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Dead Sea pollen provides new insights into the paleoenvironment of the southern Levant during MIS 6–5

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ABSTRACT

The paleoclimate of the southern Levant, especially during the last interglacial (LIG), is still under debate. Reliable paleovegetation information for this period, as independent evidence to the paleoenvironment, was still missing. In this study, we present a high-resolution pollen record encompassing 147–89 ka from the Dead Sea deep drilling core 5017-1A. The sediment profile is marked by alternations of laminated marl deposits and thick massive halite, indicating lake-level fluctuations. The pollen record suggests that steppe and desert components predominated in the Dead Sea surroundings during the whole investigated interval. The late penultimate glacial (147.3–130.9 ka) and early last glacial (115.5–89.1 ka) were cool and relatively dry, with sub-humid conditions confined to the mountains that sustained moderate amounts of deciduous oaks. Prior to the LIG optimum, a prevalence of desert components and a concomitant increase in frost-sensitive pistachio trees demonstrate the occurrence of an arid initial warming phase (130.9–124.2 ka). The LIG optimum (124.2 ka–115.5 ka) was initiated by an abrupt grass expansion that was followed by a rapid spread of woodlands in the mountains due to increased moisture availability. The remarkable sclerophyllous expansion points to a strong seasonal moisture deficit. These results contradict previous Dead Sea lake-level investigations that suggested pluvial glacials and a warm, dry LIG in the southern Levant. Prominent discrepancies between vegetation and Dead Sea lake stands are also registered at 128–115 ka, and the potential causes are discussed. In particular, while the pollen spectra mirror increased effective moisture during the LIG optimum, the massive halite deposition is indicative of an extremely low lake level. Given that the climate amelioration triggered the migration of early modern humans to the southern Levant, we speculate that the diverse ecosystems in the region provided great potential for their residence. Across the eastern Mediterranean region, an analogous vegetation succession pattern is observed.

1. Introduction

Connecting Africa with the Arabian Peninsula, the southern Levant is a hotspot for investigating the dispersal of anatomically modern humans (AMH) to the rest of the world, since their emergence in Africa (Gibbons, 2017). Pivotal findings are the AMH remains in Israel (the Skhul and Qafzeh Caves) dated to the time range of 130–90 thousand years ago (Grün et al., 2005; Mercier et al., 1993; Valladas et al., 1988). These findings suggest the occupation by modern humans in the region during the last interglacial (LIG). The present southern Levant is covered by large areas of uninhabitable desert, whereas, in the past, the present desert barrier was probably a migration corridor with sufficient water and food resources during climate ameliorations (Breeze et al., 2016; Vaks et al., 2007).

The southern Levant is located at the boundary between the Mediterranean and the Saharo-Arabian climate zones. The sensitive response of this region to climatic variations has been documented in the geological archives (Bar-Matthews et al., 2017; Stein, 2014). Nevertheless, inconsistences exist among regional paleoenvironmental archives regarding the glacial-interglacial climate conditions. For instance, a relatively active speleothem deposition occurred in the central and southern Negev Desert during the LIG (Vaks et al., 2007). The evidence points to wetter conditions in the LIG than in the glacial periods. However, inverse climate conditions

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are indicated, due to the significantly lower Dead Sea lake stands during the LIG as compared to the glacial periods (Waldmann et al., 2010). It is prominent that the lake level at ca. 27–24 ka rose to ca. 270 m higher than the present level, resulting in the mergence of the Dead Sea and the Sea of Galilee (Bartov et al., 2003). Controversies are focused on the relative impact of the climate variables, i.e., precipitation, temperature, evaporation, and seasonality (Gasse et al., 2011; Miebach et al., 2017). In this case, more paleorecords involving independent proxies are needed.

The Dead Sea is a remarkable archive for investigating the paleoenvironment of the southern Levant. So far, studies on a series of proxies, such as sedimental lithology (e.g., Neugebauer et al., 2014), geochemistry (e.g., Torfstein et al., 2009), and pollen assemblages (e.g., Litt et al., 2012), show the great potential of the Dead Sea sediments for documenting changes in regional hydroclimate. Nevertheless, compared to the well-studied last glacial and Holocene sediments, the LIG conditions remain elusive due to the limited availability of materials deposited in the lake margin area. In 2010–2011, the Dead Sea Deep Drilling Project (DSDDP) retrieved sediment cores dated back to ca. 220 ka from the deepest part of the basin (Stein et al., 2011; Torfstein et al., 2015). The project successfully recovered LIG sediments consisting of conspicuously thick halite deposits (Neugebauer et al., 2014). Previous analyses for chronology, lithology, and isotope composition suggested that the LIG period was characterized by low lake levels and generally dry conditions (Torfstein et al., 2015).

Despite this progress, the paleovegetation as independent evidence for the LIG paleoenvironment in the southern Levant is largely unknown. Previous palynological studies in the region are mainly confined to the Holocene (e.g., Langgut et al., 2015; Litt et al., 2012; Neumann et al., 2010) and last glacial period (e.g., MIS 2; Miebach et al., 2017), whereas the LIG pollen records are rare, poorly-dated, and fragmentary (e.g., Weinstein-Evron, 1987). In this study, we present a high-resolution pollen record dated to 147–89 ka, based on the DSDDP sediment core. The main objectives are to reconstruct the paleovegetation in the southern Levant and to elucidate the response of vegetation successions to variations in regional climate. Comparisons with other regional records are made in order to provide new insights into the paleoenvironmental setting of the early modern human dispersal.

