# Coastal geomorphology of the Qatar Peninsula.

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# COASTAL GEOMORPHOLOGY OF THE QATAR PENINSULA

by

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in the Department of Geography, Swansea University,
University of Wales,

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*Dedication*

*To my parents and my wife*

# DECLARATION

In accordance with regulations for the degree of Philosophy Doctor, I declare that this work is the result of my own investigations. It has not been accepted in substance for any degree, nor is it being accepted in candidature for any other degree.

All other works referred to in this thesis have been acknowledged.

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## ABSTRACT

This study concerns the geomorphology of the coastline of the Qatar Peninsula. In all, the coastline is approximately 750km long and is dominated by Tertiary and Quaternary limestone rocks. Since little previous work has been carried out into the coastal geomorphology of the Arabian Gulf in general and Qatar in particular, a fundamental task was to undertake a classification of the coastal types. These are: 1) sand dunes and sheets; 2) sabkhas; 3) cliffs; 4) coral reefs; 5) beaches; and 6) mangroves. A second task set in this study was to investigate the processes responsible for the different coastal types. This was achieved using different field and laboratory techniques. Aerial photo interpretation enabled the nature of forms to be better understood and photos of different dates enabled temporal change to be investigated. Both Abney level and Dumpy level were used to show the forms of the different coastal types. Particle size analysis was used to differentiate the origin of sediments. Laboratory experiments of salt weathering on rocks of the Qatar shoreline indicated the effectiveness of this process. SEM analysis showed the mix of aeolian and beach transport histories in the coastal sediments.

The study shows that the following factors are particularly important in producing the distinctiveness of the Qatar coastline: these are warm sea temperatures leading to rapid chemical weathering; the prevailing NW ('Shamal') wind, which influences strongly sand supply at the coast and longshore drift direction; and a low tidal range.

# ACKNOWLEDGMENT

I am forever indebted to a great number of individuals for assistance to produce this thesis. In particular, I am grateful for the help from my academic supervisor Dr. R. Shakesby, who graciously gave me a great deal of his time, and additionally provided much valuable information and suggestions that allowed me to complete this thesis. I am very grateful to acknowledge the overseas trip which he made to Qatar to supervise the field work carried out by this research. I cannot thank him enough for his compassion, friendship and enthusiasm which he exhibited through the several years of my study at Swansea University. Special thanks go to Professor N. Stephens, who also gave me a great deal of his time to produce this thesis, and for generously giving me access to the pedology laboratory and other facilities, which I utilized during the analysis of sand samples. I would like to express very special thanks to Professor Mohamed Riad, head of the Geography Department at Qatar University, and Dr. M. Ashour for their continuous help and advice, and to the Qatar University for their help. Thanks also extend to Mr. Mohamed Almani the Cultural Attache at the Qatar Embassy for his generous support. Thanks also go to Mr. A. A. Salam, Mr. Lewis and Alan Catlif for drawing and photographing the thesis figures. The researcher is indebted to his parents, his wife, his brother, for their continuous support, inspiration, help and patience throughout the course of study. Finally, compliments are extended to my fellow graduate students and friends at the Department of Geography at Swansea University.

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# Chapter I

## Introduction

### 1.1 Statement of the problem

The Arabian Coast is low-lying with only a slight relief corresponding with a broad gentle anticline, that trends north-south or north-east-south-west (Fig. 1.1).

The coastline is partially controlled by tectonic factors while another important factor is the Holocene transgression which may be dated to about 6000 years B.P. (Doornkamp et al. 1980), where sea level may have risen slightly above the present. The coast of the Arabian Gulf has been subject to deposition and gradual smoothing of its overall outline, especially between Bahrain and Saudi Arabia and the United Arab Emirates. Waves and currents have deposited vast volumes of sediments while islands or shoals due to salt domes or reef building are extended by spits which have gradually built up above sea level (Purser 1973). Sedimentation has also led to the gradual development of sabkhas or saline mud flats, which are subject to periodic marine submergence and periodic drying out (Shin 1973). In places, Holocene and perhaps even modern beach and dune have been partially cemented into beachrock by precipitation of aragonite in the intertidal zone (Evamy 1973; Shinn 1969; Taylor and Illing 1969). Elsewhere there is extensive progradation of the shoreline by advancing sand dunes: little research has been conducted on the coast of the Gulf, and even less in Qatar. While geological investigations have been made to investigate the structural history and stratigraphy

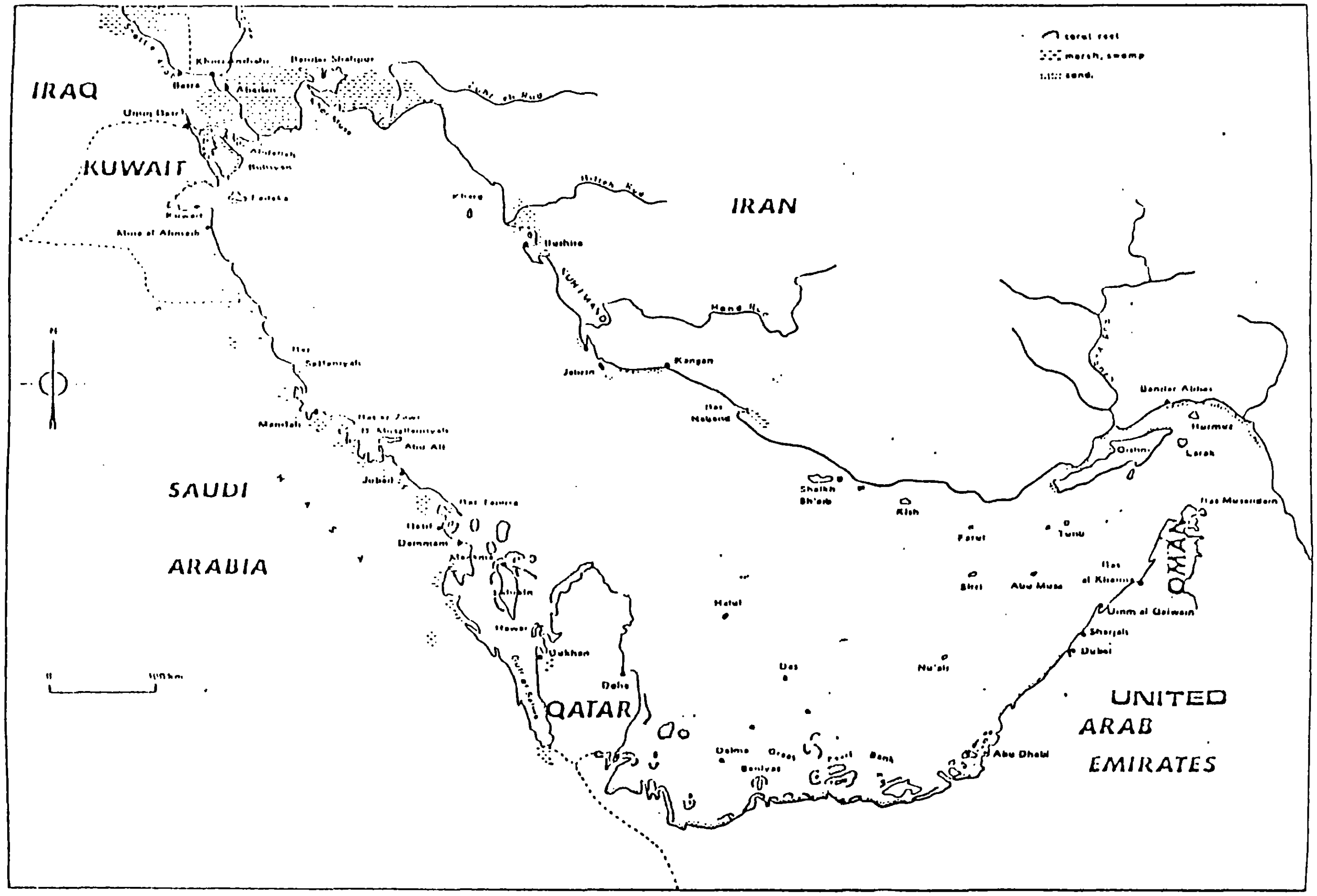


FIG. 1.1 COASTAL GEOMORPHOLOGY OF THE ARABIAN GULF.

of the area, there has been no attempt to consider the geomorphological features making up the coastline of Qatar, no attempt to make a classification of these features and no attempt to investigate the processes at work.

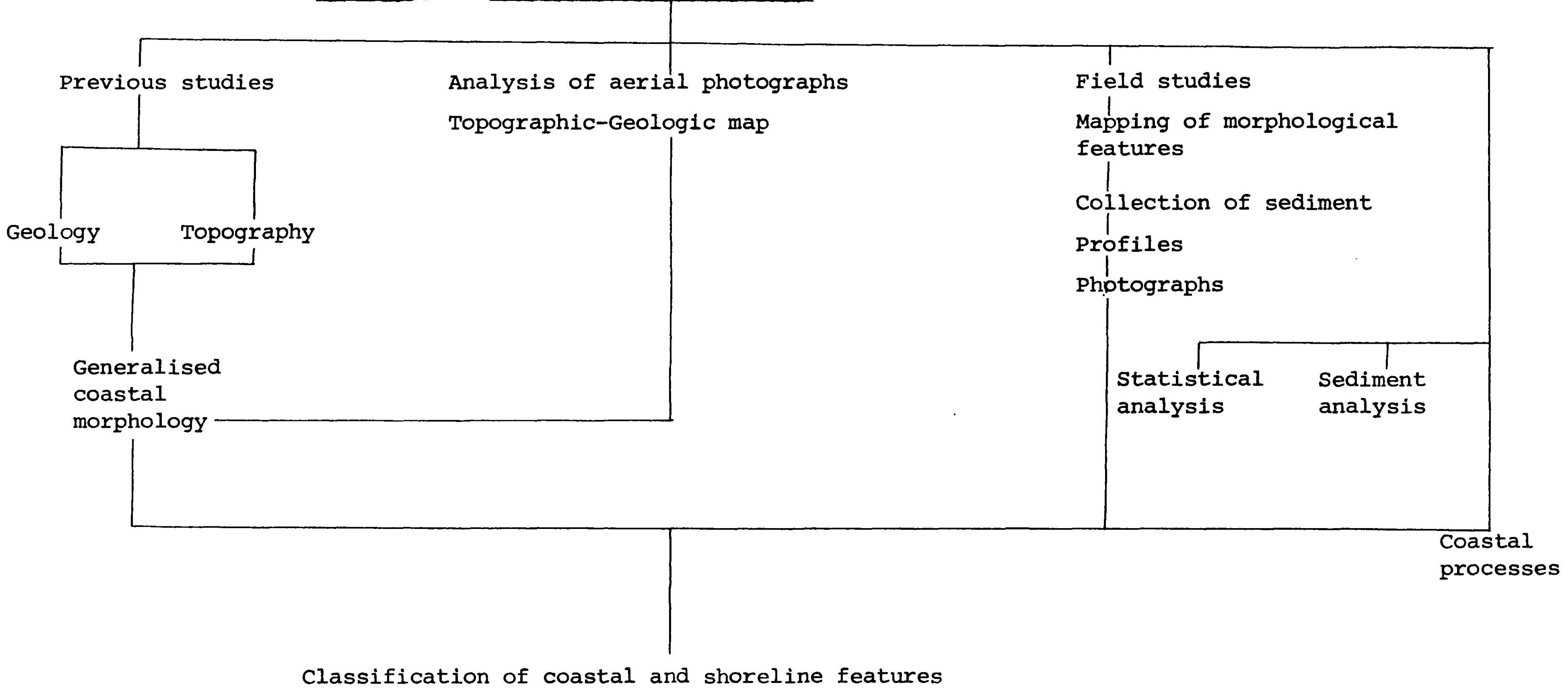
## 1.2 Objective of the study

This thesis concerns the geomorphology of the coastline of Qatar in terms of a morphological classification and detailed discussion of the origin of the different types of coastline and shoreline features.

## 1.3 Methodology

The study passed through various stages in an attempt to ascertain the important morphological features, the processes at work and coastal classification, Table 1. All previous geographical and geological studies that related to the coast of the Qatar Peninsula have been examined, although it is clear that there have been no comprehensive surveys of the coastline. The investigation was aided by the existence of various topographic maps and aerial photographs covering most of the Qatar Peninsula. The topographic maps have been used at various scales: 1:200,000 (one sheet); 1:100,000 (4 sheets); 1:50,000 (15 sheets); 1:10,000 (176 sheets). The aerial photographs were obtained from Hunting Surveys and dated 1963 at a scale of 1:38,000 and 1977 at a scale of 1:16,000. These aerial photographs enabled the morphological features of the coast of Qatar to be examined, and allowed temporal changes to be determined. Field investigations have included profiles of the shoreline where spits

Table 1.1 Methodology of the study



have developed or sand dune development has occurred, as well as identification of cliff forms and weathering processes.

Samples were collected from various locations extending along the whole coastline of the Qatar Peninsula to present the different sediment types from a variety of different environments, including beaches, dunes and sabkhas. These samples were analysed to determine a number of diagnostic features, including variation, sediment type and physical grain size characteristics using the Electron Microsscope.

The Qatar Pensinsula covers an area of about 10,600 $km^2$ between latitudes $24^o$-$40^o$ and $26^o$-$10^o$ north and longitudes $50^o$-$45^o$ and $51^o$-$40^o$ East. It is located at the north-eastern edge of the Arabian Gulf mainland protruding into the Arabian Gulf (Fig. 1.2). Its length extends from north to south for almost 180 km and its maximum width reaches 85 km. The absolute relief of the Peninsula reaches 115 metres, which is the difference between the lowest elevation point on the Dukhan Inland Sabkha (-6m below sea level) and the point of highest elevation at Taweer Al Hameer (+109m above sea level) (Fig. 1.3).

## 1.4 Geological background

The earliest investigation of the Peninsula of Qatar was carried out by the geologists of the Aramco and Shell Companies utilising terminology that had previously been adopted in Saudi Arabia.

A series of maps such as the geological map of Qatar had also been produced by the geologists of the Qatar Petroleum Company

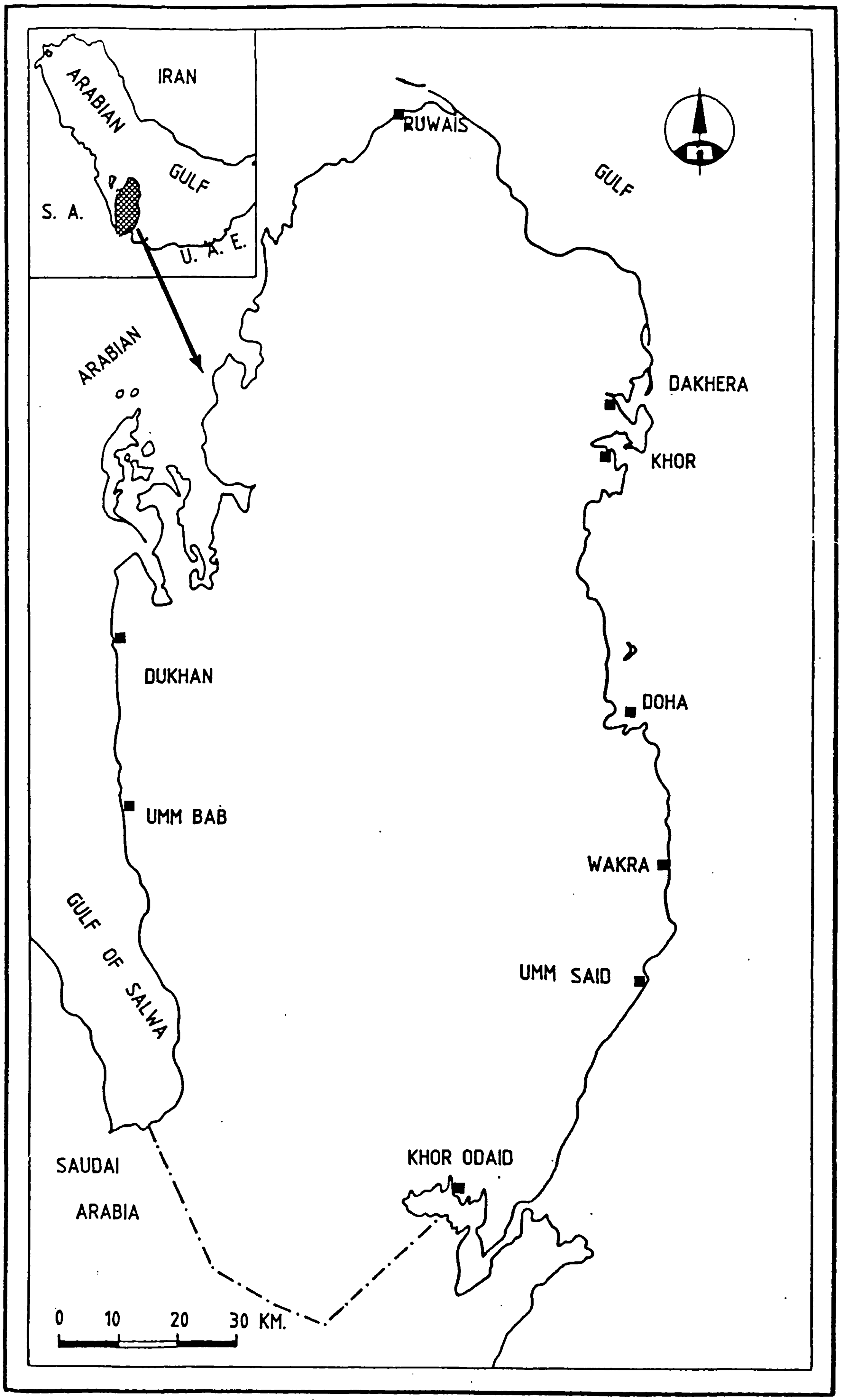


FIG. 1.2 QATAR PENINSULA: LOCATION.

(Q.P.C. 1950) mainly concerning the Dukhan area of oil field production.

In 1959 Grand Disco Ltd. produced a geological map with a scale of 1:100,000. Two reasons can be cited for producing the map: (1) to provide a detailed geological base map for the Peninsula of Qatar; and (2) to provide a base map for hydrological investigations into ground water reserves in the Peninsula. This work has been shared between Q.P.C. and Grand Disco Ltd.

A study by Cavelier (1970) is regarded as an essential and more detailed consideration of the available data than former studies. Cavelier has studied the geological make-up of the whole of the Peninsula of Qatar. He produced the first detailed geological base and shows Tertiary and Quaternary rocks and sediments.

This map is accompanied by an explanatory booklet which describes in detail the different structural features and the palaeogeographical history of Qatar, making reference in detail to the strata from the Tertiary to the end of the Quaternary. A series of French expeditions has added to this preliminary data, while a geological survey conducted in December 1976 and January 1977 was primarily intended to establish archaeological and palaeogeographical reconstructions of the Quaternary formations in the Qatar Peninsula.

## 1.5 Stratigraphy of the Peninsula of Qatar

The geological structure of the Qatar Peninsula indicates that it is part of the Arabian Gulf sedimentary basin. This basin extends from the Arabian Shield to the Zagros fold belt of Iran, with a total width of 1200 km (Table1.2). The geology of the Peninsula of Qatar is dominated by formations of Tertiary and Quaternary age, where about 80% of the surface is formed of Tertiary sedimentary sequences and the remaining 20% is covered by Quaternary deposits (Fig. 1.4). The older formation, ranging from Palaeozoic to Mesozoic in age, is exposed in two offshore islands, namely Halul and Sharauh (Fig. 1.1). Lithologically the main rock types cropping out in the Qatar Peninsula are limestone, marl, shale, evaporites, sandstone, calcarenite and dolomite.

## 1.6 Tertiary : the Rus formation

### 1.6.1 Lower Eocene

The oldest strata exposed on the Qatar Peninsula consist of the Rus formation. The greatest thickness of the Rus formation is 85m and occurs in Jabal Dukhan, near Sauda Nathil, in the Khor region and in the central part of Qatar. This formation contains a variety of chalky limestones, gypsum, dolomite and anhydrite beds. A cross section of Jabal Dukhan (Fhaihil and Dukhan Dome) reveals about 30m of deposits belonging to the Rus formation (Fig. 1.5). The total thickness of the Rus formation can only be estimated from the result of boreholes according to Grand Disco (1959), an interpretation which looks most reliable. The Rus formation displays a minimum thickness of about 28m (in Latariyah) in a sharp anticlinal position (Qatari arch) and reveals (30, 34, 42, or 44m) in the northern region where it is involved in the Simsima Dome. It is clearly thicker in the west or south-east (Doha 84m) where the gypsum layer can be observed in the offshore area.

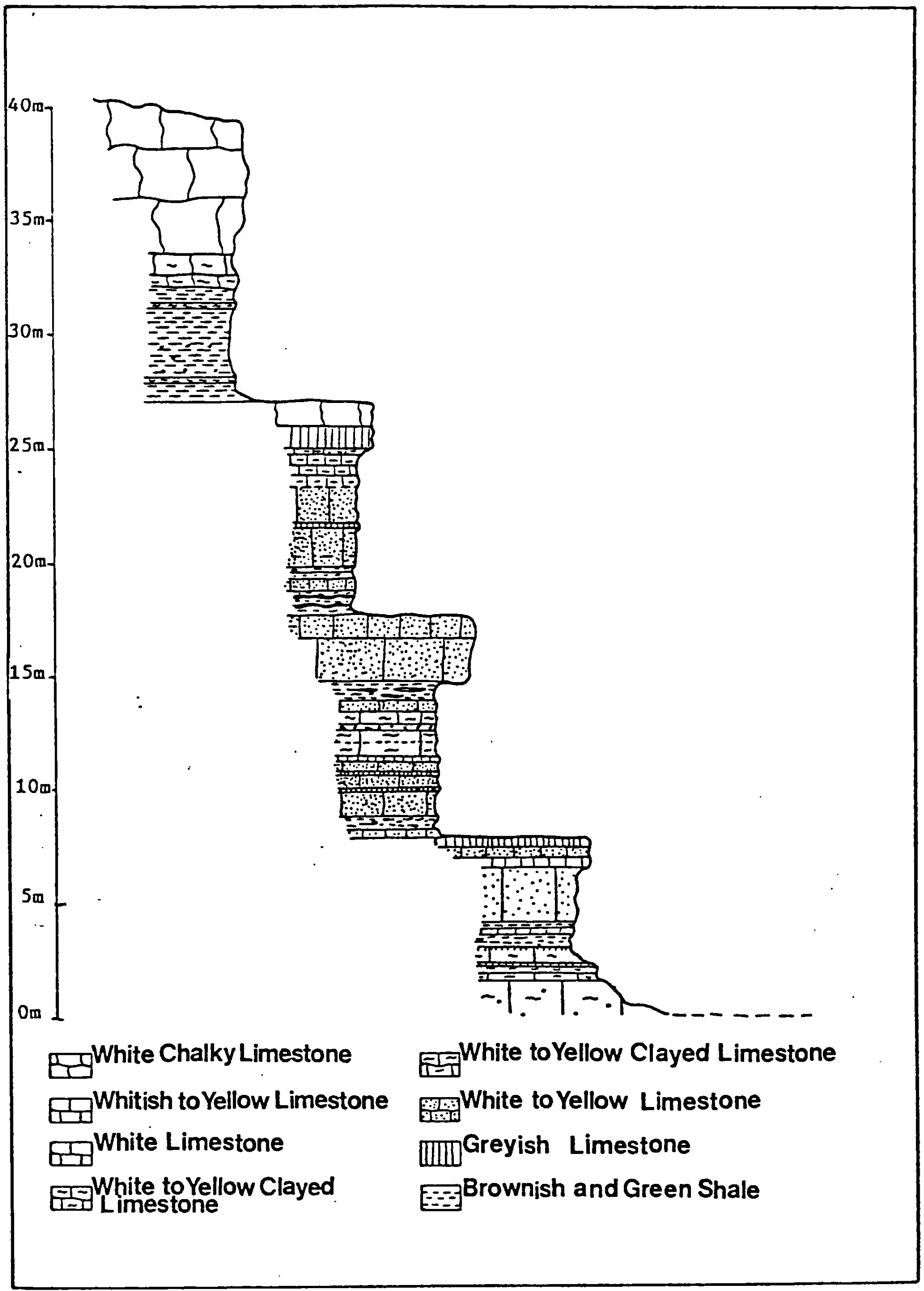


FIG.1.5 RUS FORMATION (JABAL DUKHAN) (AFTER CAVELIER 1970)

Table1.2 Lithostratigraphic Sequence of the Main Rock Exposures in the Qatar Peninsula

| Age | | | Formation | | Lithology |
|---|---|---|---|---|---|
| QUATERNARY | Holocene | | | | - Sand dunes and Aeolian sands<br>- Beach sands and bioclastics<br>- Sabkhas with salt crusts<br>- Depressions muds and silts |
| | Pleistocene | | | | - Conglomeratic and pseudo-oolitic limestones (miliolites) |
| TERTIARY | Miocene | Late | Hofuf Formation | | - Residual gravels of limestones and siliceous sands |
| | | | Dam Formation | Upper | - Clayey limestones with gypsum |
| | | | | Lower | - Marls, clays and limestones |
| | Eocene | | Daman Formation | Upper | - Abrug dolomitic limestones and marls<br>- Simsima chalky limestones and dolomite. |
| | | | | Lower | - Alviolina limestones<br>- Midra shales |
| | | Early | Rus Formation | | - Chalky limestones with marl and anhydrite |

Source: Industrial Development Technical Centre, 1980

### 1.6.2 Dammam formation

The Dammam formation can be divided into two; the Lower and Upper Dammam formations. The Lower Dammam formation includes the Fhaihil limestone, the Midra Shale and the Alveolina limestones. The Midra Shale has been a significant factor in the development of the geomorphology of the country since, in those places where a breach has occurred in the overlying protecting limestone, the softer shale has been winnowed away by the prevailing wind. These Midra shales wedge out towards the northeast with a thickness of about 8m in the west to less than 1m in the south.

