Geoheritage (2013) 5:11–22
DOI 10.1007/s12371-012-0069-x

ORIGINAL ARTICLE

Coastal Sabkha Preservation in the Arabian Gulf

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Received: 5 March 2012 / Accepted: 9 November 2012 / Published online: 25 November 2012

Abstract Recognition of the geological significance of the Abu Dhabi Coastal Sabkha in the late 1950s initiated a decade of intensive sabkha research in the region, with various research groups embarking on an extensive campaign of field-based and laboratory-based activities. Subsequent research has been more sedate, principally reflecting the needs of the regional hydrocarbon industry or the adoption of new research techniques or scientific precepts. The last decade has witnessed a resurgence of interest in the coastal sabkhas of the Middle East, with focus lately switching to the generation of dolomite at Earth's surface, and the significance of microbial communities in this and other sabkha processes. Yet, this is at a time when coastal environments throughout the Arabian Gulf are being threatened by increasingly ambitious land development activities. In the 1960s, approximately 150 km of pristine coastal sabkha existed along the eastern and central portions of the Abu Dhabi Coastline. Today, only 54 km remains. Preservation of the remaining coastal sabkhas of the United Arab Emirates requires careful and efficient planning and management integrating the experience and expertise of stakeholders, both at a national and an international level. We propose the establishment of a managed protected sabkha geoconservation area to the west of Abu Dhabi City. With minimum investment, this park would promote public awareness of the geoheritage of the United Arab Emirates (UAE), whilst also acting as a centre for sustainable geotourism and a focus for research of this fragile sedimentary system.

Keywords Sabkha · Evaporites · Coastlines · Arabian Gulf · Microbial · Gypsum and anhydrite

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Introduction

The southern shoreline of the Arabian Gulf (Fig. 1) has long been recognised as offering one of the best and most accessible examples of extensive coastal sabkha settings available to us today. Rarely do geologists visit the Arabian Peninsula without making a pilgrimage to this oft-quoted instance of the perfect setting in which to study the processes of mixed carbonate-evaporite deposition.

The word 'sabkha' is a vernacular Bedouin Arabic term employed to describe a topographically flat area of clay, silt or sand with an overlying crust of salt (Goodall and Al-Belushi 1998). A sabkha may occur in an inland interdune area as a salt-crusted depression (Thomas 1929), or in low-lying coastal salt marshes (Philby 1933; Thesiger 1946). The geological definition of a sabkha is best defined as 'a broad plain or salt flat which contains evaporites and is formed in an arid or semi-arid climate' (Harwood 1993).

Numerous studies have employed present-day coastal sabkhas of the Arabian Gulf as a Recent analogue for many ancient petroleum reservoir systems, both in the Middle East and elsewhere. The successful discovery and production of the vast hydrocarbon reserves of the Middle East has allowed for infrastructure expansion on an unprecedented scale. A colossal increase in urbanisation in recent years has resulted in a massive expansion in the development of the region, with much of the coastline being allocated to housing projects, hydrocarbon service industries or heavy industrial development. All along the southern shoreline of the Arabian Gulf, sovereign states are modifying and developing their coastlines at an ever-increasing rate. Massive dredging, island-building and shoreline improvement projects are changing the morphology, environments and dynamics of coastlines beyond recognition.

Much of our knowledge of coastal sabkha sedimentary systems derives from work undertaken in the so-called 'Abu

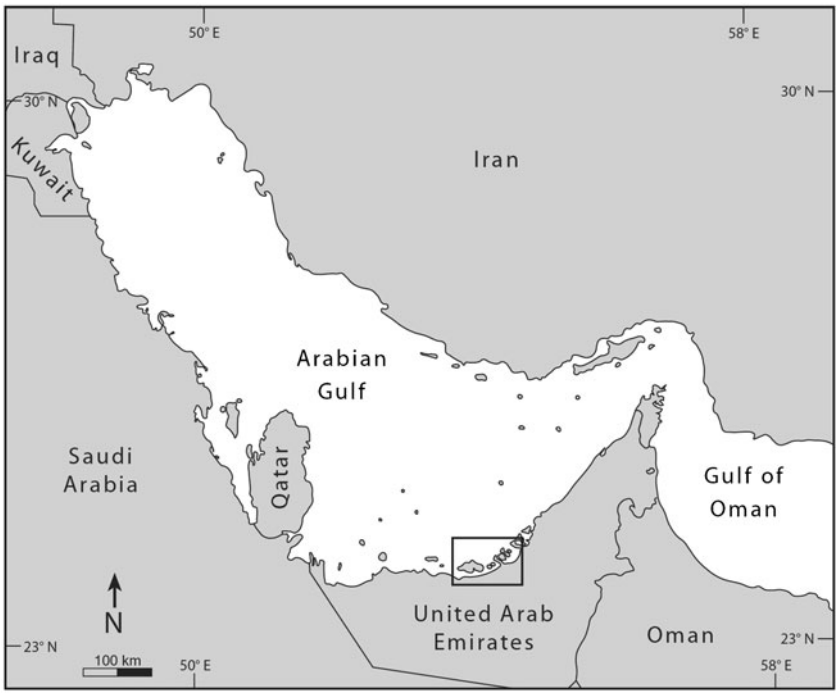

Fig. 1 Sketch map of the Arabian Gulf region, showing the location of the Abu Dhabi Sabkha (*boxed*), as shown in detail in Figs. 2 and 4

Dhabi Sabkha', in the vicinity of Abu Dhabi Island, United Arab Emirates (UAE), by the research group of the Imperial College of London during the 1950s and 1960s. With rapid urban expansion, and a consequent destruction of coastal sabkha systems, subsequent generations of geologists have had to focus their research in a rapidly diminishing number of localities.

