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Quaternary Development of the United Arab Emirates Coast: New Evidence from Marawah Island, Abu Dhabi

Graham Evans, Southampton University, Anthony Kirkham, Technoguide
and Robert A. Carter, University College London

ABSTRACT

Marawah is one of a chain of barrier islands off the coast of Abu Dhabi that separates the Khor Al Bazm lagoon from the open waters of the Arabian Gulf. The island consists of several rocky cores of Pleistocene limestone linked by areas of unconsolidated Holocene carbonates. It has the most complete Quaternary outcrop sequence in the region and the lowest exposed unit, a coralline limestone, had not been recorded previously. The Pleistocene deposits accumulated partly in a shallow-marine environment and partly under eolian conditions. The Marawah sections have revealed new data about the history of the southern Gulf in the late Pleistocene, a time interval of which little was known. The survey has shown that there were periods when sea level was close to present-day levels and other times when it was approximately 4 to 5 m higher than today. A phase of deflation and the development of a field of eolian sand dunes separated these two sea-level highstands. The unconsolidated sediments have accumulated around the Pleistocene rock cores since about 4,500 years BP to give the island its present form. Accumulation occurred because of wave action driven by the northwesterly 'Shamal' winds during periods of slightly falling or almost stationary sea level.

INTRODUCTION

Marawah Island is one of the westernmost islands of the barrier complex along the Arabian Gulf coast of Abu Dhabi (Figure 1). It is composed of Pleistocene limestones and Holocene carbonate sediments. It is known that sea level has fluctuated by several meters during the last few thousand years and the shape, or the very existence, of the island has probably been controlled by these fluctuations and by the associated sedimentological processes that have operated around its shores.

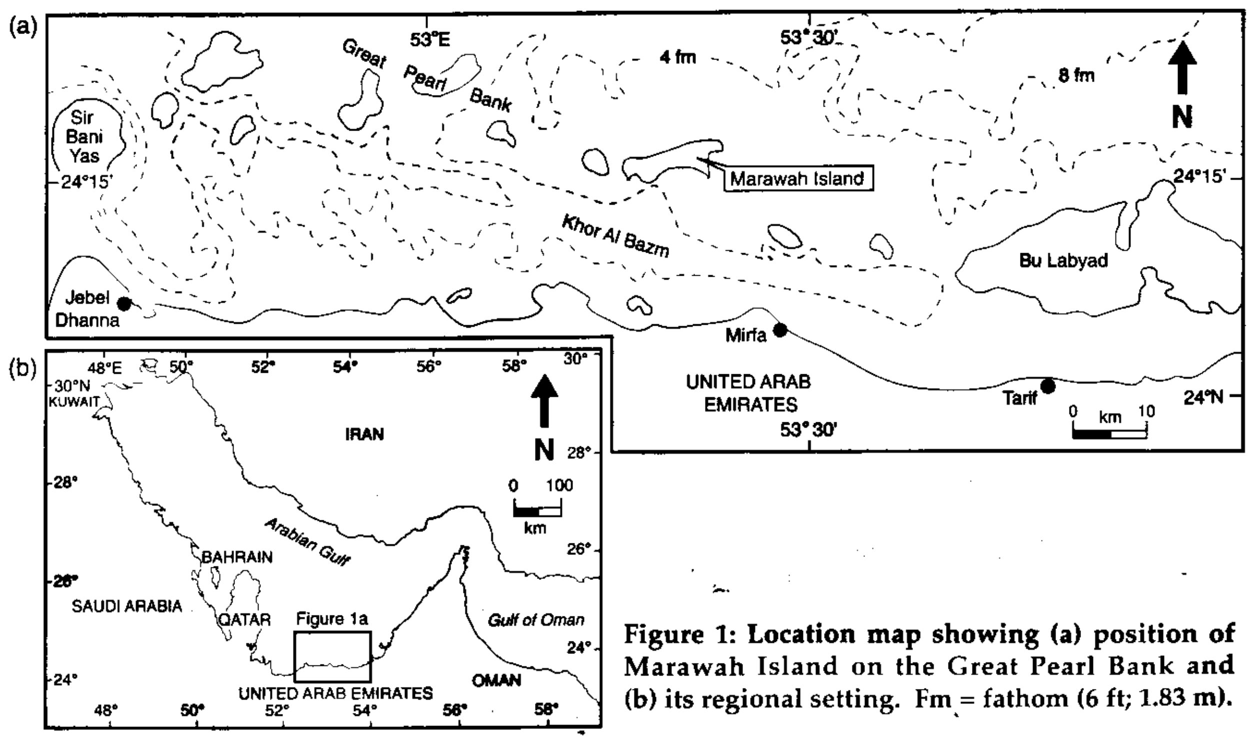


Figure 1: Location map showing (a) position of Marawah Island on the Great Pearl Bank and (b) its regional setting. Fm = fathom (6 ft; 1.83 m).

This paper describes the results of a geological field survey aimed at understanding the geological evolution of the island. Studies have shown that the island has one of the most complete records of the Quaternary in the United Arab Emirates. It is hoped that this paper will contribute to the understanding of the evolution of the southern shoreline of the Arabian Gulf in the late Pleistocene—a part of its history that until now has been relatively poorly known. Another aim of this survey of Marawah Island was to help archeologists in their search for sites of interest and to assist them in their understanding of the significance of such sites. The archeological significance of the work will be discussed elsewhere but it can be assumed that ancient inhabitants of the island built their settlements in areas that were defined by the contemporary shorelines.

Geological Setting

Marawah Island has an area of approximately 30 sq km. It is one of a chain of low islands located on a shallow submarine ridge along the western seaboard of Abu Dhabi. The ridge is in places cut by tidal channels and is separated from the mainland by the elongate Khor Al Bazm lagoon that has its main connection with the open sea to the west (Kendall and Skipwith, 1969). The submarine ridge is the inner part of the Great Pearl Bank, a prominent feature that trends parallel to the axis of the Arabian Gulf (Iranian Trend) and diverges from the Abu Dhabi coast in a westerly direction. The origin of the Great Pearl Bank is uncertain. It may be a fault-bounded structural high or a Quaternary erosional feature with Khor Al Bazm being an eroded valley (Purser and Evans, 1973).

Offshore, to the north of the island and extending to the northeast, is a wide, shallow platform that is covered with skeletal and peloidal sands fashioned into tidal ridges and fringed by a reef (Figures 2 and 3) (Purser and Evans, 1973). The southern side of the island is bordered by the deeper waters of Khor Al Bazm and it has only a narrow platform and patchy reef development.

Geomorphology

The island is elongated in an east-northeasterly direction whereas its surrounding shallow bank has a more northeasterly elongation that is oblique to the main trend of the Great Pearl Bank (Figure 2). The northern shore of Marawah faces the prevailing wind and wave direction that is dominated by the northwesterly winter storms ('Shamal'). Most of the island is less than few meters above high-water level and parts of the island are submerged during normal high spring tides. Wide expanses of standing water may develop in some low-lying areas (whose surfaces are often below the high-water level) after Shamal gales or spring tides, or as a result of flooding after heavy rain.

The highest part of the island (7.0 m) is the headland of Ra's Liffa in the extreme west just to the south of Liffa village (Figure 3b). The second-highest feature, immediately southwest of Gubba, is the 'Triangular Mesa' that narrows to the east and is capped by paleobeach ridges. Another such ridge forms the prominent 'Spine Ridge', a wall-like feature (Figure 4) that trends east-northeast for about 3 km across the eastern part of the island and is flanked by some lower, degraded, parallel ridges. These elements constitute what is termed Surface I (Figure 5a).

Much of the remainder of the island is a fragmented, low rocky platform at about 1 m (in some isolated areas about 2 m) above present sea level, that constitutes Surface II (Figure 5b). A north-south elongation of this platform forms much of the eastern part of the island. Another part forms a dissected ridge along the north coast and over much of the western part of the island. The surface of the platform is for the most part covered by a thin spread of silty sand or sandy silt containing thin, often fragmented, caliche layers (Figure 6), and slabs of the underlying rock. In a few places, cerithid gastropod shells are scattered over the surface. They occur mostly near the coast and were presumably swept onto the surface during Shamal storms. Wind blasting has commonly abraded the upper exposed coils of these gastropod shells.

Generally, sandy beaches passing landward into low accumulations of eolian sand characterize the coast. Surrounding the platforms and linking them are strand plains of cerithid-rich beach ridges of Surface III (Figure 5c). The beach ridges are banked against the Surface II platforms and have isolated