### 1.6.3 Upper Dammam formation

The Upper Dammam formation is subdivided into the Lower Simsima Dolomite and Limestone member and the Upper Abrug member.

The Lower Simsima Dolomite and Limestone underlies 80% of the total of the surface of Qatar Peninsula and its thickness exceeds 30m. It outcrops in the South Sauda Nathil area on the west flanks of the Dukhan anticline, in the Khor and Simsima areas, and in the Zekreet area. The Simsima Limestone and a Dolomite member consist of fossiliferous fine to medium-grained whitish brownish limestone. The Upper Abrug Dolomitic Limestone and Marl member outcrops in the Abrug Peninsula and on the western flank of the anticline south of Dukhan. The thickness of the Abrug member is about 12 metres and it consists of a lower stratum of soft, white, clayey, dolomitic and chalky marl which is yellowish in places. This stratum is 10 metre thick and is capped by an upper brownish, crystalline dolomite about 2m thick.

### 1.6.4 The Miocene Dam formation

The lagoonal and marine sediments of the Dam formation of Lower and Middle Miocene age overlie the Dammam formation and are found in isolated mesas in south-central and south-western parts of Qatar. This formation can be subdivided into two groups: (1) the Lower Dam, consisting of 30 metre of fossiliferous limestone, marl and clay; and (2) the Upper Dam, which has a more lagoonal character, consisting of marl, limestone, and which is located in the south-western part of the Qatar Peninsula with a thickness of up to 48m. The Dam formation also forms outcrops in relic mesas in the south-west of the Peninsula, extending from the Dukhan anticline to beyond Kharrarah.

The distribution is believed to be structurally controlled. Also of interest is the existence of Dam formation rock preserved in collapse structures, such as at Kharanah, Almarkiyah and Mukaenis.

## 1.7 The Miocene and Pliocene Hofuf formation

The younger Hofuf formation which comprises sand and gravel of Miocene to Pliocene age, exists as cappings on top of most Dam formation rock mesas and also a relic redeposited gravels on Simsima Limestone surface.

The Hofuf formation sediments, which have been considerably eroded and redeposited, were brought to Qatar by river systems flowing east and north-east across Saudi Arabia and spreading out to form a vast alluvial fan.

## 1.8 Quaternary Deposits

The marine Quaternary deposits are mainly restricted to coastal localities and consist of cemented calcarenite or pseudo-oolitic limestone. Good examples of ridges formed in these limestones are found at Wakra, Fuwairit, Jassasiyah and Ghariyah. These cemented calcarenite are exposed in cliffs or low ridges and are oriented parallel to the present-day coastline. They were probably formed during a previous inter-glacial period when sea-level was higher than at present, as indicated by raised beach terraces (Vita Finzi, 1973; Fig. 1.6) and they are the subject of detailed examination in chapters 2 and 7. The continental Quaternary deposits include redeposited Hofuf sand and gravel and mud and silt that has formed in depressions and has been derived from the Simsima Limestone, as well as from aeolian materials, such as calcareous and quartzitic sand grains mixed with calcareous fragments (Limestone and Chalk), dust and available heavy minerals such as ilmenite and magnetite. Sand sheets have been formed in the west and south-west of the peninsula and these sand sheets have been trapped along the flanks of upstanding mesas or in some depressions. Since the "Shamal" wind blows the sand predominantly south-eastwards across Qatar and into the sea, the land surface between Umm Said and Khor Odaid has extended eastwards.

### 1.8.1 Sabkha deposits

The Peninsula of Qatar contains large areas of sabkhas, which include coastal sabkhas located mostly on the east coast, and the inland sabkhas which occur east of Dukhan Settlement. In all, both types of sabkha cover nearly 700 $km^2$. They are formed from accumulations of salt-encrusted calcareous silt and sand and they are devoid

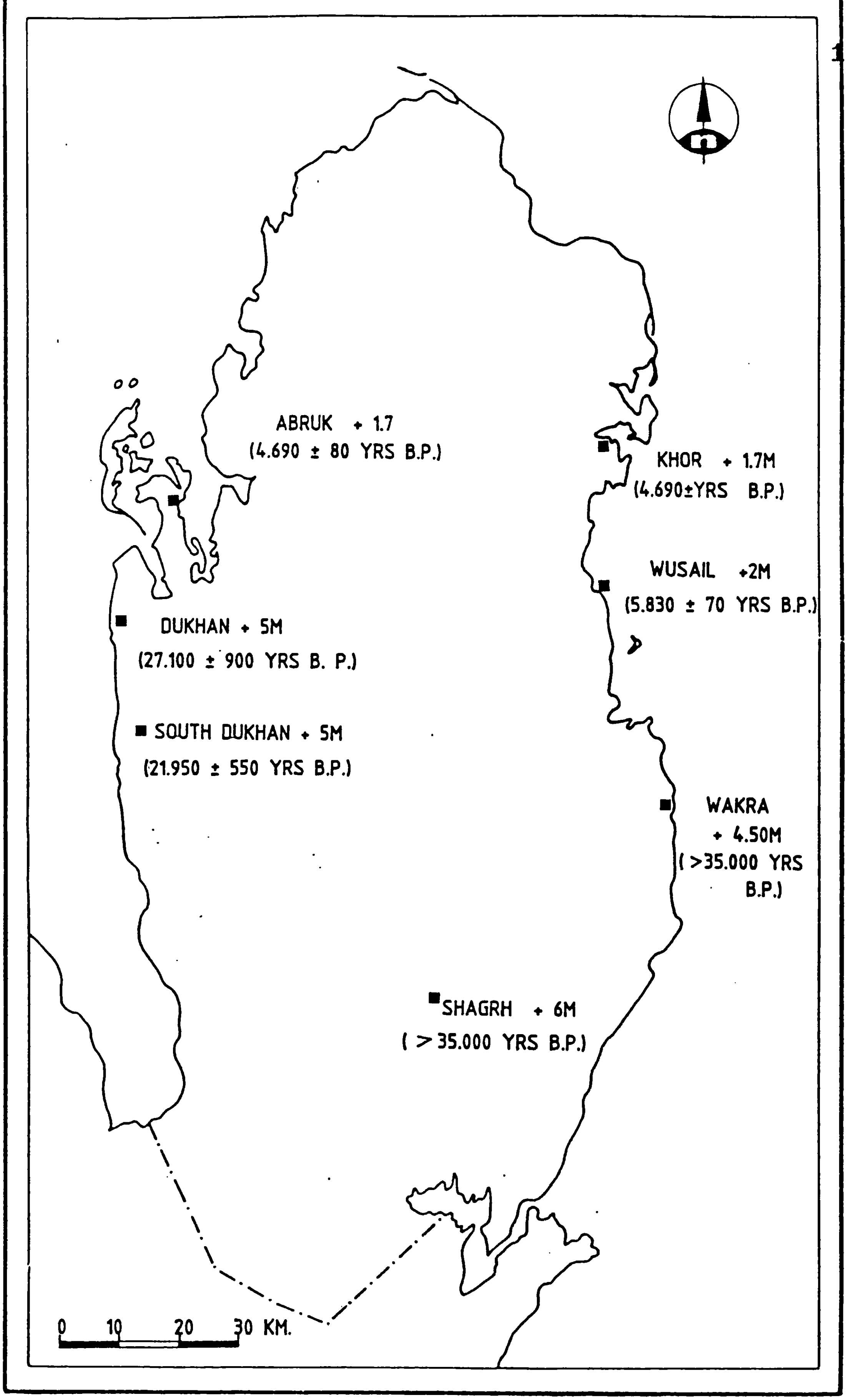


FIG.1.6 DATED RAISED BEACHES: SITE LOCATIONS.

SOURCE ; QATAR ARCHEOLOGICAL REPORT , VITA FINZI , (1973) of vegetation. The most important continental deposits of Quaternary age are the numerous aeolian sand deposits which usually occur as individual dunes of barchan type, such as in the dune field south of Umm Said. These aeolian sands are yellowish in colour and are composed predominantly of rounded silica (quartz) grains.

## Structure and evolution of the Peninsula

### 1.2.1 Introduction

Although Qatar is located within the relatively stable geological area of the Arabian interior platform (Fig1.7), its close proximity to the Gulf geosyncline to the northeast has subjected the peninsula to gentle tectonic activity which has persisted through a long period of geological time. The type of movement that has occurred has not resulted in major structural dislocation, but has produced important folding and it has significantly affected sedimentation Eccleston et-al (1981)

### 1.2.1.1 Regional movements

Gentle tilting to the north-east has affected the Arabian interior platform area since the Permian, in response to the complementary factors of subsidence and major sedimentation in the Gulf geosyncline. These movements have created a regional homocline extending from Central Saudi Arabia with gentle dips to the east and northeast.

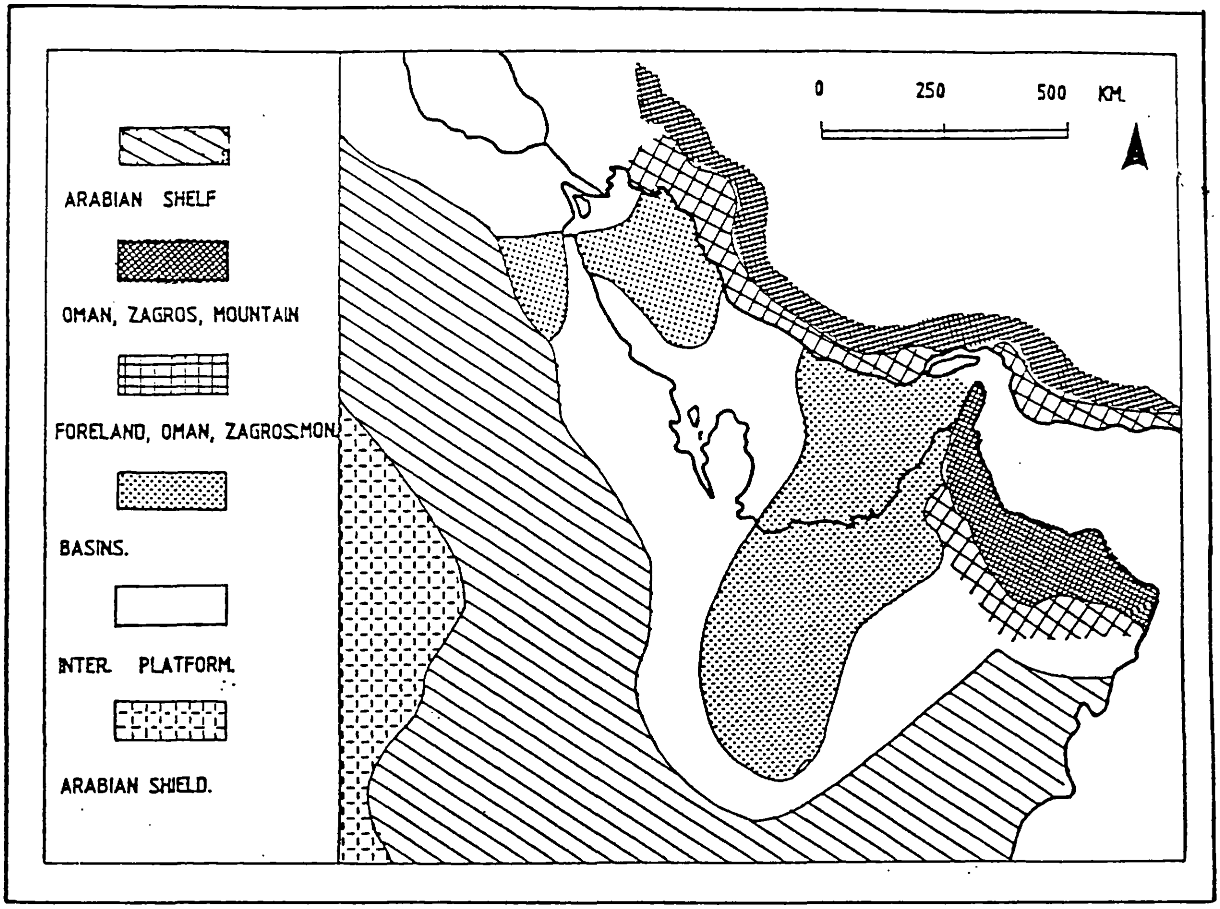


FIG.1.7 STRUCTURAL PROVINCES FOR QATAR PENINSULA AND ADJACENT AREAS.

SOURCE . SCHLUMBERGER , 1975. Eccleston et-al 1981

### 1.2.1.2 Regional folding

The more prominent folds in Saudi Arabia and along the western Gulf are shown in Figure 1.8. The gentle elongated periclines, which in many places form important oil-bearing structures, are considered to have had a halokinetic origin, that is, the movements were created by the redistribution at depth of salt which flows by plastic deformation in response to isostatic stress. Deep-seated faults are believed to have facilitated displacements and promoted salt migration and the formation of diapiric structures. Contemporaneous upward bulging of the positive or anticlinal areas has affected most of the Tertiary sequence sedimentation and may have affected even older formations Eccleston *et al* 1981

### 1.2.1.3 Folding in Qatar

The subdued surface relief and the general shape of the Qatar Peninsula reflect the basic underlying geological structures. The principal structures converge in the southern border area of Qatar but sub-surface structural information is limited.

### 1.2.1.4 The Qatar Central Pericline or Arch

A broad gentle dipping arch, or pericline, forms the backbone of the mainland. This is known as the Qatar central pericline and it culminates in the south central area with shallow pitching both northwards and southwards. In the north, another arch separates the Qatar Arch from the shallow Simsima Arch, which also pitches gently northeastwards (Fig. 1.9).

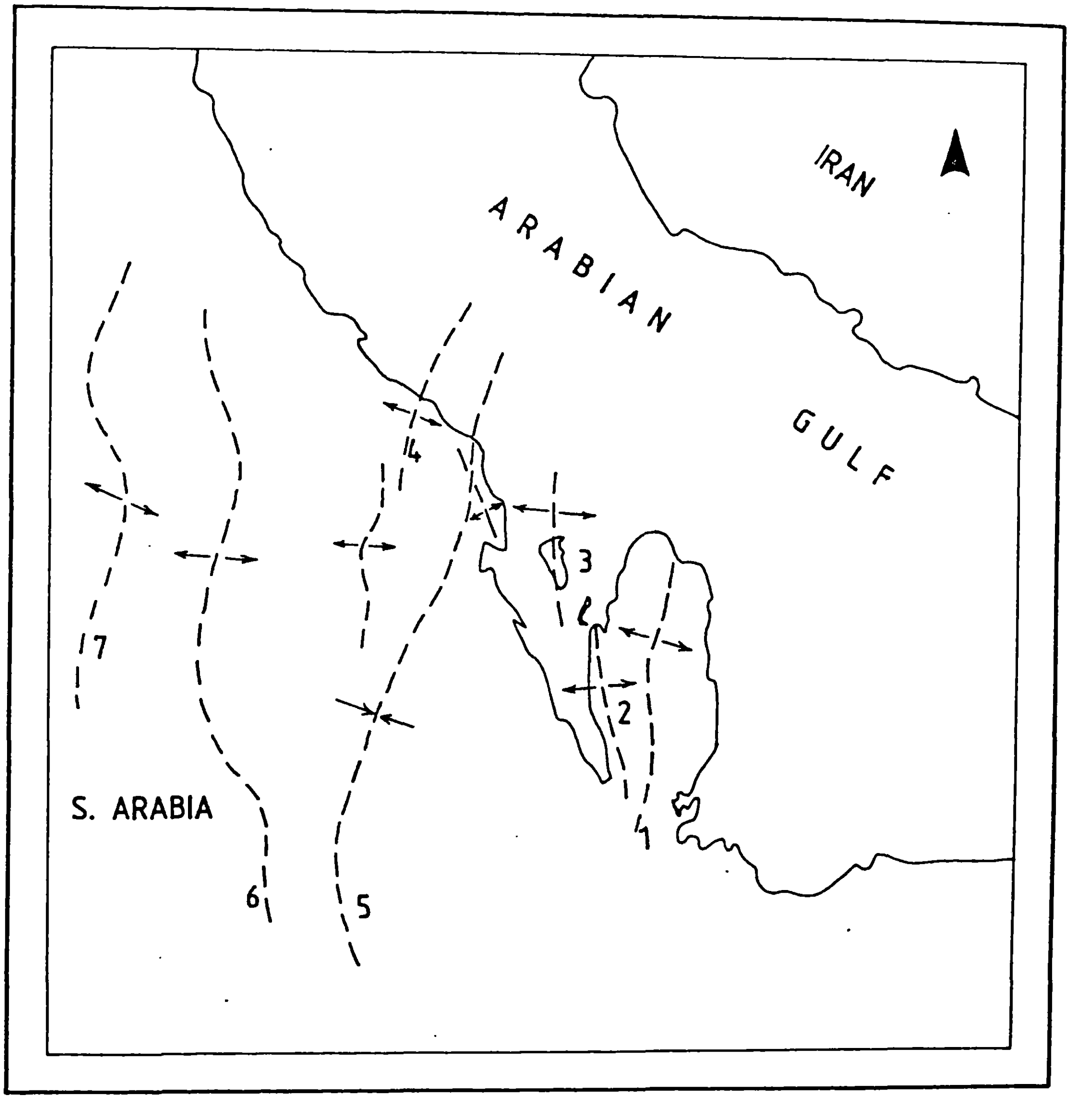


FIG. 1.8 MAJOR ANTICLINAL STRUCTURES , EASTERN ARABIA .

( AFTER ITAKONSULT , 1969 ) ECCLESTON 1981

1) QATAR PERICLINE .
2) DUKHAN ANTICLINE .
3) BAHRAIN PERICLINE .
4) DAMMAM DOME .
5) GHAWAR ANTICLINE .
6) KHURAIS ANTICLINE .
7) MA AGA LA ANTICLINE .

### 1.2.1.5 Dukhan anticline

The Dukhan anticline in the west is a more pronounced structure creating a pronounced topographic ridge culminating in a plateau surface some 40 metres above the central pericline. Dips of the strata are also steeper and while the crest elevation is relatively constant, the eventual northward pitch of the anticline is also steep.

### 1.2.1.6 Abrug fold

A complementary minor synform and antiform structure creates the Peninsula of Abrug on which a thin capping dolomite, overlying a thicker dolomitic chalky marl (Abrug members of the Upper Dammam), is preserved as outliers resting upon the general Simsima formation surfaces Eccleston et-al (1981).

### 1.2.1.7 Gulf of Salwa Syncline

The fold is known to have a gently-sloping westerly limb in Saudi Arabia and is therefore a part of the Hurijeh syncline. The shallow gulf occupies the synclinal area and the artesian feature of the Alat (Abrug) member of the Upper Dammam formation in the Salwa area is created by the confined conditions and the relative elevation of the two limbs.

### 1.2.1.8 Hurijeh Syncline

The adjacent syncline has a steep westerly and a very gentle easterly limb and several minor folds and flexures are to be found within the area which separates the two main anticlines Eccleston et-al (1981)

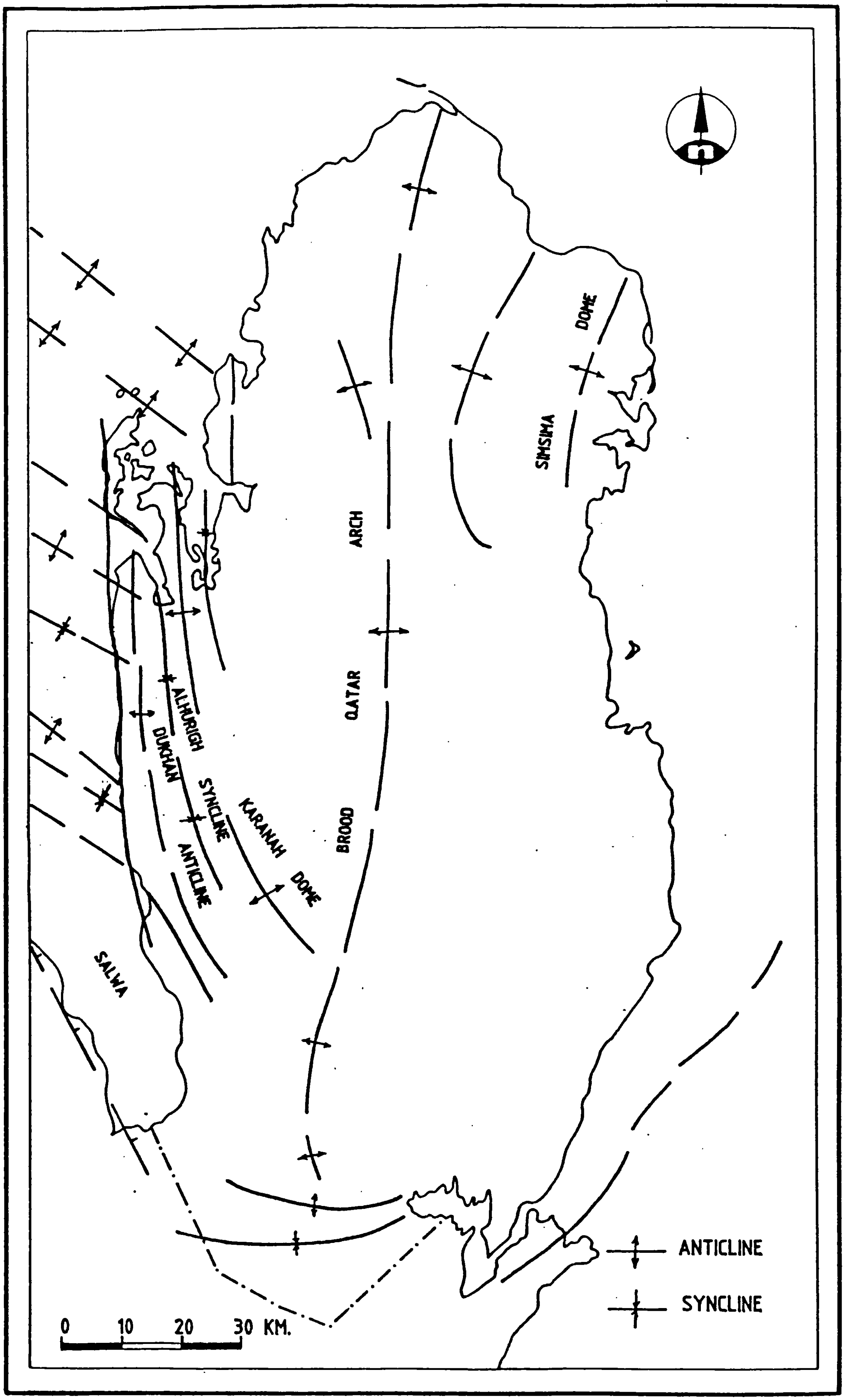


FIG.1.9 ANTICLINE AND SYNCLINE IN QATAR PENINSULA

SOURCE: IMBABI AND ASHOUR. (1985)

### 1.3.1 Major Structural Features of Qatar

#### 1.3.1.1 Main structural features

Within a general geological framework, including the neighbouring inland and offshore region, the Peninsula of Qatar appears as an elliptical 'giant' anticline, with a north to south main axis. However, it is considered that this important, gently-warped structure is not a simple one and particularly that it is limited to the west by a long and narrow well-marked fold, corresponding to the Jabal Dukhan, outlined by the outcrop of Lower Eocene rocks (Rus formation) (Fig. 1.9). The Qatari broad arch is comparatively regular, culminating in the central part of Qatar. But it is probably complicated by secondary anticlinal structures, with a NW-SE main axis to the NE (Simsima Dome, and to the SW (Karanah Dome) . The Jabal Dukhan anticline also is not a simple one. It appears to comprise several quite extensive arches, the most marked of which, that of Jaleha, is continued to the north by the Fhaihil and Dukhan Dome, and to the S and SE by those of Qalat al Darb and Sauda Nathil. To the west, the Jabal Dukhan anticline is bordered by the large Salwa Syncline infilled with thick Miocene deposits and occupied to a large degree by the Gulf of Salwa. To the east it is divided from the Qatari arch by a narrow syncline from Zekreet to the Karanah occupied to the north by the large Sabkha of Dukhan and to the south by gently rising Miocene deposits (Zekreet syncline).

#### 1.3.1.2 Tectonic style

The tectonic style of the Qatar Peninsula is essentially gentle. In particular, the maximum dips recorded do not exceed 4°

along the eastern side of the Jabal Dukhan anticline (Fhaihil Dome). (Cavelier, 1970).

No faulting has been observed on the surface. However, it is quite possible that the Jabal Dukhan anticline may be locally faulted at depth as believed by Hanson (1951), who points out the extensiveness of a fault with a throw of 22 metres.

During the Tertiary period the first minor uplift took place at the boundary of the Lower Eocene and Middle Eocene, then again at the end of the Middle Eocene.

During the Upper Eocene-Oligocene Period, the Qatari arch became sharply individualized. The upward motion, interrupted during the lower Miocene, resumed at first slightly, then increased to a maximum during the Upper Miocene-Pliocene, a period during which the Jabal Dukhan anticline became sharply individualized. Quaternary neotectonics of low amplitude are also likely to have occurred. Despite often inaccurate dating of the uplift stages, it appears clear that they are essentially Pyrenean and principally Alpine ones which resulted in the formation of the Qatari Arch.

