Desert speleothems reveal climatic window for African exodus of early modern humans

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ABSTRACT

One of the first movements of early modern humans out of Africa occurred 130–100 thousand years ago (ka), when they migrated northward to the Levant region. The climatic conditions that accompanied this migration are still under debate. Using high-precision multicollector–inductively coupled plasma–mass spectrometry (MC-ICP-MS) U-Th methods, we dated carbonate cave deposits (speleothems) from the central and southern Negev Desert of Israel, located at the northeastern margin of the Saharan-Arabian Desert. Speleothems grow only when rainwater enters the unsaturated zone, and this study reveals that a major cluster of wet episodes (the last recorded in the area) occurred between 140 and 110 ka. This episodic wet period coincided with increased monsoonal precipitation in the southern parts of the Saharan-Arabian Desert. The disappearance at this time of the desert barrier between central Africa and the Levant, and particularly in the Sinai-Negev land bridge between Africa and Asia, would have created a climatic "window" for early modern human dispersion to the Levant.

Keywords: Negev Desert, speleothems, U-Th dating, paleoclimate, out of Africa.

INTRODUCTION

The African origin of the early modern humans ca. 200–150 ka is now well documented (McBrearty and Brooks, 2000; McDougall et al., 2005), but the routes of their expansion out of Africa are still debated (Vermeersch, 2001; Petraglia and Alsharekh, 2003). Fossil remains of early modern humans and sites of African Middle Stone Age industry in the eastern Sahara (McBrearty and Brooks, 2000; Smith et al., 2004a) and Arabian Peninsula (Petraglia and Alsharekh, 2003; Rose, 2004) suggest a migration route from tropical east Africa to the north and northeast. (The African terminology, the Middle Stone Age, is used in this paper to cover the same time period described in Europe as the Middle Paleolithic; Marean and Assefa, 2005.) Archaeological data from northern Israel indicate that one of the major waves of early modern human expansion out of the African continent occurred between 130 and 100 ka (Schwarcz et al., 1988; Valladas et al., 1988; Mercier et al., 1993; Bar-Yosef, 1998; Grun et al., 2005). All possible migration routes leading from Africa to the Levantine early modern human sites (Fig. 1A) converge in the arid to hyperarid Negev, Sinai, and southern Jordan Deserts (Fig. 1B), making it a key region for understanding climatic constraints on early modern human dispersal. Derricourt (2005) argued that the Sinai-Negev Desert route was the major (and possibly the only) way out of Africa, and that the passage through this "bottleneck" region was dependent on the development of suitable climate conditions. The southern and central Saharan-Arabian Desert experienced increased monsoon precipitation during this period of early modern human emergence (Szabo et al., 1995; Rohling et al., 2002; Fleitmann et al., 2003; Osmond and Dabous, 2004), but it is not known if an increase in rainfall also occurred in the northern part of the migration corridor. Here, we present evidence for a period of enhanced rainfall activity between 140 and 110 ka in the central and southern Negev Desert, Israel, based on absolute U-Th dating of speleothems. The climate during this period consisted of episodic wet events that enabled the deserts of the northeastern Sahara, Sinai, and Negev to become more suitable for the movement of early modern humans. This period was preceded and followed by essentially unbroken arid conditions, which may indicate that climate change had a major limiting role in the timing of early modern human dispersal out of Africa.

GEOLOGICAL CONTEXT

The caves of the Negev Desert are dry today and speleothems do not form, but their presence in a number of caves clearly indicates that water reached the unsaturated zone in the past and that surface vegetation was present at times. Today, the mildly arid northern (300–150 mm/yr) and arid central parts of the Negev Desert (150–50 mm/yr) mainly receive their rainfall from Mediterranean cyclones (Dayan, 1986), as in the Mediterranean climate region of northern and central Israel. In contrast, the southern Negev is hyperarid (<50 mm/yr) (Amit et al., 2006) (Fig. 1B), and its rainfall mostly consists of rare thunderstorms bringing moisture of tropical origin (Kahana et al., 2002). The transition from the Mediterranean conditions in central Israel to the hyperarid desert in the southern Negev occurs over a distance of less than 150 km. The arid and hyperarid Sinai-Negev Deserts form the land bridge that links Africa to Asia.

