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Late Holocene vegetation and ocean variability in the Gulf of Oman

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ABSTRACT

Fossil pollen and dinocyst records in marine sequences are frequently combined to reveal the response of vegetation and ocean conditions to changes in both regional and global climate. In this study we analysed pollen and dinocysts within a clearly-laminated sediment core off the Iranian coast in the Gulf of Oman, an extremely data-poor area, to reconstruct climatic change during the Late Holocene (last 1900 years). The vegetation record from southern Iran indicates a replacement of savannah by desert formations at *c.* 910 CE, shortly after the Islamic invasion and the subsequent collapse of the Sassanid Empire. From *c.* 910 to 1145 CE, during the Medieval Climate Anomaly (MCA), the vegetation was heavily dominated by desert formations, such as Amaranthaceae, Caryophyllaceae, Asteraceae, *Centaurea* and *Calligonum*. In parallel, in the Gulf of Oman, the presence of *Impagidinium paradoxum* indicates a lack of freshwater discharge into the ocean around this time. The desert taxa of the MCA were subsequently replaced by savannah formations at *c.* 1145 CE, comprised mainly of Poaceae and Cyperaceae, corresponding to the Little Ice Age (LIA), indicating generally wetter climatic conditions. A sudden increase in *Spiniferites ramosus* (1–63%), at *c.* 1440 CE suggests an increase in the strength of the SW summer monsoon, with increased freshwater discharge into the ocean at this time. Our data indicate that over the past two millennia the NW Arabian Sea region has alternated between contrasting climatic conditions, with firstly a humid phase equivalent to the cultural period of the Sassanid Empire, a significantly drier climate during the MCA and a relatively wetter climate during the LIA. The mechanisms resulting in dry conditions during the MCA in the Middle East associated with the northward shift of the ITCZ and the intensification of the Indian summer monsoon may be similar to those causing the dry conditions which dominated the Early Holocene in the Near East. Our palaeoenvironmental proxy data support current observations that a globally anthropogenically-induced warmer climate is likely to lead to increased drought severity in the Middle East, putting additional stress on governments already struggling with poverty and social tensions.

1. Introduction

Observations show that globally-averaged combined land and ocean surface temperatures have risen by 0.85 °C over the last century (1880–2012 CE; Hartmann et al., 2013). These global rises in temperature have impacted natural and human systems on all continents (Hartmann et al., 2013). In extreme cases many regions have seen significant changes in precipitation, which led to increased floods, droughts and heat waves, profoundly altering ecosystem dynamics as well as disrupting food production and water supply (Min et al., 2011; Dai, 2013). Although model-simulated soil moisture, drought indices and precipitation-evaporation models suggest an increase in the risk of drought during the 21st century (Rind et al., 1990; Wang, 2005; Seager et al., 2007; Burke and Brown, 2008; Sheffield and Wood, 2008; Dai, 2013), large differences still occur between the globally observed and simulated drought patterns (Dai, 2013). Environmental reconstruction of regional climates over periods of known past globally-warm climates can help: i) to assess the environmental impact of globally-warm climates on terrestrial and marine ecosystems, and ii) to evaluate the capabilities and the limitations of global climate models, further increasing our confidence regarding future model predictions.

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The warmest period of the last 2000 years, prior to the 20th century, was likely between 1000–1270 CE, the 'Medieval Climate Anomaly' (MCA; Lamb, 1977; IPCC, 2013). Numerous studies have attempted to produce environmental reconstructions over the MCA, in order to define medieval warmth, concluding that the warmth was heterogeneous in terms of its precise timing and regional expression (Jones and Mann, 2004; Graham et al., 2011; Guiot, 2012; IPCC, 2013). Continental-scale surface temperature reconstructions show, with high confidence, that in some regions, multi-decadal periods during the MCA were as warm as during the late 20th century (IPCC, 2013). Recent studies indicate that medieval warmth was indeed a global phenomenon, felt as far away as the western Pacific (Rosenthal et al., 2013). Nevertheless, with only a few high-resolution records from the tropics and the southern hemisphere, it is still problematic to make accurate estimates of global temperatures over the MCA (Bradley et al., 2003). To reduce the uncertainty and to make meaningful estimates of global medieval climatic conditions and the associated ecosystem response, more palaeoclimatic series must be produced with wider geographic coverage (IPCC, 2007).

Over the last century much of the Middle East, Iran in particular, has been experiencing severe drought. In the year 2000, the United Nations estimated that drought cost Iran over 3.5 billion dollars (Abbaspour et al., 2009; Moradi et al., 2011). In many parts of Iran, water supply is solely dependent on groundwater (Abbaspour et al., 2009). Over the past two decades overexploitation of water resources has caused a drawdown in the water table in most of the 600 aquifers in Iran (Motagh et al., 2008). Additionally, models predict a future decrease in groundwater recharge in already water-scarce regions in the south and east of the country (Abbaspour et al., 2009). It is now becoming increasingly important to focus efforts on understanding the factors controlling precipitation variability in the region. It is uncertain whether recent multi-decadal drought is anomalous in the context of Late Holocene climate variability, because long instrumental records and palaeoclimatic reconstructions in the Middle East are lacking (Molavi-Arabshahi et al., 2015). Analysing palaeoclimatic reconstructions across periods of globally-warm temperatures in the Middle East will provide insight into how ecosystems may respond in the face of anthropogenic global warming.