### 1.3.1.3 Structural Lineament

The LANDSAT image of the Qatar Peninsula shows a series of parallel lines oriented north-west to south-east. These features probably represent fault and joint systems as well as the linear expression of fracture systems or shear zones in the bedrock. Where there is a large number of massive joint blocks and where the joints are tight, there are monolithic masses that resist deep weathering

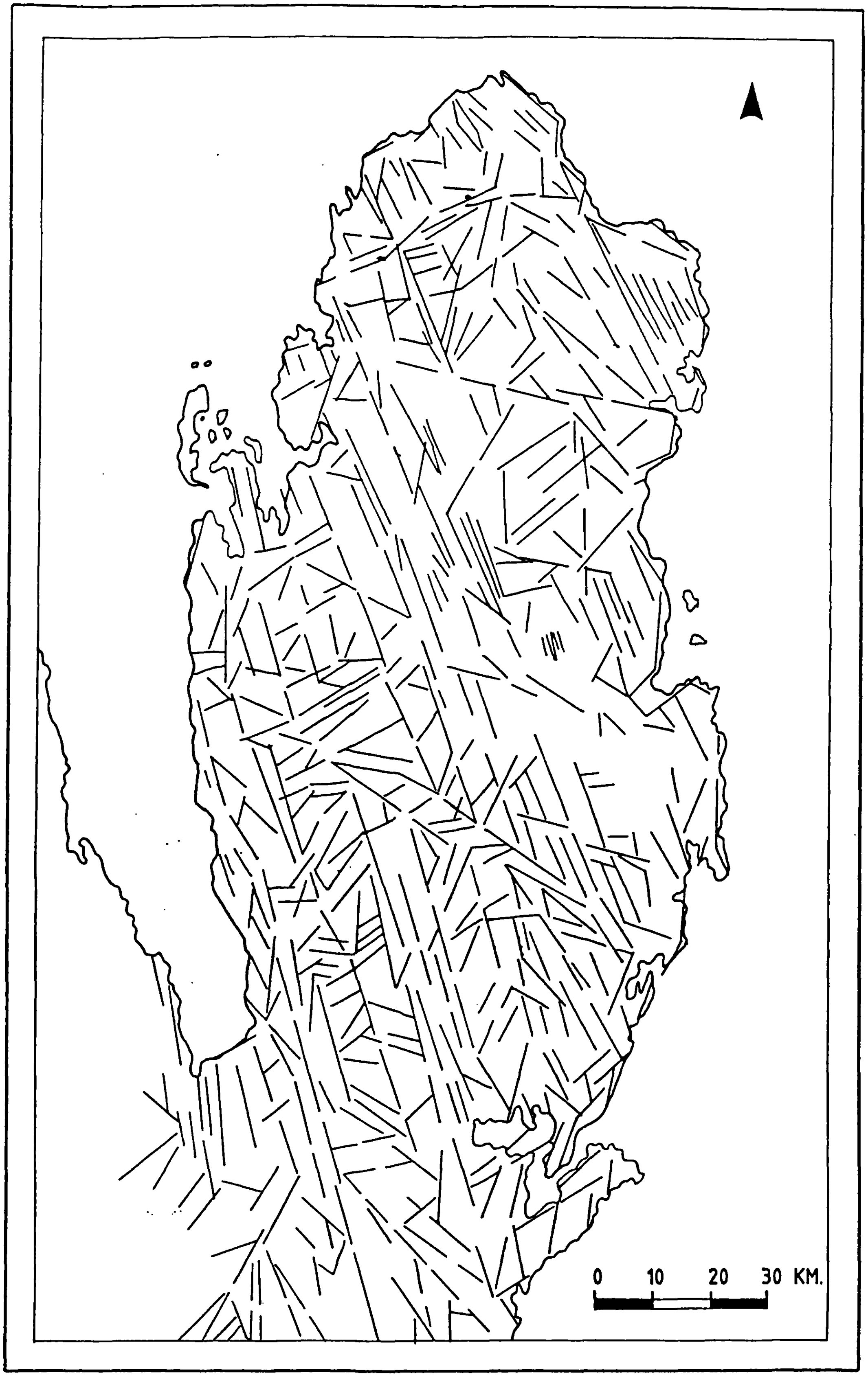


FIG. 1.10 LINEAMENTS MAP OF QATAR PENINSULA FROM LANDSAT IMAGERY. FROM ASHOUR AND EL KASAS (1984).

and erosion (Ashour and Elkassas, 1984). The interpretation of these lineament from the LANDSAT images indicates the presence of two major trends of structural lineament; these are predominantly in a NNW-SSE direction and the other in a NE-SW direction. They show large fractures or joints systems that have formed the uplift of the Qatar Arch. Eccleston et al (1981) considered the major NNW-SSE structural line coinciding with axis fold of the Salwa syncline, to be a fracture zone (Fig.1.10). The other trend, NE-SW, represents some major fractures and faults which also lie parallel to the axes of major folding systems. The coastal outline has been examined by Ashour and El Kasas (1984) from the LANDSAT images and has been shown to consist of straight or gently curvilinear elements. The total of 127 lineaments measuring a length of 245.5 km have been analysed statistically (Fig.1.11). They vary in length from 500m to 6.5 km with an average of 1.93 km and are oriented in various directions with predominant NNW-SSE and NNE-SSW trends.

The east coast shows two significant linear trends; the dominant one in a NNE-SSW direction, while on the west side, the dominant trends are directed NNW-SSE. Some of the surface lineaments are produced by aeolian features dominating the northeastern and southern parts of the Qatar Peninsula. This includes sand sheets and sand dunes. The dominant lineament is in a NNW-SSE direction; it is clearly related to the prevailing 'shamal' wind.

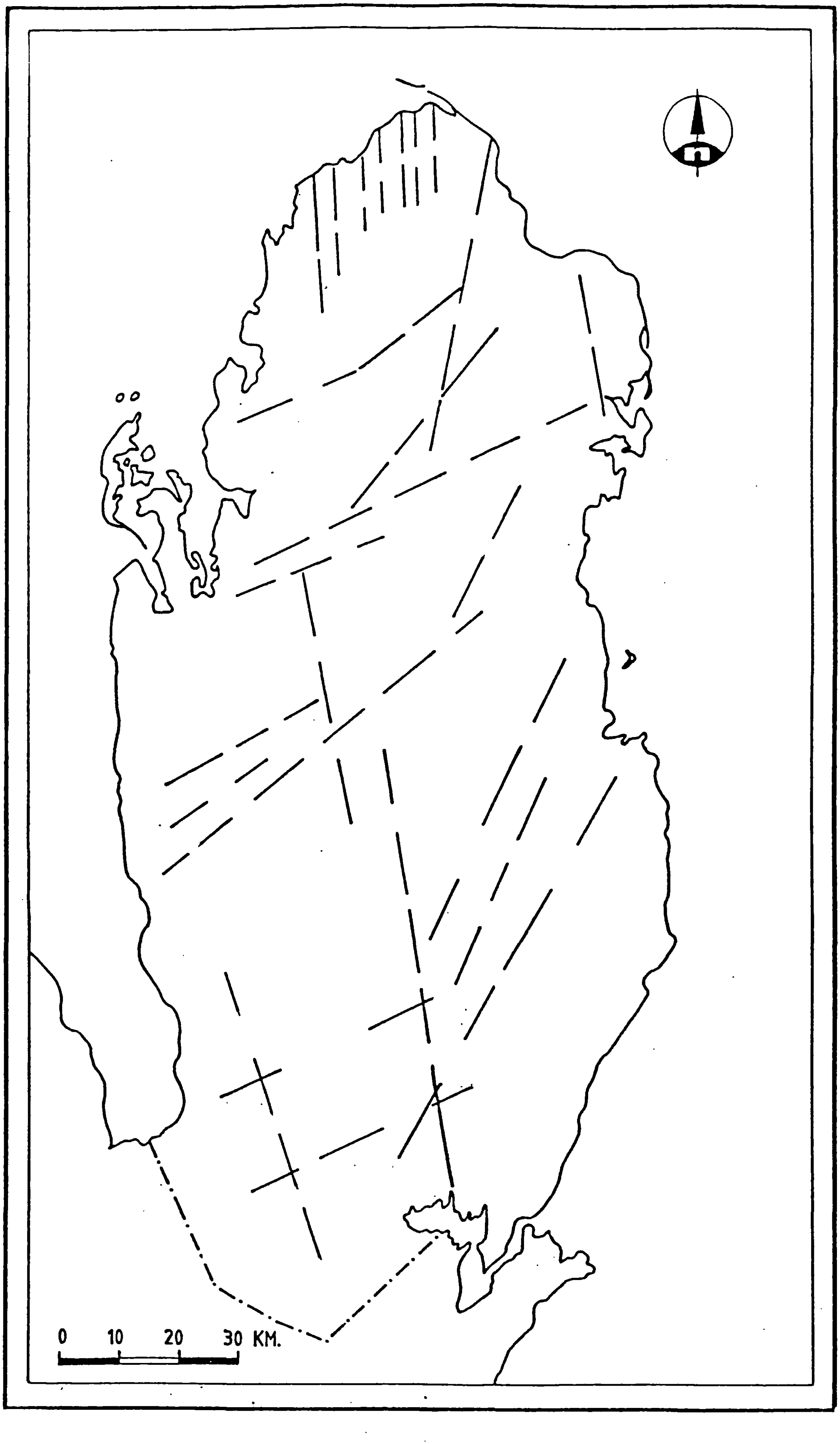


FIG. 1.11. STRUCTURAL LINEAMENTS IN QATAR INTERPRETED FROM LANDSAT IMAGERY 1980. (AFTER ASHOUR AND ELKASAS 1984).

## General physiography

### 1.4.1 Coastal features

The coastal features around the Qatar Peninsula can be divided into four groups:

#### 1.4.1.1 (a) Embayments

These embayments occur along the east coast in the embayments of Khor Odaid, Khor and Dakhera, and the west coast in the embayment of Zekreet, Hussain, Asyad, Ummelma, Feshakh and Bin Rahal.

#### 4.1.2 (b) Depositional features

There are extensive sand beaches which have resulted from substantial deposition on the Qatar Peninsula coasts, particularly in the embayments. The relatively calm sea conditions have contributed to the formation of these extensive depositional features (Fig.1.12). In addition there are many offshore sand barriers with different shapes, including multiple-hooked and simple linear sand bars. These sand bars vary in size, shape and age, some of them reaching up to several hundreds of metres in length. Some extend for several kilometres (Plate1.1) such as those found on the east coast at the entrance of Dakhera bay, and on the north coast around Ras Rakan (named as Ras Rakan Barrier).

#### 1.4.1.3 (c) Erosional features

Because most of the Qatar Peninsula lacks prominent relief features and has a low amplitude of relief near the coast (nowhere exceeding 3-11m), erosions forms which can be recognized are few

PLATE 1.1 HOOKED AND SIMPLE LINEAR SAND BAR AROUND DAKHERA AND KHOR, 1977.


1.11

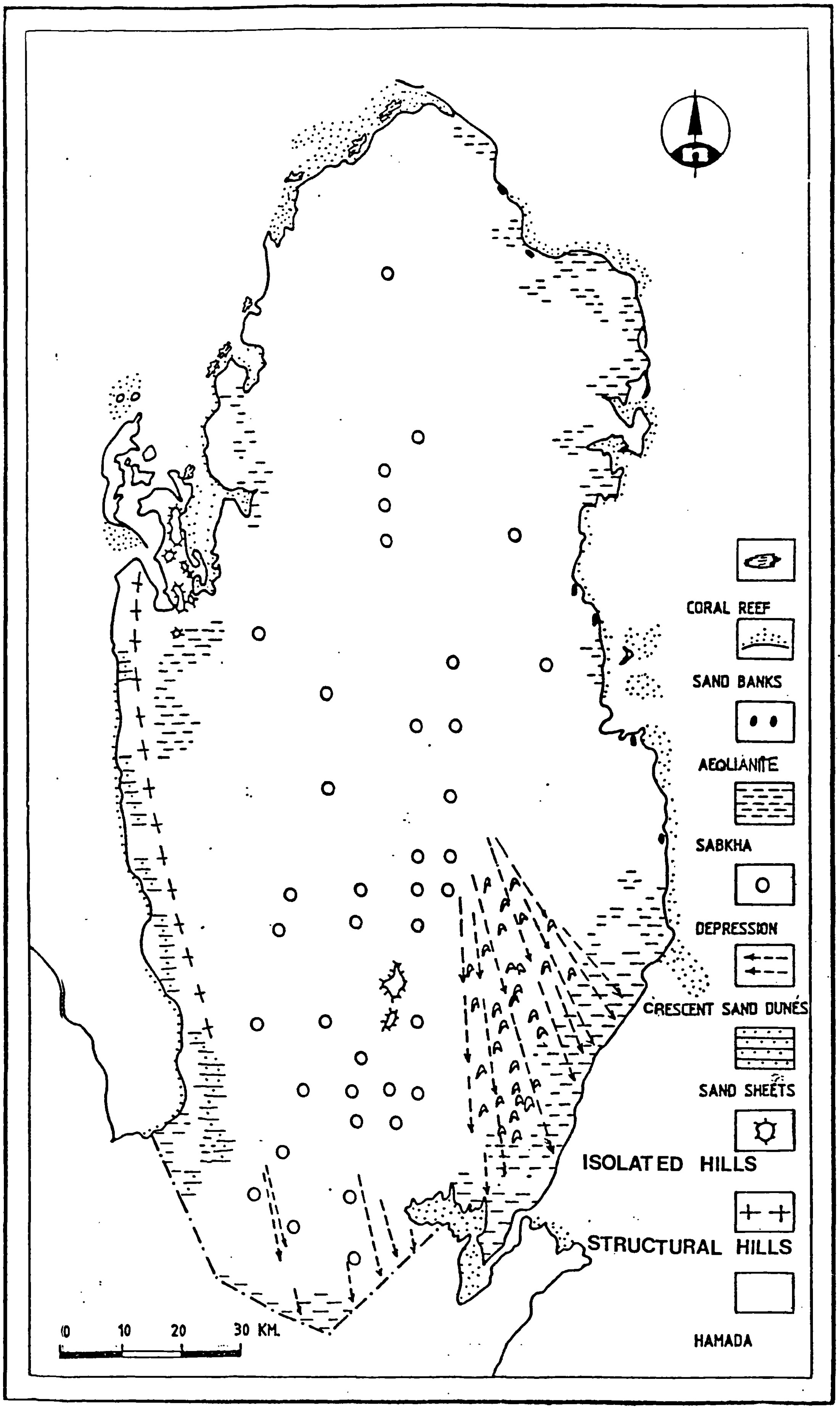


FIG. 1.12 A GENERALIZED MAP OF SELECTED GEOMORPHOLOGICAL FEATURES. (MODIFIED AFTER EMBABI AND ASHOUR, 1985)

and occur only along short stretches of coastline. Cliffs are well developed along the north west coast from Ras Abu Omran to Zubara and along the Abrug Peninsula, where flat-topped hills with steep sides overlook the sea at several localities, and around areas of Ghar Bradi and small scattered cliffs along the east coast. These cliffs produced by two groups of processes, undercutting by marine action and weathering and mass movement at the edge of the low plateau. There is limited removal of debris at the cliff foot by wave action, with the result that there are sections with cliffs varying from 2 to 11 metres in height. In some cases the plateau edge displays several wave-cut notches at heights up to 11m above sea level.

### 1..4.1.4 (d) Sabkha

The sabkhas of the Qatar Peninsula can be subdivided into two types: these are (a) coastal sabkhas and (b) inland sabkhas The coastal sabkhas cover about 75 $km^2$ or constitute nearly 7% of the total area of the Qatar Peninsula, but they are fewer on the west coast. The coastal sabkhas do not rise much above the present sea level (about 1-2 metres above sea level). Some parts of the sabkhas are still below sea level and thus tidal currents are able to transgress across their surfaces during particularly high tides, sometimes aided by strong easterly winds.

The inland sabkhas can be divided into two different locations. The first is located about 3 km east of Jabal Dukhan and south of Zekreet Bay. Its area is 60 $km^2$ and most of it lies below sea level. Within this sabkha is the lowest point on the Qatar Peninsula (-6 metres below sea level). It extends nearly 24 km in a northerly direction and about 6 km from east to west. The second inland sabkha is located along the border between Qatar, Saudi Arabia and the United Arab Emirates in three scattered areas, namely the southern part Sauda Nathil, the western part of Jawa Salama, and the eastern part of Khufus. Most of the surfaces of these Sabkhas are below sea level and cover an area of about 25 $km^2$.

### 1.4.1.5(e) Depressions

Hundreds of small depressions are spread across the surface of the Qatar Peninsula. These are completely enclosed basins, open on one side or more in the south-central part of the peninsula. These depressions vary in size and shape. Some are rounded, others are elongated or of variable platforms. Some of these depressions have a length exceeding several kilometres (e.g. Almajdah Depression) whilst others only achieve a maximum extent of several tens of metres. Several factors have contributed to the form of such depressions which are caused by solution of the limestone at the surface by run-off water from the greater part of the peninsula (Fig. 1.13).

### 1.4.1.6(f) Dry valleys

The dry valleys are characterised by the following: they occupy the northern part of the peninsula of Qatar and Jabal Dukhan (Fig.1.12) and their drainage is internal towards the nearby depressions which have a shallow depth not exceeding 2-3 metres and restricted length. They may extend up to several kilometres in length and they are usually narrow, never exceeding 100m in width.

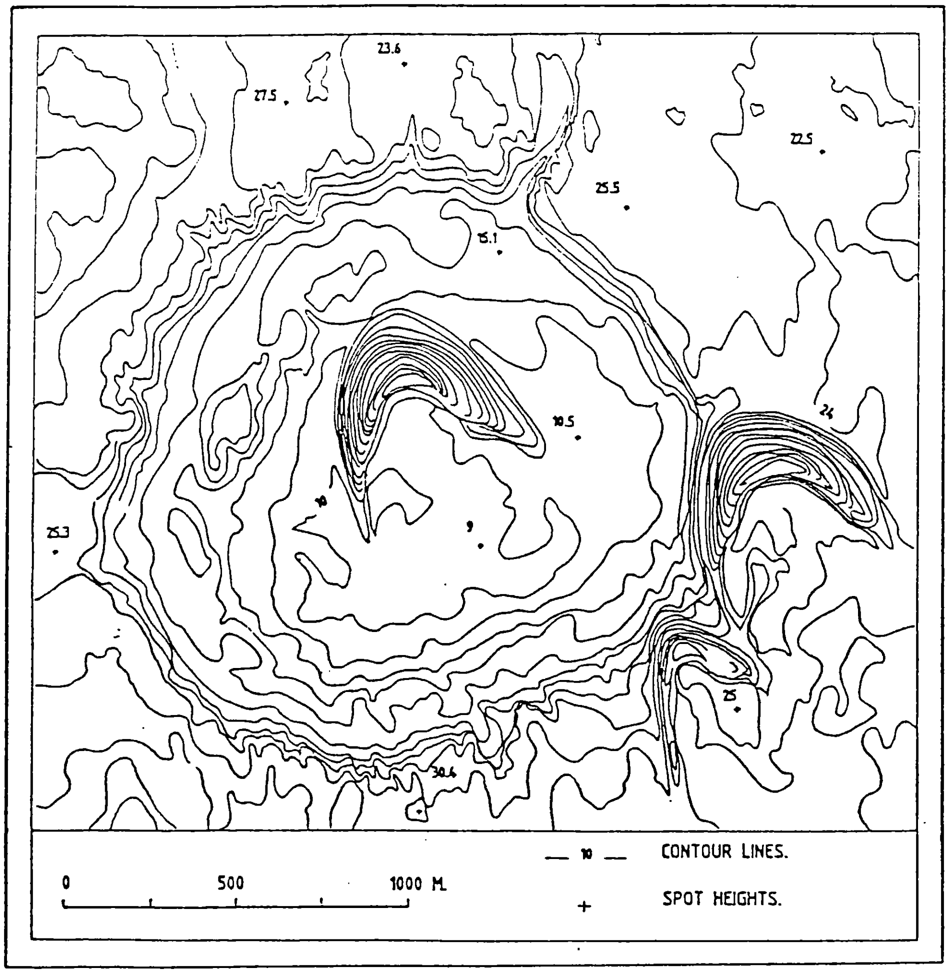


FIG. 1.13 SHOWING WELL ROUNDED DEPRESSION SOUTH QATAR.

### 1.4.1.7 Other Relief Features

Low hills are scattered in different parts of the Qatar Peninsula in the west and south, such as Jabal Dukhan, which is a local group of convex hillocks extending across the west coast for a distance of 80 km in a north-south direction. There are also flat-topped hills which are formed in horizontal strata where relatively hard rock forms a capping and which have steep slopes forming their edges. In profile the slope at the edge of these hills is concave or stepped according to the resistance of the rock strata. Some of them are small in area where the resistant rock cap has disappeared, so that the rock mass takes on a conical shape (Plate1.2 ), whilst other more extensive features have a mesa shape. Some of these hills rise between 10-15m above sea level, such as the Abrug Peninsula hills and Dakhera and Khor hills (Plate 1.3). Other hills in the south of Qatar at Tweer Al hameer rise between 80-100 metres above sea level.

### 1.4.1.8 Aeolianite Dunes

These are relic 'fossil' coastal dunes composed of cemented sand termed aeolianite. These dunes were formed during a phase of lower sea level in the Late Pleistocene. The aeolianite dunes now form low hills and are distributed widely across the Qatar Peninsula. They have formed especially within the embayment in the escarpment on the eastern side of Abrug Peninsula, and on the east coast at Jabal Fuwairt, Jabal Jassaryah and Jabal Wakra.

PLATE 1.2 RESISTANT ROCKS CAP THE MAIN STRATA AT DUKHAN AREA.

PLATE 1.3 HILLS RISE BETWEEN 10 - 15m ABOVE SEA LEVEL. AT ABRUG PENINSULA, QATAR.

### 1.4.1.9 Sand Formations

In the Qatar Peninsula there are two types of wind-created depositional landforms. Sand dunes are concentrated in the southern half of the country and sand sheets occur in the west of the Peninsula. Also, some sand sheets are found in the north-east and north-west (Fig.1.12).

## Marine and Climate Factors

### 1.5.1 Marine factors

### 1.5.1.1 Currents

Regional sea currents are oriented approximately parallel to the axis of the Gulf. They attain velocities of 3 knots . Tidal range varies between 1.5 m on the coastal barrier of Abu Dhabi, but diminishes to less than 1m within the adjacent lagoon (Evan, 1970), and averages 1-1.5 along the north east and east coast (Houbolt, 1957). The high evaporation in the Gulf water causes water currents to enter the Arabian Gulf through the Straits of Hormuz. Such currents move at 3 knots per hour in an anticlockwise direction parallel to the Iranian coastline, while moving towards the head of the Gulf. Here they change direction and return southward along the Arabian coastlines. The current then moves out through the Straits of Hormuz passing by Mosandam. There is also a current moving clockwise in a line parallel to the United Arab Emirates coastline, but it only reaches the Qatar coastline. These currents are responsible for the development of chemical and physical characteristics of the Arabian Gulf waters (Fig. 1.14). It is observed that when the

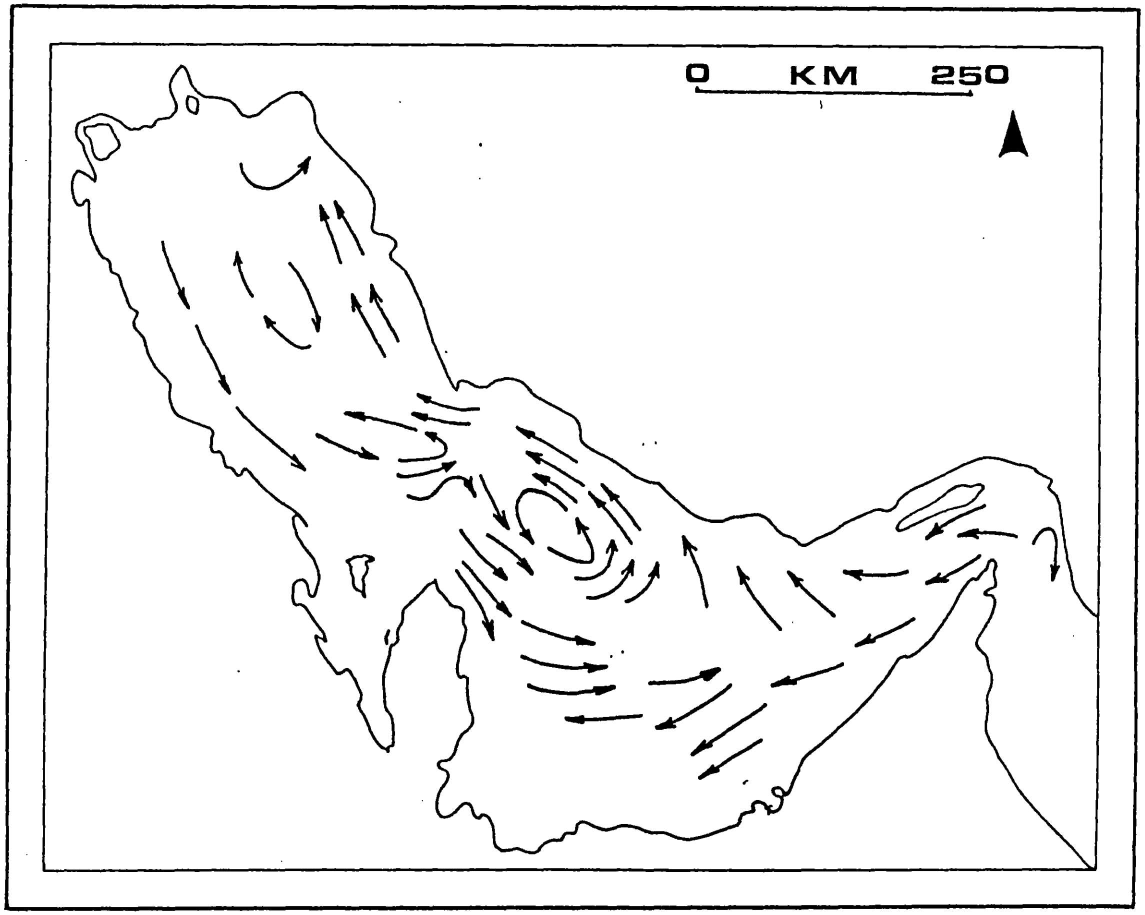


FIG. 1.14.SEA CURRENT IN THE ARABIAN GULF DURING SUMMER SEASON (AUGUST), FROM AL- KHOLI AND SOLOFEF, 1978.

southward-moving current approaches the north coast of the Qatar Peninsula it branches in two, with one current moving in a line parallel to the east coast, while the other branches passes along the west coast. When these currents are flowing alongside coastal embayments some of their water moves into these bays depositing a proportion of the load of suspended sediment. These deposits contribute to the formation of some spits which appear to be curved in a westerly direction rather than to the south (Fig. 1.14 ). Also, when the currents move out from the embayment they are capable of eroding the floor of the embayment. Despite this, since the currents move parallel to the coast.their role is confined to the transport and distribution of the sand and silt. The water current may change from one season to another and from year to year, according to weather conditions.

