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A record of Holocene climate change from lake geochemical analyses in southeastern Arabia

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Abstract

Lacustrine sediments from southeastern Arabia reveal variations in lake level corresponding to changes in the strength and duration of Indian Ocean Monsoon (IOM) summer rainfall and winter cyclonic rainfall. The late glacial/Holocene transition of the region was characterised by the development of mega-linear dunes. These dunes became stabilised and vegetated during the early Holocene and interdunal lakes formed in response to the incursion of the IOM at approximately 8500 cal yr BP with the development of C3 dominated savanna grasslands. The IOM weakened ca. 6000 cal yr BP with the onset of regional aridity, aeolian sedimentation and dune reactivation and accretion. Despite this reduction in precipitation, the lake was maintained by winter dominated rainfall. There was a shift to drier adapted C4 grasslands across the dune field. Lake sediment geochemical analyses record precipitation minima at 8200, 5000 and 4200 cal yr BP that coincide with Bond events in the North Atlantic. A number of these events correspond with changes in cultural periods, suggesting that climate was a key mechanism affecting human occupation and exploitation of this region.

Keywords: Arabia; Archaeology; Geochemistry; Holocene; Lake levels; Abrupt climate change

Introduction

It has long been recognised that the early Holocene period across Arabia was characterised by pluvial conditions with the widespread development of lacustrine sediments across the Arabian sub-continent including the Rub' al-Khali (Empty Quarter) (McClure, 1976; Gebel et al., 1989), Ramlat as-Sabatyn (Lézine et al., 1998) and Nafud (Schultz and Whitney, 1986) desert regions. The period between 9000 and 6000 ^{14}C yr BP (10 500 to 6500 cal yr BP) has been identified as a major phase of lacustrine development in Arabia (McClure, 1976; Lézine et al., 1998) corresponding with increased solar heating across the Northern Hemisphere causing intensified monsoon precipitation fluxes over Arabia, North Africa and Asia (deMenocal et al., 2000; Gasse and Van Campo, 1994). Only a few sites have been identified with records extending into the late Holocene period, and these areas appear to have been supplied by additional winter-fed rainfall derived from cyclones that originated in the Mediterranean region. These sites are found in the Nafud region of Saudi Arabia (Schultz and Whitney, 1986) and the north-eastern extremity of the Rub' al-Khali in the United Arab Emirates (UAE) where the orographic effects of the Musandam mountains accentuate the rainfall (Parker et al., 2004).

While the character of the early to mid-Holocene period is broadly known, few detailed palaeoenvironmental analyses have been undertaken as most lake sequences recorded are shallow in depth and do not form substantial lithostratigraphic sequences. Vegetation reconstruction from Arabia is scant, with few pollen studies existing (Lézine et al., 1998; Garcia Antón

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and Sainz Ollero, 1999; Parker et al., 2004). The eastern Arabian Gulf has been an important focus for humans during the Holocene as it lies at the interface between the sea, the desert, gravel plains and mountain environments. The area is situated on a major trade route between South and Southeast Asia, and Europe and the Near East. This trade route was of importance from the earliest times when it joined two "cradles of civilization" and has maintained this importance through time. This region has a rich archaeological record when compared with the desert interior and the chronological and material–cultural sequence is fairly well established for the last 8000 yr (Potts, 1990a,b). While environmental archaeological analyses have provided insight into the botanical (e.g. Ishida et al., 2003), zoological (e.g. Uerpmann, 2002) and geomorphological (e.g. Goudie et al., 2000a,b,c) contexts for a number of archaeological sites, only a few long Holocene environmental sequences (e.g. Gebel et al., 1989; Parker et al., 2004) have been identified from which a framework of climate and landscape change may be developed.