This paper presents a short review of the geomorphological and sedimentological characteristics of the Abu Dhabi Sabkha. The loss of coastal sabkha settings along the shoreline of Abu Dhabi Emirate is documented and the importance of preserving the last sections of pristine coastal sabkha is established.

Research Activity in the Abu Dhabi Sabkha

Geological interest in the region flourished during the 1950s and 1960s, as an increasing number of geologists entered the region, largely through the auspices of the hydrocarbon industry. Much of the early documentation and research of the then 'Trucial Coast' and adjacent shallow-water Arabian (Persian) Gulf was coordinated by research groups from the Imperial College of London (Butler 1969, 1970; Butler et al. 1965; Curtis et al. 1963; Evans 1966; Evans et al. 1964a, b, 1969; Evans and Shearman 1964; Kendall and Skipwith 1969a, b, 1968; Kinsman 1964, 1965; Shearman 1963, 1966) and Shell Research (Emery 1956; Illing et al. 1965; Shinn 1969; Taylor and Illing 1969; Wells 1962; Wells and Illing 1963). This pioneering work culminated in the publication of 'The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea' (Purser 1973).

Access to the eastern portion of the Abu Dhabi Sabkha has always been relatively easy; as a consequence there has been a geographical concentration of research activity in this area. Since the early 1970s, research in the Abu Dhabi Sabkha has continued apace, with the focus of activity shifting with the trends of the day. Themes of research have been diverse, including overall sabkha architecture (Al-Farraj 2005; Kirkham 1998; Lokier and Steuber 2008; Stewart et al. 2011; Strohmenger et al. 2010), recent dolomitisation processes (McKenzie 1981; McKenzie et al. 1980; Müller et al. 1990; Patterson and Kinsman 1982), microbial mat communities (Kinsman and Park 1976) and their importance in contributing organics to the sedimentary system (Baltzer et al. 1994; Kenig and Huc 1990; Kenig et al. 1990, 1995), hydrogeology and the respective role of continental and marine ground waters to the sabkha system (Chafetz et al. 1999; Patterson and Kinsman 1977; Patterson and Kinsman 1981; Sanford and Wood 2001; Wood and Sanford 2002; Wood et al. 2002, 2005), the roll and implications of sea level changes (Lambeck 1996; Park 2011; Stevens et al. 2011; Teller et al. 2000; Wood et al. 2006), the occurrence of halite and other evaporite minerals (Butler et al. 1982; Goodall et al. 2000; Lokier 2012; Warren and Kendall 1985) and the development of beach rocks and hard grounds (Lokier and Steuber 2009; Whittle et al. 1998). Most recently, there has been a significant resurgence of interest in the role of microbial communities in the mediation of Recent dolomite precipitation (Bontognali et al. 2010; Sadooni et al. 2010; Wright and Kirkham 2011). The reader is referred to Evans (2011) for a detailed review of sedimentological research in the Abu Dhabi Sabkha and environs.

In addition, the Abu Dhabi Sabkha is the most applied type of recent analogue for ancient mixed carbonate-evaporite petroleum systems, both in the Middle East and globally (e.g. Al Suwaidi et al. 2011; Alsharhan and Kendall 2002; Alsharhan and Magara 1994; Alsharhan and Whittle 1995; Grötsch et al. 2003; Lapointe 1991).

Climate

The climate of Abu Dhabi is extremely arid, with a mean annual rainfall of 72 mm, of which 74 % falls during short-lived torrential downpours between February and March (Raafat 2007). Rainfall is annually highly variable, and may be extremely limited in aerial extent. Mean annual evaporation of 2.75 m exceeds precipitation by two orders of magnitude (Bottomley 1996). Annual temperatures recorded in the Abu Dhabi Sabkha range between 7 °C during the winter and 50 °C in the summer months, with diurnal ranges of between 26 °C and 2 °C. Temperatures measured within the sediment 25 cm below the sabkha surface reach up to 43 °C during the summer, with a diurnal range of only 4 °C, and 17 °C during the winter with a diurnal range of 0.3 °C. The northwesterly Shamal dominates the winds in the area, and may produce storm-surges onto the low-angle coastal ramp setting. The warm shallow waters of the Arabian Gulf result in high humidity along the coastline, particularly during the summer when humidity may reach 100 %.