### 1.5.1.2 Tides

Tidal movement is no less important than other types of water movement if not surpassing them in respect of its effect on the coast. In general, the tidal cycle moves parallel to the longitudinal axis of the Gulf. The tides have a daily range reaching up to an average of 1m on the eastern coast up to 1.5m on the west coast. Due to the extreme flatness of Qatar Peninsula coasts, the tidal waters constantly transgress extensive areas near the coast leading to the formation of the coastal sabkhas. The tidal currents generally flow eastwards and northwestwards and ebb in the opposite direction. This gives the appearance of the tide progressing up to the Iranian coast and down the Saudi Arabian side with the range increasing from the middle of the Gulf (Fig. 1.15).

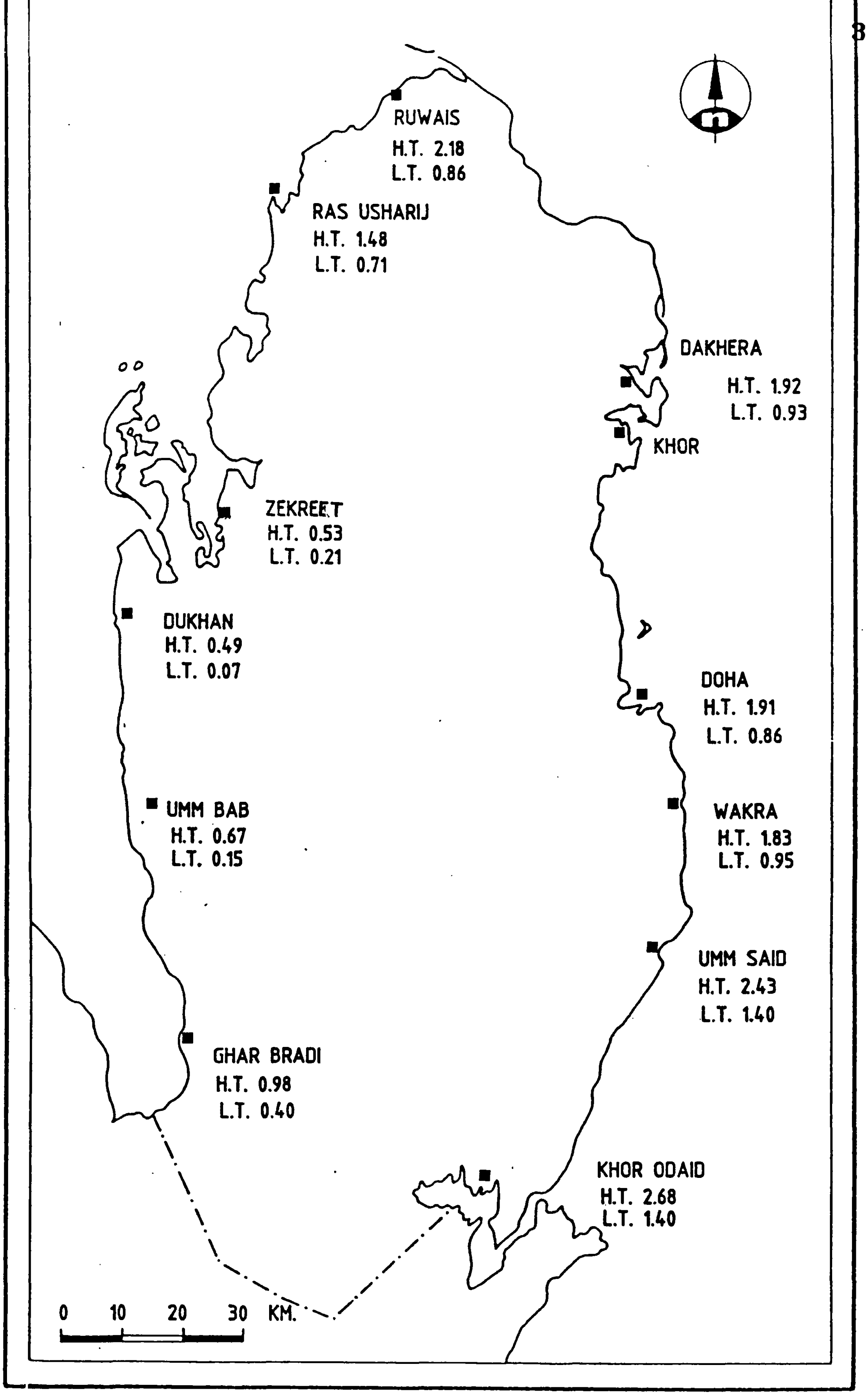


FIG.1.15 TIDAL RANGE AROUND QATAR PENINSULA.

### 1.5.1.3 Salinity

Most of the Arabian Gulf can be considered as partially restricted due to the limited water interchange within the Indian Ocean through the narrow straits of Hormuz (Fig. 1.16 ). Surface salinity in the central part of the Gulf averages between 37% and 40% while the salinity around the Gulf of Salwa reaches up to 50% due to the high temperature, and the salinity tends to decrease towards both the north and the south. The average salinity around the Peninsula of Qatar is shown in Fig. 1.17 ). It ranges between 39% north of Doha and 40% around Khor and Dakhera, Ruwais 42%, Umm Said and Khor Odaid up to 50% in the Gulf of Salwa.

The salinity of the Gulf shows a NW to SE transverse gradient. Emery (1956) recorded an average of 38% in August on the north-western side and 41% in the south-eastern part. These values are high compared to the average salinity of 35% for the world's oceans The highest salinities are, however, encountered in the Gulf of Salwa, along the Qatar Peninsula ranging from 55% at entrance to over 70% at its southern boundary (Basson, 1977), with 100% recorded in Salwa Gulf.

### 1. 5.1.4 Sea temperature

Studies by Emery (1956) found a nearly uniform summer temperature in the Gulf of around 32.2°C with a general decrease of temperature to about 23.9°C in the Arabian Sea. Compilation of winter surface temperature measurements by Blegrad, H. (1944) showed a variation of between 15.6°C in the northern Gulf and about 23.9°C at the Straits of Hormuz, due probably to extensive

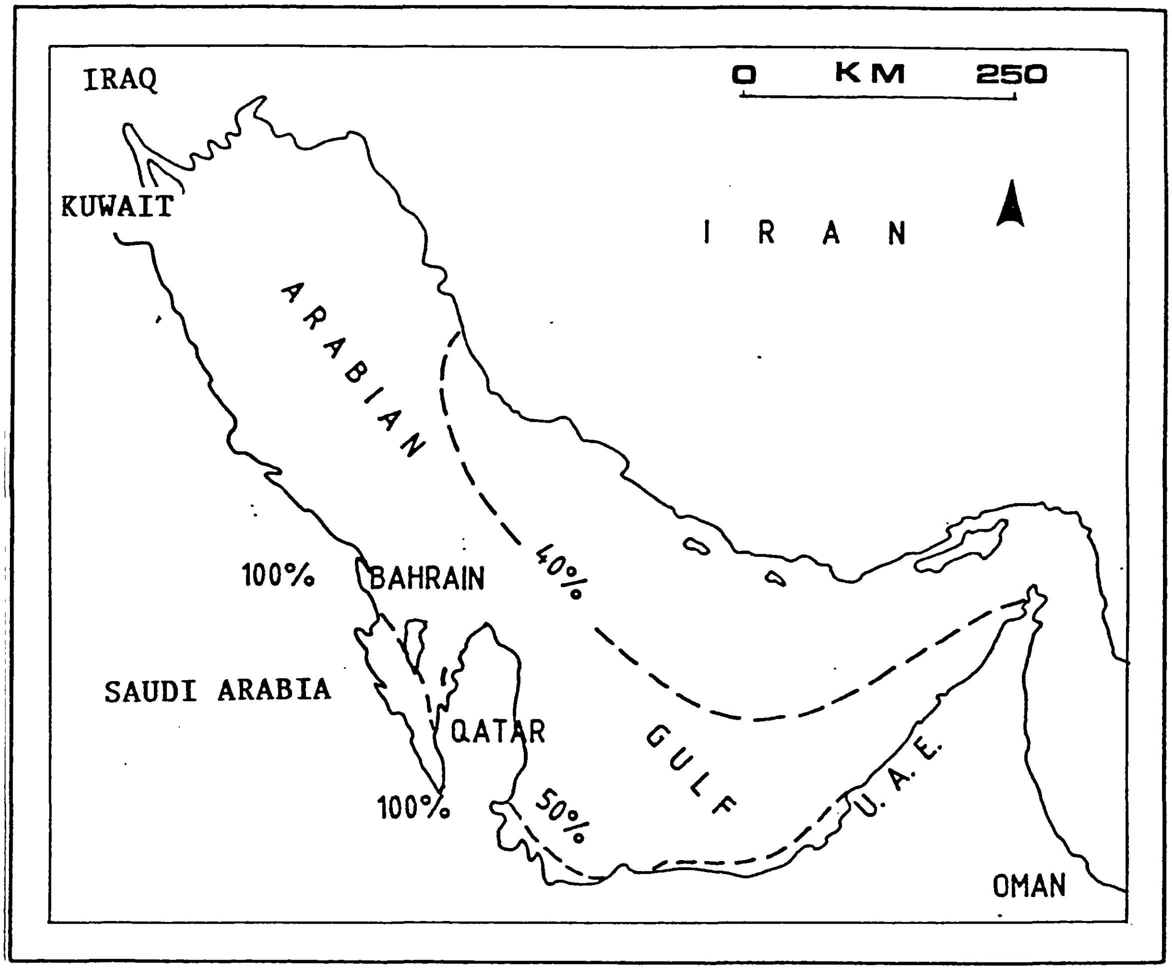


FIG. 1.16. MAP SHOWING MAJOR SALINITY WITHIN THE ARABIAN GULF (BASED ON EMERY 1956, BRETTSCHNIDER 1970, AND SHELL RESEARCH DATA).

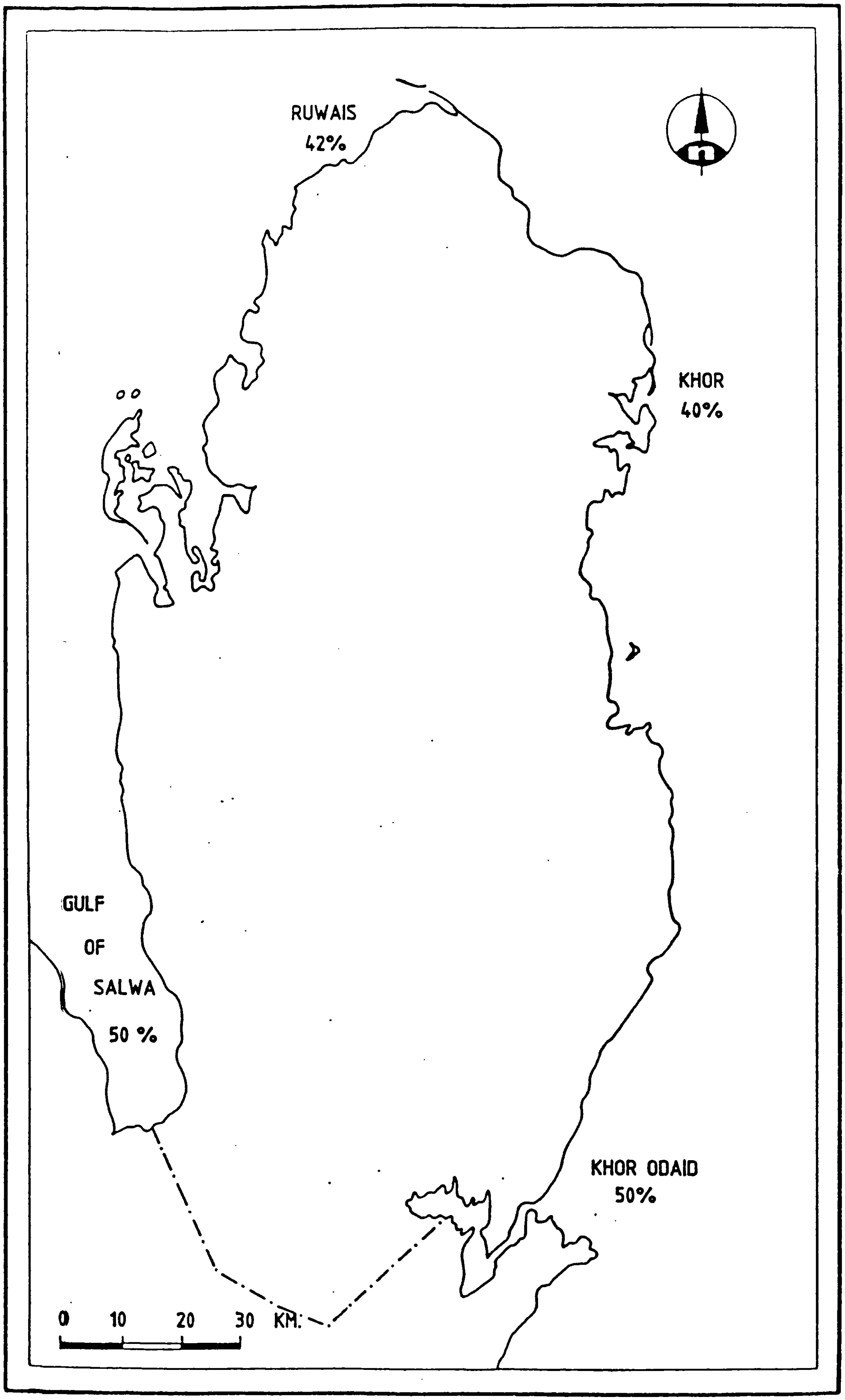


FIG. 1.17 SALINITY TRENDS AROUND THE QATAR PENINSULA.

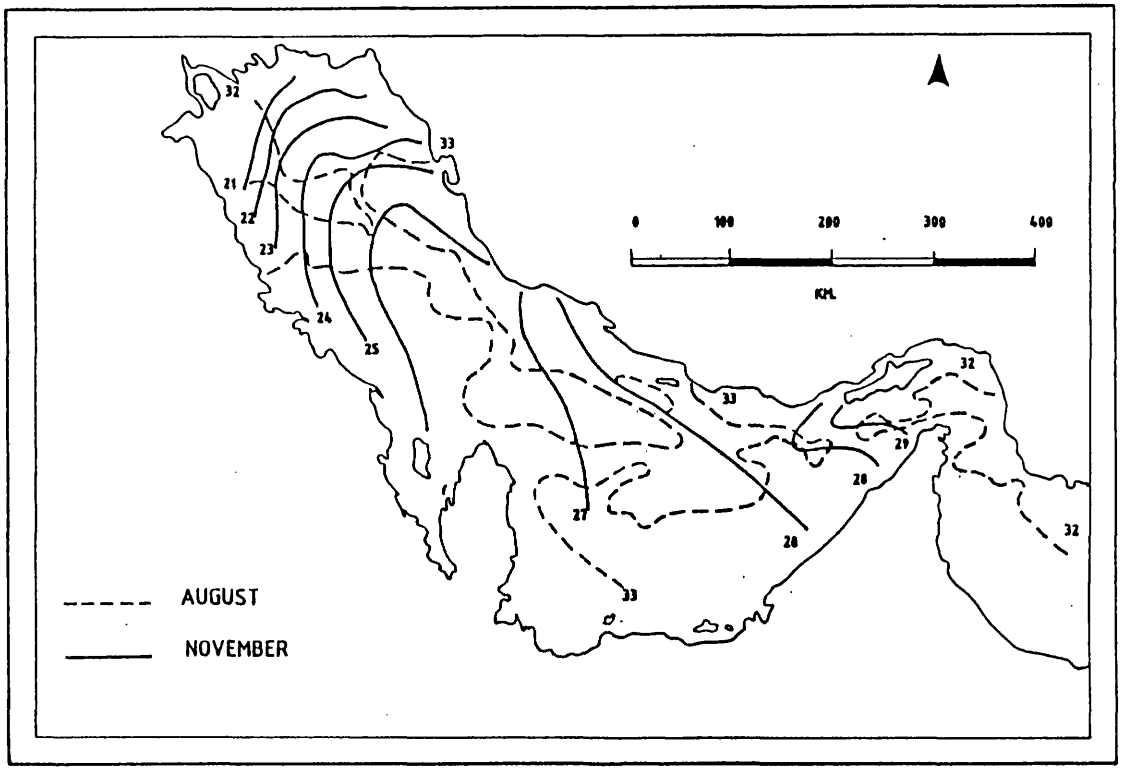


FIG. 1.18. ARABIAN GULF. SEA TEMPERATURE (C) SURFACE NOVEMBER AND AUGUST, BASED ON EMARY (1956).

vertical mixing. Emergy (1956) found only a small vertical temperature range of about 20°C. According to Emery (1956), the highest surface water temperature in the Gulf was recorded in Bahrain Bay ( 33.4°C ) decreasing slightly both in northerly (32.2°C near Kuwait) and southerly directions (32.3°C near the Straits of Hormuz). The variation of water temperature around the Qatar Peninsula fluctuates between 40°C in the summer and 15°C in winter, especially in the embayment areas. This is accompanied by an increase in the percentage of salinity in the coastal areas. The temperature data show that contrary to the great surface temperature fluctuations the differences between surface and bottom temperatures are very slight. This is also a consequence of the shallow water depth in the Gulf and because strong winds cause frequent and thorough mixing of the entire shallow water column. As a result, a thermocline is missing in the Gulf water, except during late summer (Fig. 1.18).

## 1.6.1 Climatic factors

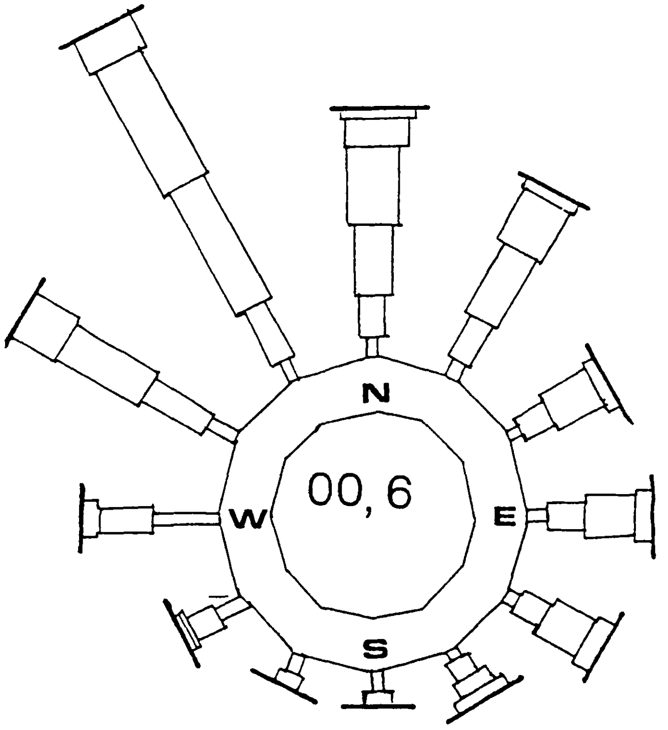
### 1.6.1.1 Air temperature

Qatar has a hot desert climate with mild winters and very hot summers. Temperature recorded at Doha International Airport, 15°C and the mean minimum temperature does not drop below 5.8°C. The lowest temperatures recorded are those for January, with an absolute maximum of 29.0°C and an absolute minimum of 8.8°C. Consequently there is never a danger of frost. From March onwards temperature increases steadily with a rapid increase in May. Maximum temperatures are reached in July or August with a mean temperature in July of 34.8°C. The highest recorded air temperature at Doha was 49°C in June 1962. It should be noted that the temperatures given were measured with instruments placed inside the standard meteorological screen erected about 2 metres above the ground surface.

### 1.6.1.2 Wind

The prevailing wind in Qatar, locally known as 'Shamal', blows from the north-west and north-north west directions, with some seasonal variations over Qatar (Figure 1.19). During the winter months, the wind direction is from the north-northeast in December and changes to south-southeast in February. However, for the remainder of the year the predominant direction is north-northwest. According to Peronne (1981) 'Shamal' is an Arabic word meaning north. It is used in the meteorological context to refer to the seasonal north-westerly wind that occurs during winter as well as summer in the inner Gulf region. The winter 'shamal' occurs mainly during November to March and is associated with mid-latitude disturbances travelling from west to east. It usually occurs following the passage of cold fronts and is characterized by strong northwesterly winds (especially during December to February).

The summer 'Shamal' occurs with practically no interruption from early June and is associated with the Indian and Arabian thermal low. However, the summer 'shamal' is not as important as the winter 'shamal' in terms of affecting wave generation, direction of travel and intensity of action. According to Perrone (1981), two areas of the inner Gulf appear to experience stronger than average 'shamal'



WIND ROSE 1983

(DOHA AIRPORT)

FIGURE IN CIRCLE = PERCENTAGE OF CALMS

FIG. 1.19 WIND ROSE 1983.

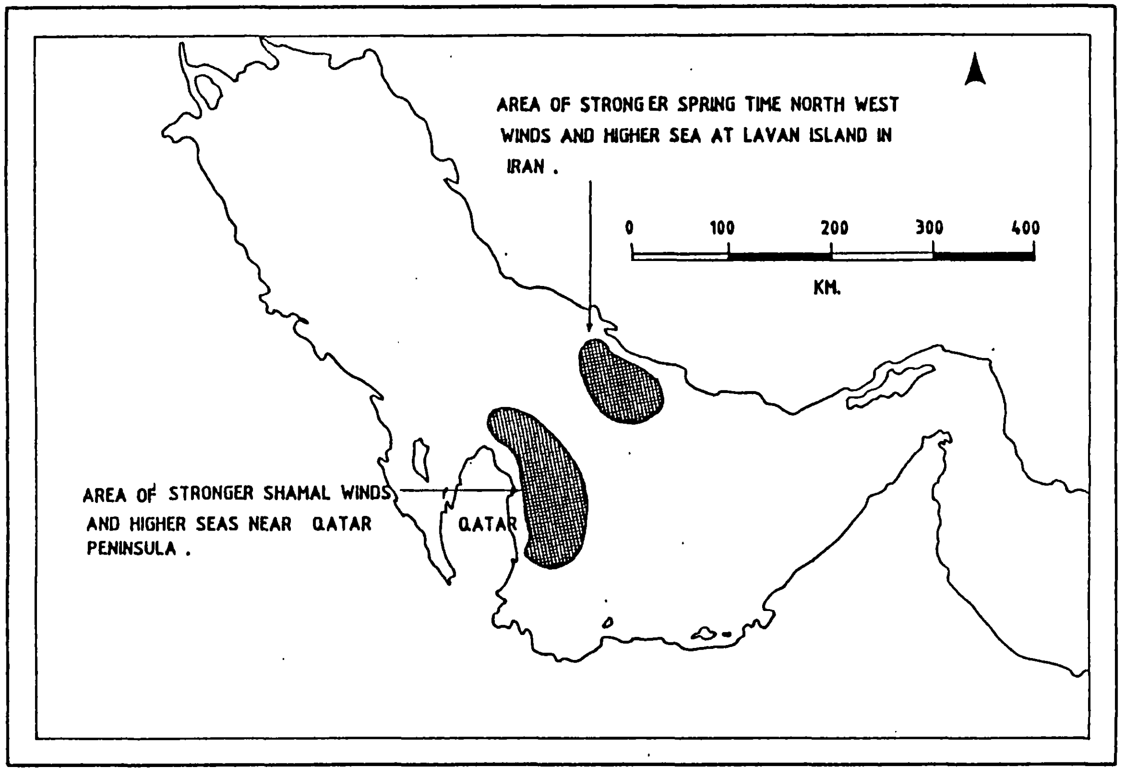


FIG.1 20 AREAS OF STRONGER THAN NORMAL NORTHWESTERLY WINDS AND HIGHER SEAS.

SOURCE : PERRONE (1981) .