Speleothem deposition has been continuous during the last 200 k.y. in the Mediterranean climate region of northern and central Israel (Frumkin et al., 1999; Bar-Matthews et al., 2003), whereas in the mildly arid steppe zone in the Jordan Valley and the northern Negev, speleothem deposition has been more sporadic, with hiatuses during dry interglacial episodes (marine oxygen isotope stage [MIS] 5.3–5.2, and Holocene) and the two last glacial maxima (Vaks et al., 2006). Further south, where present-day precipitation is below 150 mm/yr (central and southern Negev), the cross sections of speleothems younger than 200 ka are reduced to 1–3 cm, compared with tens of centimeters in the northern Negev (Vaks et al., 2006).

METHODS

Eleven speleothems (stalactites, stalagmites, and flowstone, see GSA Data Repository Table DR1[1]) were collected from five caves located along a north-south transect of the central and southern Negev Desert, from the present-day 150 mm isohyet to the 30 mm isohyet (Fig. 1B). The caves occur in Middle Cretaceous limestone and dolomite host rock. The speleothems were sectioned, and up to 500 mg of powder was drilled out from different laminae using 0.8–1.2-mm-diameter drill bits. Stable isotope tests (Hendy, 1971) performed on several of the speleothems indicate equilibrium deposition. The procedures for accurate U-Th dating using

[1]GSA Data Repository item 2007202, Table DR1 and Figure DR1, is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

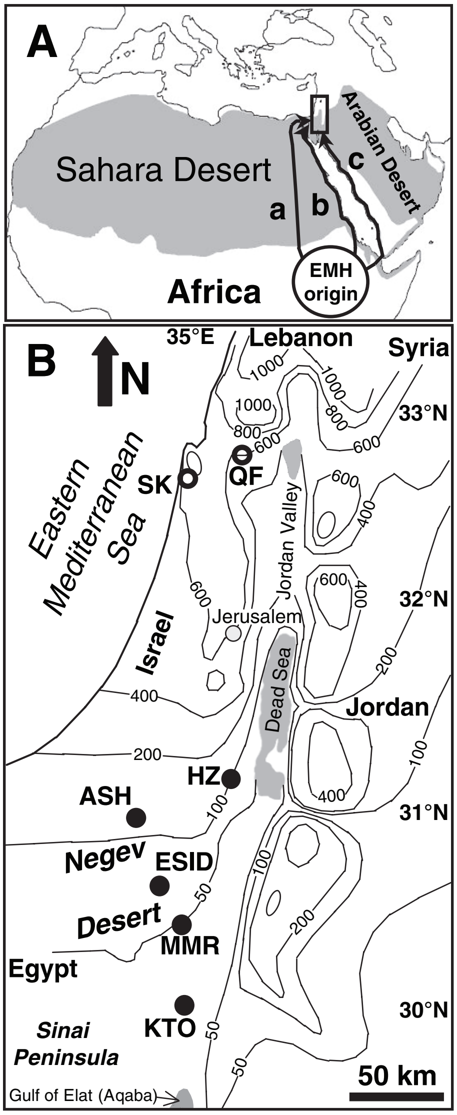

Figure 1. Location maps. A: Saharan-Arabian Desert (gray shading indicates rainfall below 100 mm) and three possible routes for migration of early modern humans (EMH) toward Levant early modern human sites, passing through desert areas of Sinai, Negev, and southern Jordan: (a) along Nile River, (b) along African Red Sea coast, (c) along Arabian Red Sea coast after crossing Bab-el-Mandeb Straits (after Petraglia and Alsharekh, 2003; Rose, 2004). Rectangle indicates southern Levant area shown in Figure 1B. B: Southern Levant area showing location of five studied cave sites in Negev Desert. Caves are denoted by black circles and labeled as follows: HZ—Hol-Zakh; ASH—Ashalim; ESID—Even-Sid; MMR—Ma'ale-ha-Meyshar; KTO—Ktora Cracks. Open circles indicate caves with early modern human remains in northern Israel: Skhul (SK) and Qafzeh (QF). Lines represent rainfall isohyets (in mm/yr). Present-day Negev Desert can be divided into three subzones: northern—300 mm to 150 mm isohyets; central—150 mm to 50 mm isohyets; southern—50 mm isohyet to Gulf of Elat (Aqaba).