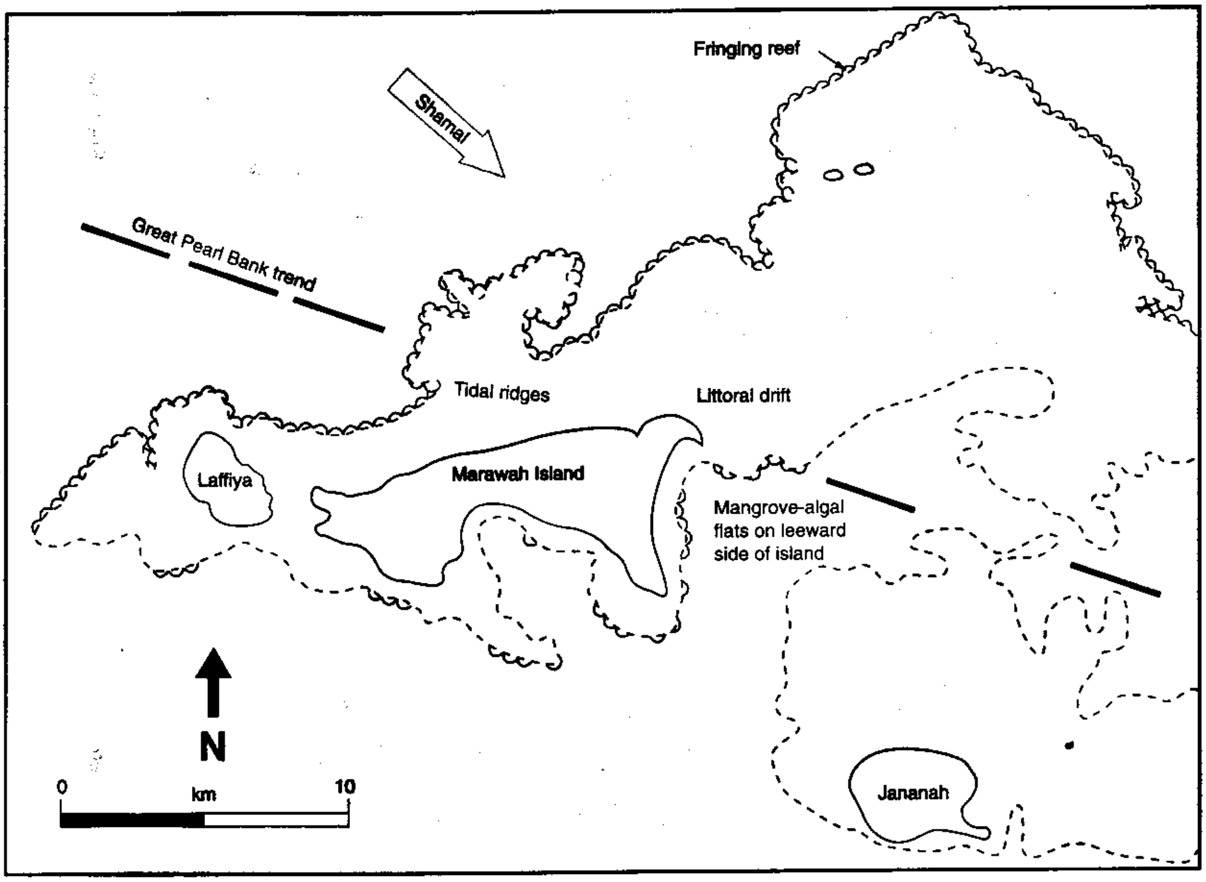


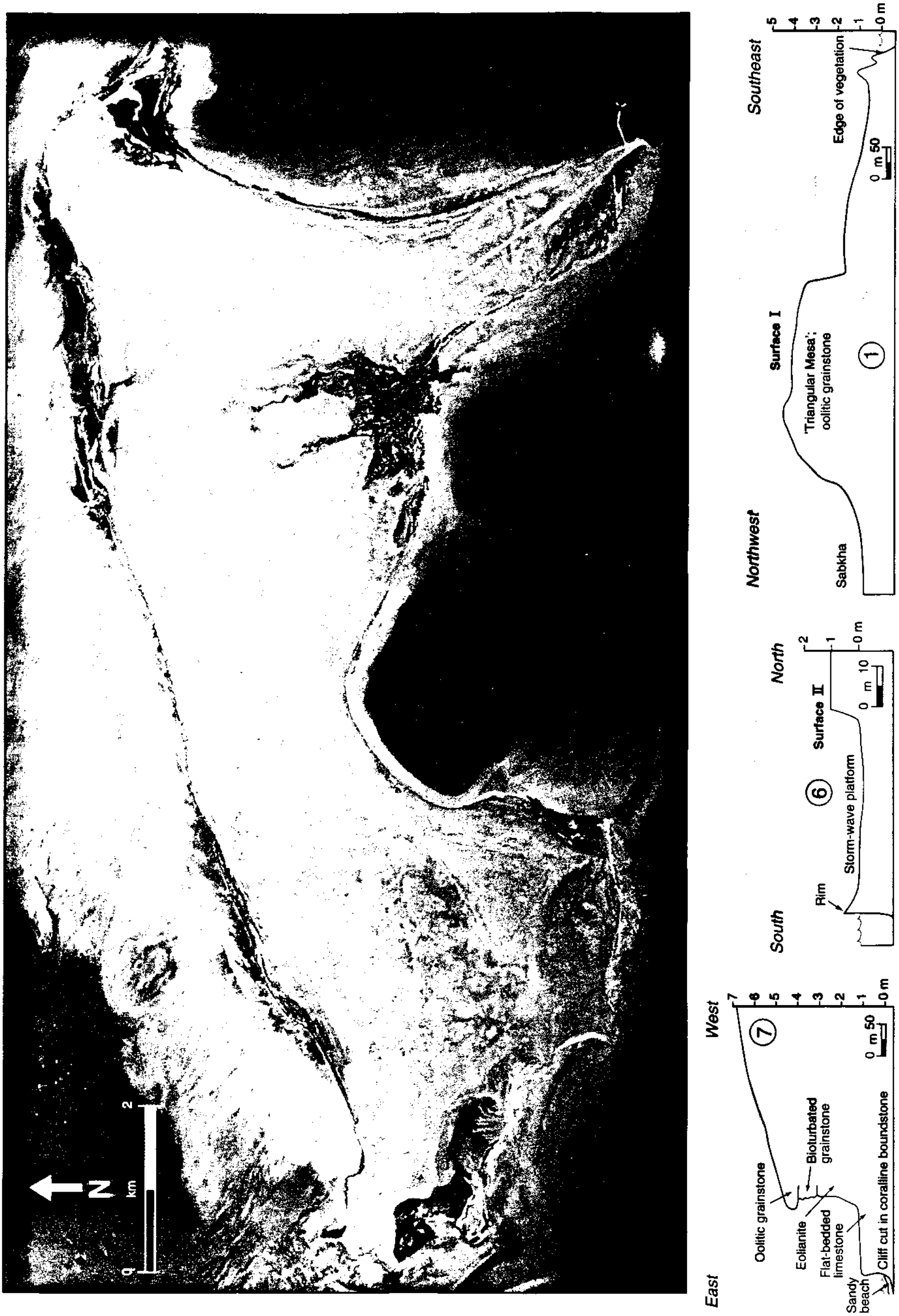
Figure 2: Marawah and its geomorphological setting.

them from the sea in some places (Figure 7a). A low, highly deflated, dune ridge along the seaward edge of a Surface II platform on the north coast forms the southern limit of one such coastal strand plain (Figure 5c). Small spits that splay out from where the Surface II rock platforms reach the coast, enclose small intertidal areas of microbial ('algal') mats and mangrove thickets. Elsewhere, beach ridges developed around outliers (formerly islets) of the platform to infill the intervening low areas.

Sabkhas occur between the slightly higher areas of the Surface II dissected platform in the center of the island and elsewhere away from the coast. They are filled with saline deposits whose level is often below high-water level (Figures 5b and 7b). The sabkhas are very treacherous and are difficult to cross after rain or sea flooding. In the southeast of the island (east of Gubba) is an area of intertidal microbial mats and associated mangroves crossed by tidal creeks. The sabkhas and microbial-mangrove flats are also Surface III features.

Eolian dunes are not common on the island, but low dunes are present on the margins of the microbial and mangrove flats east of Gubba. Dunes are also present south of Marawah, inland of a belt of mangroves. Elsewhere, small fields of nebkha occur on the Surface II dissected platform.

Where the Surface II rock platforms reach the coast, low cliffs are developed that are commonly finely fretted due to intense boring and have an overhanging visor at about normal high-water level (Figures 8a,b). In some places, wave-cut platforms just above the level of normal high water occur where the rocky outcrops reach the coast. They may be as much as 10 m in width, display an elevated seaward rim, and are free of sediment. Fossilized mangrove roots are commonly well exposed on the wave-cut platform and are especially well developed at Ra's Liffa (Figure 8a). It is probable that they have a complex history (discussed below). At other localities, the rock platforms are protected by strand plains of laterally stacked beach ridges (Figure 8c).


N
km
0
2
East
West
7
Oolitic grainstone
Eolianite
Bioturbated grainstone
Flat-bedded limestone
Sandy beach
Cliff cut in coralline boundstone
0 m 50
South
North
Rim
6
Storm-wave platform
Surface II
0 m 10
Northwest
Southeast
Sabkha
"Triangular Mesa"; oolitic grainstone
Surface I
1
Edge of vegetation
0 m 50

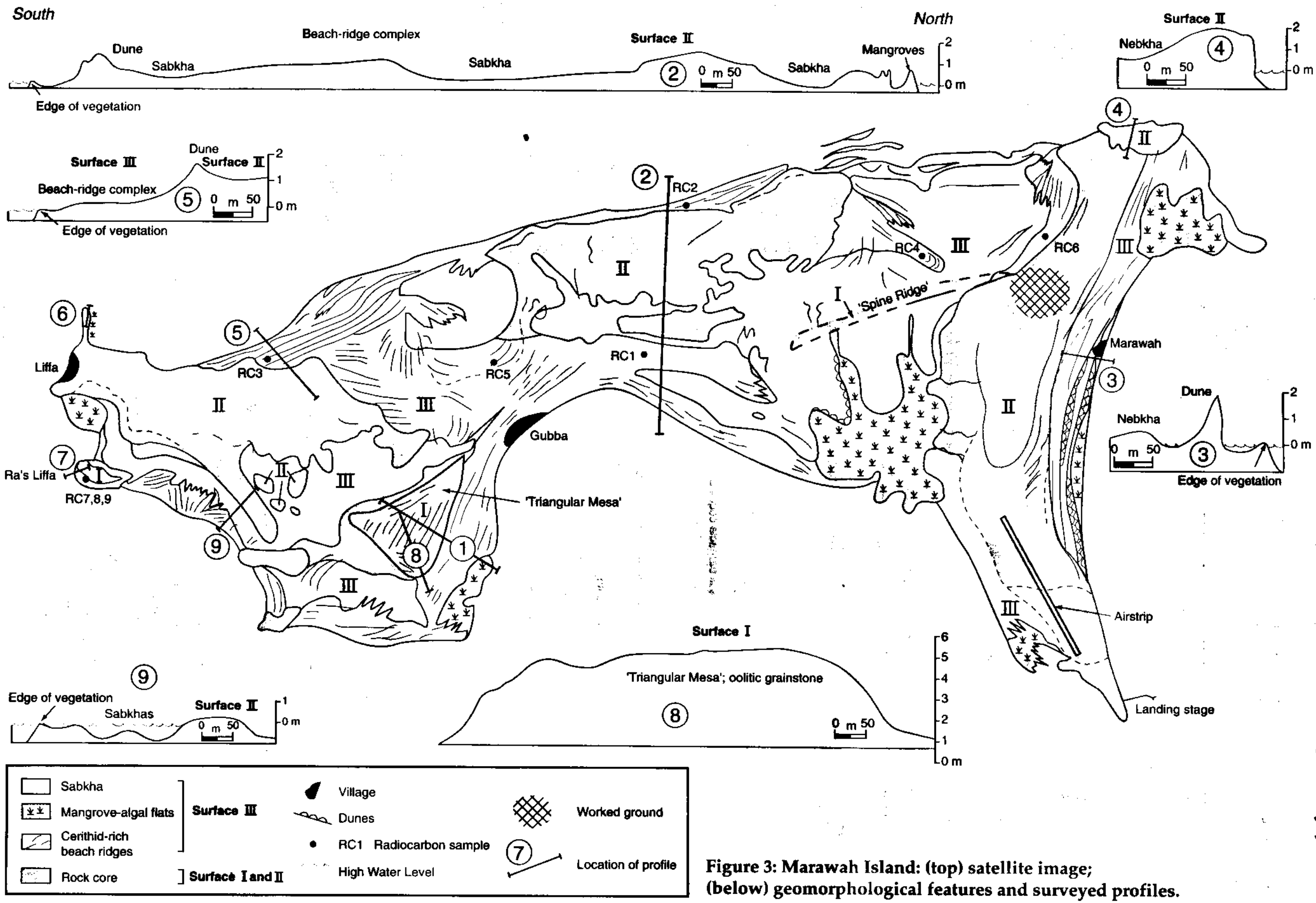


Figure 3: Marawah Island: (top) satellite image; (below) geomorphological features and surveyed profiles.