The Context of the Abu Dhabi Coastal Sabkha

The Arabian Gulf is a shallow epicontinental sea occupying a crescentic northwest to southeast oriented basin (Fig. 1), floored by the continental crust of the northern margin of the Arabian Plate. This shallow microtidal (1–2 m) sea is almost totally landlocked with net evaporation far exceeding the limited influx of fresh water, thus salinities remain elevated throughout the year. Salinities of between 45 and 46 gl^{-1} are typical along the open marine coast of Abu Dhabi, while more restricted environments record salinities up to 89 gl^{-1} (Lokier and Steuber 2009). The floor of the Gulf shallows towards the Arabian Peninsula to form a laterally extensive carbonate ramp geometry. It is this extremely low-angle ramp geometry that promoted the development of the extensive coastal sabkha system that, until recently, characterised much of the Abu Dhabi coastline. Abu Dhabi's coastline is locally protected from open-marine conditions by a number of peninsulas and offshore shoals and islands that are associated with the approximately east–west trending Great Pearl Bank.

The Abu Dhabi coastal sabkha system is a featureless low-lying plain up to 33 km wide and bounded by the aeolian dunes of the Rub al Khali in the south and the Arabian Gulf to the north (Fig. 2). The landward portion of this plain is characterised by a deflated dune system capped by an ephemeral halite crust. These dunes were deposited during the Quaternary glaciation, when reduced global sea levels of 120–130 m below present (Fleming et al. 1998; Hanebuth et al. 2009; Peltier and Fairbanks 2006) exposed the floor of the Arabian Gulf, thus allowing the northwesterly Shamal winds to transport sand, sourced from Iran, towards the south and east and an extensive dune system to develop over much of the basin's floor (Sarnthein 1972). With the end of the Last Glacial Maximum (LGM) at between 19 and 20 ka (Clark et al. 2009; Yokoyama et al. 2000), eustatic sea-level rise flooded the Arabian Gulf. Sea levels continued to rise until they reached, and by-passed, the position of the present shoreline at just prior to 6 ka (Lambeck 1996). Holocene transgression peaked at between 1 and 2 m above present levels, between 4 and 6 ka (Evans et al. 1969; Williams and Walkden 2002), before retreating to near-current levels between 2.3 and 2 ka (Uchupi et al. 1996; Williams and Walkden 2002). With the stabilisation of sea level, and the removal of a source of aeolian sediment, the Pleistocene dunes were deflated to the level of the newly established groundwater capillary zone (Evans et al. 1964a).

The seaward portion of the coastal sabkha is characterised by the displacive growth of shallow subsurface gypsum and anhydrite hosted in a carbonate-dominated sediment with locally-preserved laminated microbial mats (Fig. 3); this sequence is, again, capped by ephemeral halite (Lokier 2012). These lithologies record the progradation of the shoreline (Evans et al. 1969) following late Holocene eustatic sea level stabilisation. The supratidal sabkha and intertidal sedimentary system prograded into the Arabian Gulf at an average rate of 0.75 m/year (Lokier and Steuber 2010; Lokier and Steuber 2008), thus progressively narrowing the lagoon separating the mainland from the offshore islands. At the surface, the seaward portion of a coastal sabkha system is topographically flat, unvegetated and featureless; the subsurface, however, is far more heterogeneous. Complex subsurface facies geometries result from the interplay of primary depositional sedimentary facies and early post-depositional displacive evaporite development.

The upper intertidal zone of the Abu Dhabi Sabkha is clearly distinguished by a 200–600 m wide microbial mat. The shoreward margin of this microbial community is limited by desiccation, while the seawards extent is controlled by the grazing activity of herbivorous marine fauna, particularly gastropods and decapods. The lower intertidal to shallow subtidal zone of the coastal sabkha of Abu Dhabi is dominated by carbonate sands, which locally experience early cementation to form giant polygons with well-defined overthrust margins (Kendall and Skipwith 1969a; Lokier and Steuber 2009).

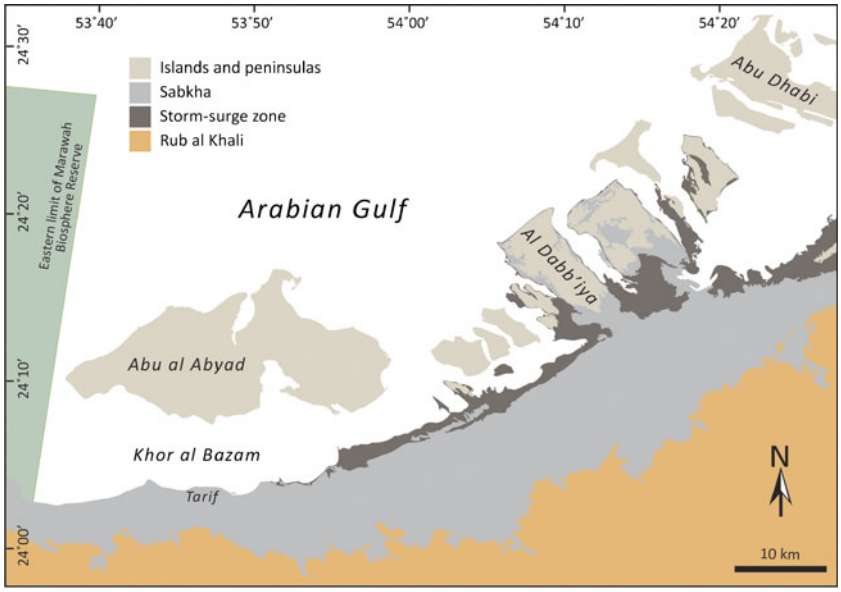

Fig. 2 Sketch map highlighting the geomorphological zones of the Abu Dhabi Sabkha to the west of Abu Dhabi Island (see Fig. 1 for location of area)

