

# Pleistocene Carbonate Seif Dunes and their Role in the Development of Complex Past and Present Coastlines of the U.A.E.

Anthony Kirkham

Reservoir Characterization, Research & Consulting, Inc.

## ABSTRACT

Isolated outcrops of Pleistocene carbonate aeolianites and their cappings of shallow water Pleistocene marine limestones are described largely from Al Dabb'iya on the eastern end of the Great Pearl Bank, Abu Dhabi. Their sedimentological characteristics and depositional settings are discussed in relation to mainland Pleistocene aeolianite trends observed from satellite images. A comparison of the internal dune cross-bedding with dune morphologies suggests changing wind regimes that probably resulted from meteorological changes induced by the onset of a Pleistocene glacial period. The complex palaeo-geomorphology imposed by the dunes strongly influenced later Pleistocene coastal marine sedimentation that was concentrated in a series of shallow embayments separated by low-relief seif dunes forming peninsulas. Similar marine settings extended into the Holocene along parts of the United Arab Emirates coastline and still persist locally.

## INTRODUCTION

Quaternary rocks and sediments are areally the most abundantly exposed in the United Arab Emirates. They mainly comprise siliciclastic aeolian dunes that extend southwards into the Rub' Al Khali sand sea of Oman and southern Saudi Arabia (Figure 1; Glennie, 1992; Glennie et al., 1994; Goodall, 1995). Less well known are the Pleistocene carbonates that are mainly concentrated along the coastal areas of Abu Dhabi where they often outcrop as distinctive zeugen (plural of zeuge) comprising aeolianites capped by overhanging, calcretized marine deposits.

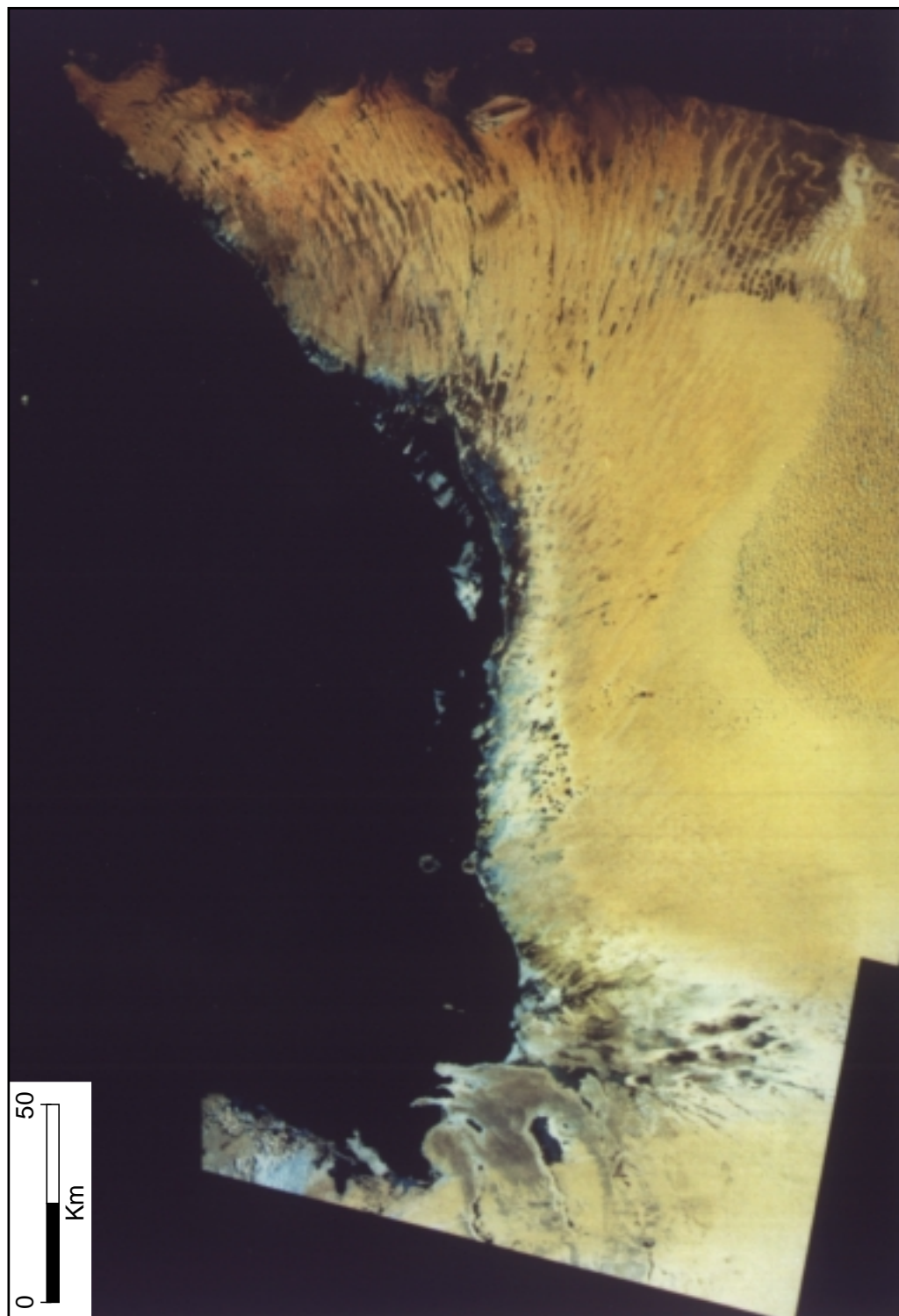
The carbonate aeolianites are often referred to as "miliolite" because of their reputed abundance of miliolid foraminiferids, although the content of miliolids rarely warrants the description. The same term is applied to similar carbonate aeolianites as far afield as Iran (where it was first used), India, Oman and Northern Egypt.

Whilst these carbonates are familiar features of the Abu Dhabi coastal landscape, relatively little is known about their depositional settings because geologists have generally been far more focused on their surrounding and overlying Holocene carbonates and evaporites for which this area is world famous (Purser, 1973). This paper first describes one of the most concentrated collections of Pleistocene carbonate outcrops located at the northwest corner of Al Dabb'iya, a former Great Pearl Bank barrier island that became joined to the mainland by Holocene leeward accretion. It then discusses their implications regarding the complex morphologies they imposed upon later Pleistocene and Holocene coastlines elsewhere in the United Arab Emirates. The paper is not intended to address the detailed diagenetic characteristics of the Pleistocene carbonates. Figures 2 and 3 indicate locations referred to in the following discussion.

## GEOLOGICAL SETTING

Miocene jebels comprising horizontally bedded fluvial and lacustrine strata sometimes rise to >20 m above sea level along the inland margins of the mainland coastal sabkhas. Isolated mesas of the same strata also occur as inliers on the coastal sabkhas, although the nearest such outcrop is about 20 kilometres (km) to the south-southeast of the northern coast of Al Dabb'iya. A relatively thin Pleistocene-Holocene succession overlies the Miocene across most of the coastal sabkhas of Abu Dhabi.