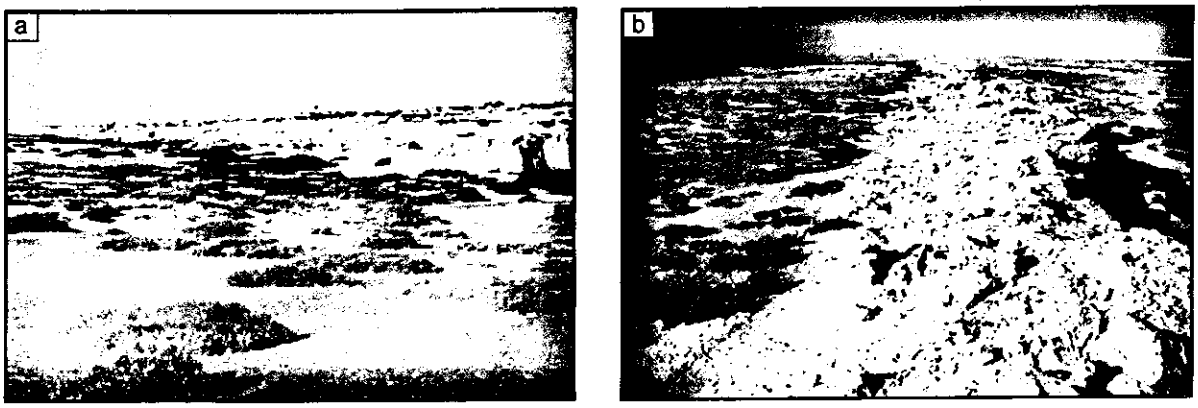


Figure 4: 'Spine Ridge', a prominent wall-like outcrop of marine bioturbated skeletal grainstone capped by oolite. It is of Pleistocene age and has an average height of about 3 m. (a) lateral view as seen from the south, (b) view along the axis of 'Spine Ridge' looking west.

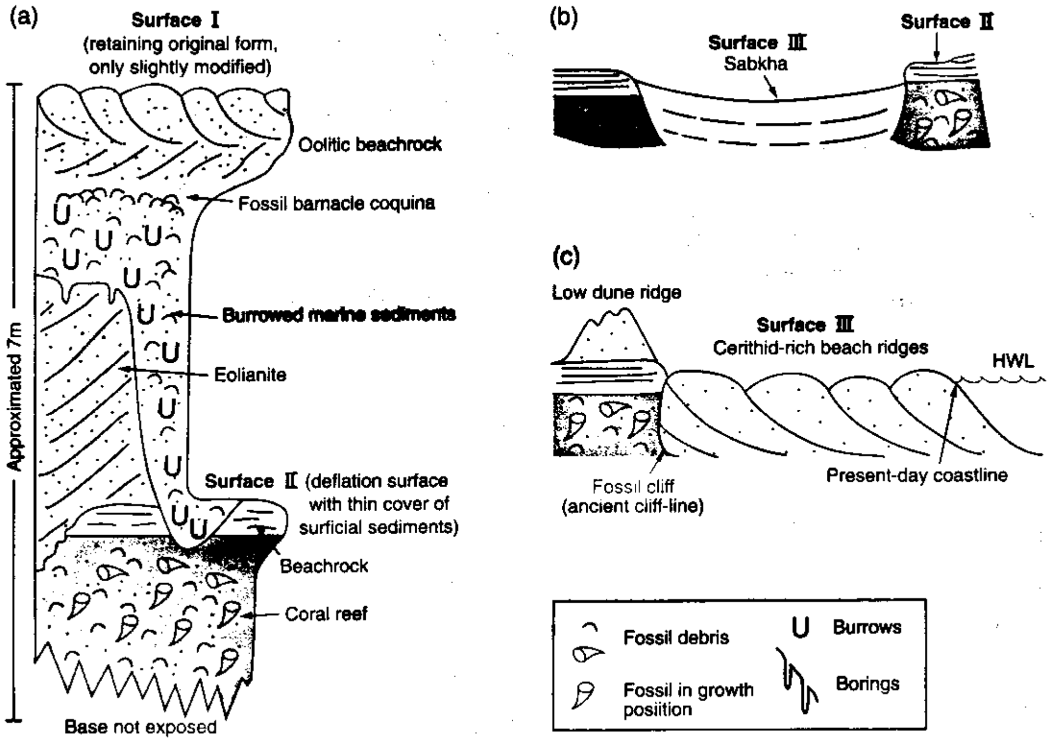


Figure 5: The relationship between prominent surfaces on the island and geology; (a) represents the sequence at Ra's Liffa.

QUATERNARY STRATIGRAPHY

The most complete Quaternary succession crops out at Ra's Liffa (Figure 5a). The oldest deposit exposed on the island is a highly coralline limestone with some in situ coral bouquets dominated by *Porites* (Figures 9 and 10a). It is commonly a rudstone composed of fragmented coral and other skeletal debris and in places is bored by *Lithophaga*. It forms the basal parts of the low cliffs around rocky headlands and small, offshore islets. Its true thickness is unknown but rarely more that 1 m is exposed except at Liffa where the exposure is approximately 2 m thick. Internal stratification is absent although its top is essentially horizontal excepting at Liffa. This coralline unit is usually overlain by a thin (< 30 cm), flat-bedded and locally cross-stratified, skeletal grainstone showing fenestral structures that indicate former intertidal/beach environments (Figure 10b). Immediately south of Liffa, the structures may represent paleospits. Rare, thin, mud-cracked stromatolitic structures and pisoliths occur within this upper unit in the northeast of the island.

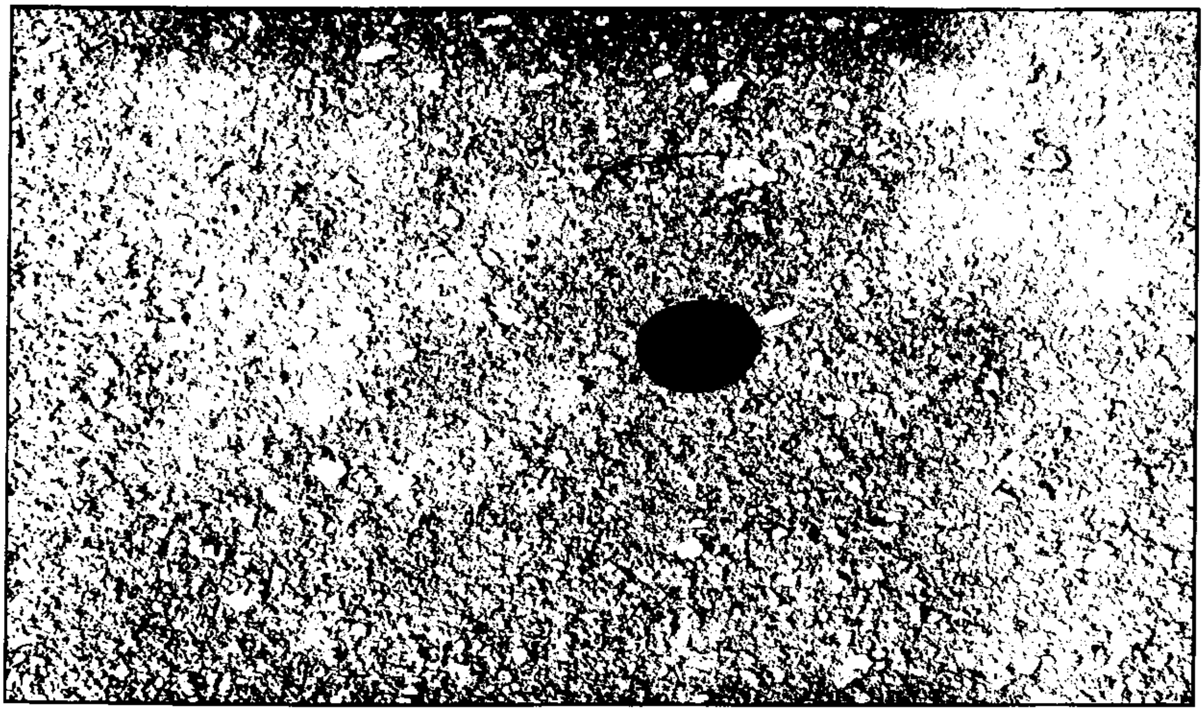


Figure 6: Silty-sand and sandy-silt on a Surface II location with small flakes of caliche and numerous cerithid gastropods exposed at the surface. The cerithid shells commonly have their upper exposed coils abraded by wind blasting. Camera lens cap for scale.

Immediately north of Liffa, the top of the coralline unit disappears beneath sea level and is directly overlain by a slightly quartzose, carbonate grainstone. This is well-sorted sand-grade sediment that is laminated and has well developed, large-scale, cross-stratification that dips generally to the southeast. It shows an absence of macrofauna and a lack of bioturbation. These characteristics suggest that it is an eolianite (Figures 10c and 11a) that is identical to a similar rock-type widespread on the coast of Arabia. It has been termed 'miliolite'—a term given to it by Carter (1849)—who compared it with similar eolianites from Kutch in India that contain abundant miliolids. It is not clear whether the eolianite fills a depression in the underlying unit or whether the top of the coralline unit has been eroded. The intervening flat-bedded skeletal grainstone is locally absent. A similar relationship was seen at Ra's Liffa.