2. The Dead Sea and its setting

The Dead Sea is a hypersaline terminal lake (ca. 27.5% salinity; 76×17 km; 760 km^2; Fig. 1). It occupies the Dead Sea Basin (DSB) in the Dead Sea Transform, which developed due to the breakup of the African and Arabian plates. This process was accompanied by the formation of narrow valleys and the uplifting of their shoulders at the plate boundary (Garfunkel, 1997). The northern DSB is deep, with a bottom depth of 730 m bmsl (below mean sea level) and a water depth of ca. 300 m. The southern DSB is very shallow and serves as an evaporation pond (Neev and Hall, 1979).

The Dead Sea catchment (Fig. 1B) is ca. 42,200 km^2. The Jordan River drains the northern sub-humid areas to the arid DSB in the south and delivers ca. 1100×10^6 m^3 water to the Dead Sea per year. The ephemeral Nahal Arava originates from the arid south and feeds the Dead Sea with limited volumes of water (ca. 5×10^6 m^3), although the catchment is large. Groundwater, such as from springs, marginally contributes to the Dead Sea (Greenbaum et al., 2006).

The southern Levant is controlled by the Mediterranean climate in the north and the Saharo-Arabian desert climate in the south. The highly varied topography further modulates the regional climate, leading to a steep gradient of temperature and precipitation distribution (Fig. 1C; Goldreich, 2003). The north and the highlands are characterized by hot, dry summers and cold, wet winters, while the south and the low-lying areas undergo semi-arid to arid conditions. For instance, Jerusalem has a mean annual precipitation (MAP) of 400–600 mm/year, whereas the Dead Sea area receives a MAP of 50–100 mm/year (Greenbaum et al., 2006). The majority of moisture originates from the Mediterranean Sea and is brought by winter cyclones (e.g., the Cyprus Low; Goldreich, 2003). During the autumn, the southern arid/semi-arid areas are subject to convectional short-lived rainstorms produced by the Red Sea Trough. Some tropical moisture is delivered by the upper tropospheric jet as well (Dayan and Morin, 2006).

The varied precipitation and topography determine the convergence of three phytogeographical territories in the southern Levant (Fig. 1C): the Mediterranean, the Irano-Turanian, and the Saharo-Arabian territory (Zohary, 1962, 1973). The Mediterranean trees and shrubs are found in the mountains and coastal plains with a MAP of >400 mm (Danin and Plitmann, 1987). The maquis is mainly composed of deciduous oaks (*Quercus boissieri* in the upper mountains and *Q. ithaburensis* in the lower elevations), evergreen oaks (*Q. calliprinos*), pistachios (*Pistacia lentiscus* and *P. palaestina*), olive trees (*Olea europaea*), carob trees (*Ceratonia siliqua*), and Aleppo pines (*Pinus halepensis*). The Irano-Turanian vegetation is a dwarf-shrub steppe that covers the semi-arid to arid areas. The most important components are wormwood (*Artemisia herba-alba*), grasses, and stands of *Pistacia atlantica* (van Zeist and Bottema, 1991). The Saharo-Arabian desert elements are mainly goosefoot species (Chenopodiaceae) such as *Suaeda* spp. and *Atriplex* spp. They are accompanied by tamarisk (e.g., *Tamarix nilotica*), *Retama raetam*, *Zygophyllum dumosum*, and *Haloxylon persicum* (Danin, 1992). The Sudanian plant communities occur in the oases. The dominant plants are tropical Savannah elements represented by *Acacia* spp., date palm (*Phoenix dactylifera*), *Tamarix aphylla*, and *Ziziphus spina-christi* (Zohary, 1962).

3. Material and methods

3.1. Drilling campaign and stratigraphy

The coring of the DSDDP was conducted in the northern DSB (Stein et al., 2011). The top depth of the borehole 5017-1A (31°30′28.98″ N, 35°28′15.60″ E) was at 297.46 m below lake level. The total drilled length of this borehole was 455.34 m, retrieving 405.83 m sediments with a recovery rate of 89.13% (for details see Neugebauer et al., 2014). The sediments recover four stratigraphic formations (Fm.). The Amora and Lisan Fm., accumulated during the glacials, mainly consist of marl sediments and mass transported deposits. The Samra and Ze'elim Fm., formed during the interglacials, primarily consist of halite and some marl deposits. In this study, the investigated sediments are deposited at depths between 340.6 and 199.22 m blf (meters below lake floor), covering the whole Samra Fm. and upper part of the Amora Fm. (Fig. 2).

3.2. Chronology

U-Th dating was applied by Torfstein et al. (2015) to primary aragonites of the investigated 5017-1A core sediments. Several samples at the same horizon were dated and an average single sample U-Th age was calculated for each horizon. Anchor ages of the concerned sediments were obtained by comparing the $\delta^{18}O$ values of 5017-1A aragonites with the $\delta^{18}O$ profile of the marine isotope stack LR04 (Lisiecki and Raymo, 2005). By combining the radiometric dates with the anchor ages, the initial chronological frame was established (Torfstein et al., 2015) and was subsequently adapted in this study.

The average single sample U-Th age of 102.091 ka at 220.03 m