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Orbital-scale climate variability in Arabia as a potential motor for human dispersals

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ABSTRACT

The Arabian Peninsula is situated at an important crossroads for the movement of Pleistocene human populations out of, and into, Africa. Although the timings, routes and frequencies of such dispersals have not yet been confirmed by genetic, fossil or archaeological evidence, expansion into Arabia would have been facilitated by humid periods driven by incursions of monsoon rainfall, potentially from both Indian Ocean and African monsoon systems. Here we synthesise terrestrial and marine core palaeoclimatic data in order to establish the spatial and temporal variability of humid periods in Arabia between late Marine Isotope Stage (MIS) 7 and 3. Incursions of monsoon rainfall occurred during periods of insolation maxima at ca. 200–190, 170, 155, 130–120, 105–95, 85–75 and 60–55 ka, providing multiple 'windows' of favourable climatic conditions that could have facilitated demographic expansion through Arabia. Strong summer monsoons are generally associated with mid-high latitude interglacials, however, enhanced monsoon convection also brought rainfall into Arabia during global glacial phases, possibly due to a strengthened winter monsoon and a greater influence of southern hemispheric temperature changes. Key periods for dispersal into northern regions of Arabia correspond with the synchronous intensification of both eastern Mediterranean and monsoon rainfall systems at insolation maxima during MIS 7 and MIS 5, which may have facilitated demographic connectivity between the Levant and the Arabian interior. Environmental conditions throughout southern and southeast regions were also favourable to expansion during these times, although strong monsoons in these regions during MIS 6 and MIS 3 suggest further opportunities for demographic expansion and exchange. Terrestrial and marine evidence show that during early MIS 3 (ca. 60–50 ka), a strengthened monsoon led to the activation of interior drainage systems and increased productivity in coastal zones, indicating that favourable environmental conditions existed along both coastal and interior routes at that time.

1. Introduction

The effects of climatic variability continue to play a key role in debates concerning the adaptation and development of human populations both past and present. At the macro scale, climatic and environmental change have been linked to hominin diversification, speciation, extinction and migration events (e.g. Foley, 1994; Trauth et al., 2007; Shea, 2008; Grove, 2011, 2012), and although direct causal links between evolutionary and climatic 'events' remain unresolved, the demography of hominin populations would undoubtedly have been influenced by climatic and environmental change. Arguably one of the places in which such changes would have been most pronounced is the Arabian Peninsula. Situated at the interface of the mid-latitude Westerlies and African–Indian Ocean Monsoon systems, periodic incursions of increased rainfall associated with these systems have episodically transformed Arabia into a heterogeneous landscape comprised of large freshwater lakes and wetland areas surrounded by extensive grasslands. While this notion of a periodically 'green' Arabia is now generally accepted, given the scale and latitudinal range of the Peninsula, during humid periods the landscape would have still exhibited a

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variety of bioclimatic zones, making some regions more conducive to subsistence than others. As such, it is important to move beyond a simplistic 'wet vs. dry' dichotomy when assessing the suitability of Arabia for occupation through time, by examining a spatially and temporally broad range of both terrestrial and marine palaeoclimatic indicators that reflect the spatio-temporal complexity of the Arabian palaeoclimatic record.

The early dispersals of *Homo* sapiens out of Africa during Marine Isotope Stage (MIS) 5 (ca. 130–75 ka) indicates that populations were able to expand into the previously arid/hyper-arid Saharo-Arabian desert belt during humid periods. This may be corroborated by the growing number of archaeological sites in the desert interior of Arabia dated to this period (e.g. Armitage et al., 2011; Petraglia et al., 2011, 2012; Rose et al., 2011; Groucutt and Petraglia, 2012; Groucutt et al., 2015a,b; Scerri et al., 2015), which are themselves indicators of increased humidity; during arid climatic conditions there is insufficient surficial freshwater to sustain human and animal populations in these regions. Proponents of a later rapid coastal dispersal at ca. 60–50 ka (e.g. Mellars, 2006; Mellars et al., 2013) have disregarded the climate changes of Arabia for this period, however, both coastal and interior zones would have been greatly influenced by monsoon variability. Numerous marine records have shown that seasonal productivity changes in the south Arabian coastal zone have been intimately tied to monsoon-driven upwelling over the past ca. 150 thousand years ago (i.e. Prell and Van Campo, 1986; Leuschner and Sirocko, 2003).

