Alluvial fan records from southeast Arabia reveal multiple windows for human dispersal

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ABSTRACT

The dispersal of human populations out of Africa into Arabia was most likely linked to episodes of climatic amelioration, when increased monsoon rainfall led to the activation of drainage systems, improved freshwater availability, and the development of regional vegetation. Here we present the first dated terrestrial record from southeast Arabia that provides evidence for increased rainfall and the expansion of vegetation during both glacial and interglacial periods. Findings from extensive alluvial fan deposits indicate that drainage system activation occurred during Marine Isotope Stage (MIS) 6

(ca. 160–150 ka), MIS 5 (ca. 130–75 ka), and during early MIS 3 (ca. 55 ka). The development of active freshwater systems during these periods corresponds with monsoon intensity increases during insolation maxima, suggesting that humid periods in Arabia were not confined to eccentricity-paced deglaciations, and providing paleoenvironmental support for multiple windows of opportunity for dispersal out of Africa during the late Pleistocene.

INTRODUCTION

Considerable debate surrounds the dispersal of human populations out of Africa. There are two predominant hypotheses concerning the timing of dispersal, each contrasting in their emphasis on the role of the Arabian interior and its changing climate. In one scenario, human populations expanded from an ancestral base in Africa, dispersing rapidly along the coastlines of Arabia to southern Asia ca. 60–50 ka (e.g., Mellars et al., 2013). Another model posits that dispersal into the Arabian interior began much earlier (ca. 130–75 ka), possibly during multiple phases (Groucutt and Petraglia, 2012), when increased rainfall provided sufficient freshwater to support expanding populations. Dated archeological sites in Arabia (Armitage et al., 2011; Petraglia et al., 2011, 2012; Rose et al., 2011) support an earlier model, and correspond with humid phases during Marine Isotope Stages (MIS) 5e (ca. 128–115 ka), 5c (ca. 105–95 ka), and 5a (ca. 85–74 ka).

Speleothem and lacustrine records confirm that during interglacial periods such as MIS 5e there were significant increases in humidity in Arabia, following northward incursions of monsoon rainfall (e.g., Burns et al., 2001; Fleitmann et al., 2003; Rosenberg et al., 2011). However, archives such as speleothems require >350 mm of rainfall to initiate growth (e.g., Vaks et al., 2010; Fleitmann et al., 2011), and periods of lesser rainfall that may be sufficient to sustain human populations but not speleothem growth are absent from these records. Consequently, some studies have suggested that climatic conditions during mid-high-latitude glacial periods represent a natural barrier to humans (e.g., Rosenberg et al., 2011), despite the presence of archeological sites dated to early MIS 3 (between ca. 55 and 40 ka) in the United Arab Emirates and Yemen (Armitage et al., 2011; Delagnes et al., 2012). By contrast, alluvial fan sequences have the potential to record a wide range of landscape changes and climatic events. Here we present a unique alluvial fan aggradation record from southeast Arabia spanning the past ca. 160 k.y. Situated along the proposed southern dispersal route, the Al Sibetah record is to date the most comprehensive terrestrial archive from the Arabian Peninsula, and provides evidence for multiple humid episodes during both glacial and interglacial periods.

ENVIRONMENTAL SETTING AND METHODS

Extensive bajadas emanate from the western flanks of the Hajar Mountains and extend to the Wahiba Sands in Oman (Fig. 1). Situated at the interface of the mountains and the Rub al Khali sand sea, these fans are particularly sensitive to changes in rainfall patterns and thus are excellent indicators of monsoon variability. Modern alluvial fans are largely relict under present climatic conditions; however, previous larger fans extended much further west and are now concealed beneath dunes. Several studies have highlighted the importance of these deposits as potentially important climatic indicators (Maizels, 1987; Burns and Matter, 1995; Preusser et al., 2002; Blechschmidt et al., 2009). The Al Sibetah quarry (N24.33346, E55.76125) exposes a 42 m succession within the partially buried Al Ain fan, comprising interbedded sands, conglomerates, and paleosols in multiple fining-upward cycles.

Paleoenvironmental (geochemical, carbonate isotope, magnetic susceptibility, phytolith, laser granulometry) analyses of the fine-grained sediment component (<2 mm) were used to detect the response of fan aggradation processes to climatic changes. The chronology is constrained by 12 single aliquot regenerative optically stimulated luminescence dates. Full methods and additional paleoenvironmental and chronological information are presented in the GSA Data Repository[1].