A glauconitic (?) marine, bioturbated skeletal grainstone with large crab and other vertical burrows (including *Ophiomorpha*) overlies the eolianite with a sharp, well-defined and bored contact (Figures 10d and 11b). Spreiten (nested concave-upward laminae) are conspiciuos in the burrows. In other places, such as at Ra's Liffa, it lies directly on the coralline limestone. The marine grainstone is highly quartzose as it originated largely from a reworking of the underlying eolian deposits that were at least partially lithified prior to the marine transgression. Lithification is shown by the common occurrence of laminated clasts of eolianite in the basal layers of the grainstone; by marine sediments penetrating as sheets or lenses along stratification planes in the upper part of the eolianite; and by possible borings into the erosional surface at the top of the eolianite.

The bioturbated skeletal grainstone is overlain by beach sediments that in turn pass up into a cross-stratified (decimeter scale), bioclastic, oolitic (and rarely pisolitic) grainstone (Figures 10e,f) commonly with bi-directional (herring-bone) cross-stratification (Figure 11c). However, the cross-stratification generally dips to the northwest at Ra's Liffa. The basal sediments of the oolitic grainstone are in places rich in barnacles and associated shells. These sediments form the highest elevations on the island, at Ra's Liffa. Over large expanses of the island, and particularly well developed on the 'Triangular Mesa' southwest of Ghubba, the oolitic sediments have been fashioned into a series of lithified beach ridges that still retain their depositional relief, but at a slightly lower elevation than those at Ra's Liffa. They represent the youngest of the lithified Pleistocene deposits. Caliche crusts commonly provide 'case-hardened' exposed surfaces on these oolitic grainstones.

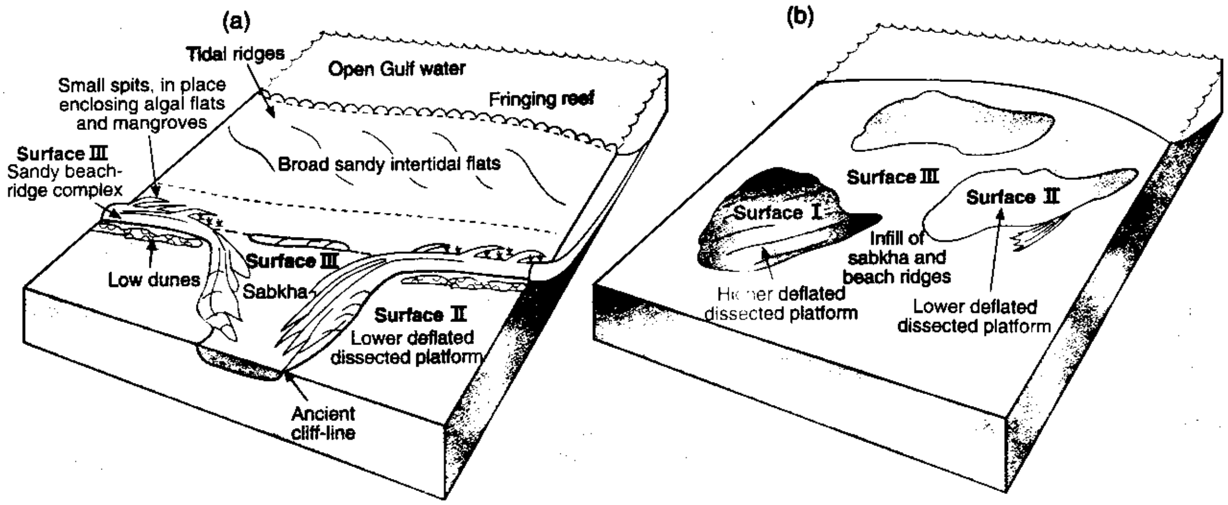
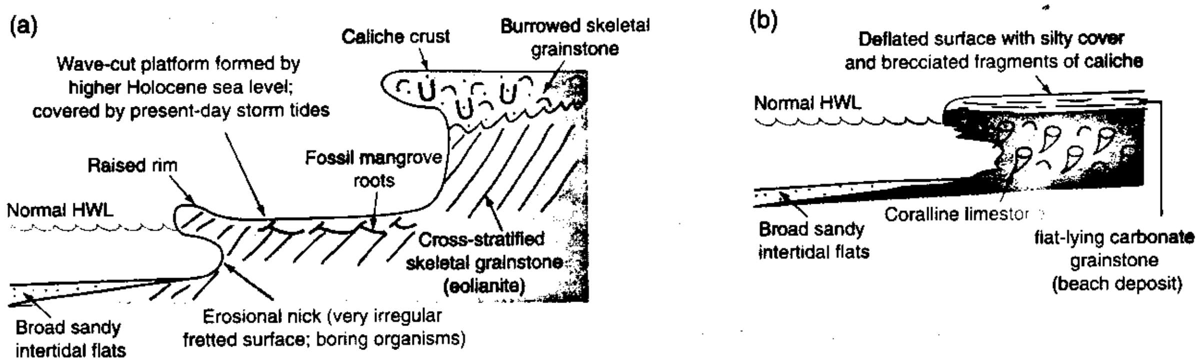


Figure 7: (a) The beach ridges are banked against the Surface II platforms and have isolated them from the sea in some places. (b) Sabkhas occur between the slightly higher areas of the Surface II dissected platform in the center of the island and elsewhere away from the coast, that are filled with saline deposits.



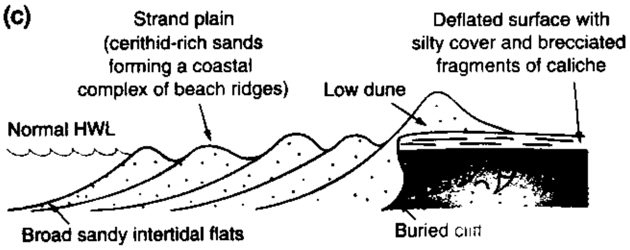


Figure 8: Types of coastline: (a) eroding coast—cliff cut in eolianite; (b) eroding coast cut in reefal and overlying Pleistocene beach deposits; (c) accreting coast—strand plain of beach-dune ridges banked against a fossil cliff. See Figure 5 for legend.

The indurated deposits are succeeded by various kinds of Holocene sediments, but occupying generally lower elevations. They are (1) unconsolidated and often laterally accreted cerithid-rich skeletal beach sands (Figure 8c), (2) sabkha deposits composed of carbonate silty sands and silts impregnated with salt, (3) eolian quartz-carbonate sands fashioned into dunes and nebkha fields, and (4) muddy skeletal and pelletal carbonate sands of the mangrove swamps/microbial flats.

Cementation by anhydrite and gypsum is relatively common in both the Pleistocene and Holocene sediments.

GEOLOGICAL EVOLUTION (Figure 12)

The earliest event recorded in the deposits exposed on Marawah Island was the development of an extensive Pleistocene reefal environment (Figure 12a). It is likely to have been analogous to the fringing reefs best developed today along the northern windward margins of the platform surrounding Marawah. However, it is impossible to deduce whether the Pleistocene reef fringed contemporaneous

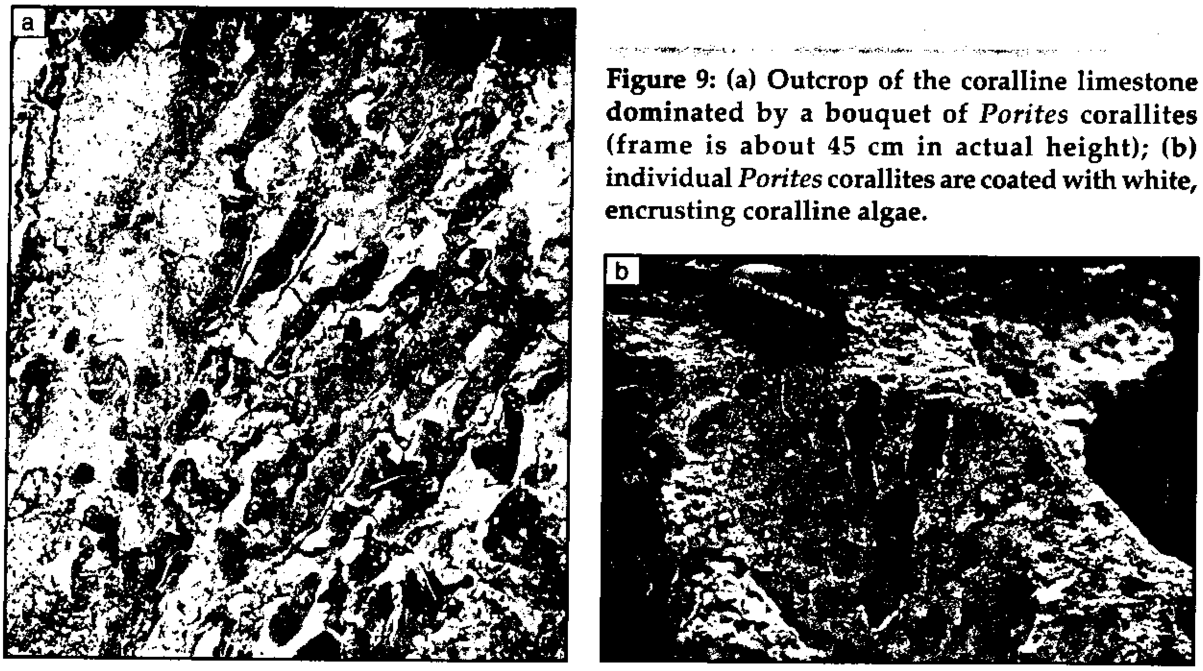


Figure 9: (a) Outcrop of the coralline limestone dominated by a bouquet of *Porites* corallites (frame is about 45 cm in actual height); (b) individual *Porites* corallites are coated with white, encrusting coralline algae.

islands or whether it began as a patch reef on the crest of part of the submerged Great Pearl Bank. It was certainly exposed to storm activity as indicated by the large amounts of coarse coralline debris. The reef appears to have been best developed along the northerly shores and possibly reflects their windward setting. Ultimately, shallowing that was probably the result of a combination of vertical reef accretion and sea-level fall ended the reefal growth at Marawah Island. Accreting intertidal/ beach deposits (Figure 12b) eventually smothered the reefal deposits.

Prolonged exposure and erosion of this marine sequence is suggested by broad infilled depressions that were probably of deflationary origin as no evidence of fluvial action has been recognized (Figure 12c). Eolian dunes that today constitute the eolianites of the rocky platforms and headlands covered this erosional surface. The eolianite extends beneath present-day sea level and fills an erosional depression immediately east of Liffa. These deposits indicate clearly that there was a drop in sea level followed by probable subaerial erosion that, in turn, was followed by the deposition of eolian sand transported from the northwest. The composition of the sand shows that siliciclastic as well as carbonate rocks were being eroded upwind at this time.