Shallow boreholes and velocity surveys indicate the Pleistocene to be about 10 m thick beneath the sabkhas of Al Dabb'iya except where it thickens and protrudes above sabkha level as zeugen. Butler (1970) recorded a similar thickness beneath the coastal sabkha northeast of Abu Dhabi Island. The



**Figure 1:** Landsat image of the United Arab Emirates (UAE). Note the long, sweeping, seif dune morphologies extending across the eastern UAE into Oman. The seifs were constructed during the Pleistocene by northwesterly 'Shamal' winds that were deflected north-eastwards along the west side of the Hajar (Oman) Mountains located within the dark area in the extreme top right of the figure. Blue coastal areas correspond to parts of the sabkhas. Part of the Qatar peninsula is located at the extreme left. See Figure 2 for further details.

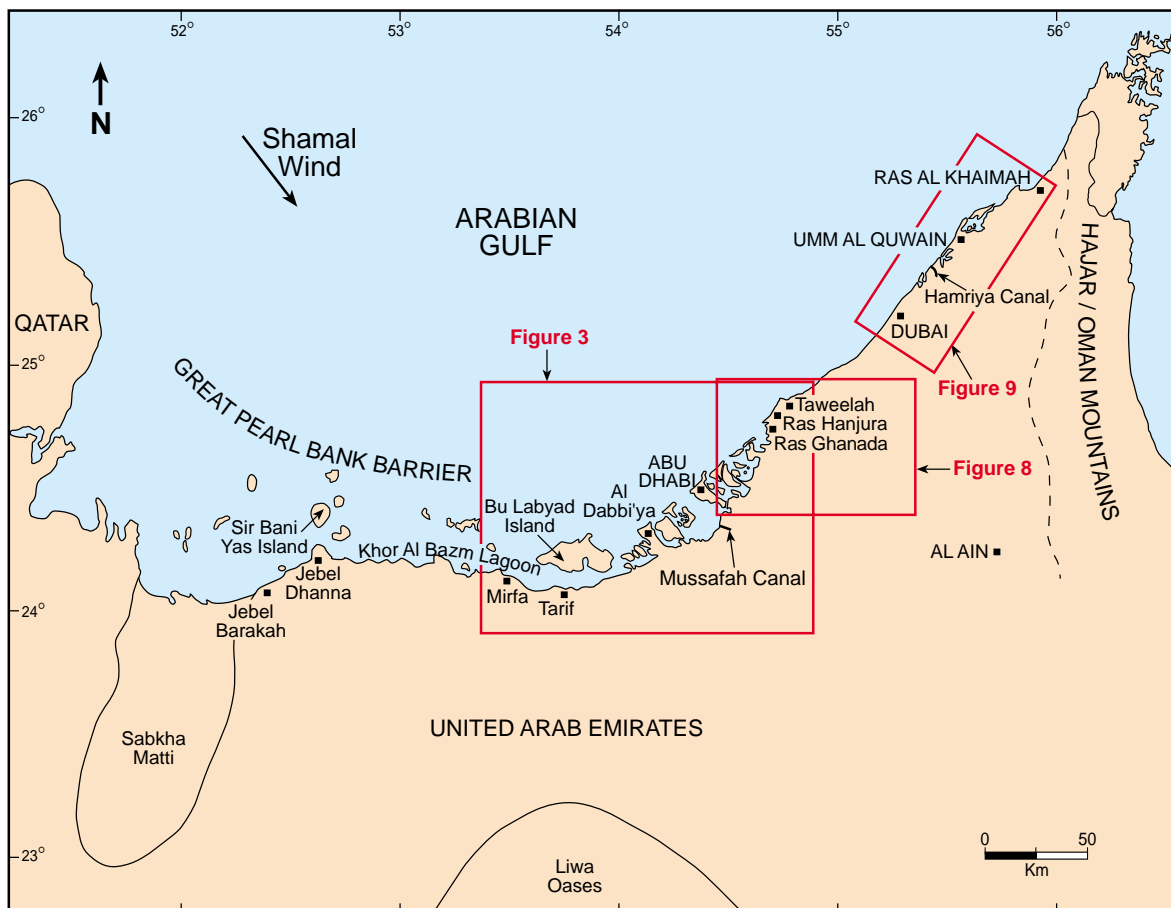


Figure 2: General location map for the entire Gulf coastline of the United Arab Emirates.

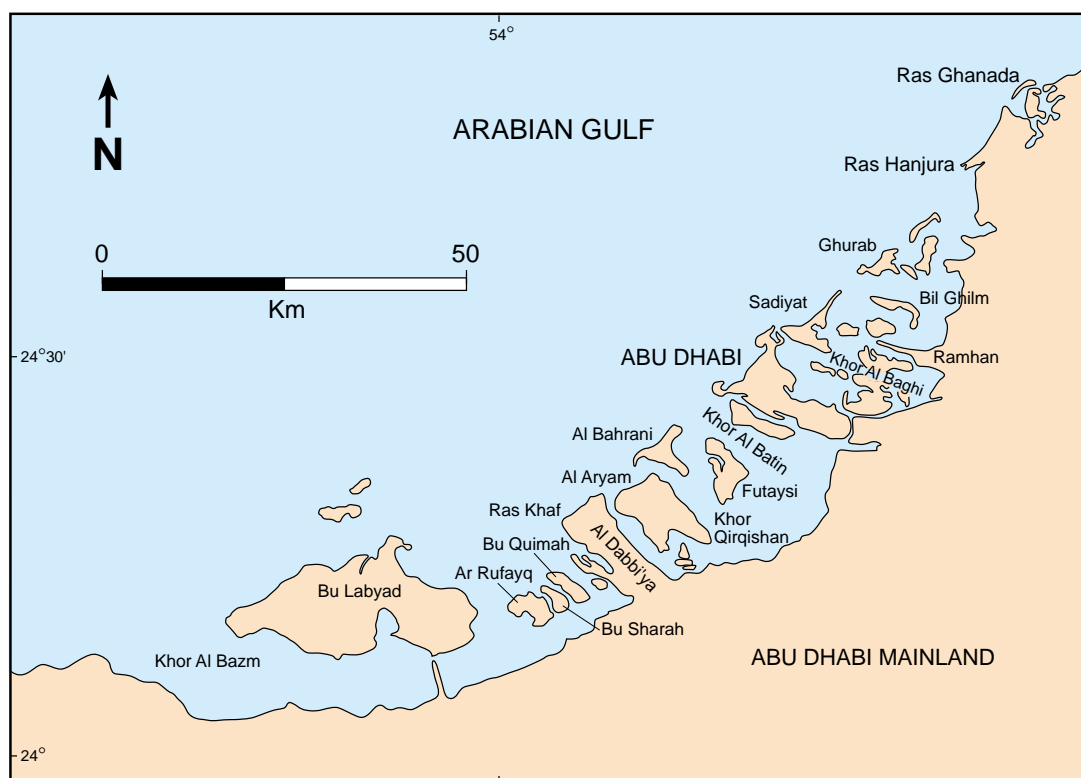


Figure 3: A detailed location map of the Bu Labyad-Ras Hanjura area.