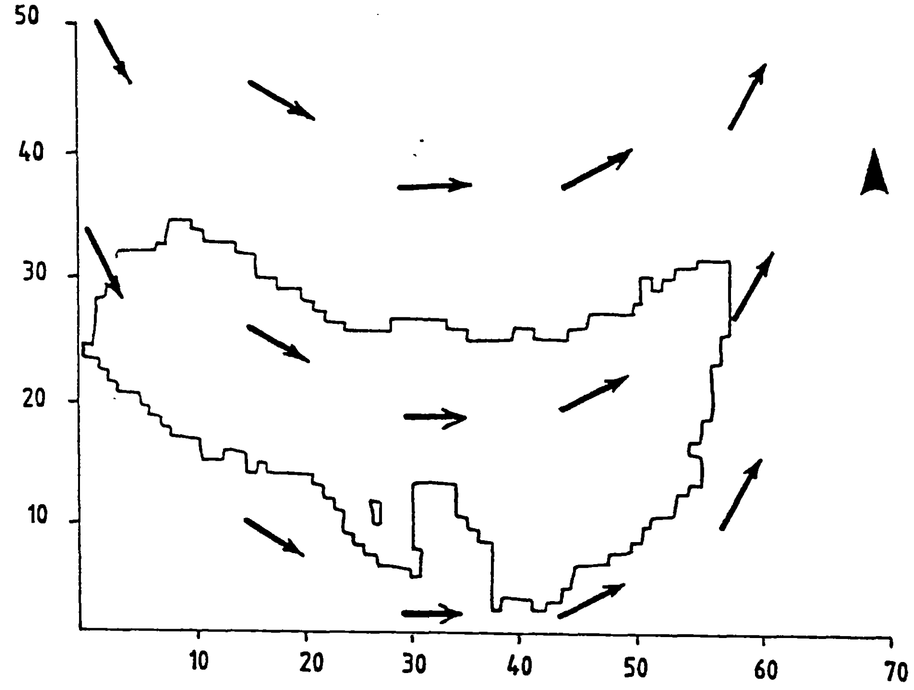


FIG.1.21 WIND DIRECTION USED IN THE NUMERICAL SIMULATION ( FROM MURTY AND ELSABH 1983),

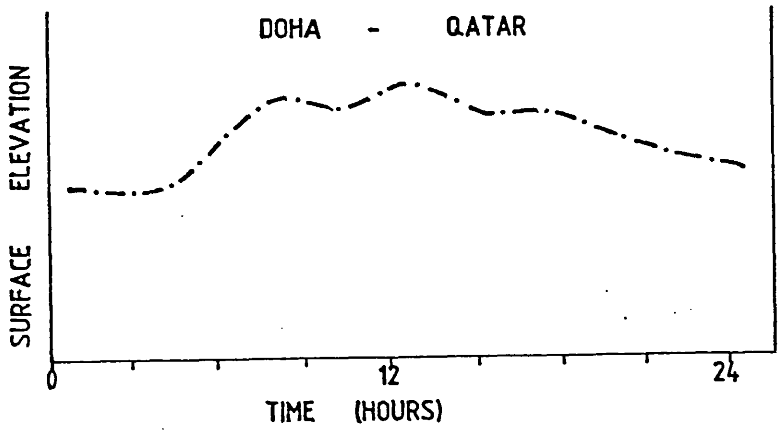


FIG.1.22 RESULT OF SIMULATION FOR LONG DURATION SHAMAL. FROM MURTY AND ELSABH (1983),

conditions. These are shown in Figure 1.20 , where it can be seen that one area lies immediately off the east coast of the Qatar Peninsula and another is near Larvan Island in Iran. The wind direction as simulated for a winter 'shamal' is shown in Figure 1.21 and 1.22. The wind speed also shows some slight variations, being generally low during the winter months with an average of 10-20 km/hour, while from March to the end of July the wind has an average speed of 35-30 km/hour. About 20% of the winds blow from other directions, including south-east, South and South-west. The relating strong South-east winds have some effects on the transport of sediments along the Qatar Peninsula coasts because wave action and surface currents are closely related to the strong north-west to south-east winds.

### 1.6.1.3 Rainfall

The Qatar Peninsula is located in an extremely arid zone and the rainfall is scanty (Fig. 1.23 ). Rainfall never exceeds 30 mm/year and decreases from north to south, the southern part of Qatar being notably drier than the northern part. The rain usually begins in October and reaches its peak in January and then decreases until ceasing completely in May. Rainfall fluctuates considerably from year to year in the Peninsula, increasing and decreasing by 350% at Umm Said, and 87% at Ruwais.

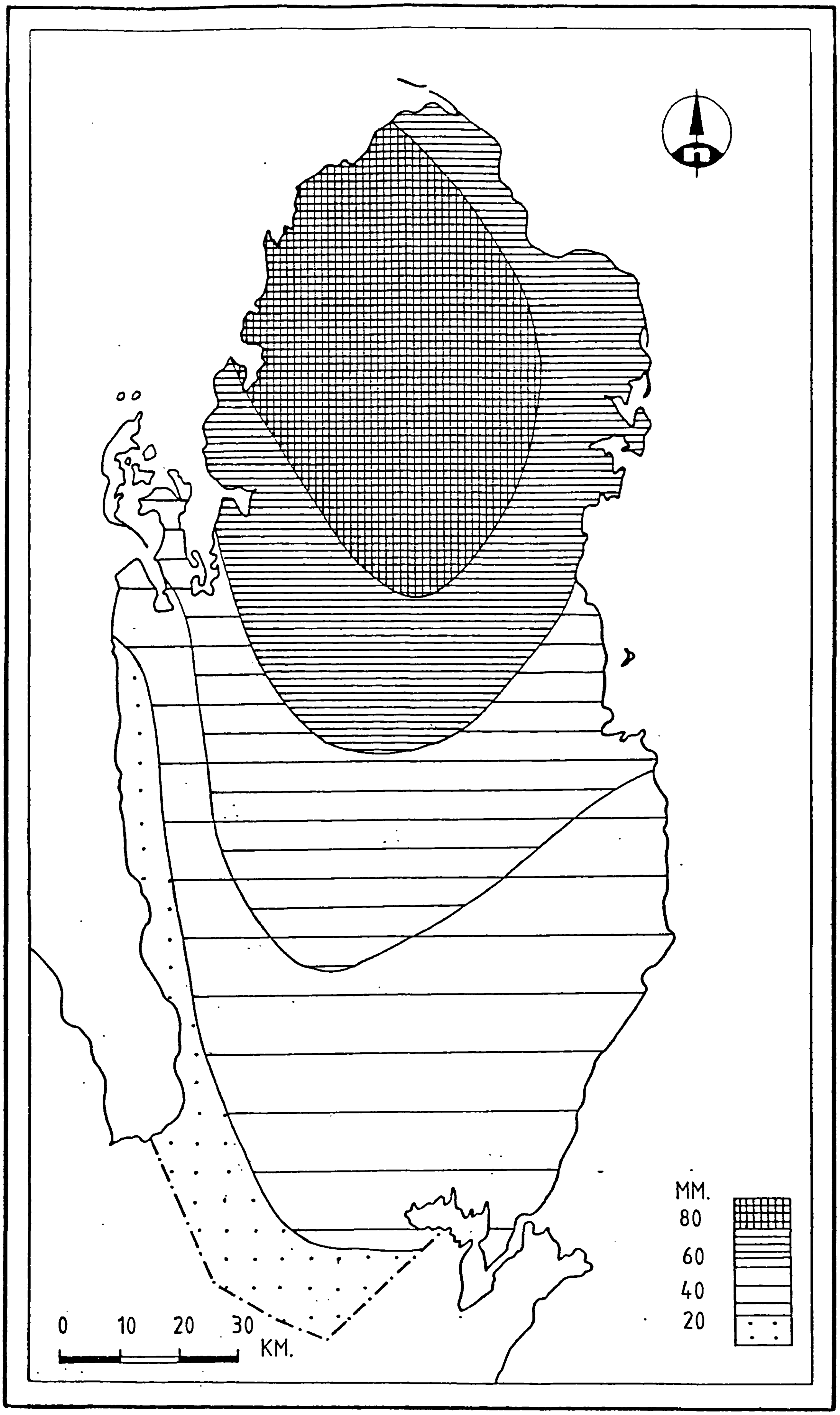


FIG.1.23 ANNUAL RAINFALL 1983 (FROM EMBABI AND ASHOUR AND MODIFIED FROM FAO REPORT NO.5 1981).

# CHAPTER II

# CLASSIFICATION OF THE QATAR COASTLINE

# CHAPTER II

## 2.1.1 Sea level changes from the Late Tertiary to the Present day

The sea levels recorded in the Arabian Gulf compare closely with other semi-enclosed sea in the world for long periods of time. The Gulf is connected to the open ocean by the narrow straits of Hormuz, and consequently sea level has been rising and falling in response to world-wide conditions particularly during the Quaternary. These sea level changes have affected the coastal morphology within the Arabian Gulf and brought about significant changes in the position of actual shoreline. In addition, tectonic movements have caused oscillations of land and sea levels from one geological period to another. Geological and geomorphological studies have indicated that sea level was much higher compared to the present during the middle of the Tertiary phase. Positive movements resulted in the rise of the submarine ridges and ultimately arise in sea level which researchers have identified from remnants of ancient marine erosion surfaces, for example in Eastern parts of the Oman mountains at a height of 375 metres (Lees, 1928). The present morphology of the Arabian Gulf has been formed through three consecutive phases, the first between the Pliocene and the beginning of Pleistocene (the pre-glacial phase); the second phase occupies the Middle and Upper Pleistocene, while the third is the Holocene or Post-glacial phase.

## 2.1.2 The Arabian Gulf during the Pliocene and Early Pleistocene (the Pre-glacial phase)

Geomorphological studies by Glennie (1970), Lee (1928), Morton (1959) and Fairbridge (1961) indicate that world sea level in the late Tertiary phase and the beginning of the Quaternary was higher than its current level. The researchers based their conclusions on ancient marine erosion surface remnants found in some parts of the world. Some ocean beds are still the subject of positive movement forming sub-marine ridges and neighbouring volcanic activities which indirectly affected the primary underground water that was ejected with gases. Some researchers recorded their observations found at different locations around the Arabian coastline. Lees (1928) pointed out the raised Narub terraces on the eastern side of the Oman hills at a level of 375 metres. Fairbridge (1961) Kassler (1973) and Glennie (1970) studied the oscillation of sea level during the Pleistocene and confirmed that the sea level during the Lower Pleistocene was 375 metres above the current sea level. Kassler observed remnants of an old marine ridge situated on the eastern site of the Oman mountains formed in the Lower Pleistocene. Glennie (1970) stated that the tectonic movement affected the formation of the ancient marine erosion surfaces found at 300 metres above sea level along the eastern coastline of Monsandam Peninsula. Holm (1960) reached the same conclusion regarding the inland Sabkhas found at 150 metres a.s.l. in Saudi Arabia.

### 2.1.3 The Arabian Gulf during Pleistocene glaciations

Geological and geomorphological studies by Wright (1937), [illegible] and Zeuner (1959) confirmed that during the Pleistocene in this area both oceanic and land areas were undergoing tectonic movement. Some geologically unstable parts of the land mass were subject to positive movement which resulted, in general, in a gradual fall in sea level (King 1975). Antevs (1928) suggested a sea level height of about -93m for much of the last glaciation, and -120 to -130m for the maximum of the last glaciation. Daly (1934) gave values of -75m for the last glaciation and -90m for the maximum, while Penck(1933) suggested -100m for the maximum of the last glacial period. King (1975) mentioned that it seemed that about -100m is a reasonable estimate. For example, evidence from the Australian continental shelf includes submerged terraces with shallow water fossil and sediments extending down to -175 to -238m (Gill 1982).

Subsequently it is believed that sea level gradually fell, reaching a maximum during the last glaciation in the Northern hemisphere when sea level was about -120 to -140 metres below present level. Studies by Sarntheim (1972) on sediments of the postglacial transgression in the Persian Gulf and Northwest Gulf of Oman. Sarntheim found that the deepest traces of sub-fossil, water line sedimentation (ooliths, reef material) are found at the shelf break in water depth of -150 to -125m. At the time of this deposition the Persian Gulf was essentially a dry, flat river valley of an ancient Shattal Arab. The oscillation in sea level during the glacial and interglacial phases of the Pleistocene resulted in the consecutive formation of a group of now submerged marine terraces and raised marine shorelines, along the Mediterranean coasts (Abu el Enin, 1986). However, any attempt to carry the Mediterranean sequences of shorelines to the Arabian Gulf is fraught with difficulties for observations of marine erosion surfaces in the Arabian Gulf are very limited. Kassler (1973) identified two marine terraces, the oldest at a level of between 30-50 metres above sea level in the Gulf of Oman.

He attributed their formation to the rise of sea level during the Middle Pleistocene. Sarntheim (1972) and Kassler (1973) confirmed that at the end of the greatest withdrawal of shoreline in the Arabian Gulf to about -120 metres during the maximum of the last glaciation about 18-20,000 years ago (Al Asfour, 1978). Sea level gradually rose to about its present level some 6,000 years ago. Thus within the Arabian Gulf, sea level began to rise during the Late Pleistocene and Early Holocene eventually to cover vast low-lying areas (I to 2 metres above datum) (Fig. 2.1).

Several studies (Fairbridge, 1961; Carry, 1961; Sarntheim 1972; Kassler 1973) in the Arabian Gulf indicate that sea level has gradually risen after the end of the maximum of the last glaciation (about 18-20,000 years ago). During the recovery of sea level from the extreme low level during the last glaciation stillstands have been recorded at -40 to -15 metres. Consequently a series of submarine terraces have been recognized by Houbolt (1957) around the northern and eastern coasts of the Qatar Peninsula. Houbolt considered that these terraces could be classified as: (1) the near-shore terrace between 5.5 and 16.5 metres below sea level; (2) first offshore terrace, between 30-31m below sea level; and (3) the second offshore terrace at -31 to -51m. These terraces slope seawards towards the axis of the Arabian Gulf and are regarded as representing the post-glacial stages of recovery of sea level (Fairbridge, 1961). Houbolt (1957) considered that the present sub-marine slope around the Qatar Peninsula was affected by the low stages of sea level during the period of glaciation and he assumed that these 'terraces' resulted

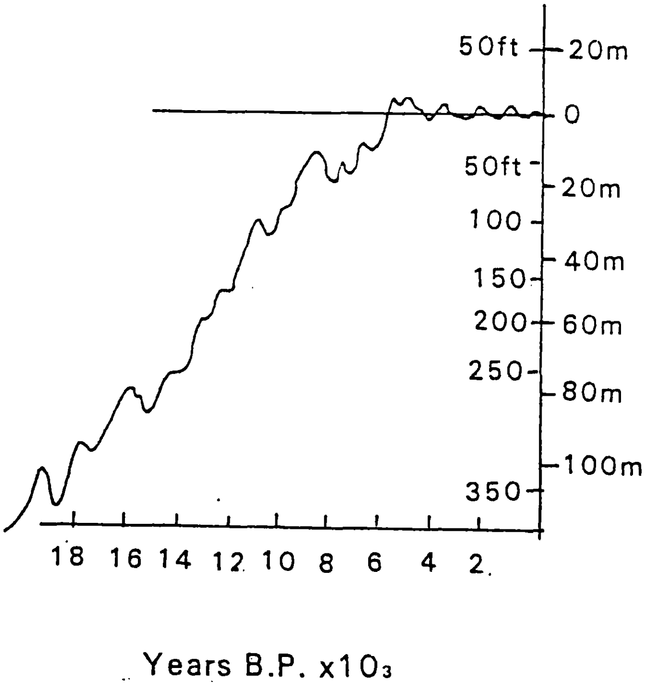


FIG. 2.1 SEA LEVEL CHANGES IN THE ARABIAN GULF.
SOURCE: AL ASFOUR, 1978.

from eustatic changes of world sea level during the post-glacial period (post 10,000 years B.P.). The result of Houbolt's work (1957) confirms the finding of Sarntheim (1972) and Kassler (1973) regarding the presence of sub-marine terraces at depths -64 to -61 metres, -53 to -40 metres and about -30 metres. Houbolt (1957) suggested that contrary to the opinions of geologists, sub-marine terraces occur in pairs so that each temporary sea level can be distinguished through a surface of accumulation and a surface of marine abrasion, the sharp gradient that separates the sub-marine terrace being termed a 'fossil coastline' or 'cliff'.

### 2.1.4 The Arabian Gulf during the Holocene

The level of the Arabian Gulf landmass continued to rise even during the Holocene. During deglaciation of the major ice sheets the level of the sea within the Arabian Gulf rose above its present level in two successive periods. In the first, the sea attained a level of +7 and +3 metres above the present level. These marine transgressions form part of the well-known Flandrian sea level rise. Evidence from Qatar is reported by Taylor and Illing (1969) who argued that the age of the strandlines in Qatar which have heights between +1.5 and 2.5 metres range between 3.930±130 and 4,340±years B.P. in age. Al Asfour (1978) found that terraces between 1.5 and 6 metres above sea level extend along the Arabian coast from Kuwait to Oman. Khalaf (1969) identified a marine terrace up to 4 metres at Ras Ashairiji and at Al Khiran in Kuwait. Kassler (1973) found terraces at +3 metres above sea level along the Arabian Gulf coasts which have been dated at 3000-4000 years B.P., in Saudi Arabia and in Qatar (along the west coast around Abrug Peninsula), (Plate 2.1 ), and the Bahrain coasts. Power, et al. (1966) referred to marine terraces of +1 to 3 metres in height along the Saudi Arabian coast, where D.H. Johnson (1973) distinguished remnants of marine terrace at +2 to +3 metres above sea-level along the Ras Tanura and Jubail coasts and some parts of the eastern coast of Saudi Arabia. Some of the most important findings reached by Evans (1969) in his analysis of thirty-six samples of beach deposits from the Coastal Sabkha in Abu Dhabi were that Arabian Gulf water level was higher than the present level by +7 metres during the period between 6000-7000 years B.P. Since 3750 years B.P., sea level appears to have fallen and this regression has resulted in the formation of new terraces known as the 'lower terrace' at a level of +3 metres above sea-level (Abu El Enin, 1986).

Subsequently sea level adjustments have brought about the present relationship between land and sea.

## 2.2 Coastal classification schemes

Many attempts have been made to classify coastlines (e.g. Johnson, 1919; Valentin, 1952; Cotton, 1954; Bloom, 1965; Inman, 1971; Shepard 1973). More recent classifications depend upon coastal history, principally whether or not the coast has been prograded by deposition or retrograded by erosion. In addition, coasts are considered as to whether or not they have been sinking (submerged) or uplifted (emerged). Hence the importance of studying sea level changes in the Gulf. Johnson (1919) proposed four types of coastline (shoreline) which were classified as follows: (1) shoreline of emergence, (2) shoreline of submergence, (3) neutral shorelines, and (4) compound shorelines, which include two or more of the other types. Valentin

PLATE 2.1 THE THREE METRE TERRACE ON THE ABRUG PENINSULA.

(1952) developed a different system of coastal classification and proposed two main types of advancing and retreating coastlines.

This classification was based largely on the morphological history of coasts. Cotton (1954) presented a scheme of deductive morphology and genetic classification of coasts, emphasizing the significance of the classic dichotomy between emergent and submerged types. He mentioned that all genetic classifications recognised submerged coasts as one major class and emerged coasts as another major class. Bloom (1965) proposed a different scheme of coastal classification, involving the variation of (a) erosion and deposition, (b) submergence and emergence, and (c) time. The variables may be presented by three mutually perpendicular axis with emergence and deposition as the positive direction on two axes in opposition to submerged and erosion as the negative direction on the second axis and the time as the third axis (Fig. 2.2 ). Inman and Nordstoom (1971) have provided a classification based on the concept of plate tectonics whereby the earth's crust is seen as a pattern of plates separated by zones of spreading and zones of convergence coasts were classified as: (a) collision coasts, (b) trailing edge coasts, and (c) wide shelf, hill-and-plain coasts.

Shepard (1973) has provided a new classification dividing coasts into Primary and Secondary types. The Primary coasts were described as coasts shaped by erosion of the land surface and subsequently drowned by sea level rise or sinking of the land, (e.g. drowned glacial erosion coasts and drowned Karst topography), as well as coasts shaped by deposition of the land surface : river deposition

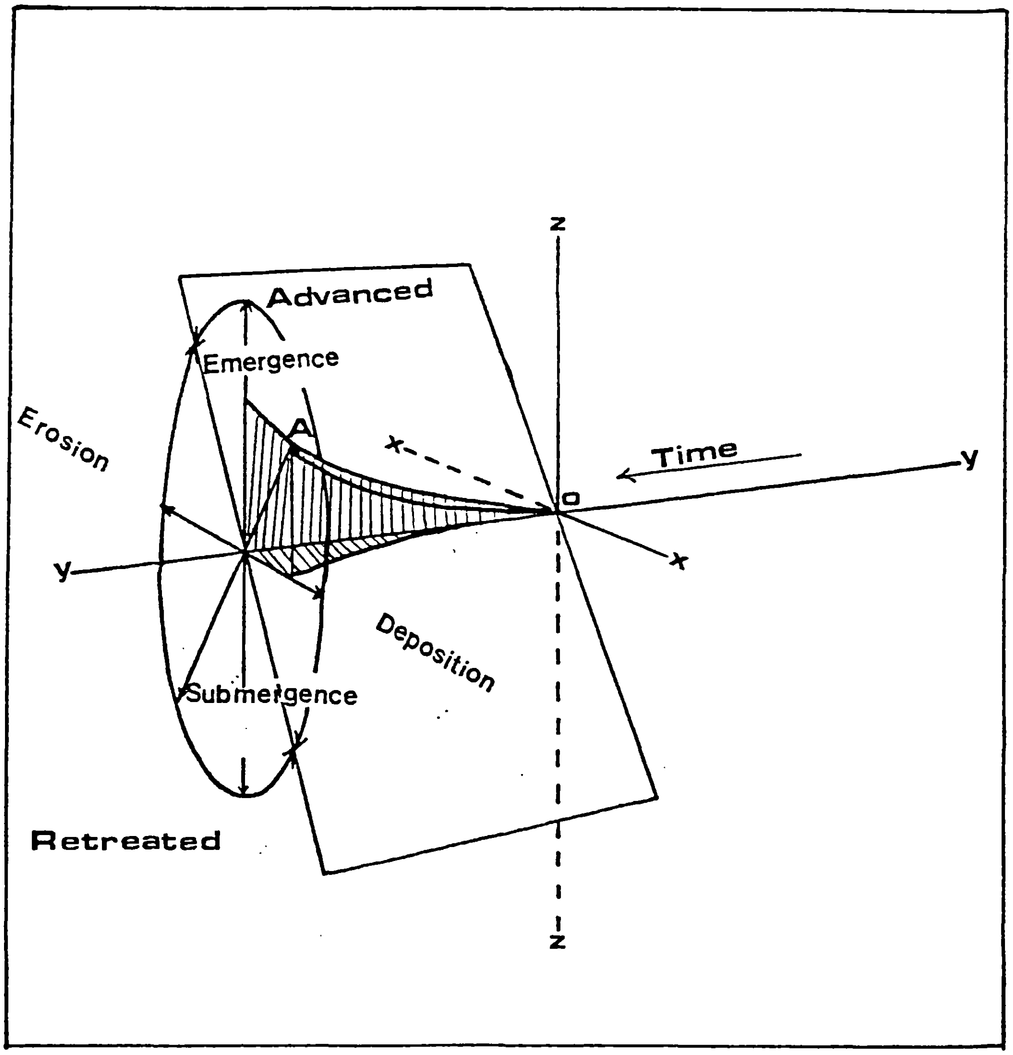


FIG. 2.2 BLOOM'S THEORY OF COASTAL CLASSIFICATION , 1965.

coasts were subdivided into deltaic coasts, alluvial fans and outwash plains. The secondary coasts were described as coasts which resulted from marine agencies and were classified as: (a) wave erosion coasts, either straightened by wave erosion or made irregular by wave erosion, (b) wave deposition coasts, subdivided into (i) coastal plains built seawards by waves, (ii) barrier coasts, (iii) cuspate forelands, and (iv) mud flats or salt marshes. Coasts prograded by biological processes were subdivided into (i) coral reefs coasts, (ii) Serpulid reef coasts and (iii) oyster reef coasts. Glacial deposition coasts were subdivided into (i) partially submerged marine, and (ii) partially submerged marine and drumlin coasts. Wind deposition coasts include coasts where dunes are bordered by a beach, fossil dunes where consolidated dunes (aeolianite) form coastal cliffs, and dune prograded coasts, where the steep lee slopes of the dunes have transgressed across the present beach. Shepard also classified some coasts shaped by diastrophic movement, such as fault coasts represented by straight steep slopes beneath the sea folded-strata coasts and salt dome coasts. Mangrove and marsh coasts are also included as a secondary feature. Finally, marine deposition coasts were subdivided into barrier coasts that included barrier beaches, barrier islands, barrier spits, bay barriers and overwash fans and cuspate forelands, beach plains and mud flats, or salt marshes. This classification (Shepard's classification) has many points of similarity with previously published classifications and it should be realized the numerous gradational types that exist which are difficult to classify.

D. W. Johnson's (1919) classification of coasts into submergence and emergence, neutral and compound types is perhaps the best known and most widely debated. If Johnson's classification is applied to the coast of the Qatar Peninsula then the north, east and north-east coastal zones coast would be found to have compound characteristics. However, stages in the evaluation of these coasts which correspond to those outlined by Johnson would be difficult to identify. For example, Johnson's 'submergence cycle' does not cover the possible development on a low-lying coast of sedimentation affected by slight eustatic rise because it is impossible to detect early stages in either emergence or submergence. The classification proposed by Valentin (1952) considered both non-cyclic and genetic factors. Coastal advancing was regarded by Valentin as due to the emergence of the sea floor or accumulation of sediment (mineral and organic). Coast retreat resulted from submergence or marine erosion. Such a classification can be applied to Qatar Peninsula coasts. For example, advancing coasts are represented by the barrier coasts and extensive spits that exist along the east and north-east coasts from north of Qatar to Dakhera and Khor and on the west around the embayments of Feshakh and Al Hussain. The coastal forms resulting from submergence or marine erosion are also present on the west coast where active cliffing is taking place between Ras Abu Omran to Abrug Peninsula, and Ghar Bradi on the southwest coast. The author agrees with Valentin (1952) and Bloom (1965) that time considerations are a very important dimension to accommodate the full range of coastal development and change.