By analysing both pollen grains and organic-walled dinoflagellate cysts (dinocysts) from sediment core OS73, off the southern Iranian coast, the aims of this investigation are therefore to: i) reconstruct the vegetation history in the region of southern Iran, ii) reconstruct marine conditions in the Gulf of Oman, both throughout the last 1900 years with focus on the MCA, and iii) suggest the likely environmental response of the region to future climate change.

2. Settings

2.1. Prevailing climate

The climate of Iran is defined as subtropical with hot and dry weather in the summer, with the primary cause of annual rainfall variability been the changing position of synoptic systems and year-to-year variation of the frequency of cyclones passing through the region (Modarres and Rodrigues, 2007). A large high pressure system is present throughout the year over the majority of south-west Asia (Snead, 1968). Over half of the country receives less than 200 mm yr^{-1} of precipitation with over 75% receiving less than 300 mm yr^{-1} (Dinpashoh et al., 2004). The country's average rainfall is 260 mm yr^{-1}, with the coefficient of variation varying from 18% in the north to 75% in southeast (Dinpashoh et al., 2004). The core OS73 site, in the Gulf of Oman, is positioned just above the northern extent of the ITCZ, placing it in the zone of climatic transition between the Indian summer monsoon and the Mediterranean depressionary system (Meher-Homji, 1971, Fig. 1). Rainfall in the Chabahar region occurs between October and June with no rainfall during the summer months. The hot, dry summers along the southern Makran coasts are almost void of rain due to 'capping' by subtropical high pressure. The annual temperature dataset is incomplete, but the available data indicate average temperatures of 33.5 °C (New et al., 2000).

2.2. Modern vegetation

Five vegetation biomes have been recognised in the Middle East by Olson et al. (2001): i) deserts and xeric shrublands, ii) temperate broadleaf and mixed forests, iii) montane grasslands and shrublands, iv) temperate grasslands, savannahs and shrublands, and v) flooded grasslands and savannahs. The most extensive biomes in the Middle East are deserts and xeric shrublands, with montane grasslands and shrublands and flooded grasslands and savannahs limited to small areas at high altitude or within the Tigris-Euphrates alluvial salt marshes, respectively (Olson et al., 2001). These five vegetation biomes have been further subdivided into twelve ecoregions that have characteristic vegetation associations which are, in turn, related to the prevailing climate conditions (Fig. 1; Olson et al., 2001).

The Iranian continent immediately north of core site OS73 lies

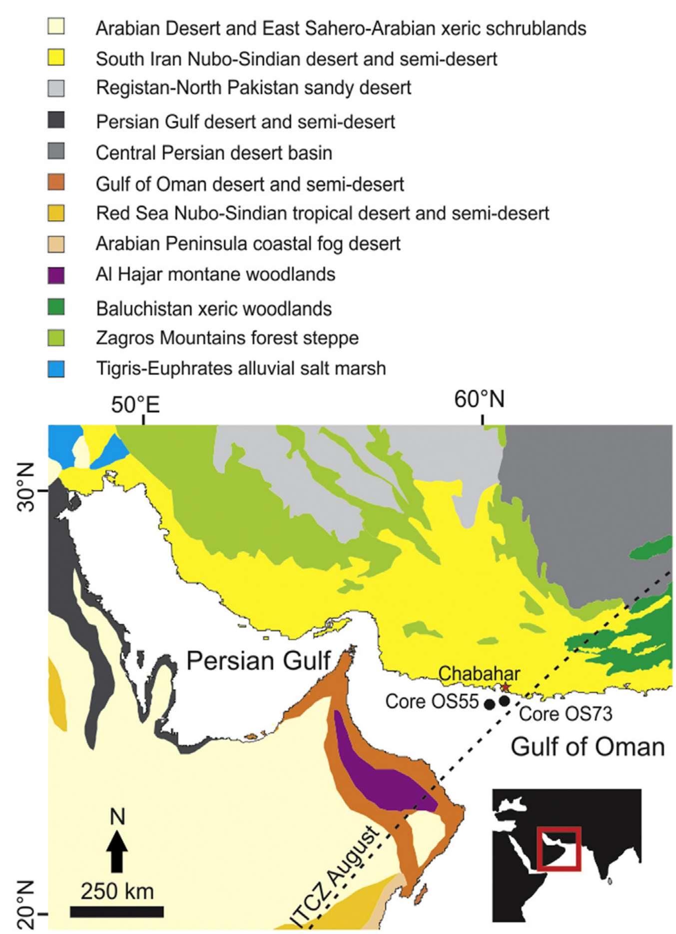

Fig. 1. Map of the modern vegetation ecoregions of NE Arabian Peninsula and S Iran (Olson et al., 2001) with the location of core site OS73 (this study), OS55 (Miller et al., 2013) and the summer ITCZ.