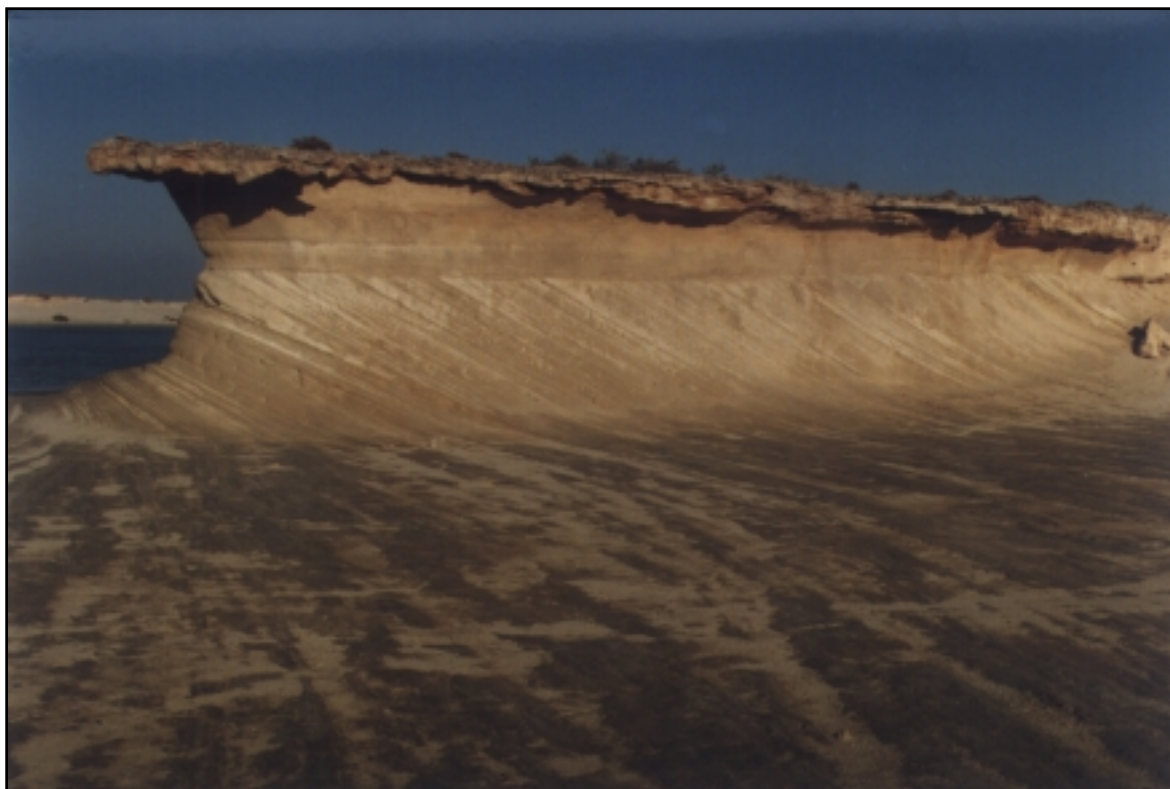
zeugen can be divided into Type 1, relatively flat-topped, and Type 2, with tops dipping at approximately 12° (Figure 4). Type 2 zeugen may reach 5 m in height although their weathering rate increases significantly if their lithified caps are completely eroded. Individual Type 2 zeugen may reach 700 m long and 40 m wide on Al Dabb'iyah. Some of the Type 2 zeugen are conspicuously aligned as pairs of discontinuous ridges 150-400 m apart and traceable along a 7 km transect (Figure 5). The sloping tops of each pair of ridges generally have opposing dips and at first sight appear to be the remnants of a crestally eroded anticline. The area has, however, been tectonically quiescent during the Quaternary and the sedimentological evidence, combined with satellite imagery, reveals the Type 2 zeugen to be erosional remnants of fossil seif dunes. The Type 1 zeugen are remnants of the inter-seif areas.

The ridges of Type 2 zeugen often form small peninsulas, such as those protruding from the northwestern coast of Al Dabb'iyah around Ras Al Khaf (Figure 5). Traced inland across Al Dabb'iyah on an azimuth of approximately N100°E, the ridges are surrounded by sabkha although much of the area in proximity to the ridges is an exposed platform of carbonate aeolianite. This platform is elevated very slightly above the level of the sabkha surface and probably represents deflation of the aeolianite down to a former water table or "Stokes surface" (Stokes, 1968). The platform aeolianite is a deflated equivalent of that forming the bulk of the adjacent zeugen. Seismic velocity surveys indicate that these Pleistocene deposits are covered by up to 3 m of Holocene sediments within about 400 metres from the ridges. Again, Butler (1970) recorded a similar Holocene thickness on the coastal sabkha northeast of Abu Dhabi.

## PLEISTOCENE CARBONATE SEDIMENTOLOGY

### Aeolian Deposits

The carbonate aeolianites exhibit very well laminated, large-scale, cross-bedded sets (Figure 4) that are often barchanoid in planar sections exposed on the deflation surfaces. Individual barchanoid dunes extended over a hundred metres along their strike directions and their dip azimuth data indicates



**Figure 4: A Type 2 zeuge with its sloping top, northwest Al Dabb'iyah. Carbonate aeolianite overlain by calichified beach sediments comprise the zeuge. Large-scale cross-beds of deflated Pleistocene aeolianite are seen in the foreground.**

