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# Eustatic control of late Quaternary sea-level change in the Arabian/Persian Gulf

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ABSTRACT

Accurate sea-level reconstruction is critical in understanding the drivers of coastal evolution. Inliers of shallow marine limestone and aeolianite are exposed as zeugen (carbonate-capped erosional remnants) on the southern coast of the Arabian/Persian Gulf. These have generally been accepted as evidence of a eustatically driven, last-interglacial relative sea-level highstand preceded by a penultimate glacial-age lowstand. Instead, recent optically stimulated luminescence (OSL) dating suggests a last glacial age for these deposits, requiring >100 m of uplift since the last glacial maximum in order to keep pace with eustatic sea-level rise and implying the need for a wholesale revision of tectonic, stratigraphic and sea-level histories of the Gulf. These two hypotheses have radically different implications for regional neotectonics and land–sea distribution histories. Here we test these hypotheses using OSL dating of the zeugen formations. These new ages are remarkably consistent with earlier interpretations of the formations being last interglacial or older in age, showing that tectonic movements are negligible and eustatic sea-level variations are responsible for local sea-level changes in the Gulf. The cause of the large age differences between recent studies is unclear, although it appears related to large differences in the measured accumulated dose in different OSL samples.



## Introduction, geologic and stratigraphic setting

### *Previously prevailing sea-level history of the Arabian/Persian Gulf*

Relative sea level in the Arabian/Persian Gulf (Fig. 1) during the Quaternary has generally been considered as controlled eustatically under relatively stable tectonic conditions, with a fall of 110–125 m and the exposure of the entire sea bed of the Gulf during the last glacial maximum (Kassler, 1973; Lambeck, 1996). This classic interpretation has been based largely on the apparent stratigraphic position and depositional interpretation of the Fuwayrit and Ghayathi Formations (Figs. 2 and 3) and deflated Holocene beach ridges that are exposed along the southern edge of the Gulf.

As part of the above interpretation it was considered that during the global low sea levels of the middle and early Pleistocene glaciations (>250 ka), an aeolian dune field of quartzose dune sand (later to become the Ghayathi Formation; Figs. 2 and 3) was transported from the northwest by the palaeo-Shamal wind and covered the present site of the U.A.E. At about 250–200 ka, sea level rose during an interglacial period and transgressed onto the Arabian Peninsula, resulting in carbonate deposition including the development of coral reefs (Evans et al., 2002; Evans and Kirkham, 2005). Subsequent regression led to these deposits being covered by carbonate-rich aeolian dune sands derived from the adjacent exposed shelf. These sands extended inland so that the aeolian dunes in proximity to the coast became almost entirely composed of $CaCO_3$ (later to become known as 'Miliolite', and considered to be a carbonate variant of the Ghayathi Formation). The penultimate sea-level rise (ca. 125 ka) resulted in deposition of shallow water intertidal carbonates (later to become the Fuwayrit Formation) above the Miliolite. Global sea level fell again during the last glaciation to 110–125 m below present-day level at ca. 18 ka (Whitehouse and Bradley, 2013). The succeeding and latest (Holocene) transgression climaxed at a height of approximately 1–2 m above present-day sea level ca. 6 ka, well below the height of many outcrops of the Fuwayrit Formation that capped the zeugen, and was accompanied by continued deflation due to drowning of the aeolian source area. As a result, carbonate aeolian dunes and their capping of marine sediment near the coast were cannabalised by the wind to leave merely remnants that form cores of the barrier islands and zeugen scattered in the lagoons and across the coastal sabkha (Fig. 3). The flat coastal sabkha surface therefore expanded landwards along its innermost reaches due to deflation (Kirkham, 1998a,b; Evans and Kirkham, 2005).

At its climax, the Holocene transgression flooded areas which now form the outer parts of the coastal sabkha. Its approximate limits are