Another classification has been proposed by Shepard (1973) and some of the subdivisions could be applied to the Qatar Peninsula. For example, it is possible to demonstrate that most of the coastal forms recorded are found in Shepard's category of Primary coasts, which he categorises as unmodified by marine processes, their character due to the sea level coming to rest against a land form that was the result of terrestrial agencies, erosion or deposition, volcanism or earth movements.

The prograding sand dunes located on the south-east coast of the Peninsula, and the 'fossil' or relic dunes that exist along the north-east coasts could be regarded as examples of this category. Examples of Shepard's Secondary coasts, where present-day marine processes (erosion or deposition or growth of marine living organisms) have been responsible for the character of the coast are also represented by the barrier coasts that exist along the east, north-east and west coasts of the peninsula; in the same broad category are the coral reef coasts.

## 2.3 Classification of the Coastline of the Qatar Peninsula

Having considered a variety of coastal classification described in the literature it was decided to adopt a strictly morphological approach, related to modern processes to achieve a classification of the Qatar Peninsula coasts because of the following criteria:

(1) The extensive low relief of the coastal zone and the lack of active cliffs : the low relief coast is characterized by

barrier beaches and beach ridges due to the abundance of sedimentary materials.

(2) The present-day marine processes have a direct effect on the coastal zone, where waves generated by the "Shamal" wind move from the north and north-west to the south and South-east for most of the year. These waves are the most important modifying processes on parts of the Coast of Qatar. In addition, the sea temperatures off the Qatar coast provide ideal conditions for the growth of coral reefs and chemical activity, especially solution, and is considered very important in the inter-tidal zone where the limestone bedrock is subjected to wetting and drying of the rock surface.

(3) The importance of the longshore movements of sediments and the supply of sediment to the coast is clearly important. Some sections of the coast receive sediment from very different sources, such as the wind-transported sand carried by wind action from the land to the sea in South-east Qatar.

(4) The Quaternary deposits are mainly restricted to coastal localities where they consist of cemented sands and coral reefs fragments exposed in cliffs or as "low ridges" which have been formed during the inter-glacial or during the Holocene when sea level was higher than at present. In addition, extensive sabkhas, or saline mud flats, have formed and together with aeolian sand deposits represent phases when the shoreline advanced inland during inter-glacials and during the Holocene.

Such is the complex mixture of coastal features that a morphological approach to classification was eventually adopted. It is now proposed to describe the broad divisions of the coastline of the Peninsula which have been identified as a result of field work and examination of maps and air photographs. Thus, difficult terms such as 'submergent', 'emergent', 'compound', 'primary' and 'secondary' are avoided and greater emphasis is placed on the sequential development of the coastal features and the importance of coastal processes.

The broad divisions of the coastline are presented in Figure 2.3 and are described as follows.

### 2.3.1 Sand dunes and Sand Sheets Coasts

The main morphological features of this type of coast include the segments with active dune, fixed dunes and sand sheets, as well as aeolianite forming the relic or 'fossil' dune systems.

Sand dunes and sand sheets make up about 15% of the total area of the peninsula. The sand dunes occur as individual and compound barchans or crescentic dunes covering up to 10% of the Peninsula and are formed into two belts found mainly in the southern half of the Peninsula. The most extensive belt is found in the south-east where it extends for about 60 km along the coast. The height of these sand dunes varies from 80 cm to 40 metres and for the most part they are moving from north-west to south-east under the influence of the "Shamal" prevailing wind. Sand sheets are sandy plains which seem to have developed from remnant deposits of the migrating barchan dunes or from strips and patches of sand deposited during storms. Some deposits are cross bedded, clearly reflecting their origin from migrating dunes and development through slow deposition of dune sands. These

sand sheets are relatively stable and provide a habitat for a diverse flora. Where vegetation cover diminishes, sand sheets become less stable because they become exposed to the strong prevailing winds, especially the 'Shamal' from the north-west, which controls the direction of movement of the sand along the Peninsula. Sand sheets are present mainly in the northern part of the peninsula and north-west of the Dukhan area. Aeolianites forming relic or 'fossil' dune features are an important feature along some segments of the coastline, where the aeolianite has been constructed into distinctive types of consolidated dune limestone as a result of lithification (Plate 2.2). The processes of dune formation and growth involving calcium carbonate sand is similar to that for quartz and sand dune formation.
Gill (1982) found extensive aeolian formation in South Australia, east of Thunder Point and at Warrnambool, Victoria, Australia. Grove and Warren (1968) recorded fossil dune on the equatorial margin of the Kalahari desert at similar latitude to Qatar ($16^{\circ}$ to $20^{\circ}$ S). In Qatar these aeolianite relic or 'fossil' dunes are well developed along the eastern coast at Wakra, Jassasyah, Fuwairt and Gharyah. On the west coast aeolianitesare found east of Abrug Peninsula. Similar deposits are found on the United Arab Emirates (UAE) where they have been dated to 2000 to 3000 years B.P. (Evan, et al., 1973). In Qatar, aeolianite is found forming a stable coastline because of its location inland of the present coastline, for example at Wakra, east of Abrug, Jassasyah and Ghariyah, where on the east coast between Fuwairit and Ghariyah, and in the north-west of the Peninsula at Ras Abu Omran, the aeolianite cliffs are actively retreating as a result of present wave action.

PLATE 2.2 AEOLIANITE OR "RELIC" FOSSIL DUNES FEATURES. ABRUG PENINSULA.

### 2.3.2 Sabkhas Coasts

These are mainly saline mud flats where the surface has been built up by the deposition of sediment in a shallow water marine environment. They are well developed in areas protected from strong wave action. Characteristically these surfaces are subjected to tidal flooding although the higher parts of these muddy flats may be inundated only at spring tides during storm conditions, or under wind-driven wave conditions when higher water level results. The finest tidal flat is that studied by Evans, et al. (1964) at Abu Dhabi and Evans et al., (1969) and Shin (1973) also studied the Sabkha flat in the Umm Said area in the south-east of the Qatar Peninsula. Schneider (1975) studied the tidal flats in the Sabkha of Abu Dhabi (UAE) Arabian Gulf and Fryberger, et al., (1983) conducted a study on the Jafurah area in the eastern province of Saudi Arabia, which extends along the Arabian Gulf coastline. Fryberger et al., (1984) also examined the coastal Sabkha of Dhahran area in Saudi Arabia.

The coast of the Qatar Peninsula is bordered for much of its length by low tidal flats which stand just above normal high tide level at +1 to +2 metres. These tidal flats are known locally as Sabkhas. They are composed of unconsolidated fine silt and calcareous sands, and they reach their most extensive development along the eastern coast to the south of Umm Said.

Similar areas of sabkhas occur on other parts of the Arabian Gulf coast, e.g. Matti Sabkha, at Abu Dhabi, UAE (Evans et al., 1964, Schneider, 1975). These sabkhas are normally flooded by high tides especially when sea level is 'raised' by easterly winds and strong tidal currents.

### 2.3.3 Cliffed Coasts

This type of coast includes coastal sector where there is clear evidence of erosion continuing to maintain 'fresh' cliff features as well as a more restricted sector of 'dead' cliffs. In this latter case, former wave cut notches are now either elevated and no longer directly affected by wave erosion, or because of the accumulation of beach material, wave action has been excluded from the cliff foot. The 'dead' cliffs have also resulted from a relative fall in sea level and they have been degraded as a result of weathering which has reduced the cliff angle to 30° or less in inclination. The cliffed coast around the Peninsula of Qatar can be divided into two types: (a) active coastal cliffs, and (b) 'dead' or relic cliffs.

The active coastal cliffs appear to be controlled by characteristics of the rock type being eroded by the marine action that is concentrated at the base of the cliffs and aided by biological activity and chemical action (usually solution) by sea water. Relatively rapid marine erosion is produced by wave action on the lower part of the cliff bringing about under-cutting and notching which lead to rock falls, slumping and other kinds of mass movement. 'Dead' cliffs represent former cliffs now abandoned by the sea, and these are mantled, especially along their base, by a cover of limestone talus. The most notable 'dead' cliffs exist in the area of Khor and Dakhera coastal cliffs, where they attain a height of between 2-11 metres above sea level (Plate 2.3 ). At Ghar Bradi (Plate 2.4 ) there are active coastal cliffs (yellow limestone cliffs) attaining heights of 2-3 metres above sea level and in the north-east active cliffs are developed in aeolianite attaining heights of 2 metres above sea level

PLATE 2.3 'DEAD' CLIFF AT KHOR BAY.

PLATE 2.4 ACTIVE CLIFF AT GHAR BRADI, SOUTH-WEST COAST OF QATAR. HEIGHT OF CLIFF IS 2m. NOTE THE PRONOUNCED OVERHANG DEVELOPED IN PLACES, AND IN THE MIDDLE DISTANCE THERE IS A ZONE WHERE CLIFF COLLAPSE HAS OCCURRED AND BLOCKS "PROTECT" THE BASE OF LIMESTONE CLIFF.

at Fuwairit (Plate 2.5 ). Low cliffs, not exceeding 2m in height (Plate 2.6) are present near Dakhera and Khor.

### 2.3.4 Coral reef coasts

The reefs are built by coral and other organisms and they occur widely in tropical waters between latitudes 30°N and 3°S in the western parts of the Pacific, Indian and Atlantic Oceans. They occur also in the Arabian Gulf and Red Sea, where they form mainly fringing reefs. Along the Qatar coast in the north-west and west reef corals grow between low water mark and at about 6 to 8 metres in depth.

Studies by Kinsman (1964) near Abu Dhabi have identified coral reefs growing at between 10-15m below sea level. The reefs are mainly built by coral polyps and small marine organisms that take up calcium carbonate from seawater and grow into a variety of skeletal structures (Bird, 1984). The coral reefs extend from Ras Rakan to Abrug Peninsula with a total distance of about 50 km and for the most part they can be considered as fringing reefs. The reefs depend upon several factors, including sea water temperature of between 26-29°, a maximum depth of about 20-25 metres (and cannot live at depths much exceeding 45-55 metres) and coral reef development requires an adequate supply of oxygen and various nutrients. Emara *et al*. (1985) found the concentration of dissolved oxygen (percentage saturation) in the inshore and offshore area varied from winter to summer in the north and east of Qatar. Salinity is also important as coral polyps can survive only in a salinity of between 34-40 parts per thousand but, if the salinity exceeds 48 parts per thousand, all forms die or are damaged.

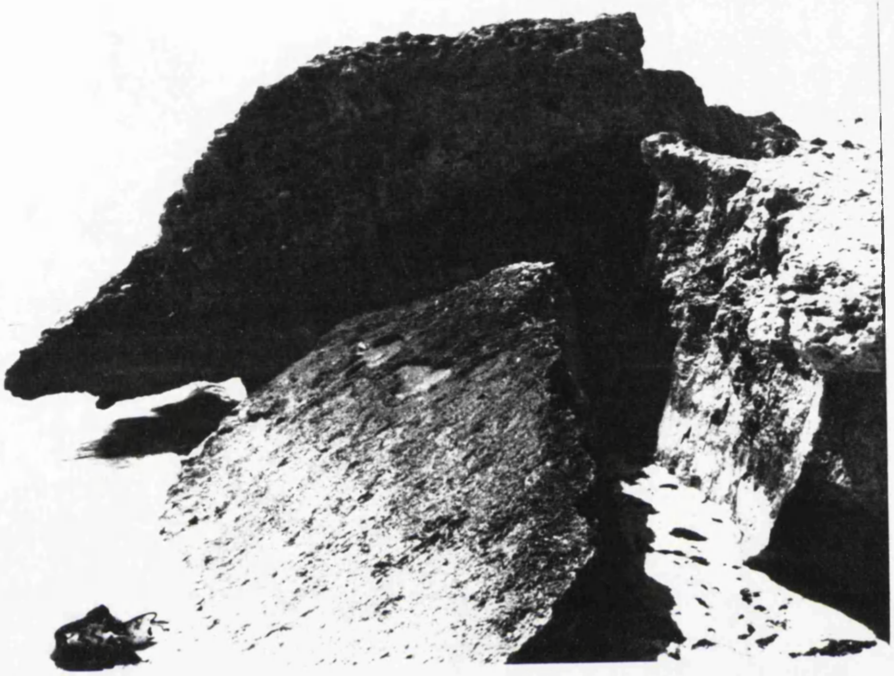


PLATE 2.5 AEOLIANITE FORMATIONS AT FUWAIRIT WHERE ACTIVE CLIFF EROSION IS IN PROGRESS. UNDERCUTTING BY WAVE EROSION HAS LED TO THE COLLAPSE OF BLOCKS OF AEOLIANITE.

PLATE 2.6 ACTIVE AND DEAD CLIFFS AT DAKHERA AREA.

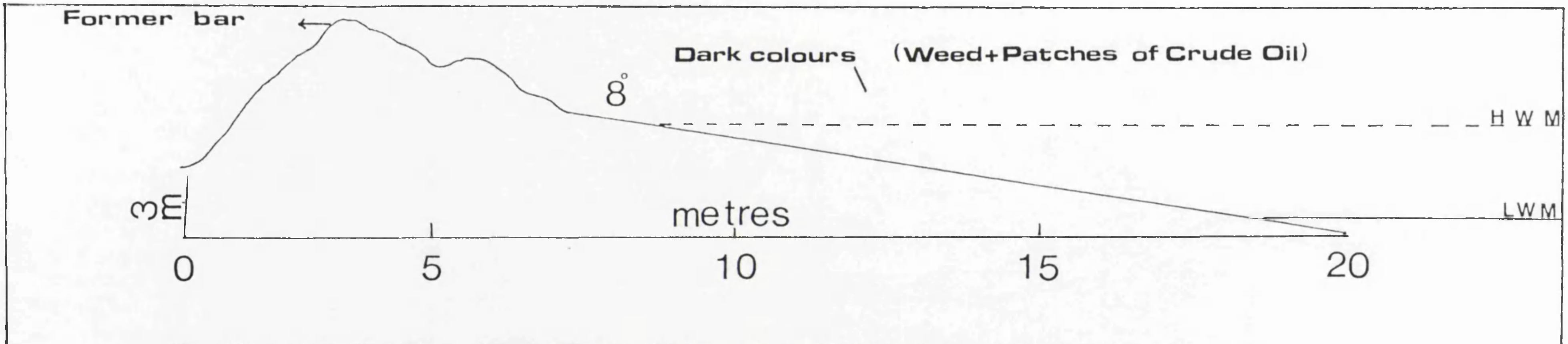
Along the north-west and west coast of the Qatar Peninsula these conditions are satisfied and coral reefs are found to extend from low water mark to about 6-8m depth. The sea water temperature averages 26°C during November and 33°C during August (Fig. 1.18, see Chapter I) and the salinity exceeds 42% (Fig. 1.17 ; see Chapter 1).

## 2.3.5 Sand beaches coasts

The term beach is applied to shoreline deposits which, following Johnson (1919), have accumulated mainly in the intertidal zone, although certain beach deposits extend above high water mark and below water mark. Barrier beaches are narrow strips of low-lying beach sediments which have accumulated mainly in the offshore zone. Shepard (1973) have indicated that barrier beaches generally consist of elongated sand ridges lying parallel to the shore that rise slightly above high tide level. King (1973) has described them as resulting from constructive action on sandy beaches. The barrier beaches represent significant accumulations of marine sediments and are found especially in:

(a) the coastal zone from Wakra to the south of Doha
(b) along most of east and north-east coasts, and
(c) extending from Abrug on the west coast to the south-west coast near the Gulf of Salwa (Fig. 2.3 ).

On their landward side these barrier beaches are characterized by low angle slope between 6°-8°, while the beach bar extends above the normal level of high tide (Plate 2.7 ). Sometimes these barrier beaches or offshore bars enclose lagoons, as for example around the coast of Dakhera and Khor. These sandy beaches are created by wave



Profile showing the slope of sandy beaches North East of Qatar.

PLATE 2.7 N.E. COAST, SHOWING PARALLEL BARRIER BEACH AND THE FORMER BARS, HAVING 8 SLOPE DIPPING SEAWARD. NOTICE THE DARK COLOURS WHICH HAVE RESULTED FROM SEA WEED AND PATCHES OF CRUDE OIL DRIFTED ONSHORE BY WAVE ACTION.

action aided by longshore currents in the shallow water of the peninsula where waves break offshore and thus expend much of their energy on the sea floor. Eroded materials are thrown up and then pushed forward to be deposited at a little distance from the shoreline. The result of this action provides ideal conditions for the creation of longshore bars parallel to the shoreline (Plate 2.7).

Beach berms also form an important morphological feature of the shoreline where extensive sand accumulations are present. They are characterized by a marked break of slope at the seaward edge of a nearly horizontal 'platform' in sand. The break of slope is usually a little above the mean high water mark and these features are usually stable features of the shoreline.

### 2.3.6 Mangrove Coasts

Some coastal segments are associated with mud flats and the accumulation of fine sand (Chapman, 1976). According to Macone (1968), the typical coastal vegetation consists of several species of trees and a few shrubs which are able to grow between tide marks in highly saline conditions.

The vegetation is able to grow and expand only in protected areas that are reached by waves having only low energy, as for example in bays, lagoons and estuaries on the leeward side of the barrier island.

Factors favouring the development of a broad fringing belt of coastal mangrove include a large supply of sediments, low coastal relief. These features are all present on the Qatar Coast between the Khor and Dakhera embayments (Fig. 6.2 ) but only in protected shallow water. Snead (1972) described mangrove formations on the arid shores of the Red Sea and Persian Gulf. In Qatar mangrove vegetation is found well developed on muddy salt flats which are common in the area of Khar and Dakhera, where much of the sediment is deposited by the tidal action and where protection is afforded by spits or offshore bars. The mangroves at Khor and Dakhera along the coast have a width of 5 km. The height of mangrove vegetation varies from 1 to 3 metres in different locations (Plate 6.2). According to Batanouny (1981), these mangrove are dominated by Avaicinnia marina and current expansion of the area dominated by mangrove is indicated by an abundant of seedlings and growing shrubs, with the trees increasing in age and size landward (Bird, 1984). This is supported by field observation as recorded in Chapter 5 and it is illustrated in photographs (plate 6.2 A and B). The coastal classification of the Qatar Peninsula coastline can be summarized in Table 1.

Table 1 Coastal classification of Qatar

| | Type | Location | Characteristics |
|---|---|---|---|
| 1. | Sand dune and sand sheets | Dune : SE<br>sheets: E, NE, W. | Dunes occur as active and fixed forms and as aeolianite.<br>Sheets form expanses of sand or prograding coasts. |
| 2. | Sabkha | Mainly in E, SE, but also found in W. | Expansive flat estuarine inlets.<br>Active channels on E coast. |
| 3. | Cliffs | W, SW and NE | Both 'dead' and active cliffs in aeolianite and beach rock as well as in limestone. Notching and under cutting or common. |
| 4. | Coral reefs | N, NW and W | Typically found 2km offshore. Exposed at low tide. |
| 5. | Beaches | E, NE, W and SW | They occur as beaches, spits and barrier beaches.<br>Well developed berms are common. |
| 6. | Mangroves | NE | They comprise *Avacinnia marina* (height 1-3m). Typically form low-angled broad expanses of silt and muds. Located in protected locations. |

# CHAPTER III

# THE KHOR ODAID MARINE EMBAYMENTS

# CHAPTER III

## 3.1 The Khor Odaid marine embayments

### 3.1.1 Location and evolution of the Khor Odaid marine embayments

Khor Odaid is a large embayment with an average depth of water of 3 metres at high tide. It is almost completely isolated from the open water of the Arabian Gulf, and it is connected only by the shallow Khor Odaid channel with a maximum depth of between 3.7 and 7.3 metres, which extends for 14 km and is about 3.5 km in width.

The morphological map of the Khor Odaid area shows that Khor Odaid can be divided usefully into three main landscape types, which are indicated in Figure 3.1 .

1) The north embayment "lagoon"

This lagoon could have been formed during an undetermined period in the Quaternary when the sea resumed possession of the Arabian Gulf, occupying a shoreline close to the present one. However, a number of land areas today were then flooded, especially sand dunes areas, as well as certain sabkhas along the southern part of the Qatar Peninsula: the latter was then almost isolated from the Arabian Peninsula.

2) Southern embayment "lagoon"

This part of Khor Odaid area was initiated by the flooding of a topographic "low" associated with an original anticlinal and synclinal structure of the bed rock (Fig. 3.2 ).

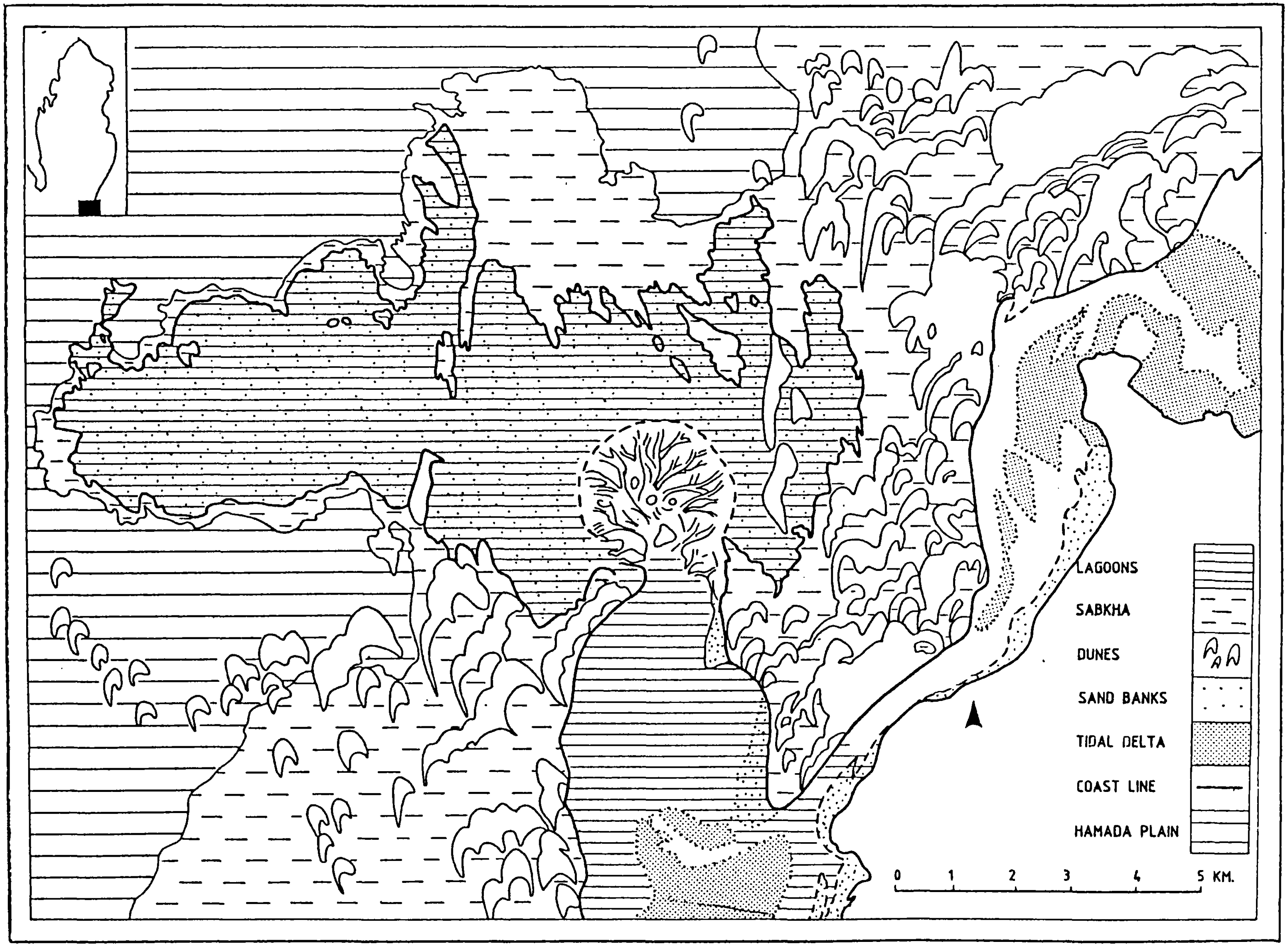


FIG. 3.1 KHOR ODAID MORPHOLOGICAL MAP.