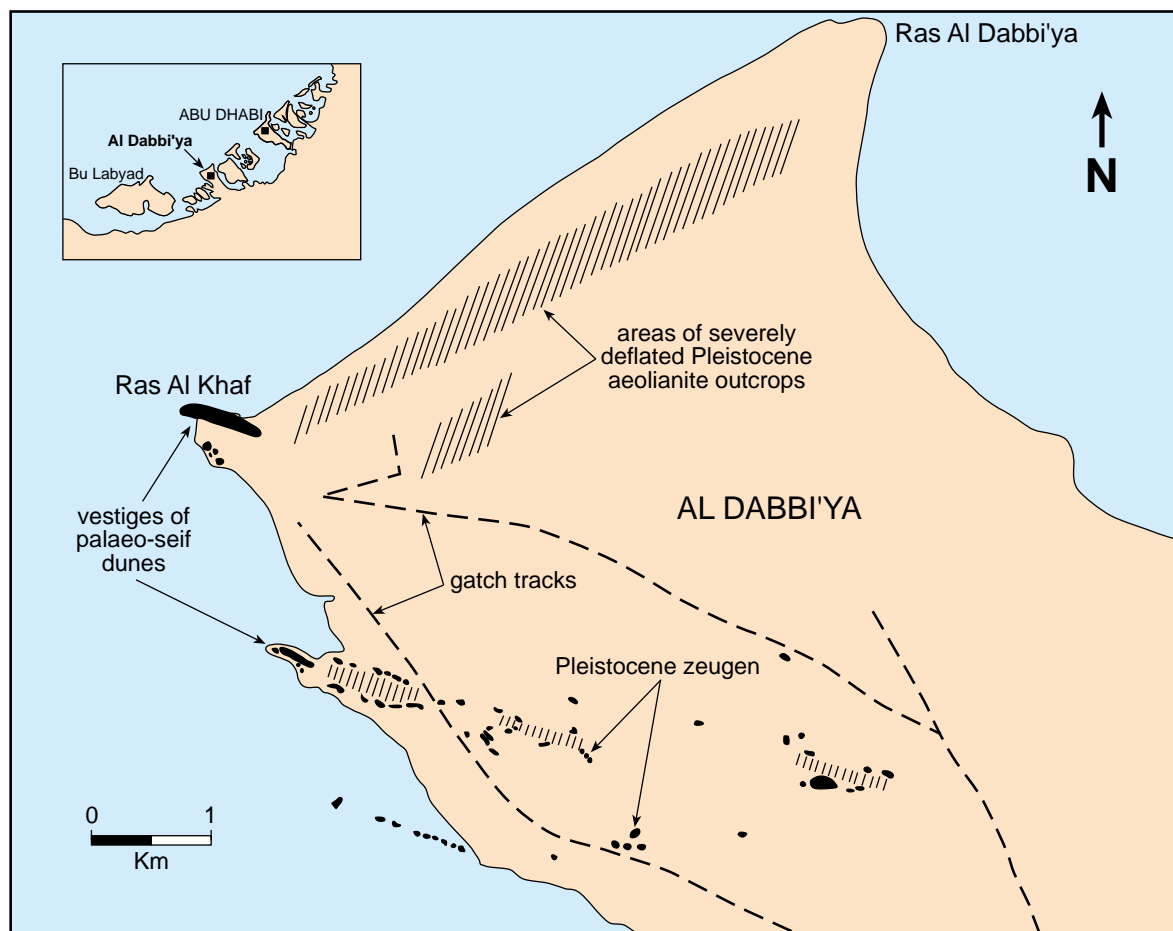


Figure 5: Pleistocene zeugen distributions of northwest Al Dabb'iya.

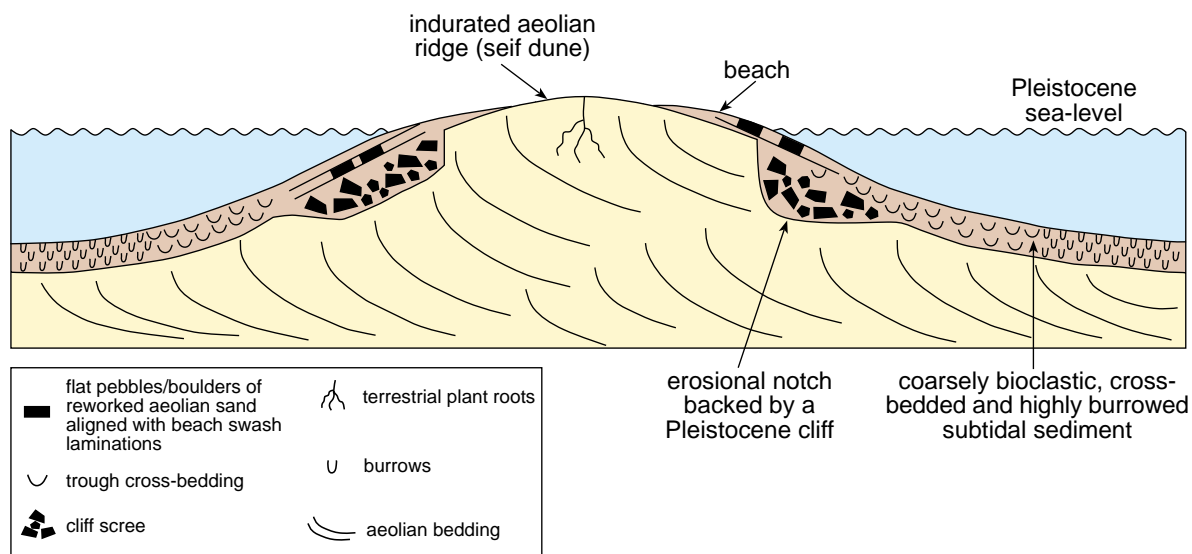
a prevailing wind direction of approximately N130°E, which is oblique to the trend of the fossil seifs. Locally they display rhizoliths that may penetrate several feet into the aeolianite.

Their rock fabrics at outcrop are highly mouldic but reasonably well indurated due to meteoric leaching of aragonitic components and reprecipitation as well developed, intergranular, often meniscus, calcite cements. They also contain a significant amount of quartz-dominated siliciclastic grains. Evans et al. (1973) provided a chemical analysis of the aeolianites and concluded that they were similar in texture and composition to the brown, unconsolidated, cross-bedded, quartzose carbonate sand which underlies the coastal sabkhas. However, Pleistocene carbonate aeolianites often directly overlie uncemented, Pleistocene, siliciclastic aeolian sands on the Holocene coastal sabkhas of Abu Dhabi (Kirkham, in review). Kassler (1973) reported comparable occurrences of Recent carbonate sediments overlying uncemented quartz sand further northwest in the Gulf of Salwa.

### Marine Deposits

Whilst usually less than a metre in thickness on Type 1 zeugen, the marine deposits vary between <1 m and 3.5 m in thickness over distances of several metres within Type 2 zeugen (Figure 4). Usually they thicken down the zeugen slopes but occasionally they thicken up-dip such as at the northern extremity of the palaeo-seif forming the peninsula immediately south of Ras Al Khaf. The more elevated marine sediments typically show beach swash laminations sometimes associated with well developed fenestral pores. They unconformably overlie the carbonate aeolianites which have an erosionally "plucked"