The period of eolian activity was followed by a further rise in sea level (Figure 12d) and the superimposition of a densely burrowed skeletal calcarenite over the eolian dunes that by now had become lightly cemented, presumably by meteoric precipitation. Locally this transgression led to the complete removal of the eolianite and the deposition of the bioturbated calcarenite directly onto the coralline limestone. The degree of induration of the eolianite was sufficient to encourage possible boring, but insufficient to deter occasional burrowing. Rounded boulders of the eolianite and fragments of coral are the few obvious signs of transgressive lag deposits. The lack of a classical fining-up sequence representing the transgression is attributed either to the speed of the transgression or to homogenization by intense burrowing. There is, however, a coarsening-up trend at the top of the bioturbated unit that reflects a succeeding regression. It is represented by the oolitic grainstone that is often rich in fossil barnacle coquinas (Figure 5a) at its base on Ra's Liffa.

This regression represents the final episode recorded in the Pleistocene rock sequence on Marawah Island. The oolitic sand sheet was fashioned into a laterally accreting complex of beach ridges that are well preserved on the 'Triangular Mesa' southwest of Gubba and its extension to the east. At the 'Triangular Mesa', the oolite sand overlies bioturbated marine carbonate grainstone as at Ra's Liffa, but at a slightly lower elevation. Nevertheless, these lower sands are interpreted as the diachronous equivalent of those at Ra's Liffa. They were simply deposited at a slightly later time as sea level fell. On the mesa they show three interfering trends.

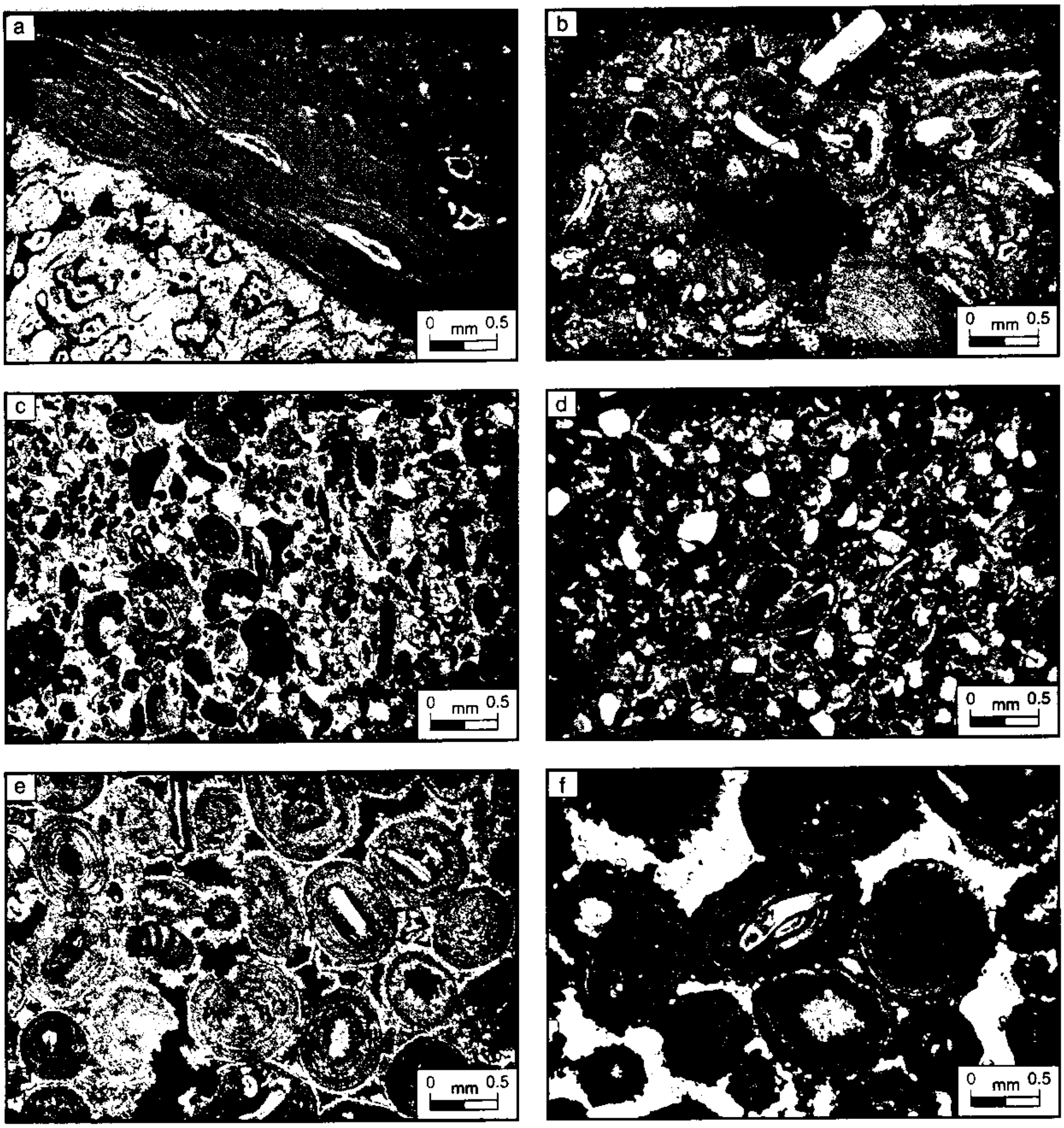


Figure 10: Photomicrographs of selected lithologies: (a) *Porites* encrusted with coralline algae; (b) beachrock overlying the coralline limestone ('bird's eye' structures are well preserved); (c) eolianite containing abundant quartz grains (many of the skeletal carbonate grains are leached and preserved only as moulds); (d) bioturbated marine grainstone overlying the eolianite (it probably represents reworked eolianite because textures and constituents are so similar); (e) oolite from Ra's Liffa (ooliths have carbonate nuclei and well-developed cortices; grains are coated with isopachous fringe cements); (f) an unusual pisolitic sample collected from the same oolitic sequence as 11e; intergranular pores are almost occluded by gypsum cement.

Following the deposition of the oolitic grainstone there appears to have been a second significant sea level fall that led to a second period of intense subaerial erosion on Marawah. The capping of oolitic grainstone was breached and has been removed from most of the island. It survives only at Ra's Liffa and on the 'Triangular Mesa' and its associated ridges (including 'Spine Ridge') extending to the east. The underlying burrowed skeletal grainstone and the eolianite appear to have been considerably more susceptible to erosion and have been stripped from most of the island wherever the protective oolitic layer was breached. Eolian deflation probably caused this erosion and this is continuing today over much of the island. It is possible that there was some fluvial erosion with the development of small

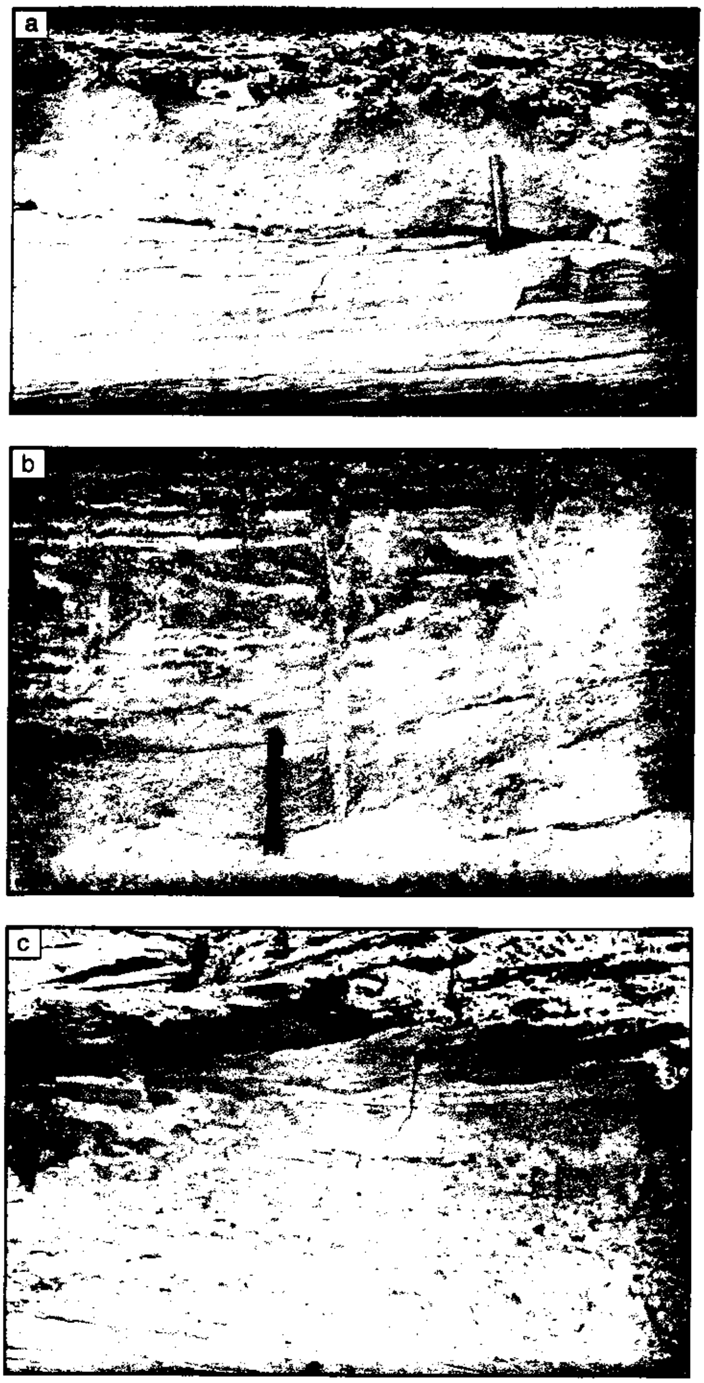


Figure 11: Outcrop photographs to illustrate typical lithologies. (a) Eolianite with large-scale cross-bedding is overlain by bioturbated marine carbonate; hammer head marks top of eolianite. (b) Deep vertical burrows with spreiten (nested concave-upward laminae) within the marine sediment that directly overlies the eolianite at Ra's Liffa; white bioclasts are part of the fill near the bases of the burrows. (c) A sequence of eolianite overlain by shelly, bioturbated marine sediment that in turn is capped by cross-bedded oolite (top of hammer handle in lower center for scale). The oolite commonly displays herringbone cross-bedding and is locally rich in Pleistocene barnacles and other bivalve shells.

gullies and wadis, but no evidence of fluvial deposits has been discovered so far.

