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Late Quaternary sea-level changes of the Persian Gulf

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ABSTRACT

Late Quaternary reflooding of the Persian Gulf climaxed with the mid-Holocene highstand previously variously dated between 6 and 3.4 ka. Examination of the stratigraphic and paleoenvironmental context of a mid-Holocene whale beaching allows us to accurately constrain the timing of the transgressive, highstand and regressive phases of the mid- to late Holocene sea-level highstand in the Persian Gulf. Mid-Holocene transgression of the Gulf surpassed today's sea level by 7100–6890 cal yr BP, attaining a highstand of >1 m above current sea level shortly after 5290–4570 cal yr BP before falling back to current levels by 1440–1170 cal yr BP. The cetacean beached into an intertidal hardground pond during the transgressive phase (5300–4960 cal yr BP) with continued transgression interring the skeleton in shallow-subtidal sediments. Subsequent relative sea-level fall produced a forced regression with consequent progradation of the coastal system. These new ages refine previously reported timings for the mid- to late Holocene sea-level highstand published for other regions. By so doing, they allow us to constrain the timing of this correlatable global eustatic event more accurately.

Introduction

The present-day morphology of the Abu Dhabi coastline of the United Arab Emirates is interpreted to have developed during the late Holocene as sediment accreted around Pleistocene age limestone cores, associated with the eastern termination of the Great Pearl Bank, and prograded into the recently flooded Persian Gulf (e.g. Evans et al., 1969; Purser and Evans, 1973; Lokier and Steuber, 2008). However, establishing the timing of the Holocene sea-level maximum for the Persian Gulf, and, hence, the initiation of late Holocene progradation of the Abu Dhabi shoreline, has been problematical. This study employs sedimentary sections hosting a cetacean skeleton as a data source to provide new evidence for the constraint of the Holocene sea-level maximum in the Persian Gulf.

During the Last Glacial Maximum (LGM), between 26.5 and 19 ka (Clark et al., 2009), eustatic sea level lay between 120 and 130 m lower than present-day sea level (Fleming et al., 1998; Peltier and Fairbanks, 2006; Clark et al., 2009; Hanebuth et al., 2009). During this time, the sea floor of the Persian Gulf was exposed and terrestrial aeolian processes became dominant. The northwesterly Shamal wind blew sand, sourced from Iran, towards the south and east and an extensive dune system developed over much of the basin floor (Sarnthein, 1972). With the end of the LGM, between 20 and 19 ka (Yokoyama et al., 2000; Clark et al., 2009), a pulse of fresh water caused a rapid sea-level rise of 10 m (Clark et al., 2009; Hanebuth et al., 2009), followed by a slower, relatively sedate, increase. Marine waters reached the Strait of Hormuz at approximately 14 ka and by 12.5 ka had entered the Gulf itself and a true seaway had been established (Lambeck, 1996).

The objectives of this study are to utilise a whale-beaching event to refine the timing and amplitude of the Holocene sea-level maximum in the Persian Gulf and establish the paleoenvironmental and sequence stratigraphic context of the coastal system at that time. By understanding these factors it will be possible to establish better-constrained sedimentological and stratigraphic models for the development of the Holocene sabkhas of the southern shoreline of the Persian Gulf. These systems are the oft-cited analogue for many of the petroleum reservoirs of the Middle East, thus, an understanding of their mode of formation is imperative to the interpretation of ancient petroleum systems and the development of accurate reservoir models.

Location of study area

The study site lies in the Mussafah Channel situated in the Mussafah Industrial Zone of Abu Dhabi (Fig. 1). The Mussafah Channel is an 8.3 km long dredged channel that was excavated through the coastal Sabkha sequence during the early 1980s. As no further development of the channel took place, the unsupported walls collapsed and eroded back to expose fresh surfaces. Erosion continued until 2006 when a cetacean