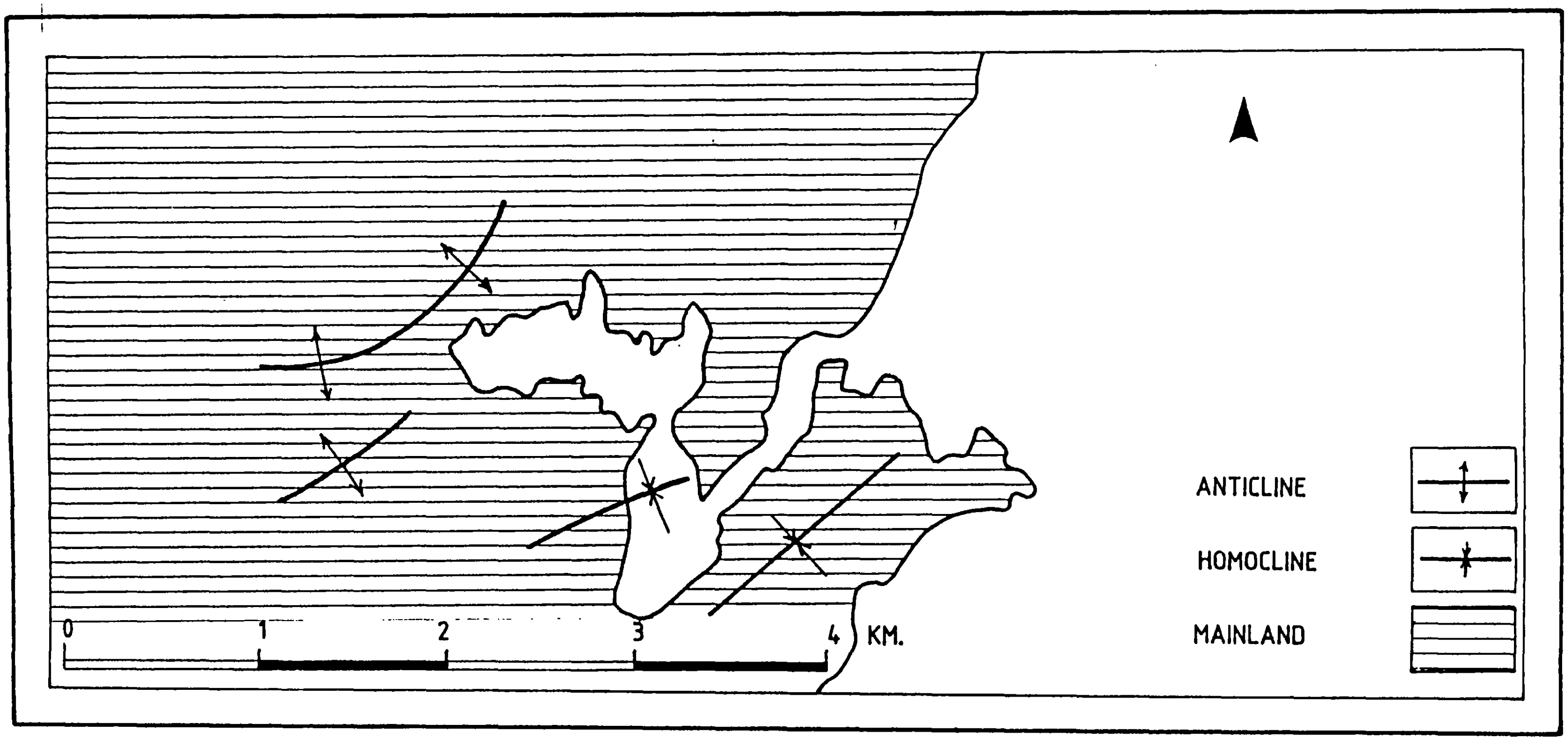


FIG.3.2 GEOLOGICAL STRUCTURES OF KHOR ODAID AREA.

SOURCE : PURSER , 1973.

### 3) Khor Odaid Channel

This feature was also initiated by the flooding of the same topographic "low" and a variety of shoreline and coastal features have been recorded within or near the channel, including sabkhas, sand banks, the tidal channel itself, tidal delta (ebb and flood tidal delta) and nearby sand dunes.

These morphological features were investigated using aerial photographs at a scale of 1:16,000, topographic maps at scales of 1:50,000 and 1:10,000 and field observation and measurement.

## 3.2 Landforms and processes in the Khor Odaid area

Sabkha is an Arabic term for coastal and inland flats or playas where quantities of fine silt and calcareous sands have accumulated. They are extensively developed in this area and are located at heights generally above the present tidal range representing earlier Holocene sea inundations. However, the sabkhas are also present in Khor Odaid in two areas: (1) north of the Khor Odaid channel, and (2) south of north lagoon and west of the south lagoon (Fig. 3.1 ). In both these areas the surfaces of the sabkhas rise only to 0-2 metres above present sea level (4 metres above datum), and consist predominantly of fine deposits, especially sand and silt (particle sizes of the sediments are discussed in more detail in chapter 9). Examination of the aerial photographs shows that most of the sabkhas are twice daily inundated by sea water which subsequently evaporates. Thus the surface becomes covered by a gypsiferous crust which varies in thickness from 1cm to 5cm over extensive parts of sabkhas. Such deposition occurs regularly. It will also be noticed that the 'older' sabkhas have been 'invaded' by the south-east moving barchan dune system. These dunes act as an active dune.

### 3.2.1 Sand banks

The sand banks of Khor Odaid area occur along the eastern and southern coast of the embayments "lagoons" and occupy almost the whole of the northern embayment "lagoon", while they are largely absent from the west coast of the southern embayment "lagoon" with the exception of a narrow coastal strip (Fig. 3.3 ). The formation and the movement of these sand banks can be plotted from the aerial photographs of 1977 and 1963 which show that tidal currents enter the Khor Odaid Channel, tend to erode the north bank of the channel and deposit sediment on the east bank. When tidal currents reach the southern lagoon, they tend to deposit some of their sediment load along small strips of the west bank. The tidal currents then flow northward and deposit some sediment, subsequently circulating around the south coast of the north lagoon from where they return to deposit the remaining sediment on the west bank of the south lagoon (Fig. 3.3 ). Two aspects of such tidal currents are vitally important in understanding how sediment moves around the embayments. These are, first, the trace of maximum velocity of the tidal current and, second, the nature and morphology of the sea bed. These two factors determine the size of any sediments that can be entrained and the circulating pattern which will control the transport route.

### 3.2.2 Tidal Channels

The tidal channels located at the entrance to the northern embayment "lagoon" form a highly sinuous pattern, forming especially during ebb tidal flow. Wetted channel banks (at a height of 2m above sea level) (Plate 3.1) are exposed during low water and blocks of sediment tend to fall into the channel along rotational slip planes.

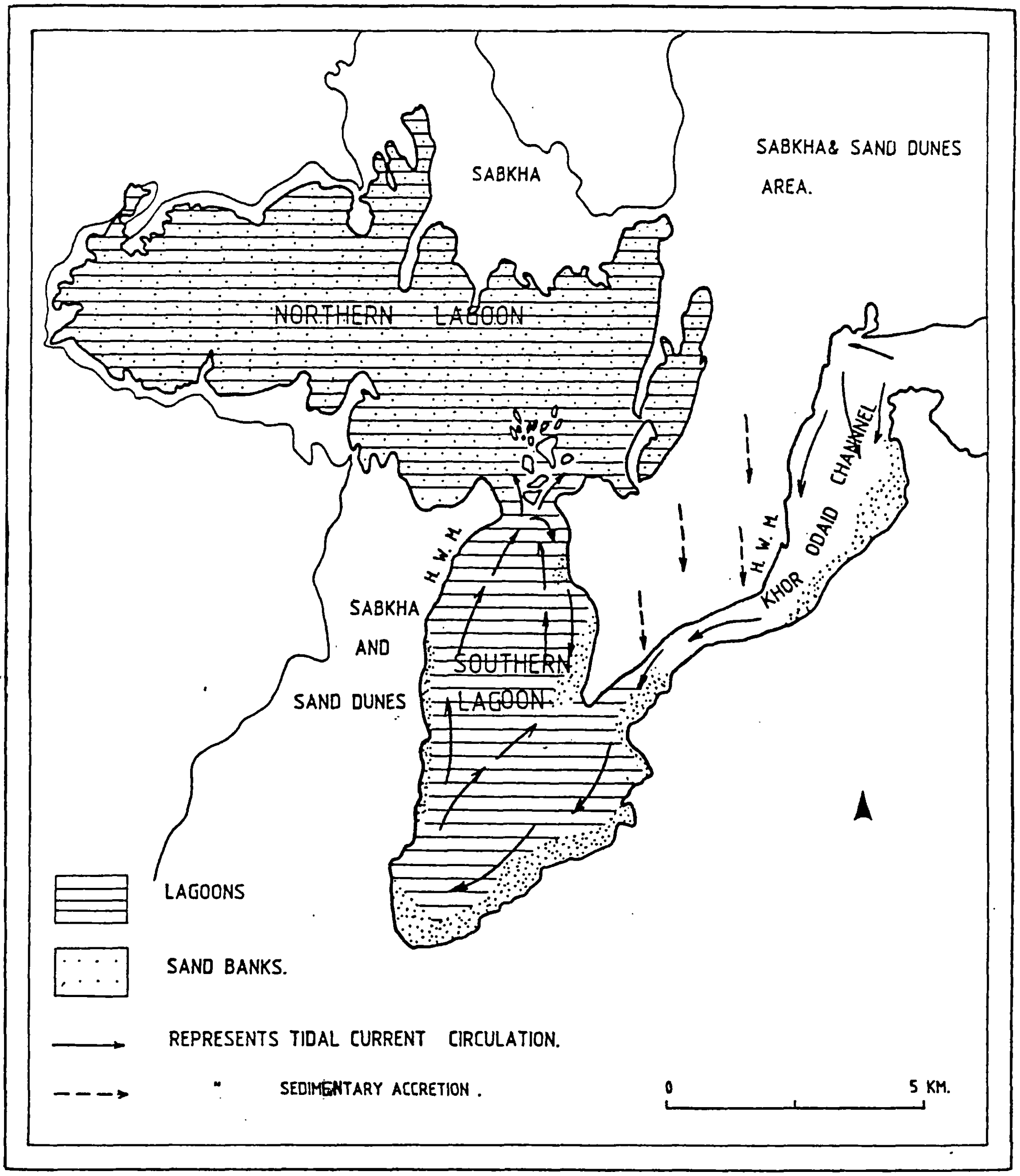


FIG.3.3 TIDAL CURRENT CIRCULATION IN KHOR ODAID AREA AND SEDIMENTARY ACCRETION.

PLATE 3.1 W REPRESENTS WETTED CHANNEL BANKS WITHIN TIDAL CHANNEL.


sand
banks
w
w
w

These processes contribute substantially to channel bank erosion. The tidal range clearly affects the extent of channel development on ebb discharge. It is also the major control of channel depth. As pointed out by Chapman (1964) in considering tidal channels, the tidal range also appears to influence the channel pattern. The tidal channel at the entrance to the northern lagoon consists of a net of small distributary channels with a dendritic pattern which is illustrated in Plate 3.1). The main reasons for their formation include: (1) the abundance of unconsolidated sediments that are affected by both high and low tide action; and (2) the combination of strong daily tidal currents, and the narrow entrance to the northern embayment.

### 3.2.3 Tidal Deltas

The tidal deltas of the Khor Odaid coastal area are wholly submerged, facing landward "flood deltas" and represent the result of deposition at the head of the southern lagoon by incoming "flood" tidal currents. The other delta is an ebb tidal delta which faces seaward and owes its construction to deposition in the sea by outflowing "ebb" tidal currents. The basis of delta formation reflects a balance between wave energy, tidal influence and availability of sediment load (Fig. 3.4 and Plate 3.2), and (Fig. 3.5 and Plate 3.3).

The ebb-tide delta exists at the entrance and in the middle of Knor Odaid channel. It formed and continues to develop as sediment is carried by tidal water from the two lagoons, some of the sediment being derived from the slumping of the faces of the coastal sand dunes forming the north side of the channel (Fig. 3.4). The

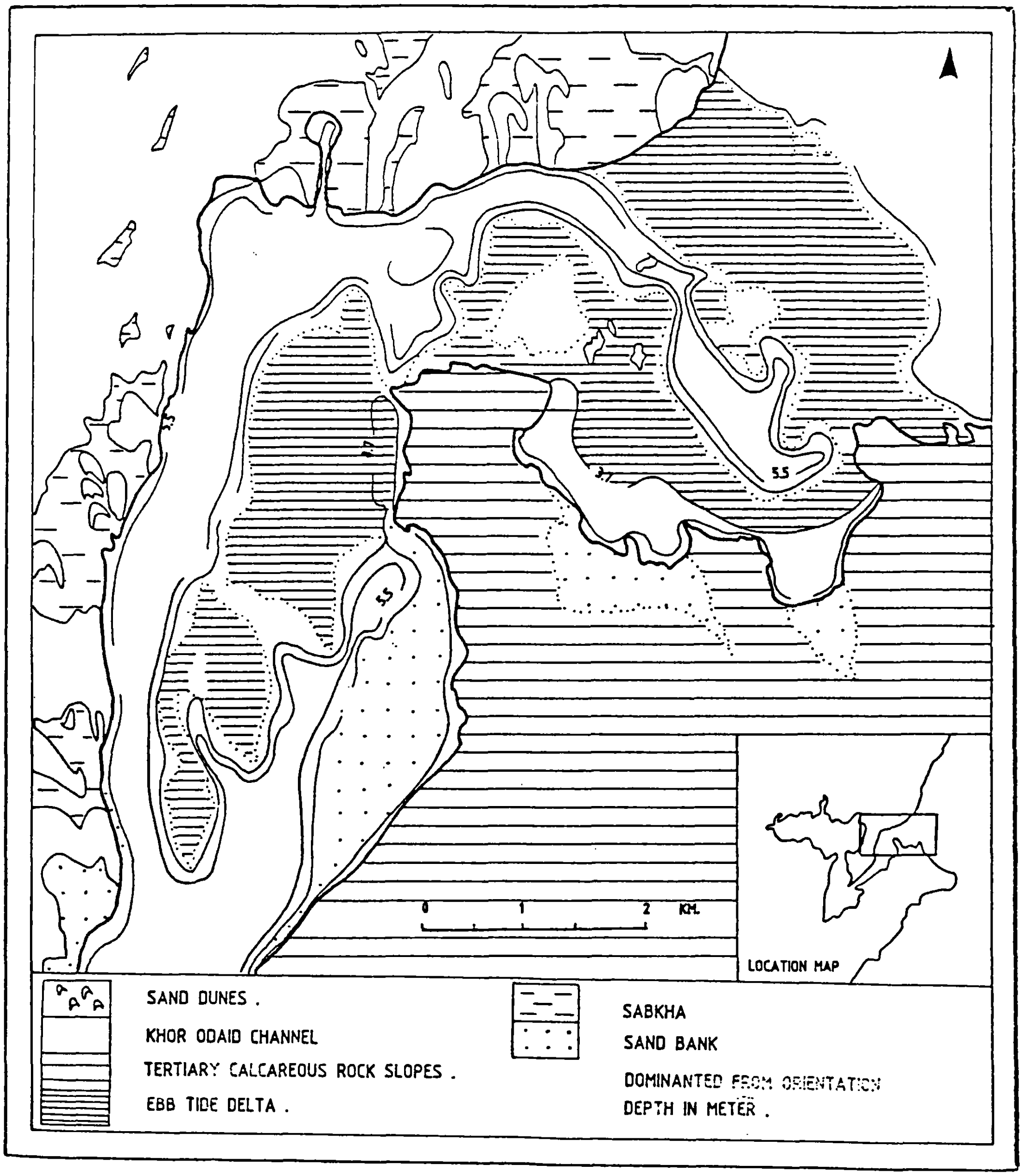
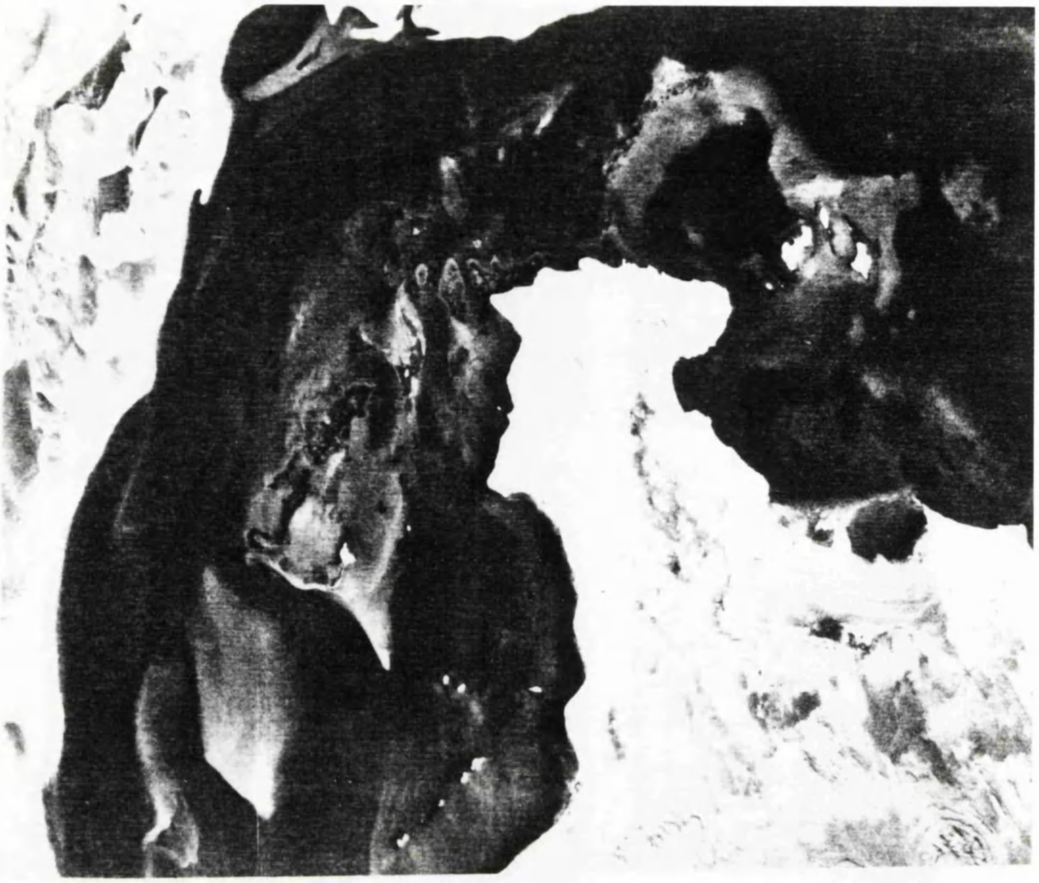


FIG. 3.4 EBB-DELTA TRANSFERRED FROM AERIAL PHOTOGRAPHY 1977.
SOURCE: QATAR LANDSAT.

PLATE 3.2 EBB-TIDE DELTA. AERIAL PHOTOGRAPHY1977.

PLATE 3.3 FLOOD-TIDE DELTA.(1) FLOOD RAMP;(2) FLOOD CHANNEL(3) SPILL OVER LOBE. SOURCE: AERIAL PHOTOGRAPHY1977 (HUNTING SURVEY).




4
1
2
3

components of these deltas include a main ebb channel, which usually shows a slight to strong dominance of ebb currents over flood tidal currents. The main ebb-tide channel is flanked on either side by a linear bar which forms a levée-like deposit built by the interaction of ebb and flood-tidal currents (Hays, 1969). The overall morphology of the Khor Odaid ebb-tide delta is thus a function of the interaction of tidal currents, availability of sediments and relationship to the flood channels.

### 3.2.4 Flood-tide delta

The morphology and bedforms of flood-tide deltas have been described, for example, by Hays (1969), Hine (1975) and Bothroyd and Hubard (1975). The flood-tide delta in the Khor Odaid area is situated at the entrance to the southern lagoon. It comprises sediment transported by the sea during tidal action within the Arabian Gulf. This delta now extends within the southern lagoon for nearly 3.5 km from east to west (Fig. 3.5 ). From the aerial photographs taken in 1963 and 1977, it would appear that no perceptible change has occurred throughout the 14 years of development and evolution of the ebb and flood-tide delta. It could be that this flood delta has reached a state of equilibrium.

The flood-tide delta consists of a flood ramp that is formed on the seaward-facing sandy slope over which the main force of the flood current is directed and the ramp is typically covered with flood-oriented sand ripples. In addition a flood channel, which is dominated by flood currents is found on the flood ramp. The flood-tide delta also consists of a spillover lobe which are bodies of

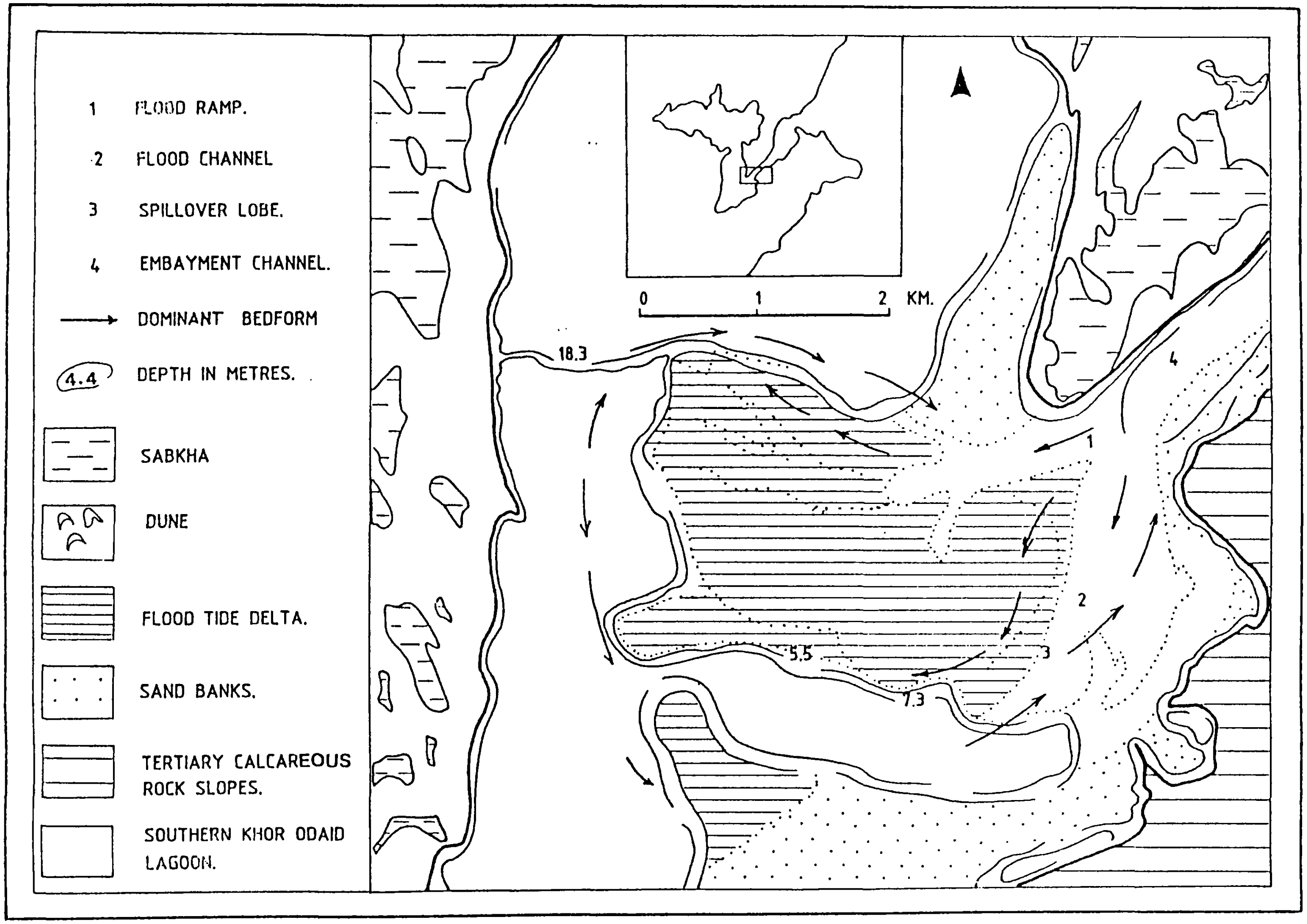


FIG.3.5 FLOOD TIDAL DELTA , OVERLAID FROM AERIAL PHOTOGRAPHY 1977

sediment formed by unidirectional currents and they flow over low areas.

### 3.2.5 Coastal Sand dunes

Large coastal sand dunes occur at several locations around Khor Odaid. These sand dunes now overlie the sabkha surface and while there is a high degree of exposure to north-westerly winds, Some sand dune movement still takes place across the sabkha. Dune formation owes its origin to an episodic history of aeolian sedimentation during the Quaternary and consists of distinct suitesof Barchan dunes.

The Khor Odaid sand dunes can be divided into two groups according to their locations:

1) The first group is located on the Arabian Gulf north of the Khor Odaid channel and east of the northern lagoon, and the northern part of the southern lagoon. Here coastal sand dunes are encroaching on to the sabkha surface that extends north from Umm Said to Khor Odaid. The area is characterized by the extensive nature of the coastal dunes, the exposed edges of which are being continually reworked by wave and current action generated under flood-tide and ebb-tide conditions.

2) These sand dunes are similar in general form and they continue to encroach on Khufus sabkha which is located to the south and to the west of the southern lagoon (Fig. 3.1) and similarly suffer erosion of their margins under wave and current action.

## 3.3 Sediment analysis

Grain size parameters of investigated sediment samples were calculated on the basis of their cumulative curves using statistical equations developed by Folk and Ward (1957). Four statistical size parameters were calculated namely: Graphic Mean Size ($M_2Ø$), inclusive Graphic Standard Deviation (Sorting, $S_1$), Inclusive Graphic Skewness ($SI_1$) and Graphic Kurtosis ($K_G$). The definitions for these parameters are mentioned in Chapter IX.

Mechanical analysis was undertaken of the sand dune and sabkha sediments. The sediments collected from the coastal sand dunes reveal a small range in grain size, from fine to medium sand. The particle size curves (Fig. 3.6) show a well-sorted sand with a mean size of 0.04mm (Fig. 3.7).

The sediment shows a strong positive skewness (Sk = 0.02) (Fig. 3.8) and it is mesokurtic (KU = 0.99) (Fig. 3.9).