On the other hand, the underlying flat-bedded intertidal/beach deposit grainstone and the coralline unit appear to have been more indurated and resistant to erosion perhaps because they are older and better cemented. They became exposed to form the low-level, dissected platform that occurs over much of the island with its surface approximately 1 to 2 m above present-day sea level. In places, this more recent erosion has exhumed the paleotopography.

Wavecut platforms have been formed in the eolianites and the younger bioturbated marine limestones where they extend down to the lower levels (Figure 13). These platforms have associated mangrove roots irrespective of the stratigraphic level they truncate. Abundant fossil mangrove rhizoliths (root casts) with indications of pneumatophores (aerial roots) are seen in plan view on wave-cut platforms at Liffa and Ra's Liffa (Figure 14). The mangrove rhizoliths penetrate these deposits and post-date both of them. They formed (and their roots subsequently became fossilized) during the climax of the Flandrian transgression (about 4,000 years BP) when sea level may have been about 1 m above that of today. The mangrove rhizoliths were able to penetrate the older sediments because the Flandrian transgression had removed casehardened exteriors to expose the softer cores of the associated paleohighs.

Although the wavecut platform was probably partly or wholly cut during the period of assumed high Holocene (Flandrian) sea level, it is being reoccupied and modified under present-day storm (Shamal) conditions to expose the rhizoliths.

Beach-ridge complexes are continuing to develop along the eastern coasts. Spit complexes occur on the northeast coast of the island north of Marawah and immediately west of the landing stage

(Figure 3b). A series of small spits, recurved to the northeast are forming along the exposed north coast to enclose narrow microbial flats and are extending the coastline seaward and isolating the low cliffs of the dissected platform from the sea. A comparatively large area of intertidal flats with microbial mats and associated mangroves has developed in the leeward part of the island, east of Gubba and south of 'Spine Ridge'.

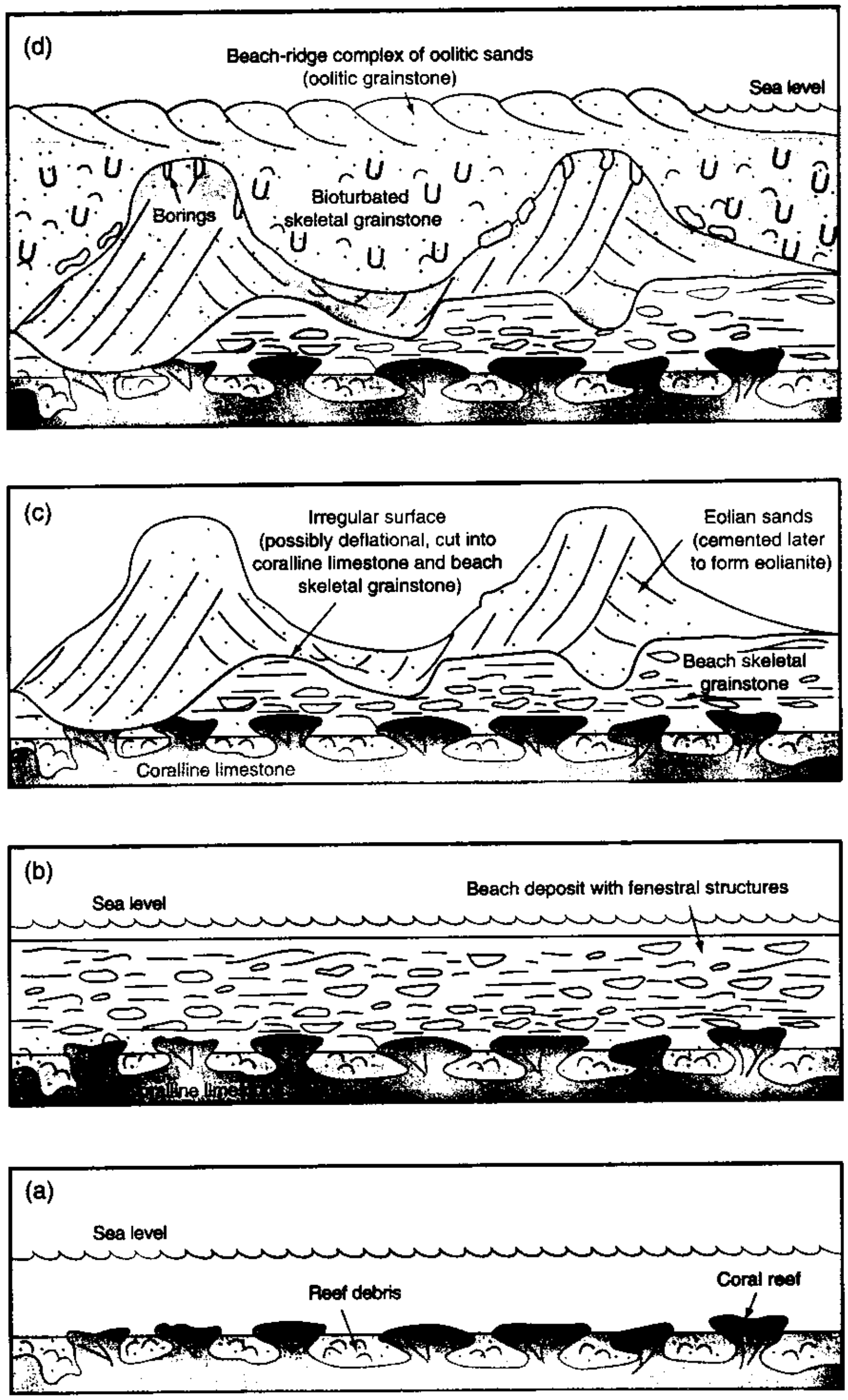


Figure 12: Schematic sketches showing the Pleistocene evolution of the island: (a) establishment of a reefal platform; (b) accretion of beach intertidal-supratidal sediments; (c) exposure, extensive deflation followed by deposition of eolian sand; (d) transgressive (early phase) drowning of the dune sands; completion of transgression and development of a regressive complex of oolitic grainstone ridges capping the earlier Pleistocene deposits.

During the Flandrian transgression, the sea inundated low areas around the dissected Pleistocene platforms (Figure 15) and these were gradually filled with Holocene sediments, although deflation probably continued on the exposed parts. Two former inlets existed on the north coast (Figure 3) and these have been filled by complexes of cerithid-rich, shelly, beach-ridge sand and finer supratidal sabkha deposits. Some recurved spits extend east from Ra's Liffa where they have enclosed intertidal flats colonized by microbial mats and mangrove thickets. Southeast of Ra's Liffa, beach-ridge complexes have linked small rocky headlands or islets and these extend around the south of the island to form a narrow coastal plain on which the village of Gubba is located. This process is continuing today. Inland, depressions between the fragments of the dissected older platforms have become infilled with sediment carried by the Shamal winds and floods, and have trapped fine-grained, silty sand and minor evaporites to form treacherous sabkha flats.

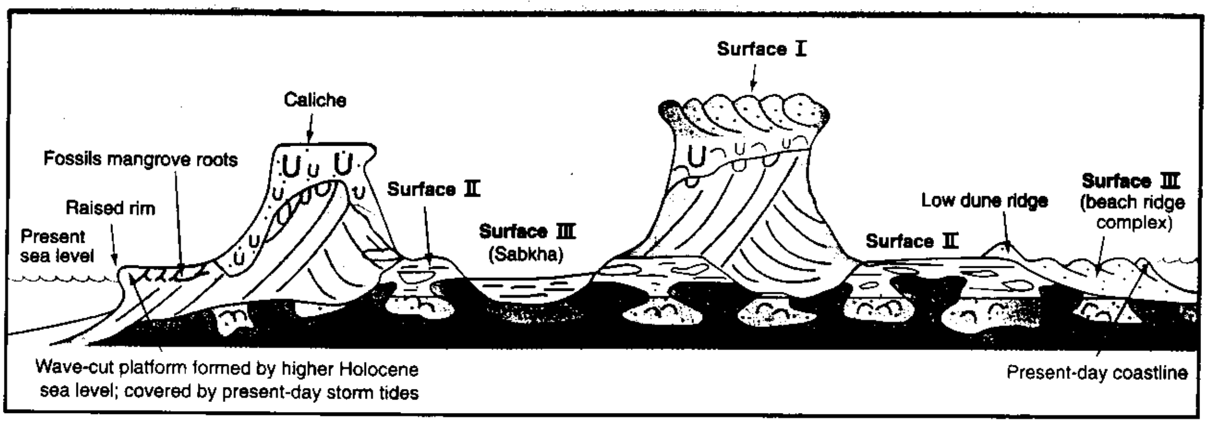


Figure 13: Schematic section across Marawah Island summarizing the various geological and topographic features.

Most rock surfaces have thin caliche rinds produced by capillary action. Curious solution basins and pits, which have presumably been produced by ponding of present-day rainfall, have developed on the oolitic grainstone of the 'Spine Ridge'. Common anhydrite and gypsum cementation of surficial deposits may be a relatively recent diagenetic stage as they postdate carbonate cementation.

Figure 14: A mangrove rhizolith (root cast) on the wave-cut platform at Ra's Liffa. The bases of truncated pneumatophores (aerial roots) are visible along the top of a radial root.

In summary, the island has been formed by the amalgamation of numerous fragments of a dissected landscape by infilling, with coastal plain and sabkha sediments being deposited in the intervening low-lying areas. The general evolution of the island's morphology and its relation to the various geological events—three transgressions separated by periods of deflation—is shown in Figures 15 and 16. Deflation continues to be an important process in the evolution of the landscape.