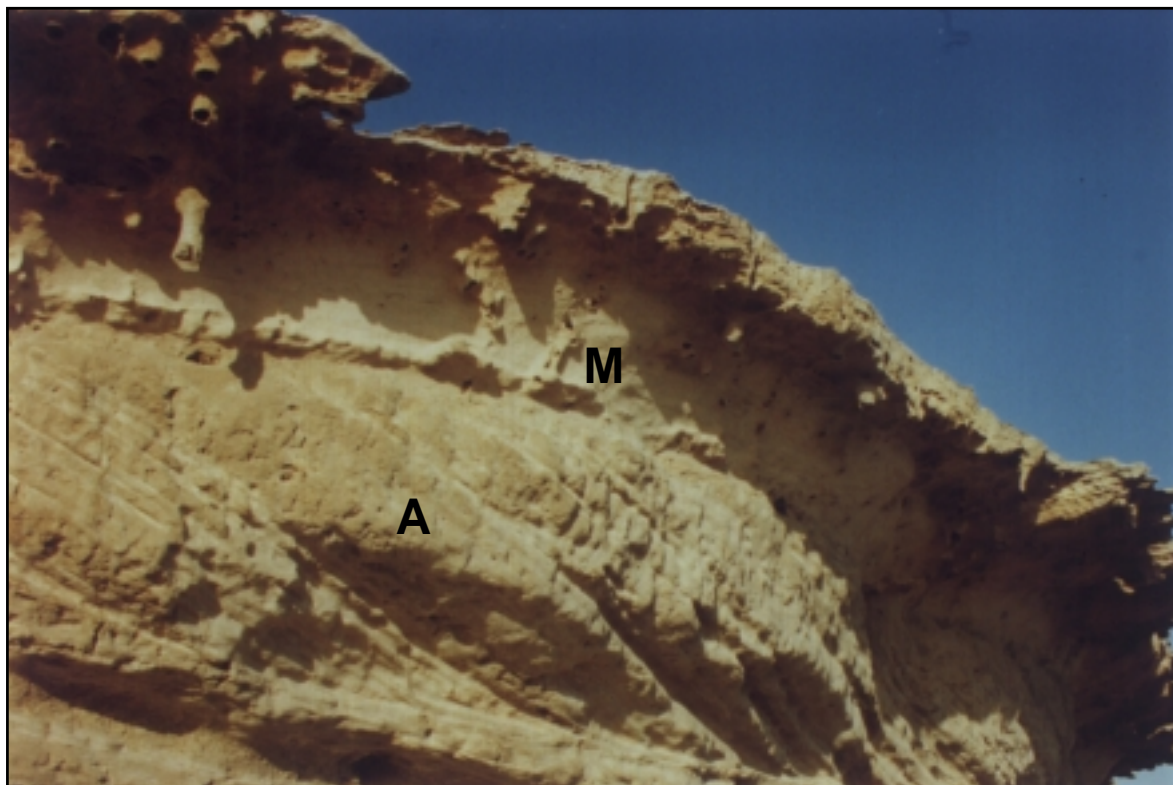
**Figure 6: Schematic cross-section through a Pleistocene seif dune and its marine capping.**

upper surface. Marine erosion gave rise to common conglomeratic horizons that often consist of orientated, flat pebbles of aeolianite aligned with the swash laminations. Elsewhere, the aeolianite is found as stacked, angular boulders up to 2 m across and enveloped by the laminated beach deposits (Figure 6). They represent fossil cliff scree deposits that can be examined in both horizontal and vertical exposures, such as on "Stokes surfaces" and cliff sections respectively. Storm beaches or spits of cross-bedded mollusc coquinas also developed on the flanks of some of the fossil seifs as exposed on northeast Futaysi Island. In contrast to the underlying aeolianite which contains significant quartz, the marine sediments are relatively pure carbonates (Scholle and Kinsman, 1974).

Vertical hollow pipes with cemented walls are common within the uppermost beach sediments on Type 2 zeugen (Figure 7). They may extend downwards for up to half a metre and also protrude upwards for a few centimetres above the general level of the Pleistocene weathered surface because their cemented walls have rendered them more resistant to erosion. They are best exposed beneath the overhanging zeugen caps. Lacking evidence of branching, they are interpreted as vertical burrows rather than roots and are reminiscent of crab burrows which are common on modern beaches of the Emirates.

Traced laterally to lower elevations on individual Type 2 zeugen, the beach deposits pass into trough cross-bedded units, less than a metre thick, that indicate bimodal transport directions parallel to the strike of the fossil seifs and were probably deposited by tidal currents. Herring-bone cross-bedding is well developed on the northern coast of Bu Labyad Island. Eventually they grade further down-dip into intensively burrowed sediments with *Thalassinoides*(?) plus rich assemblages of gastropods and disarticulated bivalve shells, including oysters. Such changes can occur within a distance of 50 m and represent the transition to deeper water facies across a beach profile. *Ophiomorpha* burrows penetrated the underlying aeolianite. Mangrove rhizoliths also occur on the lower slopes and exposures on Futaysi Island reveal them to be transgressive in origin.

In the inter-seif areas, the marine sediments of lower lying, Pleistocene exposures locally contain small growths of the coral, *Porites*, and red algae. Over a metre of marine, horizontally-bedded, Pleistocene oolites also occur at the northwest point of Al Rufayq Island but they reach about 5 metres thick in a large-scale, cross-bedded, aeolianite dune near the eastern tip of Bu Labyad. Its bedding azimuths are consistent with the palaeo-Shamals that blew from the northwest. The marine sediments are reasonably well cemented at outcrop but may remain highly friable in the subsurface, as revealed by quarrying operations.



**Figure 7: A zeugen with basal carbonate aeolianite (A) capped by burrowed marine sediment (M) that has been calichified. The duricrust forms the overhang. Vertical crab (?) burrows with cemented walls are more resistant to weathering and protrude like stalactites from the overhang.**

### Calcretes and Gypcretes

The uppermost 10 to 50 centimetres of marine sediments have been cemented to form calcretes, or caliches, and it is these weathering-resistant duricrusts that form the overhanging ledges of the zeugen. They also form on aeolianites where marine sediments are absent due to erosion or non-deposition. The uppermost layers of calcrete have frequently buckled to form hollow domal features up to a metre in diameter. They also sometimes formed polygons which curl upwards at their edges to form teepee-like structures up to a metre across. Although the polygons resemble Holocene beachrock phenomena seen elsewhere in the Emirates, they are actually equivalent to pedogenic features associated with calcretes formed at 80 m elevation a few tens of kilometres inland to the southwest, within palaeosols capping former interdune sabkhas of a deflated Pleistocene siliciclastic dune system.

These calcretes have not been accurately dated but they are interpreted as Pleistocene rather than Holocene because the current climate does not provide the alternating wet and dry conditions normally required to form significant duricrusts. However, one cannot exclude the possibility that they formed during the Holocene Climatic Optimum about 6 thousand years before the present (ka BP) when there was more rainfall. Whilst they are probably dominated by low-magnesium calcite, Scholle and Kinsman (1974) discovered aragonitic and high-magnesium calcite cementation, and even dolomitization, forming pisolitic caliche crusts within marine Pleistocene sediment outcrops northeast of Abu Dhabi Island. The crusts were undated but Scholle and Kinsman speculated upon their genesis during higher Pleistocene or Holocene sea level stands.

Gypcretes, over 0.5 m thick, occur on some Pleistocene zeugen and are also very common on the tops of coastal Miocene mesas. Sometimes they comprise thin, very finely crystalline gypsum sheets above the Pleistocene limestone, but they typically consist of coarsely crystalline gypsum which varies from

massive to stacked irregular sheets associated with horizontal sheet-cracking of the limestone. As with the calcretes, they commonly create polygonal teepee-like structures up to about a metre across. The gypcretes appear to post-date the calcretes because, unlike the latter, they also drape the deflated carbonate aeolianites. Whilst they may have begun to form during the Pleistocene, it is believed that some gypcretes are still developing and partly deriving their sulphate from sea mists. Even on zeugen that are 2 to 3 m high and located several kilometres into the supratidal zone, the upper few millimetres of gypcrete can contain a faint green rind of algae that may be surviving on moisture precipitated in the form of marine-derived aerosols and desert dews.