The timing of humid periods in Arabia has been broadly established through both marine and terrestrial records, although discrepancies between these sets of archives have become apparent. Terrestrial records (predominantly lakes and speleothems) have indicated that significant intensifications of the monsoon system occurred at ca. 130–120 ka (MIS 5.5), ca. 105–95 ka (MIS 5.3), ca. 85–75 ka (MIS 5.1) and during the early Holocene (ca. 11–6 ka; e.g. Burns et al., 1998; Fleitmann et al., 2011; Rosenberg et al., 2012; Lézine et al., 2007), with a long arid period between MIS 5 and the early Holocene believed to be too hostile for demographic expansion (Rosenberg et al., 2012). Marine records, however, indicate that increases in monsoon intensity have been far more frequent, corresponding with insolation maxima every ca. 23 thousand years (e.g. Clemens and Prell, 2003; Ziegler et al., 2010; Caley et al., 2011a). The paucity of evidence in the terrestrial record for major wet phases between MIS 5 and the Holocene has led some researchers to suggest that glacial boundary conditions drive monsoon variability, with expansion of the major ice sheets suppressing the northward movement of the Inter Tropical Convergence Zone (ITCZ) and associated monsoon belt (Fleitmann and Matter, 2009; Rosenberg et al., 2012). Conversely, evidence from marine records appears to show a strong coherence between monsoon variability and orbitally driven insolation changes, with monsoon intensity increasing during both northern hemispheric glacial and interglacial periods. Additionally, the extent to which westerly-derived rainfall periodically extended southwards into the Arabian interior during glacial periods is also poorly understood. These contradictions, combined with a tendency to frame Arabian terrestrial records in accordance with northern hemispheric global ice volume patterns, have inhibited our understanding of early demographic expansions into the peninsula.

In order to address these issues, we present an overview of the modern climatic setting of Arabia, together with a synthesis of critical aspects of terrestrial and marine records from in and around the peninsula, in order to develop a framework of palaeoclimate variability. This synthesis focuses on the period between MIS 7 and early MIS 3, as this interval encompasses three critical periods in the development of human populations: i) the emergence of *Homo sapiens* in Africa by ca. 200 ka; ii) the dispersal of human populations out of Africa and into the Levant at ca. 130–90 ka; and iii) the expansion of populations into Asia at ca. 60–45 ka. Rapidly emerging evidence, particularly of glacial-phase climatic complexity in Arabia, highlights the requirement for an updated palaeoclimatic framework for the peninsula for these key periods, which will help shed new light on human demography in the region.

2. The Arabian climate

2.1. Modern climatic setting

The climate of the Arabian Peninsula results from the complex interaction of several atmospheric systems. The greater monsoon system, which stretches from the Atlantic coast of West Africa across the Arabian Sea and Asia to northern Australia, conveys energy and affects climate on a global scale (Clift and Plumb, 2008). Monsoon-derived rainfall is at present limited to the southernmost regions of the Arabian Peninsula, with the Yemen Highlands and Asir Mountains of Saudi Arabia receiving up to 1000 mm of annual rainfall (Parker, 2009). This seasonally reversing annual system is driven by a land–sea thermal contrast and incoming solar radiation (insolation) changes. During the summer, increased surface heating of the Eurasian landmass in response to greater insolation draws the ITCZ and associated monsoon belt northward to a position more than 12° away from the equator (Fig. 1). This latitudinal shift of the ITCZ is accompanied by the development of a monsoon trough of intense horizontal wind shear extending from the Rub al-Khali to the Tibetan Plateau (McGregor and Nieuwolt, 1998), with a resultant southwesterly wind regime. A corresponding high-pressure system, the Mascarene High, occurs simultaneously across much of the southeast Indian Ocean (Krishnamurti and Bhalme, 1976) and is typified by a large outflow of northward-moving air. Once across the equator, this outflow (the cross-equatorial Findlater, East African or Somali Jet) becomes a south-westerly, splitting into two branches at around 10°N, 60°E, and reaching maximum intensity between June and August (Findlater, 1969; McGregor and Nieuwolt, 1998), turning anticyclonically to sweep over parts of Arabia and India (Boos and Emanuel, 2009). Not only does this remarkably stable, moisture-laden jet bring significant volumes of precipitation to the Indian sub-continent, it also gives rise to intense upwelling of cold, nutrient-rich water along the coasts of Yemen and southern Oman, coincident with convergent downwelling in the central and eastern parts of the Arabian Sea (e.g. Nair et al., 1989; Honjo and Weller, 1997; Rixen et al., 2005; Prasanna Kumar et al., 2001).

In addition to monsoon-sourced rainfall, the Arabian Peninsula is also affected by mid-latitude Westerlies (MLW) that originate in the eastern Mediterranean (Enzel et al., 2008) and progress across the Arabian Gulf during the winter months, causing enhanced cyclogenesis throughout the eastern Mediterranean, Red Sea, southern Iran and northern Arabia (i.e. Eshel and Farrell, 2000; Arz et al., 2003). Deep depressions from the eastern Mediterranean may penetrate as far southeastward as eastern Saudi Arabia (Barth and Steinkohl, 2004) and central Oman (Weyhenmeyer et al., 2000). This northwestern source of rainfall constitutes some 40–50% of the total precipitation of northern Arabia (Fisher and Membery, 1998). Anticyclonic circulation around a semi-permanent high pressure cell over northern Arabia, combined with cyclonic circulation around the Asian low pressure system, also gives rise to low-level winds known as the Shamal (Edgell, 2006). These blow northwest to southeast down the Arabian Gulf, before changing direction to cross the Rub' al-Khali (Glennie and Singhvi, 2002), reaching their peak during the summer months. Although the extension of MLW rainfall into southeastern regions of Arabia is aided by the convection of moisture from the Gulf, a