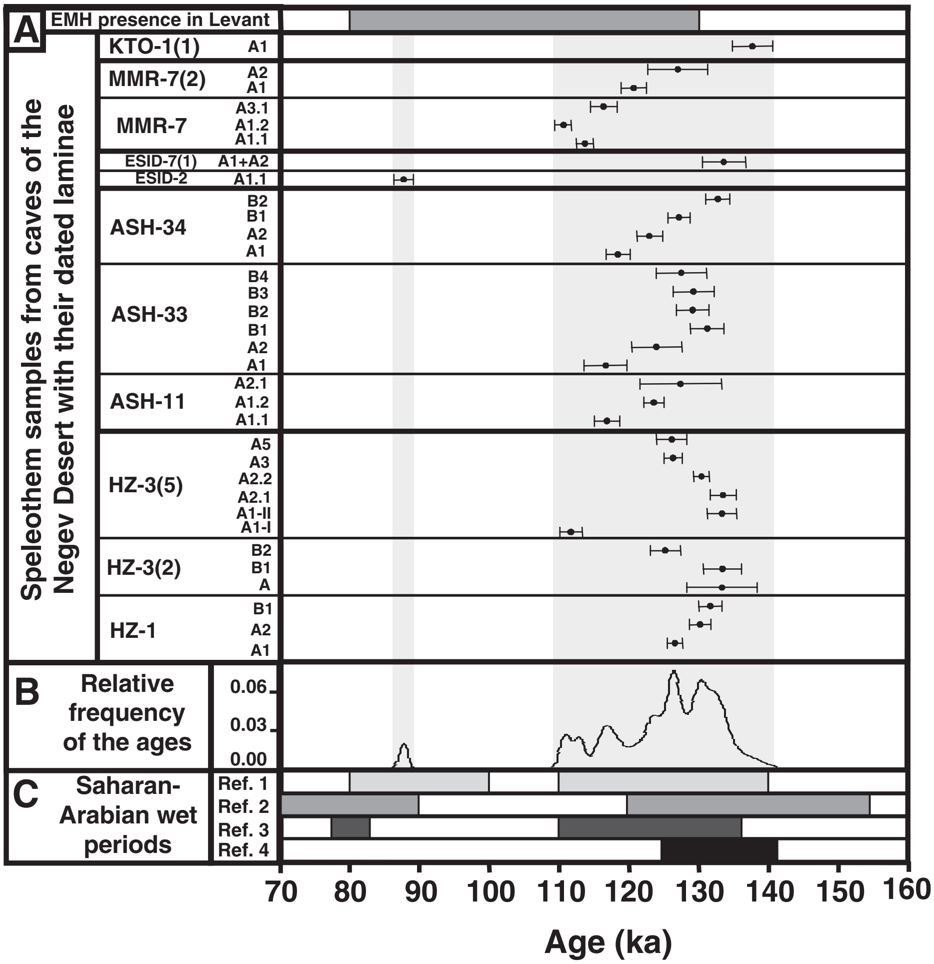

Figure 2. Speleothem ages and enhanced rainfall periods in Negev Desert determined in this study compared to data on occupation of caves in northern Israel by early modern humans (EMH) and periods of enhanced monsoonal rainfall in southern Saharan-Arabian Desert. A: U-Th ages (with 95% confidence [2σ] error bars) of speleothem samples of Negev Desert. Speleothem samples are identified along vertical axis, and data for each speleothem are separated from one another by thin horizontal lines. Bold horizontal lines separate data for different caves (cave locations appear in Fig. 1B). Stratigraphic order of laminae in each individual speleothem is from bottom to top of row. Dark-gray rectangle shows range of ages of wet period indicated by speleothems. Bold gray bar below upper horizontal axis indicates archaeological period associated with early modern human remains in Skhul and Qafzeh Caves in northern Israel (Schwarcz et al., 1988; Valladas et al., 1988; Mercier et al., 1993; Bar-Yosef, 1998; Grun et al., 2005). B: Relative age-frequency curve calculated from age data, showing fraction of samples that formed in same age interval at 95% confidence level. C: Periods of enhanced monsoonal activity in southern and central parts of Saharan-Arabian Desert indicated by horizontal bars: Ref. 1—Osmond and Dabous (2004); Ref. 2—Szabo et al. (1995); Ref. 3—Fleitmann et al. (2003), and Ref. 4—Smith et al. (2004b). Figure shows that early modern human presence in Levant started at peak wet phase of the desert.