## PLEISTOCENE CARBONATE DEPOSITIONAL MODEL

By interpolating between the mainland seif dunes and the fossil seifs of Al Dabb'iyah, one is compelled to deduce that they belong to the same dune system (Figure 1). The mainland seif dunes extend for well over 100 km and may be separated by flat inter-dune areas up to 5 km wide, described in Arabic as "sahls", meaning "easy goings", although the relict Al Dabb'iyah seifs were less than 2 km apart. Their spacing generally varies proportionately with the heights of the seifs which increase inland and reach several tens of metres. The original height of the dissected palaeo-seifs along the present day coastal region is doubtful because of crestal erosion. The lack of protective Pleistocene beach carbonates, perhaps with beach rock cements, over their crests possibly accounts for preferential erosion along their axes. There are, however, several examples of well preserved, but relatively small, Pleistocene seifs on Al Dabb'iyah and Futaysi that are not crestally incised. They are less than 10 metres in height but their current dimensions may reflect partial deflation. The lack of opposing bedding dips on opposite flanks of the palaeo-seifs is also attributable to loss by deflation. Only the precursory barchanoid bedding that had survived remodelling during seif construction is now preserved in the cores of these relict seifs.

The barchanoid dune-bedding indicates wind transport oblique to these eroded seifs but can be reconciled by acknowledging the meteorological variations accompanying the glacially driven climatic changes. Detectable variations in prevailing wind direction and strength would have occurred as the trade wind belts migrated north and south in response to polar ice cap fluctuations. An increase in wind strength could have remodelled the surface of the barchanoid dune field into the surviving seif dune field (K. Glennie, personal communication). Except for the localised coastal dunes, the current aeolian dune fields are largely out of phase with the milder wind system dominated by the modern Shamals (Glennie, 1992). Stronger winds (palaeo-Shamals) were typical of earlier Pleistocene periods during glacial maxima. The strongest winds would have created the seif dunes extending southeastwards across much of northern Abu Dhabi from the contemporaneous coastline.

Aeolianites may extend 80 km inland. In general, the ratio of carbonate/siliciclastic components of the dunes increases towards the coast where they were correspondingly more calcite cemented. The palaeo-geomorphologies of the seif dune system nearer the coast has largely survived because they were cemented relatively early due to the effects of meteoric diagenesis. This cementation is reflected by the beach pebbles and scree boulders of carbonate aeolianite in the Pleistocene beach deposits that cover the lower flanks of the palaeo-seifs.

As they were inundated by later Pleistocene marine transgressions they imposed a highly embayed coastline. Their flanks were overlapped by beach carbonates of the flooded, interdune, tidal embayments - some of which were sparsely colonised by the *Porites* and red algae. Trough cross-bedded units observed along the sides of the aeolianite ridges are the products of these tidal regimes. The sea beds of the embayments were sometimes undulatory judging by the surface topographies and different elevations of the relatively low lying Type 1 zeugen between the palaeo-seifs.

## DATING THE SEIF DUNES

The depositional history of these Pleistocene carbonates must be understood against the background of glacially driven, sea level fluctuations which led to some relative sea level stands greater than 100 m above and below current level.



The sedimentary episodes cannot be precisely identified without methodical luminescence-dating of the aeolianites or carbon-dating of the Pleistocene-Holocene marine deposits. The carbonate aeolianites probably accumulated during sea level lowstands when former sea bed carbonates were exposed to provide a significant aeolian sediment source. As Hadley et al. (in press) conclude that the Quaternary Arabian Gulf was first transgressed during the Late Pleistocene, it follows that the carbonate must also be Late Pleistocene or younger.

The last major sea level fall climaxed about 18 ka BP when relative sea level was -120 m and the entire Arabian Gulf was emergent as the sea retreated to the Strait of Hormuz. However, various authors have dated some carbonate aeolianites as much older than that. For instance, Hadley et al. (in press) dated the carbonate dunes as mainly 160-250 ka BP (70 ka minimum). Glennie (in press) recognised two ages of carbonate aeolian activity at 112 and 230 ka BP in the Emirates, although Juyal et al. (in press) state the oldest known aeolian event in the Emirates is dated as 175 ka BP from siliciclastic dunes of Liwa whilst also recording an age of 141 ka BP from the same area. They also dated carbonate aeolianites in the Emirates as 64 and 90 ka BP.

The Flandrian transgression climaxed at about 5 ka BP but a probable 1-2 m relative sea level fall has occurred since 3.75 ka BP (Evans et al., 1973). The Pleistocene beach deposits described above are far more lithified and found at elevations that are well above the Flandrian storm beaches, which they demonstrably pre-date. The Pleistocene beaches were probably deposited at least 75-125 ka BP, which represents the previous interglacial period with relatively high sea level (Glennie, 1996). As the Pleistocene beach deposits onlap the carbonate aeolianites, it is reasonable to assume that the latter formed at latest during 125-190 ka BP, which marks the preceding glacial period.

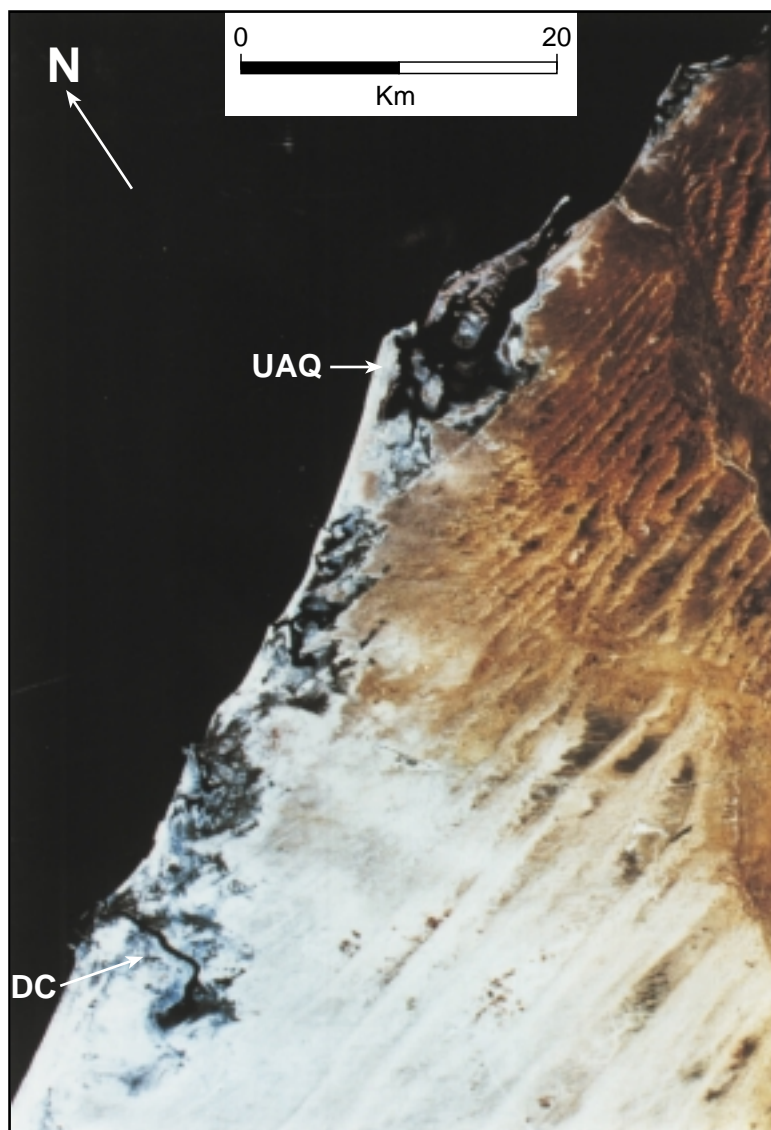
However, there may have been younger aeolian events which were not as well preserved. For instance, small remnants of well-sorted and well-laminated limestone loosely cemented to the eroded side, or palaeo-cliff, of one of the eroded seif ridges of Ras Al Khaf suggest that younger aeolian dunes banked against older aeolianite. They could therefore correlate with the last major sea level fall which climaxed about 18 ka BP. Dalongaville et al. (1993) dated some aeolian dunes in Northern Emirates as having formed between 9-20 ka BP. Kassler (1973) dated some miliolite as 20-30 ka BP.