PALEOENVIRONMENTAL RECONSTRUCTIONS AND CHRONOLOGY

The Al Sibetah quarry comprises medial-distal alluvial fan sediments visible in multiple exposures 20–100 km downfan (Fig. 1). The fan is very low gradient (0.2°–0.5°), featuring imbricated gravel beds ~20 km from the fan apex, indicative of a fluvial (climatic) rather than a gravity-driven (base-level change) regime. The mixed clast and fine-grained sedimentary composition of the sequence is typical of mixed-load streams with braided reaches. Stream gravels, typified by high susceptibility values, fine upward into calcareous silts and sands, paleosols, or eolian material over 13 aggradation phases (**Fig. 2), each indicating a gradual waning of stream flow. Thick** homogeneous paleosols with extensive rootlets and bioturbation represent gradual sedimentation, landscape stabilization, and grassland development, which typically occurs over many years. Six periods of stream channel aggradation followed by soil and grassland development occurred during late MIS 6, with a mean depositional age of 158.7 ± 12.9 ka. This is in keeping with a peak in summer monsoon intensity and insolation between ca. 160 and 150 ka (e.g., Clemens and Prell, 2003). Phytolith data indicate a mix of C_3 (more humid) and C_4 (more arid) grassland types, with C_3 pooid phytolith morphotypes accounting for between 27% and 60%, and panocoid and chloridoid values ranges being 4.7%–10% and 3%–10%, respectively. The $\delta^{13}C$ values from pedogenic carbonates indicate an overall increase in the proportion of C_4 grasses across the landscape throughout late MIS 6 (−4.89‰ to +0.99‰). Soil and grassland formation and increased regional humidity are generally accompanied by a depletion of $\delta^{18}O$ values, increased hydrolysis, and decreased salinization, and decreased particle size and magnetic susceptibility values following the cessation of detrital and clastic influx (Fig. 2).

Three phases of stream channel activation and grassland development occurred between ca. 130 ka and ca. 88 ka, representing wet phases during MIS 5e (ca. 128–115 ka), MIS 5c (ca. 105–95 ka), and MIS 5a (ca. 85–74 ka). MIS 5e channel gravels are asymmetric in cross section with greater imbrication and depth, reflecting a localized increase in gravel accumulation and point-bar development indicative of a larger meandering channel. Soil formation and vegetative processes were restricted during MIS 5 (likely due to a more mobile channel with strong currents), and the zone of grassland formation was farther downfan. The $\delta^{13}C$ values during MIS 5 are between −3.45‰ and +0.58‰ and indicate a dominance of C_4 grasses throughout the landscape; however, a higher proportion of detrital and clastic material makes climatic interpretations from isotope data problematic. Panicoid values are highest (13%) during MIS 5e, with an overall higher proportion of woody taxa in the region during MIS 5 than MIS 6, and the highest values during MIS 5e. More mesic conditions are observed during MIS 5e and MIS 5a, and more xeric conditions during MIS 5c. This is supported by generally lower hydrolysis and greater salinization during MIS 5c.

MIS 5 sediments are overlain by a 2-m-thick sequence of eolian material dated to ca. 73 ka, reflecting dune mobilization and increased aridity during MIS 4. These are overlain by stream-channel gravels, which represent the redevelopment of a braided channel network during a subsequent humid phase. This stratigraphic unit was identified in distal exposures of the Al Sibetah fan at Remah (Fig. 1) ~40 km to the southwest and dated to ca. 55 ka (Farrant et al., 2012), and is indicative of increased rainfall during early MIS 3. No Holocene-age fan aggradation was recorded at Al Sibetah; however, an age of ca. 5 ka was recorded in overlying dune sands, representing a phase of dune formation during the mid-Holocene that broadly corresponds with the end of increased Holocene rainfall in Arabia (Parker, 2009).

DISCUSSION

The sequence at Al Sibetah provides a unique record of climate-driven landscape changes in Arabia between MIS 6 and MIS 3. This period coincides with key processes in human evolution: the origin of *Homo sapiens* in Africa (ca. 200–150 ka), the early dispersal of humans out of Africa (ca. 130–80 ka), and the post-MIS 5 dispersal into Asia during MIS 3 (ca. 60–50 ka). The availability of freshwater in the southern dispersal zone during these periods would have been critical to the demographic expansion of early human populations. Increased vegetation and grassland development within range of the mountains would have provided an attractive location for hunting, while the development of shallow aquifers along the bajada would have extended potable water resources for many months of the year by feeding springs and water holes.