Comparison with Other Parts of Abu Dhabi

Marawah Island has a more complete Quaternary section than on any of the other barrier islands, or indeed anywhere on the mainland of the United Arab Emirates. The basal coralline unit with its overlying beach deposit has been found only on Marawah but other aspects of the Marawah succession have analogs in the exposures of central and eastern Abu Dhabi. There, barchanoid eolianites were modeled by paleo-Shamal winds into linear seif dunes that were then onlapped by late Pleistocene beach deposits (Kirkham, 1997). Tidal embayments that were developed between the seif dunes and the onlapping beach deposits pass laterally into highly burrowed and homogenized subtidal sediments similar to those that overlie the eolianites of Ra's Liffa. The eolianites of Marawah may also have had seif dune morphologies, as suggested by the northwesterly trend of the eolianite ridge that forms Ra's Liffa, although the orientation of this feature may be merely due to deflation by the Shamal wind. Rip-up clasts are common in the basal sediments of the post-eolianite marine sequence and mangrove rhizoliths are extensively exposed on wave-cut platforms of mainland Abu Dhabi. Kenig et al. (1990), recorded transgressive mangrove paleosols near Abu Dhabi Island. Satellite images clearly show comparative Holocene storm beaches formed as either parallel ridges or 'winged spits' that curl around the flanks of islands and headlands (Kirkham, 1998a).

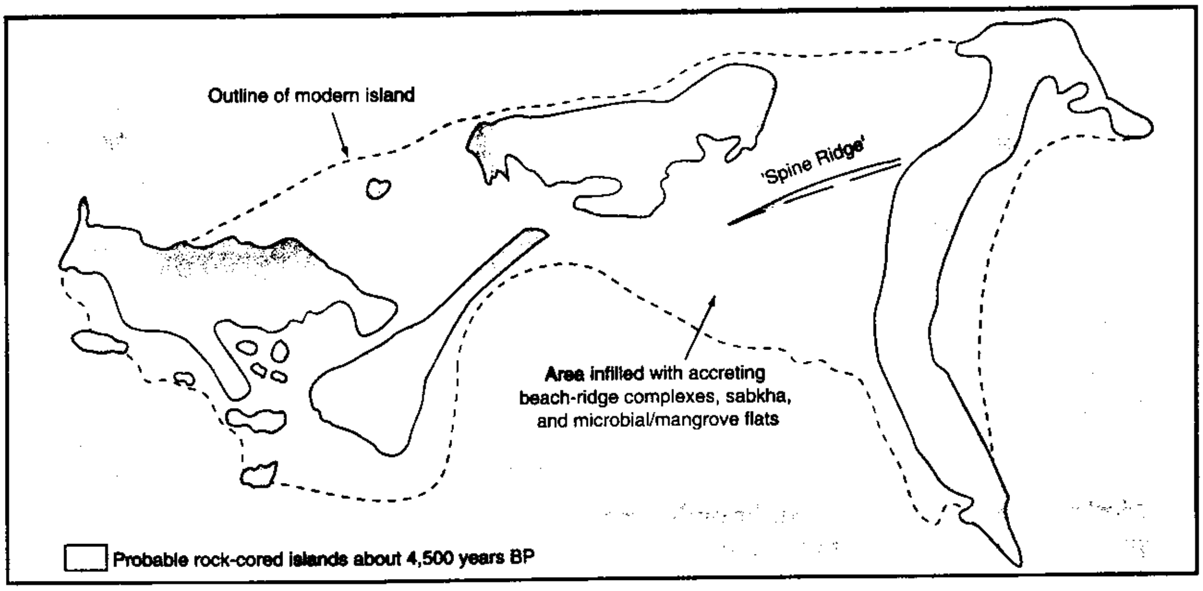


Figure 15: Sketch of probable configuration of Marawah Island at about 4,500 years BP, showing the distribution of small rock-core islands that were ultimately linked by infilling with Holocene sediments.

DATING THE GEOLOGICAL EVENTS

An attempt has been made to relate the transgressive and regressive events (Figure 16) interpreted from the Marawah Quaternary outcrops and known Quaternary events elsewhere in the United Arab Emirates to the timings of sea-level fluctuations. Kirkham (1998a) concluded that a marine transgression inundated the Pleistocene eolianites of central Abu Dhabi during the last interglacial period when sea level was about 5 to 6 m above the present-day level. The oolitic beach deposits that lie above the eolianite on Marawah Island at a similar height were probably deposited at the same time (about 125,000–75,000 years BP). This is a minimum age for the oolites as sea level has not been so high since then. Luminescence dating of the siliceous fraction of the underlying eolianite could possibly provide a maximum age for the oolites. Radiocarbon dating of these deposits at Ra's Liffa indicated an age of greater than 16,000 years BP. Kirkham concluded that the eolianites dated from the preceding glacial period, at least 190,000 to 125,000 years BP. The coralline sequence is clearly even older and possibly accumulated during the earlier interglacial period. The subsequent erosion that pre-dated the deposition of the eolianite could have occurred at the beginning of the 190,000 to 125,000 years BP glacial period. However, more extensive dating is needed to confirm these suggestions.

Sea level in the Arabian Gulf dropped to 120 to 130 m below present level during the last glacial period. This regression climaxed at about 18,000 years BP when the Arabian Gulf was drained as the sea retreated to the Strait of Hormuz. Then began the Flandrian transgression that dominated the Holocene stratigraphy of the Gulf (Lambeck, 1996). The evidence from Abu Dhabi indicates that the transgression climaxed at about 4,500 years BP with sea level possibly reaching 1 m above the present level (Evans et al., 1969), although elsewhere it has been claimed this occurred earlier (Lambeck, 1996). Kirkham (1998b) discussed the evidence to support a fall from this high level to present-day level. The latest regression has led to the development of the strandline spit and beach complexes that have infilled with 'winged spits' the low areas between the remnants of the dissected Pleistocene platform and which have prograded seaward, particularly along the northern shore of Marawah. Radiocarbon dates from these beach complexes support this general Holocene evolution.

Radiocarbon Dating

Six radiocarbon dates were obtained from cerithid beach ridges that surround the rock cores of the island (see Figure 3b for sample locations). The oldest sample, RC1, is from a ridge with a crest approximately 0.5 to 0.7 m above the present high-water mark, situated about 1 km from the coast just

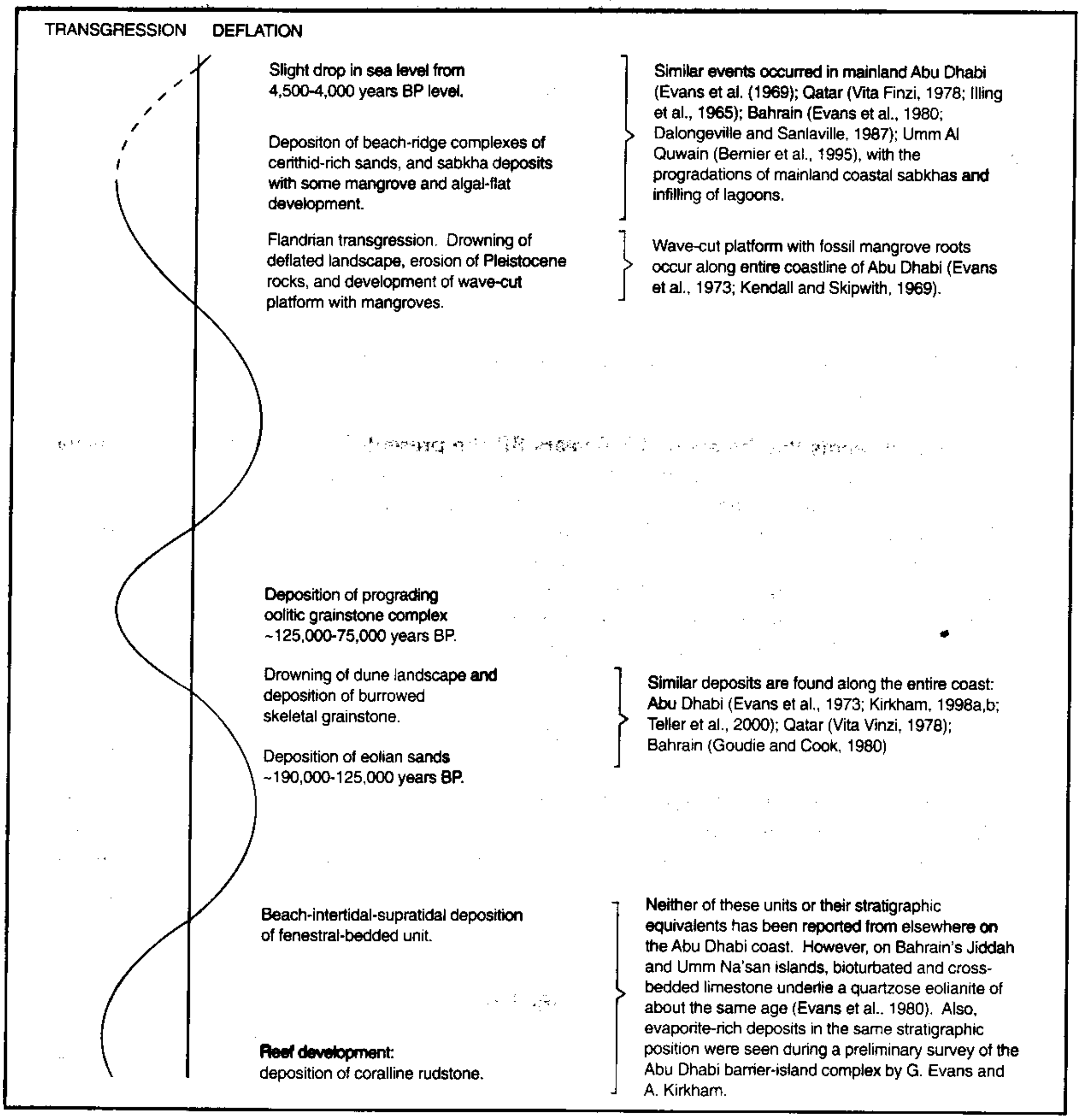


Figure 16: Quaternary transgressions and regressions as indicated by the geology of Marawah Island.

east of Gubba. The result indicates that beach-ridge development began on the south of the island at 4,500 ± 100 years BP, slightly above present-day sea level.

Four dates are from beach ridges that fill embayments extending inland between rock cores on the exposed northern coast of the island. All sites have elevations within 1 m of the present high-water mark. The oldest date is RC5 (2,670 ± 40 years BP) for a beach ridge on the innermost part of an infilled embayment between the rock core at the western end of the island and the central-north rock core. The embayment had been largely infilled by 2,230 ± 50 years BP, as indicated by the radiocarbon date of RC3 taken from a beach ridge on the inner margin of a narrow strand plain that extends across the northern seaward end of the embayment. The other large embayment extends inland from the north coast between the north-central rock core and the most easterly rock core. It began to be filled about 1,900 to 2,000 years BP as indicated by the radiocarbon dates of RC4 on its western side (1,900 ± 80 years BP) and RC6 on its eastern side (1,970 ± 40 years BP).