multicollector–inductively coupled plasma–mass spectrometry (MC-ICP-MS) at the Geological Survey of Israel are described in detail in Vaks et al. (2006). Thirty-three samples were dated (Fig. 2A based on data in Table DR1). Although some speleothems were 20–30 cm thick, only the outermost laminae of overall thickness of 5–30 mm were dateable (Fig. DR1, see footnote 1). Some laminae were less than 2 mm thick, which limited the sample size for dating to 10–20 mg. However, the increase in analytical uncertainty in these samples was minor due to the relatively high U concentrations (see Table DR1). A relative age-frequency diagram was calculated using Isoplot/Ex 3 software (Fig. 2B) (Ludwig, 2003). The higher age-frequency peaks indicate more intensive speleothem deposition.

RESULTS AND DISCUSSION

The ages of speleothem deposition in the five caves mostly cluster between ca. 140 ka and 110 ka (interglacial MIS 5.5 and 5.4), with an additional minor deposition interval at ca. 88 ka (beginning of MIS 5.1) defined by one speleothem age (Fig. 2A). The speleothem age-frequency distributions (Fig. 2B) show that the major depositional period was between 133 and 122 ka.

No speleothem deposition was found between 185 and ca. 140 ka (MIS 6) (Fig. DR1, between ca. 110 and ca. 90 ka (MIS 5.4–5.2), and after ca. 85 ka (i.e., during the most of the interglacial MIS 5.1, the last glacial period, and the Holocene). We therefore conclude that the central and southern Negev Desert was arid to hyperarid during these periods. The lack of deposition during the glacial periods contrasts with the continuous deposition of speleothems in the Mediterranean climate zone (in northern and central Israel; Bar-Matthews et al., 2003), and with the speleothem deposition during glacial periods in northern Negev (Vaks et al., 2006). Hol-Zakh, the northernmost cave studied in this work (Fig. 1B), and the northern Negev Tzavoa Cave studied by Vaks et al. (2006) are located only 10 km apart, yet the two caves are characterized by a sharp present-day precipitation gradient (150–160 mm/yr at Tzavoa to 90–100 mm/yr at Hol-Zakh), which is marked by thinning of the speleothem laminae at Hol-Zakh and a different chronology of speleothem deposition events.

Speleothem deposition in an otherwise arid to hyperarid region indicates an increase of rainfall above the caves, leading to recharge of water in the unsaturated zone. The increase in precipitation in the Negev Desert could have occurred because of a southern shift of the Mediterranean cyclones and/or an increase in their intensity. However, the periods of enhanced rainfall most probably would have been short in duration and alternated with long droughts. The data supporting this hypothesis of episodic rainfall are: (1) only thin, 5–10 mm speleothem laminae were deposited in the caves, and (2) the absence of calcite horizons in middle-late Quaternary gypsic-salic soils of the southern Negev indicates that precipitation levels greater than 80 mm/yr could not have persisted for periods longer than tens to hundreds of years (Amit et al., 2006). Thus, the wet episodes were too short to cause the development of calcite horizons in the soils but long enough to allow the formation of thin speleothem laminae in the caves.

Although the wet episodes were short, they would have had a significant environmental impact. The caves are located at shallow depths (2–20 m) below the tops of the hills, and thus their catchments are small compared to those of wadi channels, which would have seen significantly greater amounts of water and increased vegetation cover. Pollen records show a significant contemporaneous development of vegetation cover over the entire region (Weinstein-Evron, 1987), and increased spring discharge is marked by travertine deposition in the hyperarid southeastern parts of the Negev Desert (Livnat and Kronfeld, 1985). Higher rainfall is also indicated by the Eemian record of perennial lakes in basins occupied today by playas in southern Jordan (Petit-Maire et al., 2002).