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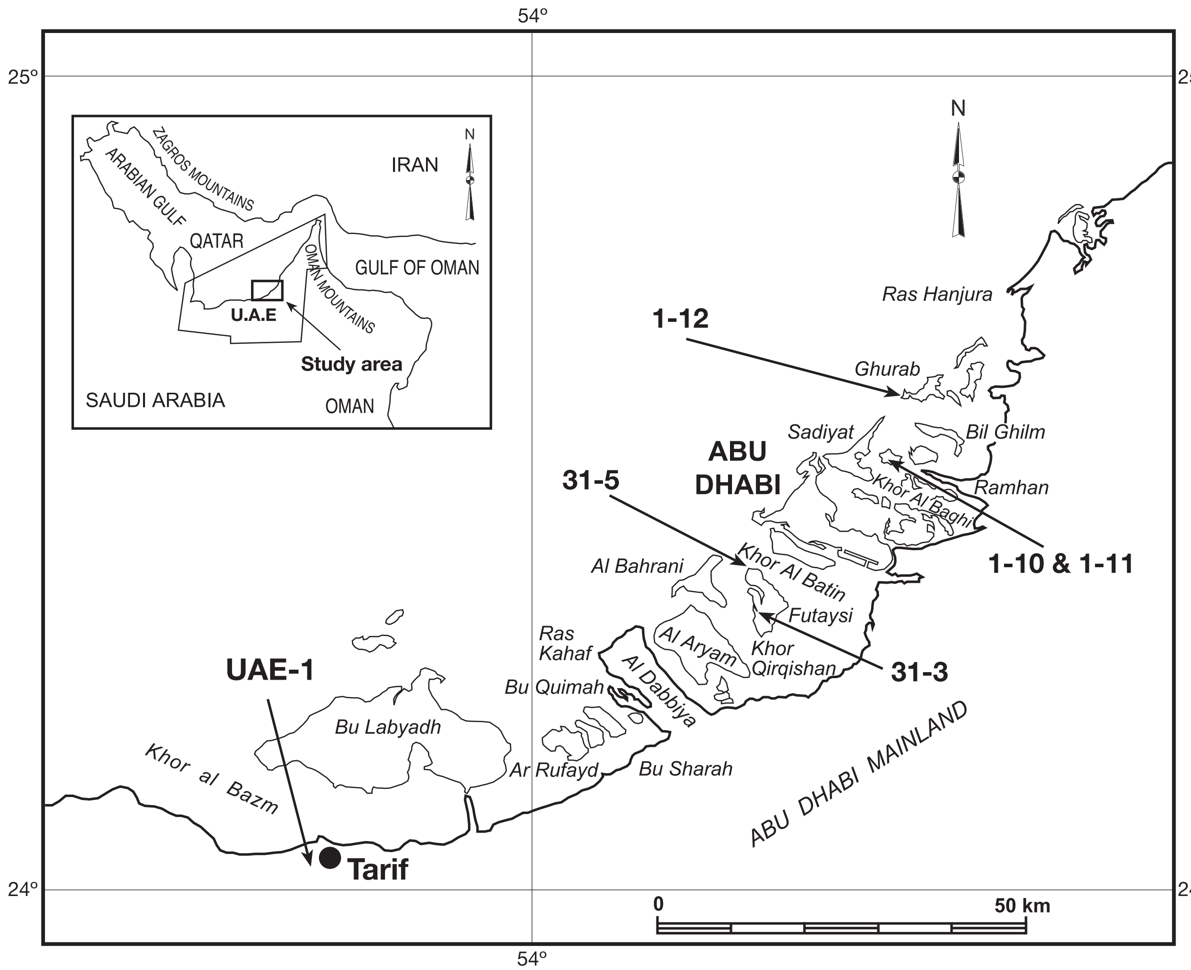


**Figure 1.** Map of sampling area with sampling points in this study. Inset shows broader Arabian/Persian Gulf Region.

marked by beach sand ridges on the current coastal sabkha which have been dated as 4–6 ka (Evans et al., 1969; Kirkham, 1998b; Evans and Kirkham, 2002; Kirkham, 2011). This transgression initiated the erosion of wave-cut platforms around Fuwayrit-capped zeugen and one such platform has Holocene carbonate sediment dated at ca. 2 ka resting upon it (Kirkham and Evans, 2008). During the Holocene, lagoons formed as a result of the development of offshore barrier islands which extended landwards mainly by leeward accretion. Since the climax of the transgression and the formation of the mainland beach ridges, a forced regression to present-day sea level created a series of intertidal deposits, microbial mats and a cap of evaporites offlapping into the lagoons along the relatively low-energy mainland coast. The coast has undergone progradation of 3–4 km to produce the outer part of the coastal sabkha (Evans et al., 1969; Patterson and Kinsman, 1977; Kirkham, 1998b). The presence of the lagoons has prevented a significant supply of aeolian sand from the barrier islands to the mainland. Hence deflation has continued and the inner sabkha has continued to expand landward. Even where the area of active carbonate sand production abutted against the mainland coast, this has merely produced a narrow beach ridge complex that within a very short distance passes into a deflated desert surface, as is well illustrated along the coast of Sabkha Matti, western Abu Dhabi.

*Chronostratigraphy and recent dating of the key formations*

Assuming that interpretation of the depositional environments is broadly accurate, the ages of the Fuwayrit and Ghayathi Formations are critical for their use as sea-level indicators. Published ages are summarised in Table 1 and outlined below. The Fuwayrit Formation (Fig. 2) was originally formalized by Williams (1999) as a thin marine limestone deposited in the penultimate interglacial, which once probably covered much of the coastal area of the UAE. Later, Williams and Walkden (2001) suggested that the underlying Miliolite is the coastal equivalent of the Ghayathi Formation of Hadley et al. (1998) (Fig. 2). On one of the offshore barrier islands, Marawah, the Miliolite overlies a coralliferous limestone dated using U–Th method as 280–160 ka (Evans et al., 2002; Evans and Kirkham, 2005). The dating of the Ghayathi (Miliolite) Formation itself has yielded rather variable results, which may potentially be due to the range of techniques applied and the likely polyphase activity of dunes. Furthermore, some of the OSL dates may be from the inland Madinat Zayad Formation, which also appears to be polyphase (Farrant et al., 2012). Glennie and Kendall (1998) recognised two phases of Miliolite deposition at ca. 230 ka and ca. 112 ka, but later Glennie and Singhvi (2002) recognised four periods of Shamal-related enhanced dune building activity around 160–130, 110, 60–50 and 15–12 ka. Hadley et al. (1998) dated its inland equivalent, the Ghayathi Formation, as middle Pleistocene (>160 ka) using luminescence techniques. Later Williams and Walkden (2002) quoted ages of 126–119 ka for the lower part of the Miliolite on the coast, although they stated it could be older (145–130 ka) and they seem to have included some inland samples of unspecified lithology. The latest work by the British Geological Survey in their detailed survey of the region has further stressed the complexity of the chronology of the dune systems which have developed and been modified several times during the Quaternary (Farrant et al., 2012). They obtained a wide spread of dates which range from 8.7 $\pm$ 0.7 to >131.0 $\pm$ 11.0 ka, underscoring