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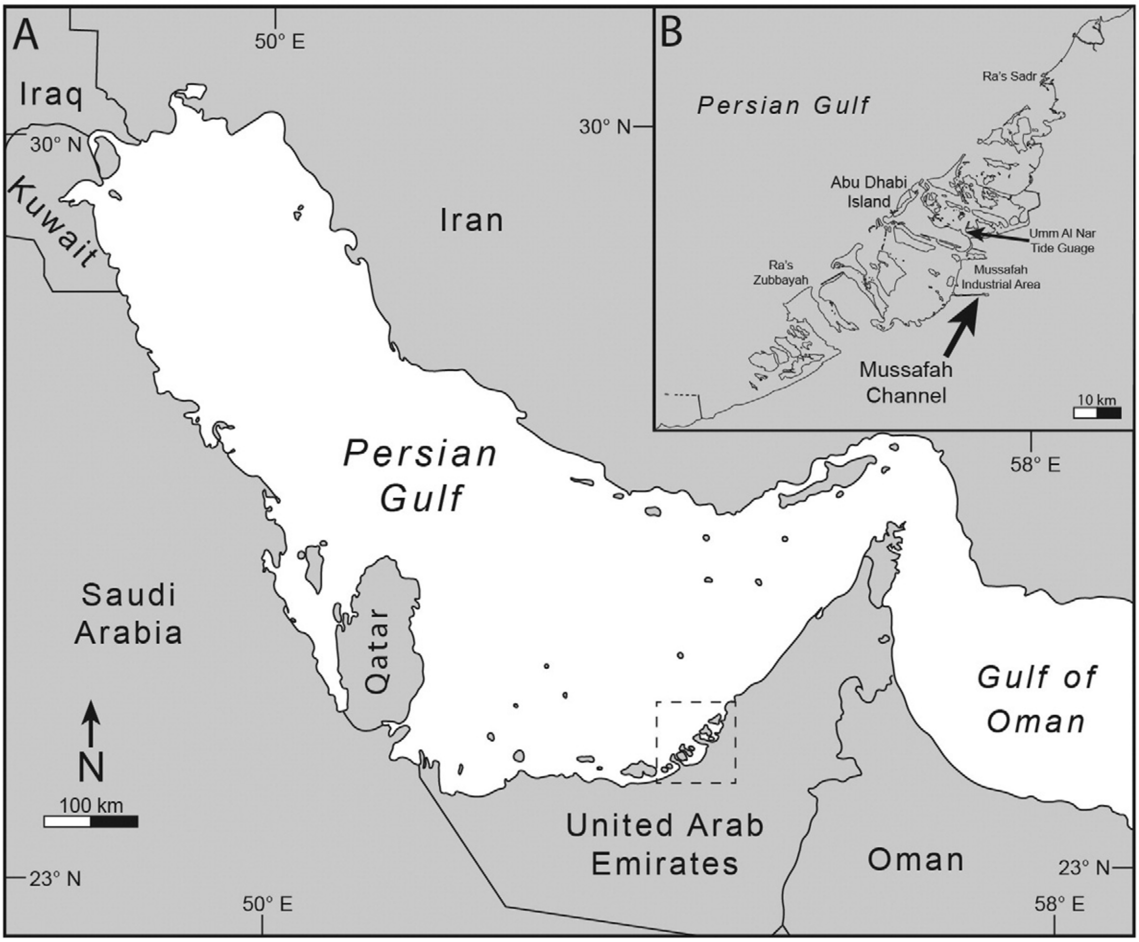

Figure 1. Map of the Persian Gulf region. The dashed box indicates the location of panel B. B) Detailed map showing the location of the Mussafah Channel.

mandible was exposed at the eastern termination of the channel. Excavation revealed a largely intact skeleton of a baleen whale of the genus *Megaptera* (Stewart et al., 2011) of which the front 10 m was recovered, including the most-diagnostic cranial and forelimb parts.

Geographic and climatic setting

The Persian Gulf is a shallow epicontinental sea lying in a crescentic northwest to southeast oriented basin floored by the continental crust of the northern margin of the Arabian Plate (Fig. 1). The Zagros Mountains bound the northern shores whilst the south and west shorelines are bordered by the low-relief Arabian Peninsula. Water depths are shallow, with an average depth of 35 m and rarely exceed 100 m. The floor of the Gulf dips gently north-eastward with the deepest water areas lying close to the southern coast of Iran.

The Persian Gulf coastline of the emirate of Abu Dhabi forms part of a low-angle carbonate ramp depositional system. The supratidal zone of this ramp is characterised by an active sabkha setting in which recent evaporite minerals are precipitating within the shallow subsurface and an ephemeral halite crust at the surface (Lokier, 2012). The sabkha grades seawards into a broad intertidal mud flat with well-developed microbial mat communities characterising the upper intertidal zone and a polygonal hardground in the lower intertidal zone (Lokier and Steuber, 2009). The hardground extends offshore into the shallow, carbonate-dominated subtidal setting. The mainland coast of Abu Dhabi is locally protected from open-marine conditions by a number of peninsulas and offshore shoals and islands (Fig. 1) associated with the east–west trending Great Pearl Bank. The limited fetch of the Persian Gulf inhibits wave development, thus, low-energy conditions dominate. The tidal regime of the Persian Gulf is microtidal (1–2 m).

The very low-angle geometry of the Abu Dhabi coastline results in this region being extremely sensitive to fluctuations in sea level. Even small changes in relative sea level will result in significant lateral shifts in facies belts. For example, current estimates of eustatic sea-level rise of 3.3 mm/yr (Cazenave and Nerem, 2004; Leuliette et al., 2004) would result in marine transgression of the Abu Dhabi shoreline at a rate of 8.25 m/yr. This transgression is, to some extent, countered by progradation of the sabkha system (Lokier and Steuber, 2008). The sensitivity of this coastal system to minor sea-level fluctuations provides an opportunity to apply these findings beyond the immediate region of the Persian Gulf to further constrain the timing and extent of the mid- to late Holocene global sea-level highstand.

The climate at the Abu Dhabi coast is extremely arid with a mean annual precipitation of 72 mm (Raafat, 2007). Rainfall is often extremely localised, occurring as brief heavy rainstorms concentrated during the months of February and March. Some regions may not experience any rainfall for periods in excess of a year. Evaporation rates are high with an annual mean of 2.75 m (Bottomley, 1996) resulting in elevated salinities of 45–46 g l^{-1} along the open-marine coast of Abu Dhabi and up to 89 g l^{-1} in restricted lagoons (Lokier and Steuber, 2009). Coastline temperatures 50 km west of Abu Dhabi City range between 7°C at night during the winter and 50°C during daytime in the summer (Lokier et al., 2013). The prevailing wind is the north-westerly Shamal. The shallow warm waters of the coast generate high coastal humidity, often reaching 100% during summer months.