There is clearly a requirement for further research to clarify the Pleistocene chronostratigraphy. Fossil barnacles are quite common encrustations on the sides and tops of the zeugen and may be ideal for carbon-dating. These barnacles are about 2 m or more above present day sea level and lived during a relative highstand. They populated the splash zone of the contemporaneous cliff line during the Flandrian or earlier transgression, and their carbon-dating may at least provide a minimum age limit for the palaeo-seifs or palaeo-cliffs.

## NORTHERN EMIRATES' ANALOGUES

The coastal Pleistocene seifs become more reddish (Figure 8) and more siliciclastic towards the Northern Emirates partly because the offshore sea bed profile is steeper and offered a less extensive aeolian carbonate provenance during lower relative sea levels. It is also partly because they are located an appreciable distance downwind from the effective carbonate provenance in view of the northeasterly deflection of past and present prevailing wind currents by the Hajar Mountains (Figure 1). Their lower original carbonate contents rendered them less prone to calcite cementation but more prone to deflation and marine erosion. Pleistocene zeugen are rare to the north of Dubai.

North of Umm Al Quwain, small, isolated outcrops of large-scale, cross-bedded dune sands with marine-reworked tops littered with assemblages of loose, marine molluscan shells occasionally rise approximately 2 m above the level of the supratidal flats that surround them. Conglomerates comprising orientated, flat, calcareous boulders of well laminated aeolian sand can be found buried in the supratidal flats. They are well exposed, for instance, in the banks of the Hamriya channel, immediately south of Umm Al Quwain, where they are being recycled by present day marine erosion of the channel banks. These boulders are analogous to those preserved in the Pleistocene beach carbonates of the Al Dabb'iyah ridges and represent a transgressive marine lag.



**Figure 8: A satellite image showing vestigial seif dunes protruding into back-barrier lagoons and sabkhas between Umm Al Quwain (UAQ) and Dubai Creek (DC). The east-northeasterly colour change of the seifs from white to reddish reflects the downwind compositional change with decreasing carbonate and increasing silica under the influence of the Pleistocene 'palaeo-Shamal'. The image pre-dates the construction of the Hamriya Channel.**

Along the inner edges of the northern supratidal flats, deflated seif dunes exhibit continuous, perched shell horizons at a height of about 5 m above present day sea level. They mark a former strand line, but care must be taken not to confuse them with shelly spoil heaps left by ancient tribes. Apparent sea level stands of this area do not necessarily correspond very well with those further west because tectonic adjustments related to the Zagros Orogeny have probably had more of an influence. Dalongeville et al. (1993) identified several Holocene sea level stands in the area which they speculated were related to tectonic adjustments affecting the entire Gulf region.

Deflated seif peninsulas still exist along the coastal areas between Umm Al Quwain and Ras Al Khaimah (Dalongeville et al., 1992 and 1993; Figure 8). Tidal flooding of the inter-dune areas is locally well displayed in that area which provides an excellent modern analogue of the Pleistocene sedimentary settings with digitate shorelines.

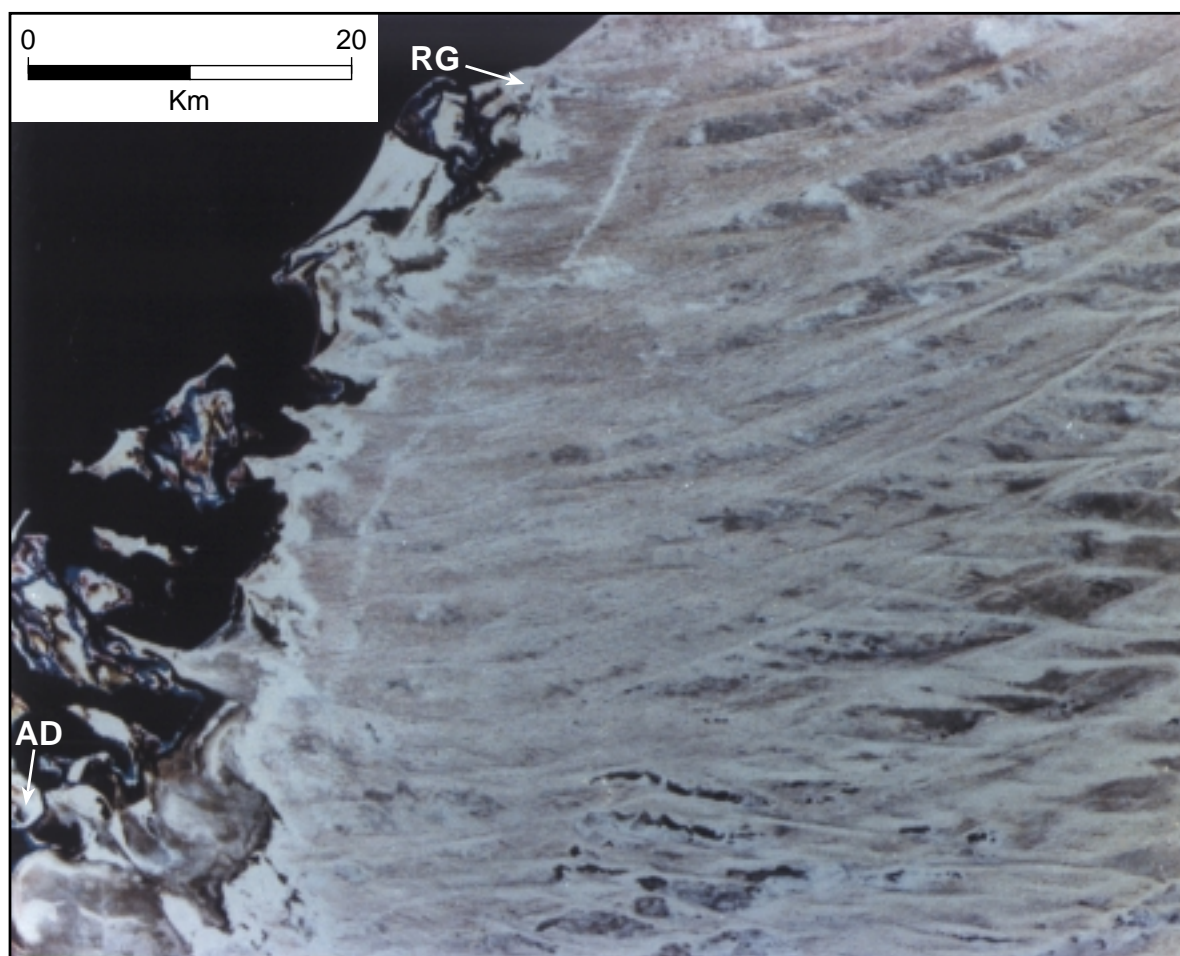
### **INFLUENCES OF PLEISTOCENE AEOLIANITES ON HOLOCENE SEDIMENTATION PATTERNS**