Increased freshwater availability ca. 160–150 ka was accompanied by the development of savannah-type grasslands with a woodland component. While increased humidity at this time is documented in the Levant, central Negev, and southern Jordan (Bar-Matthews et al., 2003; Petit-Maire et al., 2010; Vaks et al., 2010), speleothem data from southern regions of Arabia suggest a continually hyperarid climate, with monsoon rainfall displaced substantially south due to increased glacial boundary conditions (Fleitmann et al., 2011). This study presents significant evidence for increased rainfall during MIS 6 in southern Arabia, demonstrating that the inland convection of monsoon rainfall is not prevented during glacial periods. This corresponds with marine evidence for monsoon intensification ca. 165–150 ka (e.g., Malaizé et al., 2006; Caley et al., 2011), and incipient soil formation reported in the Wahiba between ca. 160 and 140 ka (Preusser et al., 2002; Radies et al., 2004).

Fan activation throughout MIS 5 is consistent with speleothem and lake records from Oman, Yemen, and Saudi Arabia (i.e., Fleitmann et al., 2011; Rosenberg et al., 2011), and with an early expansion of human populations out of Africa (Groucutt and Petraglia, 2012). MIS 5e channel flow was typified by a larger fluvial system, which at times may have extended to the Persian Gulf coast (Farrant et al., 2012), facilitating demographic connectivity between mountainous and coastal regions. Drainage activation in the southernmost reaches of the bajada during MIS 5 led to the formation of the ~1400 km^2 paleolake Saiwan (Rosenberg et al., 2012), while to the north, extensive braided stream development occurred at Wadi Dhaid (Atkinson et al., 2013). Findings from Al Sibetah also indicate that MIS 5c was the weaker of the three MIS 5 humid periods, with decreased woody taxa and more xeric conditions than MIS 5e or 5a. It is important that the timing of freshwater availability and grassland development at Al Sibetah coincides with the occupation of Jebel Faya ca. 130–90 ka (Figs. 1 and 3), suggesting that fan drainage processes may have facilitated population movements through the region during that time.

Other studies have stated that ca. 75–10 ka, intense aridity prevailed in Arabia (e.g., Fleitmann et al., 2011; Rosenberg et al., 2011), preventing population movements through the interior. The posited major expansion of human populations out of Africa ca. 60–50 ka is in keeping with this notion, suggesting an exclusively coastal route (Mellars et al., 2013). However, paleoenvironmental evidence from Arabia indicates that sufficient freshwater resources existed in the interior to support expanding populations. Drainage activation between ca. 60 and 50 ka is recorded in several regions (Krbetschek, 2008; McLaren et al., 2009; Farrant et al., 2012; Parton et al., 2013), congruent with an increase in monsoon intensity recorded in marine records (e.g., Clemens and Prell, 2003; Govil and Naidu, 2010), speleothem data from Socotra (Burns et al., 2003), and a Middle Paleolithic site in Yemen dated to ca. 55 ka (Delagnes et al., 2012). Therefore, the notion that arid conditions during MIS 3 would have prevented dispersals through the Arabian interior is no longer tenable and thus challenges an exclusively coastal route of migration. It is significant that the periodicity of increased rainfall presented by the Al Sibetah and surrounding regional records suggests that incursions of monsoon rainfall, and in turn, periods of demographic expansion through the interior of Arabia, may have been driven by insolation maxima (Fig. 3), rather than mid-high-latitude deglaciations.

CONCLUSIONS

The Al Sibetah alluvial fan sequence provides a unique and sensitive record of landscape change in southeast Arabia between MIS 6 and MIS 3. Phases of monsoon-driven alluvial fan aggradation occurred during both glacial and interglacial periods, in line with insolation maxima. The occurrence of humid periods not previously identified in lacustrine or speleothem records highlights the complexity and heterogeneity of the Arabian paleoclimate, and suggests that interior migration pathways through the Arabian Peninsula may have been viable approximately every 23 k.y. since at least MIS 6.