The Abu Dhabi Sabkha, Past and Present

The largest continuous stretch of coastal sabkha in the Arabian Gulf originally extended for approximately 150 km along the coastline and near-shore islands of Abu Dhabi Emirate, between Ra's Sadr in the east and Tarif in the west.

Fig. 3 Stratigraphic section through the Abu Dhabi coastal sabkha at N 24° 07.051, E 054° 02.994 (see Fig. 4a for location of section). **A** – halite crust and underlying carbonate mud, **B** – organic-rich carbonate mud, **C** – anhydrite with small gypsum crystals, **D** – gypsum lathes up to cm-scale, **E** – laminated microbial mats with sub-vertical cracks infilled with carbonate mud, **F** – cerithid gastropod lag, **G** – mixed carbonate and siliciclastic mud containing detrital clay and silt-grade quartz along with lenticular gypsum lathes up to 10 cm in diameter, **H** – siliciclastic mud with high organic content immediately overlying a hardground

With the advent of oil shipments in the early 1960's, the UAE was able to initiate a programme of urban and industrial growth (Table 1). This development has been concentrated along the coastline of the emirate in the vicinity of Abu Dhabi Island, with massive land-reclamation activities and infrastructure development totally modifying extensive areas of the coastal environment (Fig. 4). Dredging activity has deepened off-shore channels, whilst simultaneously remodelling coastlines and creating new artificial islands (Fig. 5). Urban development has been rapid. Abu Dhabi City has expanded from a cluster of small villages in the 1960s to a modern metropolis covering an area of approximately 782 sq km in 2011 (Hellyer et al. 2011).

In order to minimise the risk inherent with dependence on a single sector, Abu Dhabi is increasingly diversifying into a range of industries beyond the petroleum sector and associated petrochemical industries. Oil revenues are being employed to expand into a range of new economic sectors, including heavy industry, aluminium smelting plants, manufacturing, new port and infrastructure facilities, and a nuclear energy program. Many of these new industries require significant areas of coastal development (Fig. 5).

As the economy has continued to develop, roads, pipelines and channels (Fig. 6) have increasingly bisected the sabkhas; these disturb ground water flow and result in the surface ponding of rainwater that would have previously flowed into the Gulf. A further risk to the groundwater system of the sabkha is the large-scale watering of roadside trees and shrubs. Much of this water enters the sabkha to dilute the subsurface continental and marine brine.

Of the 150 km of coastal sabkha present along the eastern and central part of the Abu Dhabi coastline in the 1960s, only 54 km (36 %) remains today (Fig. 4). Much of this is

Table 1 Anthropogenic threats to the sabkha environment

Threat	Impact		
	Physical destruction	Geochemical	Hydrological
Offshore dredging activity	•	•	•
Onshore channel construction	•	•	•
Land reclamation	•		•
Residential construction	•		•
Industrial construction	•	•	•
Road carriageway construction	•		•
Railroad construction	•		•
Agricultural activity	•	•	•
Landscape watering	•	•	•
Drainage	•		•
Oil and gas pipeline construction	•		•
Landfill		•	•
Groundwater extraction	•	•	•

limited to short (2–5 km) isolated stretches located on the less-accessible areas of peninsulas and near-shore islands. By 2004, the longest remaining single stretch of coastal sabkha was a relatively pristine 42 km laterally continuous section situated immediately to the west of Al Dabb'iya peninsula and extending almost to Tarif. Since 2004, this section has been developed as a series of fish farms reducing its length by 54 %, with only 20 km now remaining. This last section has largely survived due to its proximity to the Al Dabb'iya oil field.

The Future of the Abu Dhabi Sabkha

With urban and industrial development increasingly expanding along the coastline away from Abu Dhabi City, the future of the Abu Dhabi Sabkha appears to be bleak. Yet, this is at a time when there has been a strong renaissance of interest in this unique sedimentary system.

Improved Analogues

As many of the hydrocarbon reservoirs of the Middle East move into the mature phase of production, there has been an increased awareness of the need to re-evaluate earlier reservoir models, many of which were developed outside of a sequence stratigraphic framework. This shift has driven a revival of interest in the modern sabkha system as a potential analogue for ancient petroleum systems throughout the region.

