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Temporal evolution of a carbonate coastal system, Abu Dhabi, United Arab Emirates

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ABSTRACT

The southern shore of the Persian/Arabian Gulf comprises a low-angle carbonate–evaporite ramp system that provides a rare Recent analogue for ancient epeiric settings, including many carbonate petroleum reservoirs. During the 1960s several studies documented the distribution of naturally occurring shallow-marine facies in the shallow marine environments proximal to Abu Dhabi Island. Subsequent coastal engineering projects have significantly modified the coastline and sublittoral zone – many sedimentary environments have been lost, with marine sites now sited beneath buildings, parks or roads. The data from the earlier studies are used as a pre-anthropogenic base-line in order to document and assess the temporal changes in the characteristics and distribution of carbonate sedimentary facies as observed today. The locations of earlier sample sites were revisited in order to represent the complete range of shallow-marine sedimentary environments. The shallow subtidal environments adjacent to Abu Dhabi Island continue to be areas of active carbonate sedimentation. Temporal changes in facies belt geometries and occurrence are assessed. Changes are recorded for most of the investigated sedimentary settings, both in terms of sedimentary environment distribution and sediment composition. Offshore reefs and their associated back-reef lagoons are no longer present. Ooid shoal and delta complexes are much-reduced in their aerial extent, now being replaced with shoreface facies or dredged channels. Significant dredging activity has increased tidal flow to lagoon environments thereby increasing connectivity to open-marine conditions. However, land reclamation has substantially reduced the volume of the area of the lagoon environments. Despite these changes, many facies display surprising resilience to anthropogenic activities with no discernible change in sedimentary facies or biotic distributions. Understanding these modifications, and their associated driving mechanisms, allows discrimination between anthropogenic and naturally-occurring environmental perturbations. This, in turn, develops our understanding of the temporal evolution of shallow-marine carbonate facies under natural and anthropogenic influences.

1. Introduction

During the early to mid-1960s a number of studies examined the distribution of shallow-marine facies and biotic communities in the shallow off-shore coastal zone proximal to Abu Dhabi Island in the United Arab Emirates (UAE) (Bate, 1971; Evans et al., 1973; Kinsman, 1964; Murray, 1965, 1966a,b, 1970). At the time of these investigations, this was a largely pristine natural environment with very little, if any, anthropogenic footprint. Since that time, development has been rapid, with major coastal engineering projects having modified the coastline and sublittoral zone almost beyond recognition. While each of these earlier projects focused on specific aspects of the shallow-marine system, when considered together they provide a well-constrained pre-anthropogenic base-line for the distribution of sedimentary facies prior to the onset of anthropogenic activities.

The primary objective of this study is to assess how anthropogenic activities have modified the shallow-marine benthic environments around Abu Dhabi Island and to explain the resultant changes in the distribution of sedimentary facies. This study also aims to clarify those environments that are most vulnerable to anthropogenic disruption and those that may be more resilient. This provides a resource for policy makers to employ for informed mitigation of environmental perturbation when planning future coastal infrastructure developments in similar arid subtropical settings. These outcomes will also provide criteria by which sedimentologists can assess the sedimentary signature in an area where the degree of anthropogenic influence is unknown.

2. Geographic and climatic setting

This study focuses on the shallow coastal environments immediately adjacent to Abu Dhabi Island on the southern shoreline of the Persian/Arabian Gulf.

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2.1. The Persian/Arabian Gulf

The Persian/Arabian Gulf, hereafter referred to as the Gulf, is an epeiric 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 Gulf has a total area of 227,000 km^2 measuring 360 km across at its widest point and extends for 1000 km from the Shatt al-Arab delta in the northwest to the Strait of Hormuz in the east. The basin is almost totally landlocked with connection to the world's oceans being restricted to the relatively narrow (50 km wide) Strait of Hormuz. This shallow microtidal (1–2 m) sea has an average water depth of only 35 m; the basin floor dips gently north-eastward with the deepest water areas lying adjacent to the southern coast of Iran. The Zagros Mountains bound the north and east shores while the south and west shorelines are bounded by the low-relief Arabian Peninsula. Today, the floor of much of the Gulf is dominated by fine-grained to muddy carbonate sediments (Evans, 1966; Uchupi et al., 1996) and Holocene hard grounds (Shinn, 1969). These sediments generally become richer in siliciclastic material towards the Iranian shore of the basin (Emery, 1956).

2.2. The Abu Dhabi shoreline

The southern shore of the Gulf exhibits a low-angle ramp geometry that passes from a supratidal evaporite sabkha, through a laterally-extensive and complex intertidal setting, into a subtidal carbonate-dominated depositional environment (Evans et al., 1964b). The complex coastline in the region of Abu Dhabi Island is characterised by numerous islands and peninsulas (Fig. 2). These features have been interpreted to have developed during the Holocene as sediments accreted around Pleistocene limestone cores atop the eastern end of the Great Pearl Bank (Purser and Evans, 1973). Where lateral spit accretion dominated, this extended islands parallel to the shoreline, thus resulting in the partial isolation of lagoons from open-marine conditions (Harris, 1994). Locally, the leeward accretion of sediment to islands resulted in attachment to the mainland to form peninsulas. Where channels have become restricted, this has promoted ooid delta formation seawards of the barrier islands.

2.3. Climate

The location of the UAE beneath the Northern Subtropical High results in an arid climate for Abu Dhabi with a mean annual rainfall of only 72 mm. Precipitation typically occurs as transitory, localised, torrential rainstorms during February and March (Raafat, 2007). A mean annual evaporation rate of 2.75 m exceeds rainfall by two orders of magnitude (Bottomley, 1996). Temperatures measured at the coastline 50 km west of Abu Dhabi Island range between 7 °C at night during winter months and often exceed 50 °C on summer days. Warm, shallow coastal waters ensure high coastal humidity, particularly during summer when humidity can reach 100%. The prevailing wind is the northwesterly Shamal.

2.4. Anthropogenic changes

Prior to the 1950s, the coastline of the UAE could be considered as almost entirely natural. However, with the commencement of oil exports, in the early 1960s, Abu Dhabi initiated a program of urban and industrial development that has continued to gather pace ever since. This development has resulted in significant modification of the Abu Dhabi coastline and shallow-marine system, particularly in the areas immediately adjacent to Abu Dhabi Island (Lokier, 2013). Major dredging projects have deepened off-shore and near-shore channels whilst simultaneously remodelling coastlines and creating new artificial islands (Fig. 2). These geomorphic modifications have, in turn, resulted in changes in local hydrodynamic regimes and the adjustment of coastal sedimentary systems.

Fig. 1. Map of the Arabian/Persian Gulf region showing the location of Abu Dhabi Island and the study area as indicated by the dashed box.