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FIGURE CAPTIONS

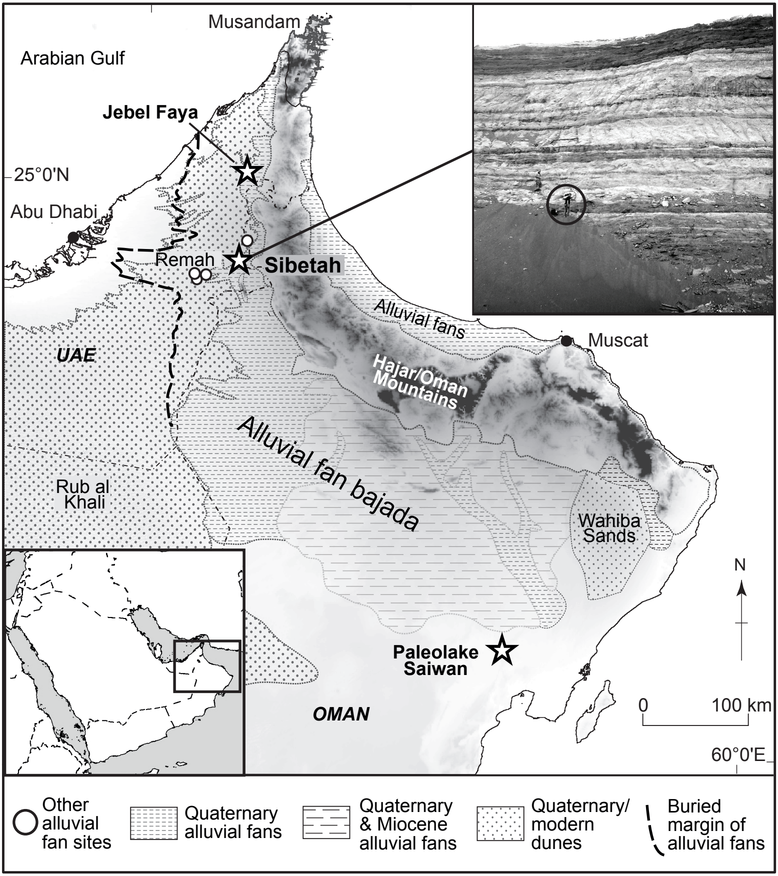
Figure 1. Map showing location of the study site and extent of bajada system in southeast Arabia, including other identified sections of the Al Ain fan (UAE—United Arab Emirates). Inset is photo of the exposed quarry site (person circled for scale). Jebel Faya (Armitage et al., 2011) and paleolake Saiwan (Rosenberg et al., 2012) are also shown.

Figure 2. Stratigraphic record and photograph of the sequence at Al Sibetah (southeast Arabia), showing aggradation phases 1–13, optically stimulated luminescence (OSL) ages, geochemical data (hydrolysis, salinization), carbonate isotope values ($\delta^{18}O_{carb}$, $\delta^{13}C_{carb}$), magnetic susceptibility values, and particle size analysis of <2 mm fine sediment fraction.

Figure 3. Comparison of paleoenvironmental records and dated Middle Paleolithic archeological sites from Arabia. Gray bars indicate humid periods relevant to this study. MIS—Marine Isotope Stage; VPDB—Vienna Peedee belemnite; XRF—X-ray fluorescence; IOSM—Indian Ocean Summer Monsoon Archeological sites: A—Shi'bat Dihya, Yemen (Delagnes et al., 2012); B—JQ1, northern Saudi Arabia (Petraglia et al., 2011); C—JKF, northern Saudi Arabia (Petraglia et al., 2012); D—Aybut Auwal, southern Oman (Rose et al., 2011); E—Jebel

Faya (assemblages A–C), United Arab Emirates (UAE) (Armitage et al., 2011). Paleoclimatic records: F—fluvial deposits, central Saudi Arabia (McLaren et al., 2009); G—Aqabah paleolake, UAE (Parton et al., 2013); H—Al Ain alluvial fan (UAE) at Remah (i), (Farrant et al., 2012) and Al Sibetah (ii); I—paleosols, Wahiba Sands, Oman (Preusser et al., 2002), J—paleolake Saiwan, Oman (Rosenberg et al., 2012); K—paleolakes Mundafan and Khujaimah, southern Saudi Arabia (Rosenberg et al., 2012); L—Moomi Cave speleothems, Socotra, Yemen (Burns et al., 2003); M—speleothems from Hoti Cave (Oman) and Mukalla Cave (Yemen) (Fleitmann et al., 2011); N—Arabian Sea productivity records from foraminiferal assemblages (solid line) (Caley et al., 2011) and bromine X-ray fluorescence counts (dashed line) (Ziegler et al., 2010); O—summer monsoon stack (dashed line), summer monsoon factor (black line) (Clemens and Prell, 2003); P—summer insolation at 30°N (Wm^{-2}) (Berger and Loutre, 1991). Dashed boxes represent either age uncertainties or inferred ages.

[1] GSA Data Repository item 2015xxx, details on methodologies, optically stimulated luminescence geochronology, and phytolith analysis, is available online at www.geosociety.org/pubs/ft2015.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.