Much of the early work on the coastal sabkhas of the Arabian Gulf was inhibited by a lack of adequate technologies to accurately image and sample the shallow subsurface. Sampling was largely limited to shallow pits and short subsurface cores. These investigations were further hampered by the absence of an accurate chronostratigraphic framework in which to develop temporally constrained depositional models.

Advances in geophysical technologies, such as ground penetrating radar, now allow us to image the shallow subsurface of coastal environments at resolutions that were previously unimaginable (Nielsen and Clemmensen 2009; Pascucci et al. 2009; Shukla et al. 2008). Likewise, the development of increasingly accurate dating techniques, particularly optically stimulated luminescence (OSL), accelerator mass spectrometry (AMS) radiocarbon and uranium-series dating technologies, promotes the production of ever more precise chronostratigraphic frameworks (Lokier and Steuber 2008; Stevens et al. 2011; Strohmenger et al. 2010; Williams and Walkden 2002). The integration of these techniques permits the mapping of coastal sabkha facies geometries at the reservoir scale, and allows us to reconstruct their development in a sequence-stratigraphic context. By so doing, we are better able to develop accurate, analogue-constrained, petroleum reservoir models that facilitate efficient development and production strategies.

Microbial Communities

There has been a recent resurgence of interest in the extensive microbial mats, both those occurring at the surface in the upper intertidal zone and those buried in the shallow subsurface. These microbial communities have been implicated in the precipitation of authigenic dolomite (Bontognali et al. 2010; Sadooni et al. 2010; Wright and Kirkham 2011). It is believed that these microbial systems could contribute

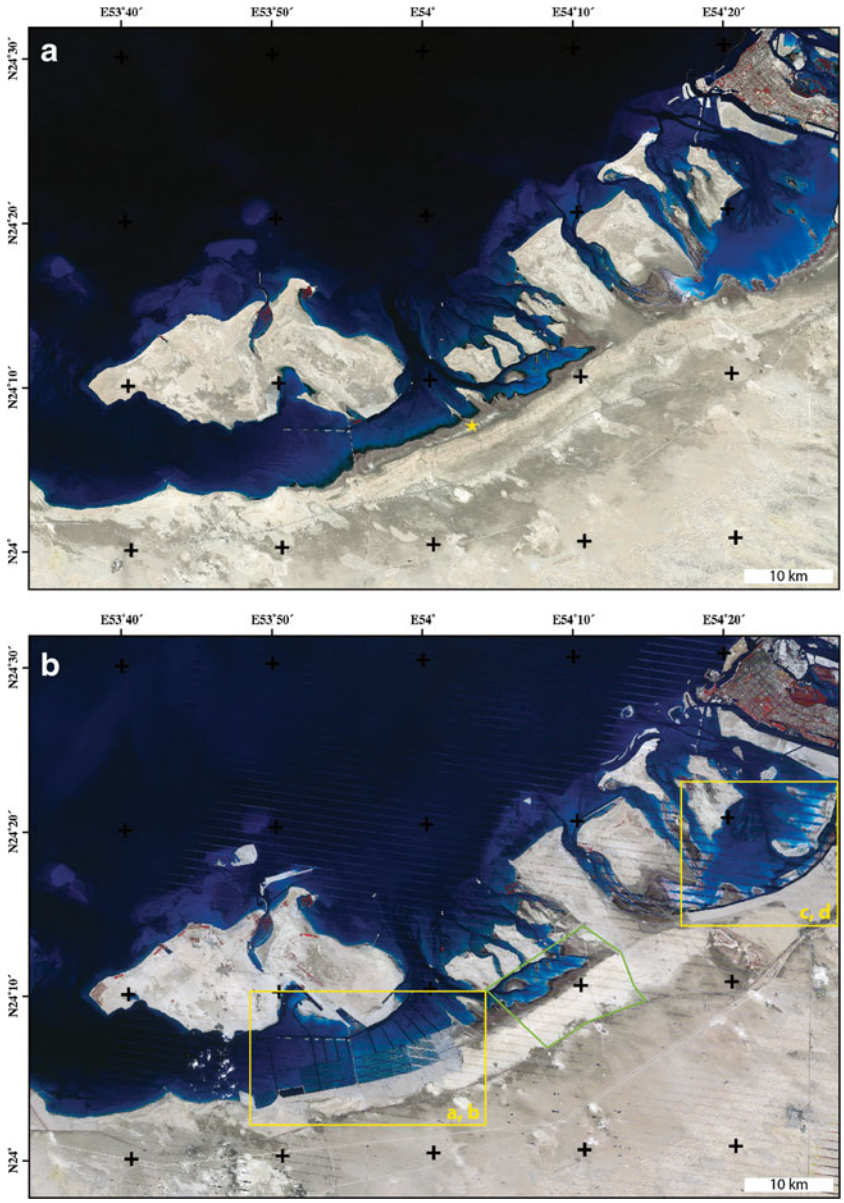

Fig. 4 Paired false colour Landsat images of the Abu Dhabi coast to the west of Abu Dhabi Island, clearly exhibiting the loss of sabkha environments over a 27 year period (band 4 – *red*, band 5 – *green*, band 2 – *blue*). **a** Landsat 5 TM image acquired 2 February 1985, star shows location of sabkha section shown in Fig. 3. **b** Landsat 7 ETM + composite image acquired between 5 March 2007 and 5 February 2012. Yellow boxes denote areas highlighted in Fig. 5. Green box indicates the extent of the proposed Abu Dhabi Sabkha geoconservation area. Sub-horizontal stripes are an artefact of the image processing procedure (images cover the same area as that portrayed in Fig. 2). Imagery courtesy of JGI Inc./JODCO