Recent work in the southeastern Arabia, in the Emirate of Ras al-Khaimah, has revealed a long Holocene lake record (8500–3000 cal yr BP) with a preserved pollen and phytolith record (Parker et al., 2004). The site reveals a number of important floristic changes in the Holocene related to changes in the duration and intensity of the Indian Ocean monsoon from the early to mid Holocene, and winter derived cyclonic rainfall during the mid to late Holocene. The early Holocene landscape was characterised by the development of Pooid C3 dominated Savannah grassland between 8500 and 6000 cal yr BP with a strong woody element of *Acacia* and *Prosopis*. Between 6000 and 4000 cal yr BP the grassland element was replaced by Panicoid C4 types as the climate became more arid. This changed to a sparse vegetation cover of Chloridoid C4 grasses and sedges since 4000 cal yr BP (Parker et al., 2004). The sediment record reveals a number of abrupt changes that are not always clearly evident in the vegetation analyses. On this basis, the geochemistry of the sediment record was investigated to look further into the nature of the stratigraphic changes.

Few lake geochemical analyses have been conducted in the Middle East and southwest Asia and those undertaken to date are based on isotopic geochemical measurements rather than elemental analyses (Lemcke and Sturm, 1997; Enzel et al., 1999, 2003). In Arabia, no lake sediment geochemical analyses have been conducted to date. Closed basin lakes are useful repositories for palaeoclimatic study as the geochemical signatures in these systems should record changes in phases of allogenic (aeolian) and authigenic (lacustrine) sedimentation, which along with changes in the hydrological regime and salinity, reflect variations in precipitation and evaporation as a direct response to prevailing climatic conditions (Eugster and Hardie, 1978; Sinha and Smykatz-Kloss, 2003).

The aim of this paper is to present a Holocene chronology of palaeomonsoon rainfall variability and fluctuations in westerly-induced winter rainfall from southern Arabia from a lacustrine sediment record. From this, a framework of Holocene climate variability is constructed against which the archaeology of the region may be set.

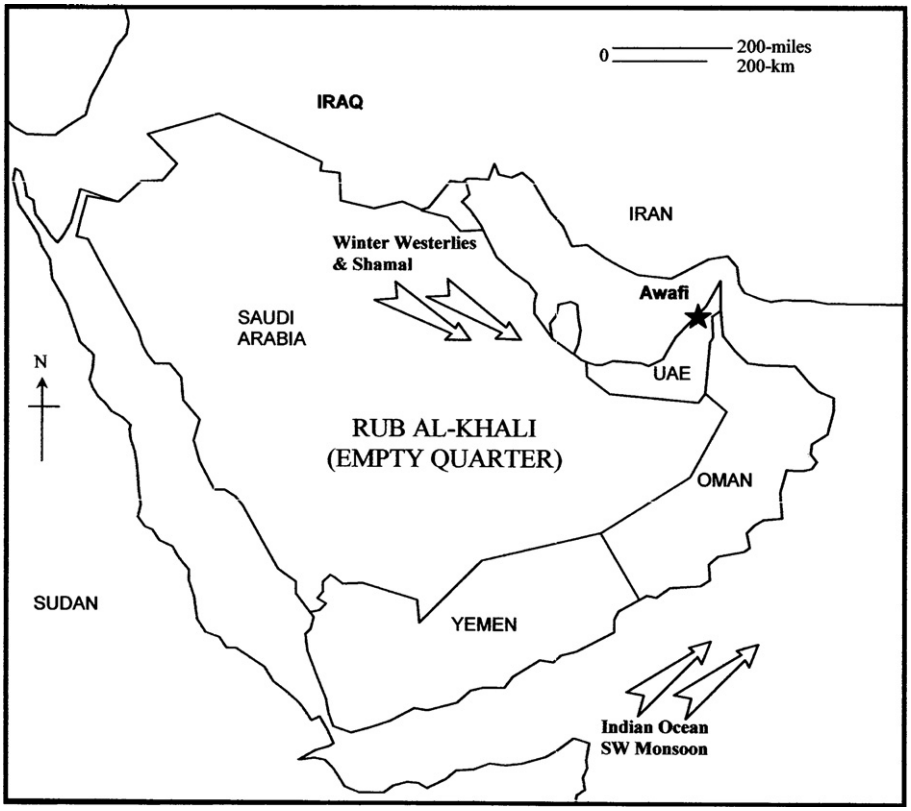

Figure 1. Map of Arabia showing the location of Awafi and the relative positions of the Indian Ocean Monsoon and westerlies (Shamal) based on Parker et al. (2004).