Figure 2 shows that the cluster of humid episodes in the Negev Desert between 140 and 110 ka was synchronous with increased monsoonal intensity in the southern Arabian Peninsula (Fleitmann et al., 2003) and the Saharan Desert (Szabo et al., 1995; Rohling et al., 2002; Osmond and Dabous, 2004; Smith et al., 2004b). This would have sustained habitable conditions for early modern humans over the entire desert belt, and not just in oases and the Nile Valley (Smith et al., 2004b). The northward movement of early modern humans through the Sinai-Negev land bridge would have been facilitated under these conditions, allowing them to reach the more hospitable climates of Levant ca. 130–100 ka, as documented by dated early modern human remains from the Skhul and Qafzeh Caves in northern Israel (Figs. 1B and 2) (Schwarcz et al., 1988; Valladas et al., 1988; Mercier et al., 1993; Bar-Yosef, 1998; Grun et al., 2005). Earlier prehistoric sites outside of Africa have not yielded unequivocal early modern human skeletal remains (Stringer, 2002; Barkai et al., 2003; Grun et al., 2005). The faunal assemblages of the archaeological layer in Qafzeh Cave (QF in Fig. 1B) show that Palearctic fauna, which dominated in the caves of southern Levant during MIS 6, disappeared at the onset of interglacial MIS 5, and African and Saharan-Arabian elements became the highest since 780 ka. These latter elements include species of micromammals, hartebeest, equids, and ostrich egg shells, all of which indicate an abundance of savannah species in the area (Rabinovich and Tchernov, 1995; Tchernov, 1992, 1996). The faunal assemblage of Qafzeh Cave thus provides supportive evidence for the northward expansion of African and Saharan-Arabian biotic zones during the period when early modern humans are first recorded in the area.

Middle Stone Age sites are found in the Negev and southern Jordan. Rink et al. (2003) suggested an age range of 90–220 ka or older for these Middle Stone Age sites. However, the absence of the skeletal remains makes it impossible to determine the hominid type.

The Nile River corridor provides a potential path to the Mediterranean Sea through the Saharan-Arabian Desert (route a in Fig. 1A). Wetter conditions in Sinai and Negev Deserts at this time would have made migration from the Nile Delta to the Levant easier. The increased monsoonal precipitation over the tropics and southern and central Saharan-Arabian Desert at 140–110 ka also would have enhanced the Nile River flow, made this route more usable, and opened new migration routes across the desert. Stringer (2000) also argued that prehistoric human expansions mainly occurred along the coasts, which provided the first and fastest migration routes. The possible coastal migration routes from Ethiopia to the Levant follow: (1) the African Red Sea coast (route b in Fig. 1A), or (2) the Arabian Red Sea coast (route c in Fig. 1A), if early modern humans crossed the Bab-el-Mandeb Straits (Rose, 2004). The Red Sea coastal routes were extremely arid before 140 ka and after 115 ka (Almogi-Labin et al., 2004). Archaeological evidence supports the proposition of Red Sea coastal migration routes. Walter et al. (2000) found that early modern humans occupied the arid Red Sea coast of Eritrea at 125 ka; Van Peer et al. (1996) reported evidence of early modern human occupation of Red Sea coastal mountains of southeastern Egypt during approximately the same period. Petraglia and Alsharekh (2003) found that Middle Stone Age sites of early modern humans (although not radiometrically dated) are concentrated in the western parts of the Arabian Peninsula and some of them are close to the Red Sea coast.

Whereas the significant increase in wet episodes over northern Africa during the 140–110 ka period could have removed the climatic barriers to human and animal migration to the north, the aridization of the northern parts of Saharan-Arabian Desert at ca. 110 ka (expressed by the cessation of speleothem deposition in the Negev caves) would have suppressed the return route from the Levant to Africa for at least 20,000 yr. The highest frequency of speleothem ages (indicating highest speleothem deposition rate) occurs in the earlier half of the 140–110 ka period, followed by a gradual decrease in deposition as conditions moved to aridity (Fig. 2B). Thus, this period of expanding aridity in the Saharan-Arabian Desert may have encouraged early modern humans to move further into the Mediterranean climate zone of the Levant and possibly to the other parts of Eurasia.

Wet interglacial events have been suggested to be crucial to the occurrence of Pleistocene migrations "out of Africa" (Derricourt, 2005). We therefore suggest that the episodic humid phase between 140 and 110 ka in the northern Saharan-Arabian Desert opened an important interglacial climatic window that allowed early modern humans to disperse out of Africa to other parts of the world.

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