to our understanding of the so-called 'Dolomite Problem' (Zenger et al. 1980), i.e. the profusion of dolomite recognised from ancient sedimentary sequences but its relative scarcity in modern sedimentary systems. A further focus of study is the role and importance of microbial communities in the development of the complex heterogeneous lacustrine and marine-influenced facies of the Brazilian and West African Pre-salt reservoirs.

The application of microbial communities in microbial enhanced oil recovery (MEOR) is attracting a great deal of attention (Gieg et al. 2008; Gray et al. 2011; Head et al. 2006; Jones et al. 2008). The employment of native microbes, sourced from sabkha and mangal environments, in bioremediation of formation waters and hydrocarbon spills (Al-Mailem et al. 2010; Bonfá et al. 2011; Cohen 2002) and other pollution scenarios (Cuadros-Orellana et al. 2006) is also an increasingly active area of research.

Due to their environmental constraint in the upper part of the intertidal zone, microbial mats are highly sensitive to changes in relative sea level. During regression the microbial mats desiccate and are buried by the prograding sabkha system, thus providing a diachronous surface recording the rate of progradation (Lokier and Steuber 2008). However, during transgression, the seaward-margin of the microbial mat belt will be inundated and subjected to increased energy regimes. This results in destruction of the microbial mat, via physical erosion and through bioerosion as a result of increased predation by grazing organisms. It is thus unlikely that a retrogradational microbial mat system will be preserved in to the geologic record.

