these humid intervals (Larrasoaña et al., 2003) (Fig. 2E), probably reflecting enhanced monsoon activity due to northward migration of the ITCZ during MIS7 and MIS5 (Brovkin et al., 1998; Tuenter et al., 2003). Interestingly, episodes of travertine deposition in the Arava Valley and speleothem growth in the Negev (Figs. 2C and 2D) coincide with known ages of sapropel depositional events in the East Mediterranean (Rossignol-Strick and Paterne, 1999; Calvert and Fontugne, 2001) (Fig. 2H). Deposition of sapropel layers is commonly associated with an increased freshwater flux into the Mediterranean triggered by strengthening of African tropical monsoons and weakening of the trade-wind system during insolation maxima in the northern subtropics (Berger and Loutre, 1991) as a response to the precession component of the Milankovitch cycles (Fig. 2I). Considering the current knowledge of sapropel ages, there is a clear relation between the timing of travertine deposition in the Arava Valley at ca. 8 ka and sapropel S1 (ca. 9000–6000 cal. yr B.P.), supporting our hypothesis for northward migration of low-latitude rainstorms and emphasizing that latitudinal shift of the ITCZ may have significantly affected, possibly indirectly, the northeastern fringe of the Saharo-Arabian desert belt during past interglacials.

Temporal northward migration of the ITCZ may have triggered monsoon rain to reach higher latitudes in the Saharo-Arabian desert belt during MIS7 and MIS5 (Rodwell and Hoskins, 1996; Tuenter et al., 2003). Nevertheless, the magnitude of the monsoonal rain systems, as well as the mechanisms that allow long-distance transportation of humidity northward to the Gulf of Aqaba and Arava Valley regions, are quite controversial and still under debate (Dayan and Morin, 2006). Alternatively, atmospheric synoptic conditions associated with the Red Sea troughs, where tropical wetness is transported to northern latitudes during Northern Hemisphere spring and autumn seasons (Dayan et al., 2008), may serve as a modern analogue for short, humid episodes recorded in the Red Sea–Dead Sea corridor during past interglacials, similar to tropical plumes intruding the northern part of the African Rift Valley.

In summary, the evidence detailed here suggests that the 23 k.y. precession cycle may have been more dominant than the 100 k.y. eccentricity component in determining the southern Levant wet episodes during past interglacials. The orbitally induced northward shift of humidity may have been even more pronounced when vegetation is taken into account (Kutzbach et al., 1996). Such fluctuations between sustained humid and arid intervals might have provided short-term climatic corridors, allowing early human migrations out of Africa (Figs. 2K and 2L), and strongly influencing speciation and later cultural development of mankind.

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[1]GSA Data Repository item 2010157, Figure DR1 (location map of travertine sampling sites at the Arava Valley), Figure DR2 (composite stratigraphic section crossing S-N the Arava Valley), and Table DR1 (U/Th, α-counting ages of the Arava travetines), is available online at www.geosociety.org/pubs/ft2010.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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