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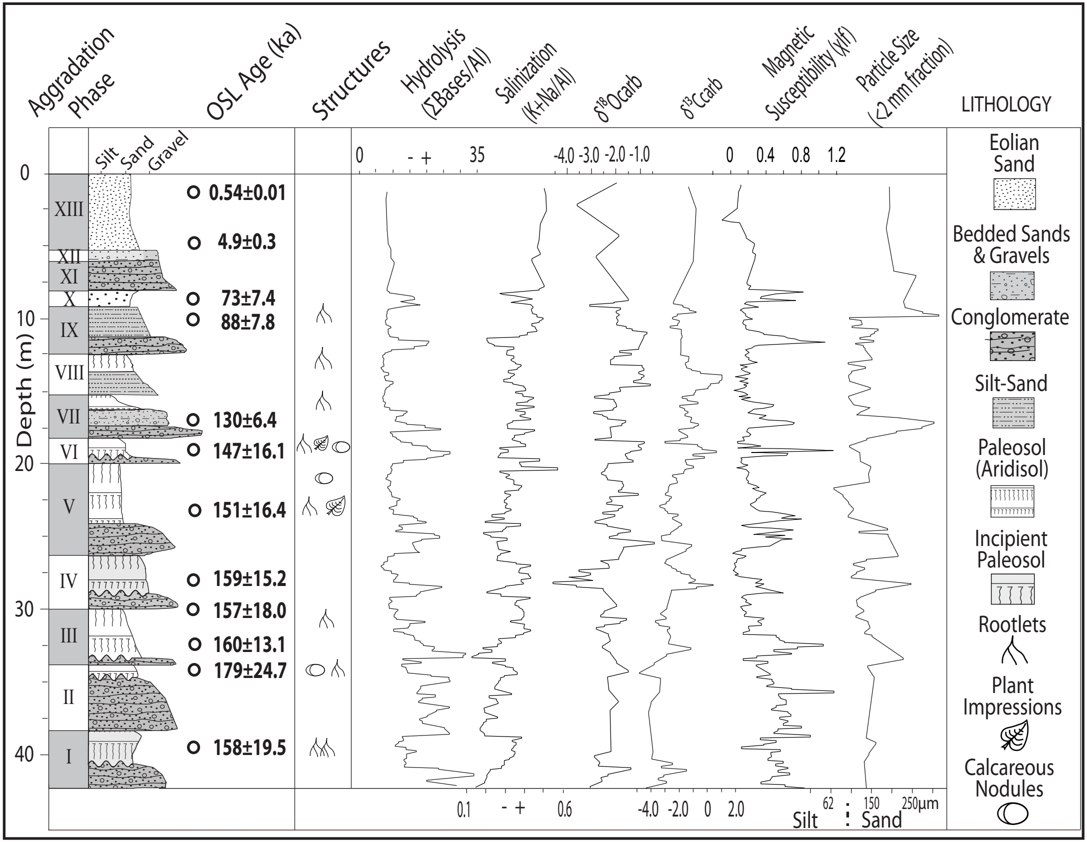

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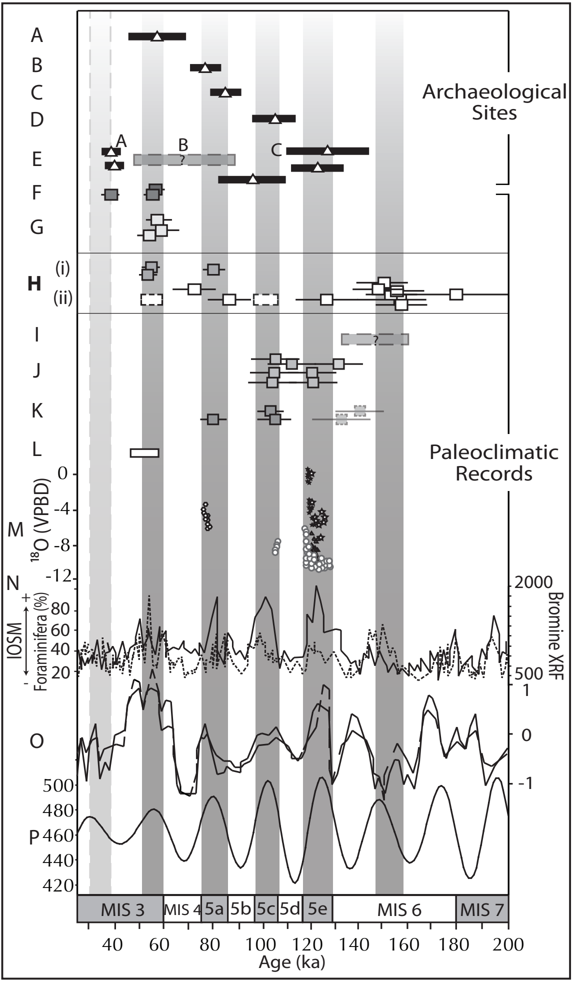

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