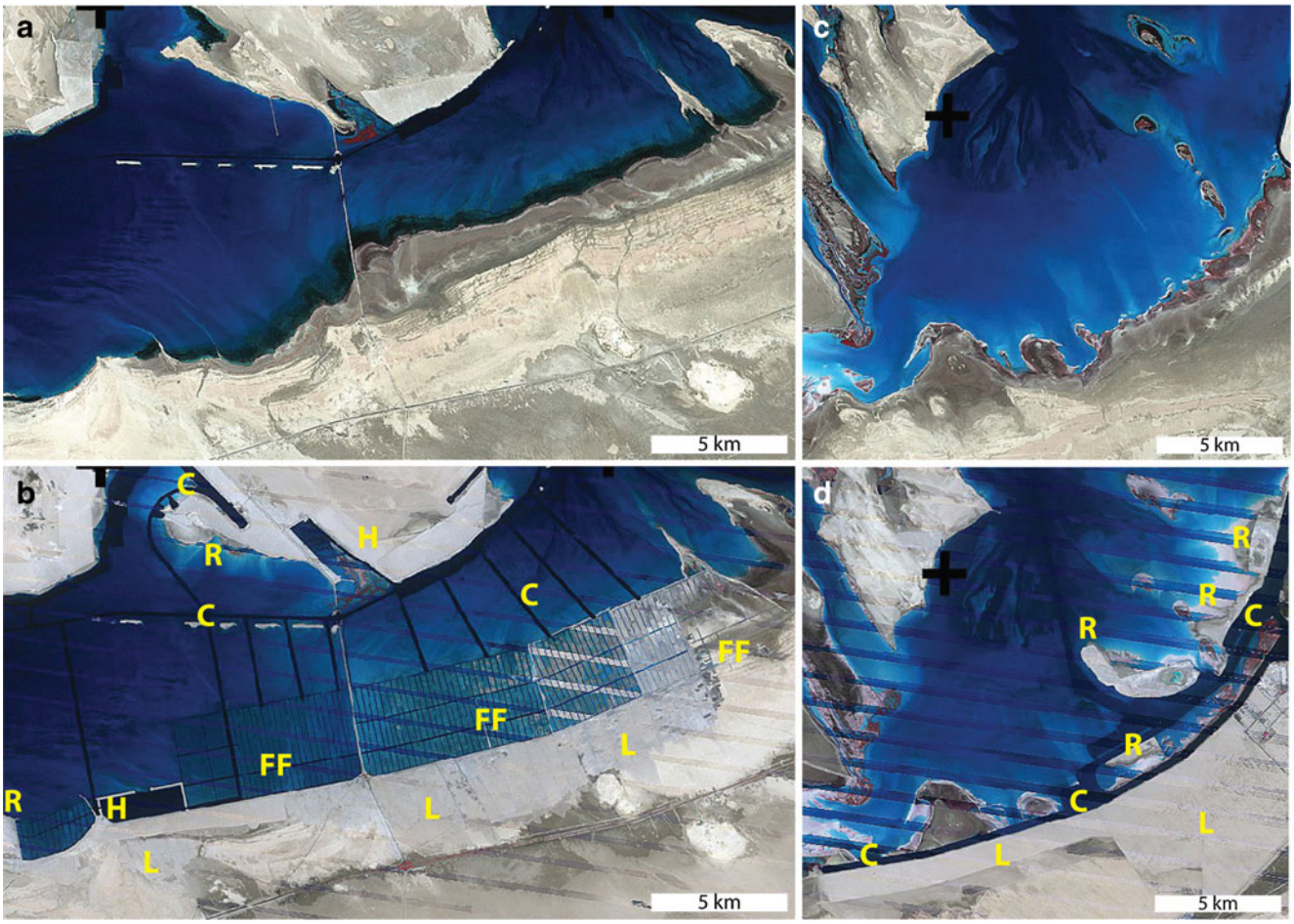

Fig. 5 False colour Landsat images, clearly showing the development of the Abu Dhabi coastal sabkha (band 4 – *red*, band 5 – *green*, band 2 – *blue*). **a** & **b** Paired Landsat 5 TM (**a**) and Landsat 7 ETM + (**b**) images showing extensive dredging of channels (C), harbours (H), and land reclamation (R) and levelling (L) associated with the development of extensive fish farms (FF) in the former intertidal to supratidal zone to the west of Tarif. **c** & **d** – Paired Landsat 5 TM (**c**) and Landsat 7 ETM + (**d**) images displaying the deep-water channels (C), land reclamation (R) and levelling (L) prior to the construction of coastal industrial and port facilities (see Fig. 4 for location of areas). Imagery courtesy of JGI Inc./JODCO

Education and Ecotourism

The coastal sabkha of Abu Dhabi lies within 3 h travel time of the cities of Abu Dhabi, Dubai, Sharjah and Al Ain. This unique coastal setting is an invaluable educational resource for the teaching of a wide range of geoscience concepts beyond those of the petroleum industry. Here, high school and university students could observe and study a wide range of sedimentological and depositional processes associated with carbonate and evaporite systems. International educational collaboration would facilitate the dissemination of observations beyond the immediate environs of the Middle East.

Interest in the coastal sabkhas of Abu Dhabi is not limited to the geosciences. The unique eco-system of the coastal

Fig. 6 Newly excavated fish-farm channel in the upper intertidal zone. Such channels prevent the flow of subsurface brines in the sabkha system. The width of the channel is 40 m with banks that are 2.5 m high, water depth varies due to localised slumping but rarely exceeds 1 m

sabkha and shallow subtidal environment hosts a diverse, and sometimes highly specialised, range of flora and fauna. Large numbers of migratory and native bird species particularly rely on the tidal flats for food and safety.

With the growth of the UAE as a regional transport hub and tourist destination, there exists a growing potential for the development of ecotourism throughout the region. Many people visit the sand dunes of the Rub al Khali or the Semail Ophiolite exposed in the mountains of the Northern Emirates, yet few know of the existence and importance of the sabkha. It is the roll of geoscientists and ecologists to raise public awareness of this unique and important environment.

Geoconservation of these unique environments requires perceptive planning, employing the knowledge and expertise of geological, geomorphological, archaeological and ecological stakeholders, to develop an effective, sustainable, management philosophy. Geoscientists who wish to protect this unique geological heritage must work to raise institutional and community awareness of the importance, uniqueness and value of the Abu Dhabi Sabkha to future generations of geoscientists, specifically, and the wider community in general.

Geoconservation

Since its inauguration in 1971, the United Arab Emirates has witnessed development at a scale rarely observed elsewhere in the world. While urbanisation, industrialisation and infrastructure development have continued apace, environmental awareness and supporting legislation have lagged somewhat behind. More recently, there has been an increased awareness of the nation's environmental heritage and responsibilities, with the establishment of The Environment Agency – Abu Dhabi (EAD) in 1996 and the Abu Dhabi Urban Planning Council (UPC) in 2007. Between them, these two bodies are responsible for environmental protection policy, planning and implementation for Abu Dhabi Emirate.

Progress has been rapid. In the last few years, the UAE has become a signatory to the Convention on Biological Diversity (CBD), which aims to promote the establishment of protected areas, with the specific aim of preserving natural habitats in order to conserve ecosystems and promote biodiversity. Within the emirate of Abu Dhabi, the responsibility for establishing and managing such protected areas lies with EAD. Conservation of fragile ecosystems has been stated as one of the five goals of the UAE's CBD National Diversity Strategic Action Plan.

Conservation Efforts to Date

In the past decade, there has been significant conservation activity throughout Abu Dhabi Emirate. By the end of 2008, some 5,019 km^2 (5 % of the geographical area) of marine protected areas had been established in the emirate. Today, there are 21 protected marine settings and one protected coastal area. There is a target to increase this to 12 % of Abu Dhabi's marine area by 2014 (EAD 2010). By far, the largest of these protected areas is the Marawah Biosphere Reserve (4,255 km^2), lying immediately to the west of Abu al Abyad island (Fig. 1). While there are some sabkhas in the Marawah protected area, these are limited in extent and have suffered significant anthropogenic degradation.