The most dramatic effect has been caused by isolated aeolianite outcrops at the seaward margins of the barrier islands along the Great Pearl Bank. Holocene spits nucleated and migrated downwind from the sides of these Pleistocene outcrops to form the present day islands, with central sabkhas, by

a process of leeward accretion towards the mainland coast largely under the influence of Shamal-driven currents (Purser and Evans, 1973; Kirkham, 1997 and in review). The carbonate dune system probably extends much further offshore than its currently exposed northern limits. The alignment of the northern limits of the barrier islands, as defined by their northerly Pleistocene outcrops, may demarcate an erosional notch similar to those described offshore by Kassler (1973) as originating from lower sea level stands. In other words, their locations may approximate to the trend of a former cliff line.

The existing tidal channels between the barrier islands could have developed partly by marine scouring of the hollows between the Pleistocene seif dunes. They may also have formed partly by Pleistocene fluvial incision, although the evidence for such fluvial activity between Ras Ghanadha and Sabkha Matti is restricted to areas behind the coastal sabkhas. They perhaps, therefore, represent karstified valleys infilled with carbonate sediment. Erosion was also considered by Kassler (1973) and Purser and Evans (1973) to explain the origin of the Khor Al Bazm.

With time, the seaward ends of the aeolianite peninsulas were severely eroded to the extent that only a few vestiges, like those on Al Dabb'iya, Futaysi and Bil Ghilm, have survived on the islands as evidence of the model described above. Some vestiges of Pleistocene seifs still protrude as peninsulas along the mainland coast, especially between Abu Dhabi Island and Ras Ghanadha (Figure 9). The embayments between the peninsulas have been progressively infilled by a series of Holocene carbonate sand bars with intervening lagoons. Spits, which are typical of much of the Emirates coastline (Kirkham and Twombly, 1995; Kirkham, in review), have initiated at the emergent seif dunes, and Miocene



**Figure 9:** A satellite image showing vestiges of carbonate seif dunes protruding into the lagoons as small peninsulas between Abu Dhabi Island (AD) and Ras Ghanadha (RG).

mesas, and tended to migrate into the adjacent embayments. Younger spits developed seaward of the older ones and sometimes spanned the entire interdune areas between headlands to form chenier-like barrier bars and storm beaches.

Many lagoonal areas behind the successive spits have become infilled with aeolian sediment and converted into sabkhas with extensive gypsum mush development. Others have maintained tortuous connections to the open sea via sometimes ephemeral channels and survive as a series of intermittently flooded areas. Northeast of the barrier island complex of the Great Pearl Bank, between Ras Hanjura and Dubai, the sediment infilling of the inter-dune areas is essentially complete. The palaeo-seifs no longer protrude seawards because longshore drift has been very efficient in smoothing out any coastal irregularities originally caused by the peninsulas and so the coastline is relatively straight.

The Holocene sedimentary strata exhibit complex depositional facies distributions within the interdune areas. However, there is relatively little mud in the system northeast of the Ras Ghanadha and so lithological contrasts are not as sharp as might be expected for a bar-lagoon system. The contrasts that do exist are even reduced somewhat by later aeolian deflation of the bar sands plus aeolian sedimentation within the often abandoned lagoons and on the sabkhas into which the lagoons may eventually evolve.

## CONCLUSION

Discontinuous ridges of Pleistocene outcrops of northwest Al Dabb'iyah indicate that the major siliciclastic seif dune trends of the mainland extended generally northwestwards as carbonate palaeo-seifs at least as far as the northern, windward margins of the barrier islands along the Great Pearl Bank. The carbonate aeolianites originally comprised a barchan dune field which was remodelled into seif dunes by prevailing winds that blew with greater strength from a slightly different direction, but still northwesterly. Their early calcite cementation rendered them relatively resistant to marine erosion and they therefore formed coastal spurs or peninsulas during later Pleistocene and Holocene marine transgressions. Pleistocene cliff lines with scree deposits accumulated along their lower flanks, which were enveloped by well defined beach deposits that can be traced laterally into penecontemporaneous subtidal carbonates. Shallow tidal embayments developed between the peninsulas. Vestiges of this type of coastal regime can still be observed along much of the modern Emirates coastline. There may have been several transgressive-regressive events since the above geological setting was first established and there is clearly a need for better chronostratigraphic data to fully understand the sequence stratigraphy.

The palaeo-seifs have experienced considerable deflation and marine erosion along the coastal fringe. In the Northern Emirates, where the Pleistocene aeolianites are more siliciclastic and less cemented, clues to their former existence west of their current limits are provided by aeolianite boulders in marine lags buried within coastal sabkha sediments. Relict stubs of Pleistocene aeolianites have been largely responsible for the development of the leeward accreting barrier islands along the Great Pearl Bank and for the establishment of spit/barrier-lagoon complexes along parts of the mainland coast during the Holocene.

## ACKNOWLEDGEMENT

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## ABOUT THE AUTHOR

*Anthony Kirkham was employed by BP Exploration for 20 years as a Sedimentologist and Senior Development Geologist. He mostly worked within reservoir engineering teams on international development projects and had long-term assignments in Norway, Egypt and Turkey. From 1994 to early 1997, Anthony worked as a Geological Specialist with Abu Dhabi Company for Onshore Oil Operations. He then became a Senior Technical Consultant with Landmark Graphics in Abu Dhabi, but recently accepted the post as a Manager of Reservoir Characterization, Research & Consulting, Inc. (RC)<sup>2</sup> with responsibility for Europe, Middle East and Africa. He received his BSc from Aberystwyth University in 1970, MSc from Imperial College, London in 1972 and PhD from Bristol University in 1977. Sedimentology, reservoir characterization and 3-D reservoir modeling are his particular areas of interest. Anthony is Secretary of the Society of Explorationists in the Emirates and a member of the Editorial Advisory Board of GeoArabia.*



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