The remaining sample is RC2. Its age suggests that the exposed north coast of the north-central core remained an erosional area until progradation of beach ridges commenced about 1,610 years BP.

A few dates were obtained on shells from the marine grainstones that overlie the eolianite rock core at Ra's Liffa. One analysis by Professor Claudio Vita Finzi using a simple (approximate) carbon-dating technique gave an age greater than 16,000 years BP (RC7) for barnacle shells from the beach grainstone at the top of the Ra's Liffa succession. Two other dates using a more exact method applied to oyster shells from the underlying bioturbated grainstone that caps the eolianite gave ages of 40,070 ± 720 years BP (RC8) and 40,980 ± 720 years BP (RC9). Radiocarbon dates of this age are not very reliable and merely show that the samples are pre-Holocene. They appear to be rather young, but it is likely that the marine sediments overlying the eolianite were deposited during the last pre-Holocene high-stand at between 75,000 to 125,000 years BP.

These few dates indicate that beach-ridge strand plain development commenced on the southern leeward side of the island about 4,500 years BP when sea level was slightly above the present level. On the north coast, it appears that the beach-ridge plain had extended around the rock cores exposed to the northwest Shamal by approximately 2,000 years BP in the western part, and slightly later in the east.

In general, it seems that by about 4,500 years BP, the present-day island consisted of isolated rocky cores that were progressively surrounded and linked by accreting beach-ridges on its leeward side at sea levels slightly above that of today and that this accretion extended seaward. Ultimately, beach ridges enveloped the rocky cores on the more exposed northern coast to produce an accretionary strand plain at a time when sea level was stationary or falling slightly. The latter situation may have been due to either a true eustatic fall or to tectonic movements. The radiocarbon dates from Marawah Island indicate a sequence of events that is consistent with that found on the mainland of Abu Dhabi; that is, a marginally higher sea level at about 5,000 to 4,000 years BP followed by coastal progradation under slightly falling or stationary sea level conditions.

CONCLUSIONS

Marawah Island consists exclusively of Pleistocene limestones and unconsolidated Holocene carbonate sediments that, with the present state of knowledge, provide the most complete exposed marine Quaternary sequence in Abu Dhabi. The oldest rock exposures consist of a coral reef that had not been recorded previously from outcrops elsewhere in the region. Three clear transgressive events are recorded by these deposits and are separated by two intervals of intense eolian denudation (deflation) and minor deposition.

Three main topographic levels can be identified on the island.

1. The highest level is a platform capped by an oolitic grainstone with a thin caliche cover. It retains its original depositional geomorphological form of a beach-ridge complex formed when sea level was approximately 5 to 7 m above its present level. This platform is present in the northwest at Ra's Liffa and is best developed on the 'Triangular Mesa' to the southwest of Gubba.

2. A low dissected platform, generally about 1 m in elevation, is particularly well developed in the east, north and west of the island. It is exposed as a low cliff around the coasts and is formed of skeletal grainstone overlying a highly coralline unit. Its top is a deflated surface covered by thin silty sand or sandy silt and a fragmented caliche crust. Locally, near the coast, it is covered with a spread of cerithids brought in by Shamal storms.

3. A depositional surface formed by coastal progradation of shingled cerithid-rich beach ridges in places with low dunes and sabkha deposits. The surface is forming under present-day sea-level conditions, but began at a slightly higher sea level.

These three levels are explicable in terms of sea-level fluctuations during the late Pleistocene and Holocene. The marine carbonates reflect relative high-stand deposits and the intercalated eolianites were deposited during low sea-level stands. Eolian erosion-deflation was responsible for dissecting the deposits into the various levels or platforms.

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REFERENCES

Bernier, P., R. Dalongeville, B. Dupuis and V. de Medwwecki 1995. Holocene shoreline variations in the Persian Gulf: example of the Umm Al Qowain Lagoon, U.A.E. Quaternary International, v. 29-30, p. 95–103.

Carter, M.J. 1849. On the foraminifera, their existence in a fossilized state in Arabia, Sindh, Kutch and Kattyawar. Journal of Bombay Branch, Royal Asiatic Society, 3, 158.

Dalongeville, R. and P. Sanlaville 1987. Confrontations des datations isotopique avec les donnees geomorphologiques et archaeologiqueus a propos des variations relatives du niveau marin sur la rive Arabe du Golf Persique. In, O. Aurenche, J. Evin and F. Hours (Eds.), Chronologies in the Middle East, p. 567–583.

Evans, G., P.R. Bush and P.H. Temple 1980. The coastal plain and offshore islands. In, J.C. Doornkamp, D. Brundsden and K.C. Jones (Eds.), Geology, Geomorphology and Pedology of Bahrain. Geo Abstracts Ltd., Norwich, UK, p. 269–327.

Evans, G., V. Schmidt, P. Bush and H. Nelson 1969. Stratigraphy and geological history of the sabkha, Abu Dhabi, Persian Gulf. Sedimentology, v. 12, p. 145–159.

Evans, G., J.W. Murray, H.E.J. Biggs, R. Bate and P.R. Bush 1973. The oceanography, ecology, sedimentology and geomorphology of parts of the Trucial Coast barrier island complex, Persian Gulf. In, B.H. Purser (Ed.), The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea. Springer Verlag, Berlin, p. 233–277.

Goudie, A.S. and R.U. Cook 1980. Aeolian landforms and deposits. In, J.C. Doornkamp, D. Brundsden and K.C. Jones (Eds.), Geology, Geomorphology and Pedology of Bahrain. Geo Abstracts Ltd., Norwich, UK, p. 269–327.

Illing, L.V., A.J. Wells and J.C.M. Taylor 1965. Penecontemporaneous dolomite in the Persian Gulf. In, L.C. Pray and R.C. Murray (Eds.), Society of Economic Palaeontologists and Mineralogists Special Publication, 13, p. 89–111.

Kendall, C.G.St.C. and A.d'E. Skipwith 1969. Geomorphology of a recent shallow water carbonate province: Khor Al Bazm, Trucial Coast, Southwest Persian Gulf. Geological Society of America Bulletin v. 80, p. 865–892.

Kenig, F., A.Y. Huc, B.H. Purser and J.-L. Oudin, 1990. Sedimentation, distribution and diagenesis of organic matter in a recent carbonate environment, Abu Dhabi, U.A.E. Organic Geochemistry, v. 16, p. 735–747.

Kirkham, A. 1997. Shoreline evolution, aeolian deflation and anhydrite distribution of the Holocene, Abu Dhabi. GeoArabia, v. 2, no. 4, p. 403–416.

Kirkham, A. 1998a. Pleistocene carbonate seif dunes and their role in the development of complex past and present coastlines of the U.A.E. GeoArabia, v. 3, no. 1, p. 19–32.

Kirkham, A. 1998b. A Quaternary proximal foreland ramp and its continental fringe, Arabian Gulf, U.A.E. In, V.P. Wright and T.P. Burchette (Eds.), Carbonate Ramps. Geological Society, London, Special Publication no. 149, p. 15–41.

Lambeck, K. 1996. Shoreline reconstructions for the Persian Gulf since the last glacial maximum. Earth and Planetary Science Letters, 142, p. 43–57.

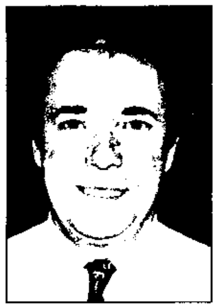
Purser, B.H. and G. Evans 1973. Regional sedimentation along the Trucial Coast, SE Persian Gulf. In, B.H. Purser (Ed.), The Persian Gulf, Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea. Springer Verlag, Berlin, p. 211–231.

Teller, J.T., K.W. Glennie, N. Lancaste and A.K. Singhi 2000. Calcareous dunes of the United Arab Emirates and Noah's Flood: the post glacial reflooding of the Persian (Arabian) Gulf. Quaternary International, 68–71, p. 297–308.

Vita-Finzi, C. 1978. Environmental History. In, Beatrice de Cardi (Ed.), Qatar Archaeological Report, Excavations 1973. Oxford University Press for Qatar National Museum, p. 11–25.

ABOUT THE AUTHORS

***Graham Evans** is an Honorary Professor of Sedimentology at the Department of Ocean and Earth Sciences, University of Southampton; Emeritus Reader in Sedimentology, University of London; and Honorary Associate Professor of Sedimentology, University of Nanjing, China. Graham received a BSc in Geology from Bristol University in 1956 and obtained his PhD in 1960 at Imperial College, London. He has taught and supervised many research students and has been involved in sedimentological research in the Arabian Gulf, Northwest Europe, Spain, Turkey and India. While at Imperial College Graham began studies in the Arabian Gulf. He was Associate Professor and UNESCO consultant at the Marine Institute of METU, Ankara, Turkey from 1978 to 1979, and visiting Professor with the Univerisdad Complutense Madrid and University of Vigo, Spain between 1991 and 1992. Graham is again working in the United Arab Emirates, Spain, and Turkey on sedimentological/ archeological problems.*



***Anthony (Tony) Kirkham** joined Technoguide as Manager Consulting Services in late 2001. He has a BSc from Aberystwyth University, Wales (1970), an MSc from Imperial College, and a PhD from Bristol University. Before joining Technoguide he was Manager of Reservoir Characterization, Research & Consulting, (UK) Ltd., and before that Tony had been employed by BP Exploration for 20 years as a Sedimentologist and Senior Development Geologist. He worked mostly within reservoir engineering teams on international development projects and had long-term assignments in Norway, Egypt, and Turkey. From 1994 to early 1997, he worked as a Geological Specialist with Abu Dhabi Company for Onshore Oil Operations. Sedimentology, reservoir characterization, and 3-D reservoir modeling are his particular areas of interest. Tony is a member of the Editorial Advisory Board of* GeoArabia.

Corresponding author: tony.kirkham@technoguide.com

***Robert (Rob) Carter** is an Archeologist at the Institute of Archaeology, University College London (UCL). He has a PhD from UCL. His speciality is the archeology of the Arabian Gulf. His current major project is in Kuwait where he is focusing on a 6th/5th millennium BC coastal settlement. In addition, he is working on sites and pottery collections in Bahrain, Qatar and the United Arab Emirates, ranging in date from the Neolithic to the Late Islamic period. Rob's interests include ancient ceramics and the development of long-distance trade and seafaring in the Arabian Gulf and the Indian Ocean.*

racbahr@hotmail.com

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