While the actions to date are laudable, they have primarily focused on projects involving high-profile environments and species with which the public is familiar and has a close affection; for example, coral reefs, dugongs and turtles. Lower profile, less symbolic environments and species have continued to decline. More recently, there has been a broader focus for environmental protection and conservation efforts, with more prosaic environments gaining increased attention. This is at a time of increased environmental awareness throughout the emirate, with public awareness having increased from 49 % in 2008 to 58.5 % in 2010 (EAD 2011).

There is increased recognition of the value and importance of the Abu Dhabi Sabkha and related environments to the UAEs and, indeed, the region's natural heritage. UPC has developed 'Abu Dhabi Vision 2030', a strategic plan for development throughout the Emirate. This plan lists the preservation of 'natural and cultural heritage for future generations' as the first of five objectives for its Coastal Development Guidelines (Abu Dhabi Urban Planning Council 2009). Further, the plans for the development of the Western Region (Al Gharbia), which includes the best surviving sabkhas, list the 'protection and enhancement of ecosystems, including coastal and marine habitats' as one of its six overarching principals. The recently established Coastal Management Committee has stated that coastal areas of significance include intertidal mudflats and sabkhas.

Geoconservation by Management

Managing the surviving sabkhas in Abu Dhabi Emirate requires increased appreciation and understanding by the public to minimise inadvertent damage through inappropriate use. There is the need for a regulatory framework to protect this resource from public and private development. This study proposes the establishment of a protected geoconservation area to include both the subaerial and subaqueous shoreline environments of the last large area of near-pristine sabkha remaining in the UAE, lying immediately to the west of Al Dabb'iya peninsula (Fig. 4b). At present, this site is far from any urban centres and is only rarely visited, typically by survey crews associated with the hydrocarbon industry. As such, there has been only a relatively low

anthropogenic impact on the surface and subsurface systems. The size of the area is constrained by surrounding infrastructure with a wide motorway defining the southern boundary; a planned railroad would further compromise any conservation to the south. The eastern and western margins of the proposed geoconservation area are also limited by roads, as well as planned infrastructure development. To the north the area is bordered by off-shore islands that accommodate oil field support infrastructure that, due to security reasons, will prohibit further landward development.

We propose that the site be developed to promote geotourism and public awareness of this unique and complex sedimentary environment. A visitor centre could be established in order to provide information and coordinate future research activities. The construction of raised boardwalks and observation platforms, as have been successfully established in other settings susceptible to erosion, would minimise the effects of visitors on the delicate microbial communities in the upper intertidal zone. The shallow dip of the sabkha, together with the low tidal range of the Arabian Gulf, would allow boardwalks to extend over a range of environments from the supratidal to the subtidal setting. This would allow visitors to examine a diverse array of sedimentary and ecosystems, including evaporite formation, microbial mats, intertidal mud flats, tidal creeks and mangroves. Information boards would provide visitors with detailed information on these settings.

Public education would be promoted through the involvement of local communities in studies. The susceptibility of the low-lying coastline of the UAE to ongoing sea level rise is increasingly becoming a focus of concern and interest to the public. The establishment of a sea-level monitoring station and associated research activities at the sabkha geoconservation area would further enhance public awareness.

The establishment of this protected area could be achieved over a relatively short time-scale, with little infrastructure development and negligible investment. Once established, the Abu Dhabi Sabkha geoconservation area would become a focal point for environmental and geoconservation in the UAE. While EAD is currently developing a comprehensive policy, legal and governance framework for environmental sustainability, entitled Environment 2030, there is an imperative need for action if this last significant area of coastal sabkha is to be preserved.

Summary

The present day coastal sabkhas of Abu Dhabi are geologically recent features that have been prograding into the Arabian Gulf for only the last 2,000 years. The importance of these sedimentary environments as a Recent analogue to the petroleum systems of the Middle East was first recognised some 50 years ago. It was consequently established that these systems could contribute towards a solution to the long-standing ‘Dolomite Problem’—an area of research that is still attracting considerable interest today. Recent studies have focused on coastal sabkha microbial communities and their potential application in enhancing hydrocarbon production and in remediation activities.

Clearly, research in this natural laboratory is at a nascent stage, yet the future of the coastal sabkhas of the UAE is far from certain. In the last 50 years, 64 % of the eastern and central Abu Dhabi coastal sabkhas have been lost to anthropogenic activities, with natural coastlines vanishing at an increasingly rapid pace.

While there has been a positive move towards more sustainable environmental development in the UAE, time for the conservation of the Abu Dhabi Sabkha is rapidly running out. We propose the establishment of a protected sabkha geoconservation area to the west of the Al Dabb’iya peninsula. Such a park could be developed as a sustainable geotourism, research station and public education facility promoting the geoheritage of the UAE and enhancing public awareness of this unique and important sedimentary system.

Acknowledgments The author is grateful to Takumi Onuma of JGI Inc. for processing the satellite images utilised in this paper. Editor José Brilha and two anonymous reviewiers are thanked for their constructive comments and suggestions.

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