Particle size analysis for the samples collected from the sabkha zone indicates that the sediment ranges in size from fine to medium-fine sands (Fig. 3.10). The particle size curve indicates that the sabkha sediment is moderately well-sorted with a mean sorting coefficient of 0.73 for all samples (Fig. 3.11). The sabkha sediments are negatively skewed (Sk = -0.11) (Fig. 3.12) and are platykurtic (KU = 0.73) (Fig. 3.10) which indicates that sabkha sediments tend to be fine and have platykurtic distributions. Analysis by Abolkhair (1985) of size characteristics of the drifting sand grains in Al-Hasa Oasis, Saudi Arabia shows that the grain sizes of sabkhas are characterised by well-sorted medium to positively fine

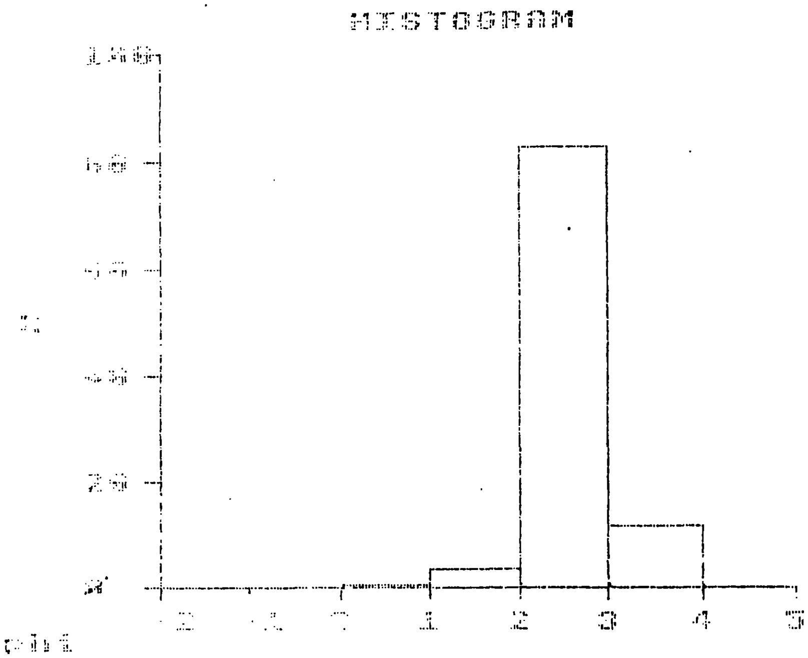


FIG. 3.6 HISTOGRAM OF PARTICLE SIZES OF DUNE SEDIMENTS, FROM KHOR ODAID.

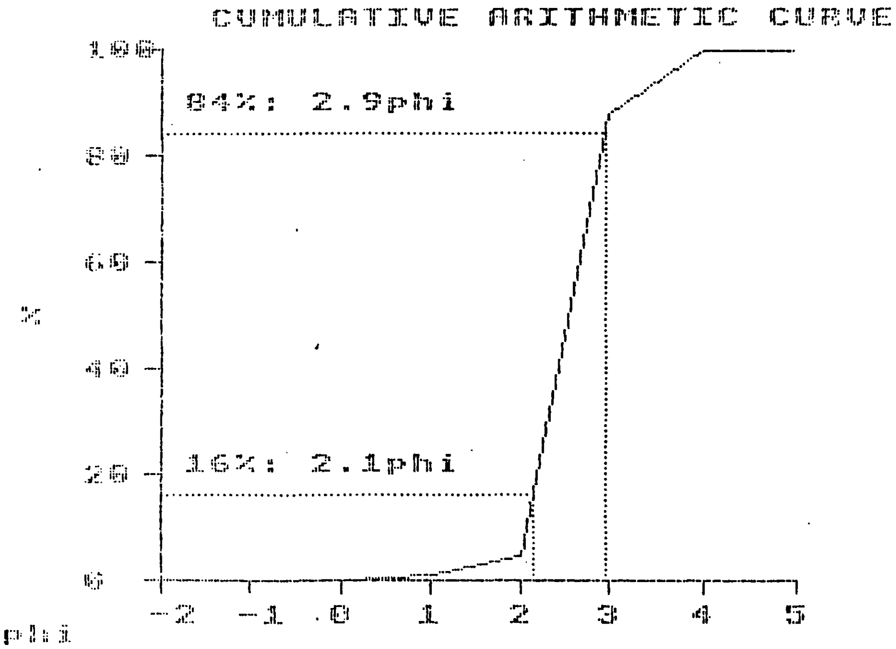


FIG. 3.7 CUMULATIVE PERCENTAGE PARTICLE SIZE OF DUNE SEDIMENTS FROM KHOR ODAID.

skewed sand with an overall average size of 2.00 and an average sorting coefficient of 0.5440. Another study by Abolkhair (1986) in the north-western Ar-Rub-Al Khali Desert (the so-called Empty Quarter of Saudi Arabia) shows that over 90% of the sand particles fall in the size intervals ranging between 1.500 and 3.00. Similar studies have also been done by Anton (1982) and Vincent (1984) for Ar-Rub-Al Khali and An-Nafud sand dunes. Embabi and Ashour (1984) studied sand dunes of the Qatar Peninsula. The sediments collected from the sand dunes revealed that the grain sizes lie between fine to medium-fine sands (mean 1.930), and between moderately and well-sorted sands (So=0.47) and they showed virtually no skew. All these studies reveal that the distribution of sand may be due to wind sorting. A similar study has also been done on Umm Said Sabkha by Shin (1973) which indicated that samples lie between the well to medium-sorted categories.

## 3.4 Summary

The Khor Odaid coastal area is located in the south-east Qatar and consists of three morphological units, the northern embayment "lagoon", the southern embayment "lagoon" and the Khar Odaid channel. Many different coastal landforms and shoreline features have been identified, such as the saline sabkhas which occur in two areas of Khor Odaid, one located north of Khor Odaid channel and the other south of the northern lagoon and west of the southern lagoon. The surfaces of the sabkhas rise between 0 to +2m above sea level (datum 4m). Sand banks are also present in the region of Khor Odaid along the east and south coasts and in the northern lagoon, and they result from the circulation of tidal currents which generally affect

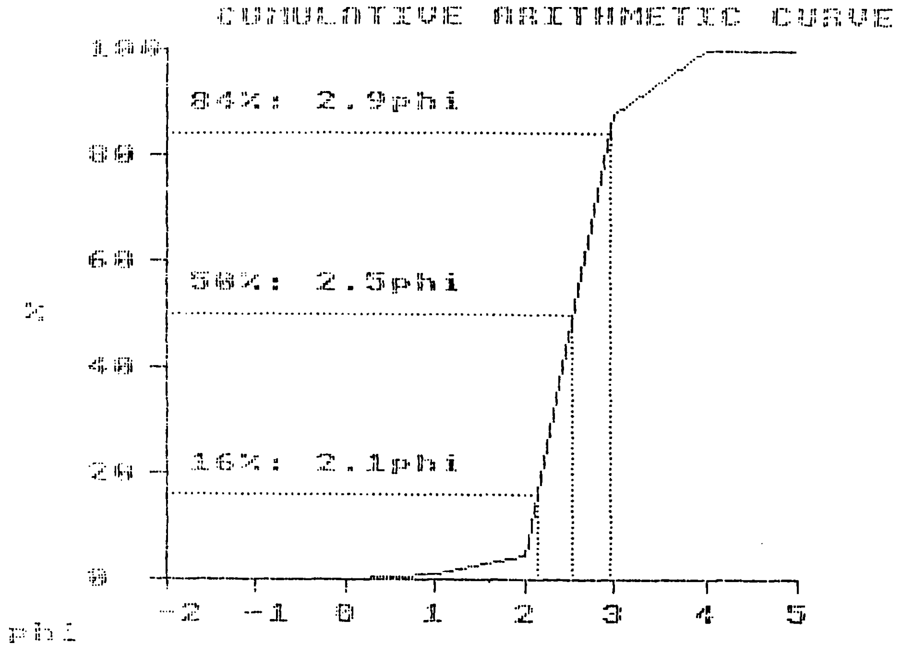


FIG. 3.8 CUMULATIVE PERCENTAGE PARTICLE SIZE OF DUNE SEDIMENTS KHOR ODAID (SK).

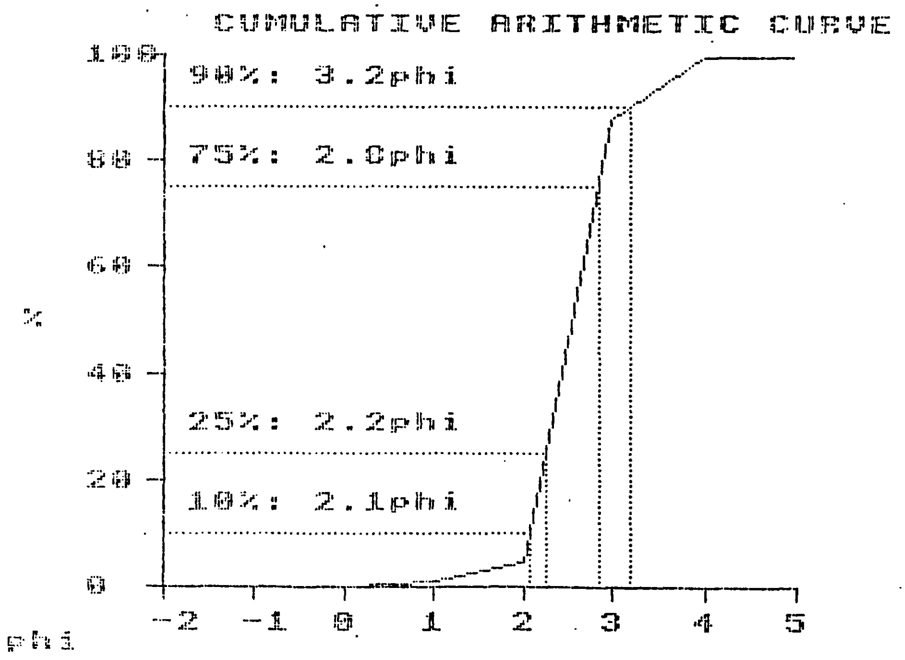


FIG. 3.9 CUMULATIVE PERCENTAGE PARTICLE SIZE OF DUNE SEDIMENTS KHOR ODAID (KU).

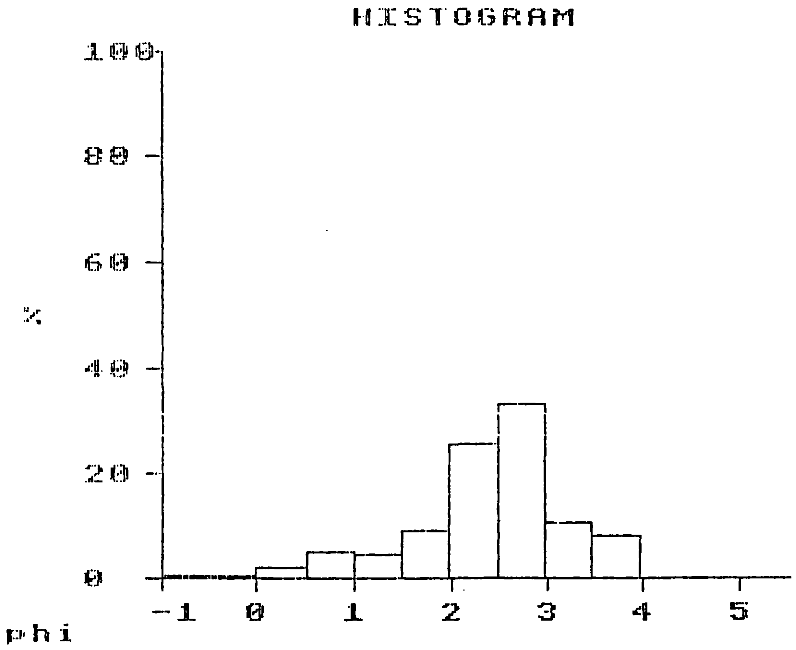


FIG. 3.10 PARTICLE SIZE HISTOGRAM OF SABKHA SEDIMENTS FROM KHOR ODAID.

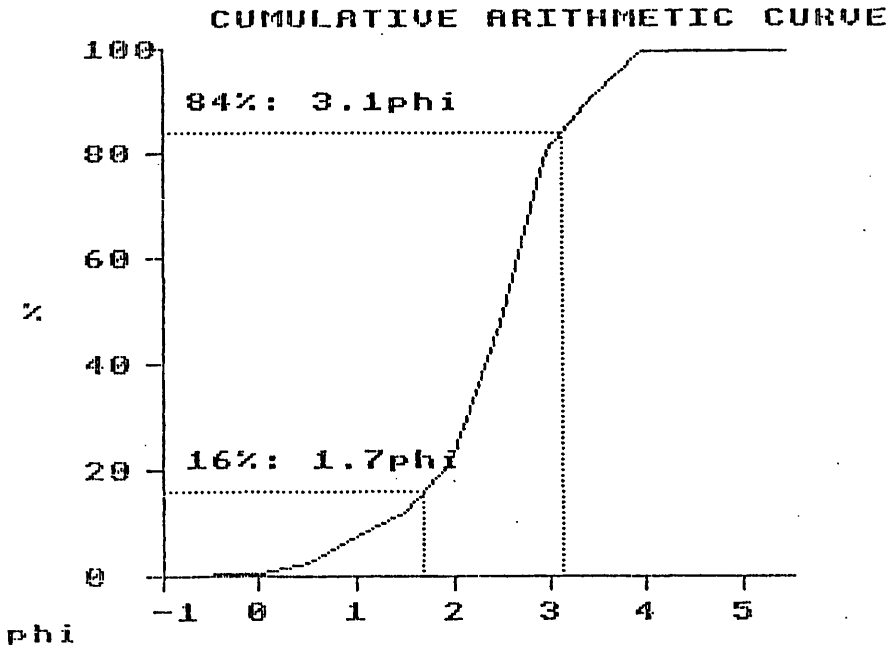


FIG. 3.11 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SABKHA SEDIMENTS KHOR ODAID.

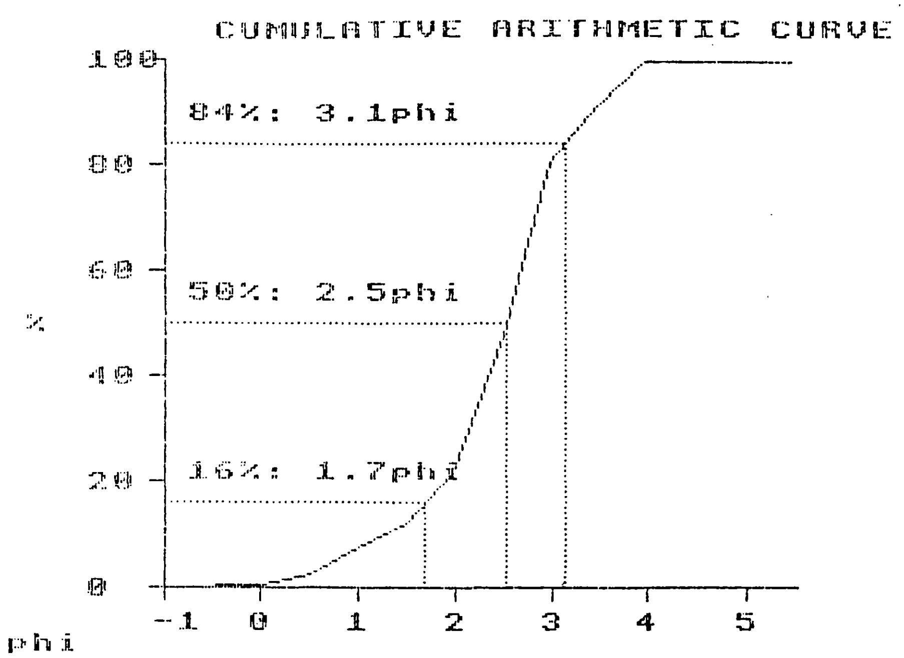


FIG. 3.12 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SABKHA SEDIMENTS KHOR ODAID (KU).

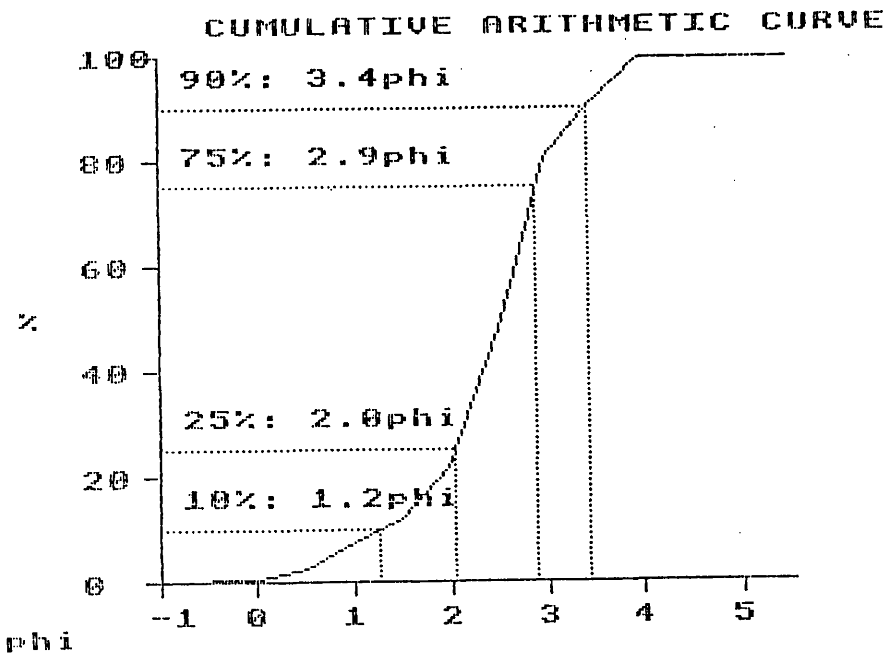


FIG. 3.13 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SABKHA SEDIMENTS KHOR ODAID (SK).

sediment movement within the entire Khor Odaid embayment. The tidal channel of the Khor Odaid area consists of a net of channels with dendritic patterns. The formation of these channels is due to the abundance of loose materials and strong tidal currents. The tidal delta in Khor Odaid region can be divided into two ebb-tide deltas and a flood-tide delta. The former are located on the entrance to the middle of the Khor Odaid channel. Their formation is due to the tidal action from two lagoons combined with sediment supply from the slumping of the advancing faces of sand dunes into the northern channel. A flood-tide delta is situated at the entrance to the southern lagoon and it extends south-westwards into the lagoon for 3.5km. Coastal sand dunes occur around the Khor Odaid embayments and occupy a large area overlying the sabkha of Umm Said to the north of Khor Odaid channel and there is another area of dunes overlying the sabkha of Khufus which lies south of the northern embayment "lagoon" and west of the southern embayment "lagoon".

Particle size analysis of the sand dunes and Sabkha sediments indicated that the sand dunes range between fine to medium sand, reflecting a narrow range of grain size which can be expected from aeolian sediments. They are well sorted (S = 0.40), have a strong positive skewness (Sk = 0.02) and are mesokurtic (Kur = 0.99). The Sabkha sediments, on the other hand, show grain size, ranging from fine to medium-fine sands. These sediments are moderately sorted (S = 0.73), negatively skewed (Sk = -0.11) and platykurtic (Ku = 0.73).

# CHAPTER IV

# UMM SAID SABKHA AND SAND DUNE AREA, SOUTH-EAST

# CHAPTER IV

# Umm Said Sabkha and the Sand dune area of the South-east Coast

## 4.1 Description of the area

The south-east coast of the Qatar peninsula near the settlement of Umm Said is characterised by barchan dunes which are prograding into the sea. The sand dunes are moving as a result of the prevailing north-north-west 'Shamal' wind. The area is underlain by Eocene rocks, the surface of which is less than 5 metres above sea level. These dunes are separated by a supratidal flat or coastal Sabkha from the sea. These sabkhas are comprised of sand and silt, extending for 50 kilometres parallel to the beach and 4-10 kilometres in a direction perpendicular to the beach (Fig. 4. 1 ). The principal body of literature on modern sediments of the Arabian Gulf Coast describes the carbonate dominate Coastal Sabkhas (Kendall and Skipwith, 1969; Illing 1965; Butler 1971; Evans 1969; Taylor and Illing 1969; Pursser 1973; Patterson and Kinsman 1986). These various works collectively describe a part of the Arabian Gulf Coast characterised by present-day carbonate sedimentation which covers vast areas of quartz sands inland from the coast. As pointed out by Handford (1981), these classic studies resulted in the development of a depositional model for sabkhas in association with hot desert coasts. Another radically different model is equally viable, however, for deposition along the desert margin of shore lines, and associated dune-Sabkha systems. Shin (1973) suggested a model for an offshore prograding dune system, where there is a desert shoreline with a strong wind from the land towards the sea.

Sabkhas around the Qatar Peninsula are subdivided into two types (Fig. 4.2 ). These are: (1) coastal sabkhas; and (2) Inland Sabkhas. (1) Coastal sabkhas are the supratidal surface by deposition of marine sediments, are distributed around the coast of the Qatar peninsula and they cover about 750 km$^2$ or constitute nearly 7% of the total area of the Qatar Peninsula. They are more prevalent along the east coast than on the west coast, particularly in the southern area to the south of the settlement of Umm Said. They cover an area from north to south of about 50 km and penetrate in places inland for a distance of about 10 km east to west. Coastal sabkhas do not rise much above the present sea level (a maximum of 2 metres). Some parts of the sabkhas are still below sea level which allows tidal currents to overwhelm their surfaces. During particularly high tides aided by strong easterly winds, sea water may penetrate for a distance of up to 3.5 km across the sabkhas.

### (2) Inland Sabkhas

These sabkhas lie far away from the coastline. One such sabkha is located about 3 km directly east of Jabal Dukhan and south of Zekreet bay. Its area is 60 km$^2$ and most of it lies below sea level. Within this sabkha is the lowest point in Qatar Peninsula (-6m below sea level). It extends for nearly 24 km north to south and 10 km east to west, while a crust of evaporite coversan area of 6 km$^2$. There is a possibility that the formation of this sabkha is linked to the homoclinal folds (Fig.1.9, chapter 1) located east of Dukhan. These homoclinal folds occupy the northern part of Zekreet Bay, while this inland sabkha occupies its southern portion. A second inland sabkha is

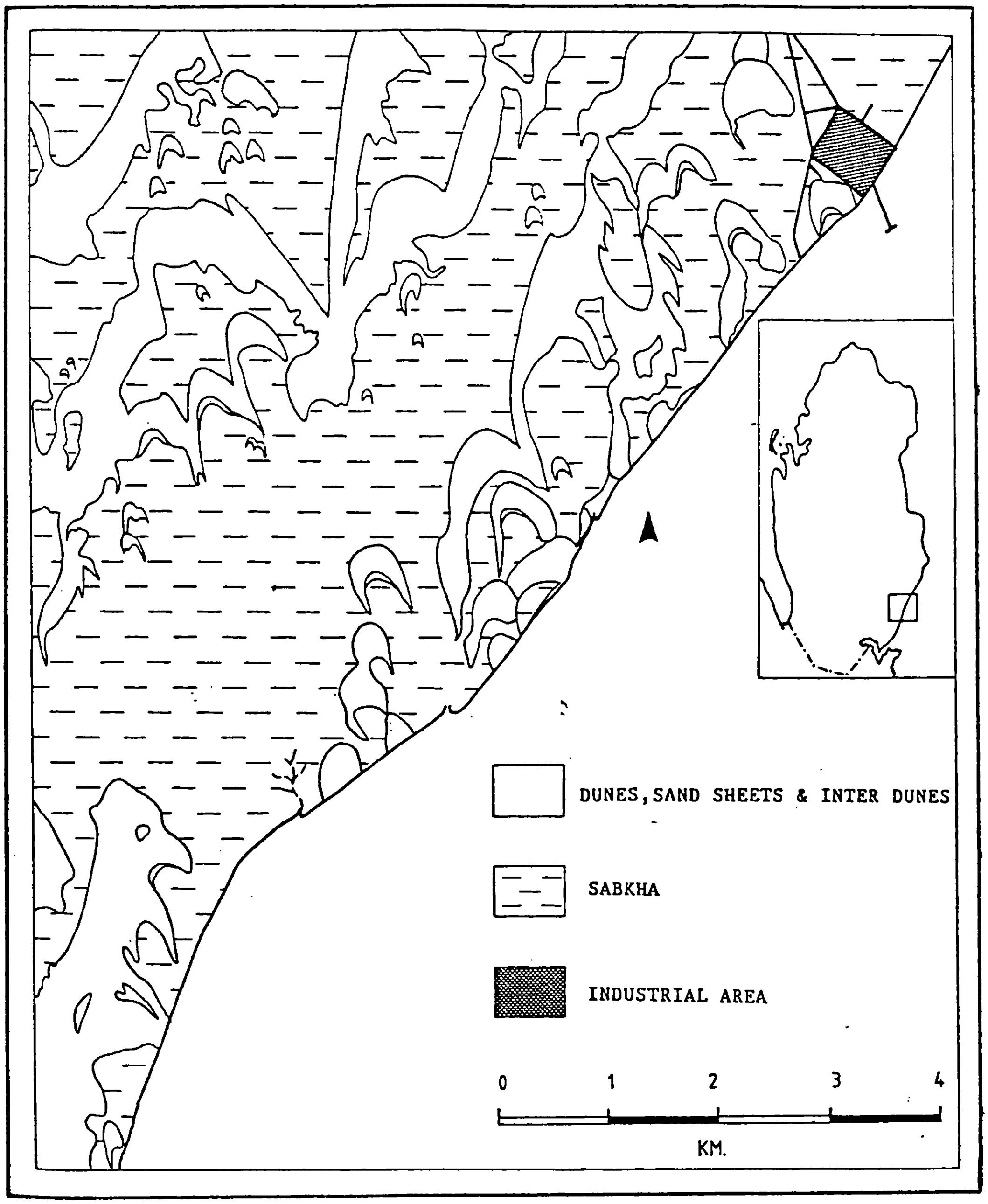


FIG. 4.1 AREA OF STUDY INTERPRETED FROM AERIAL PHOTOGRAPHY (dated . 1976 )

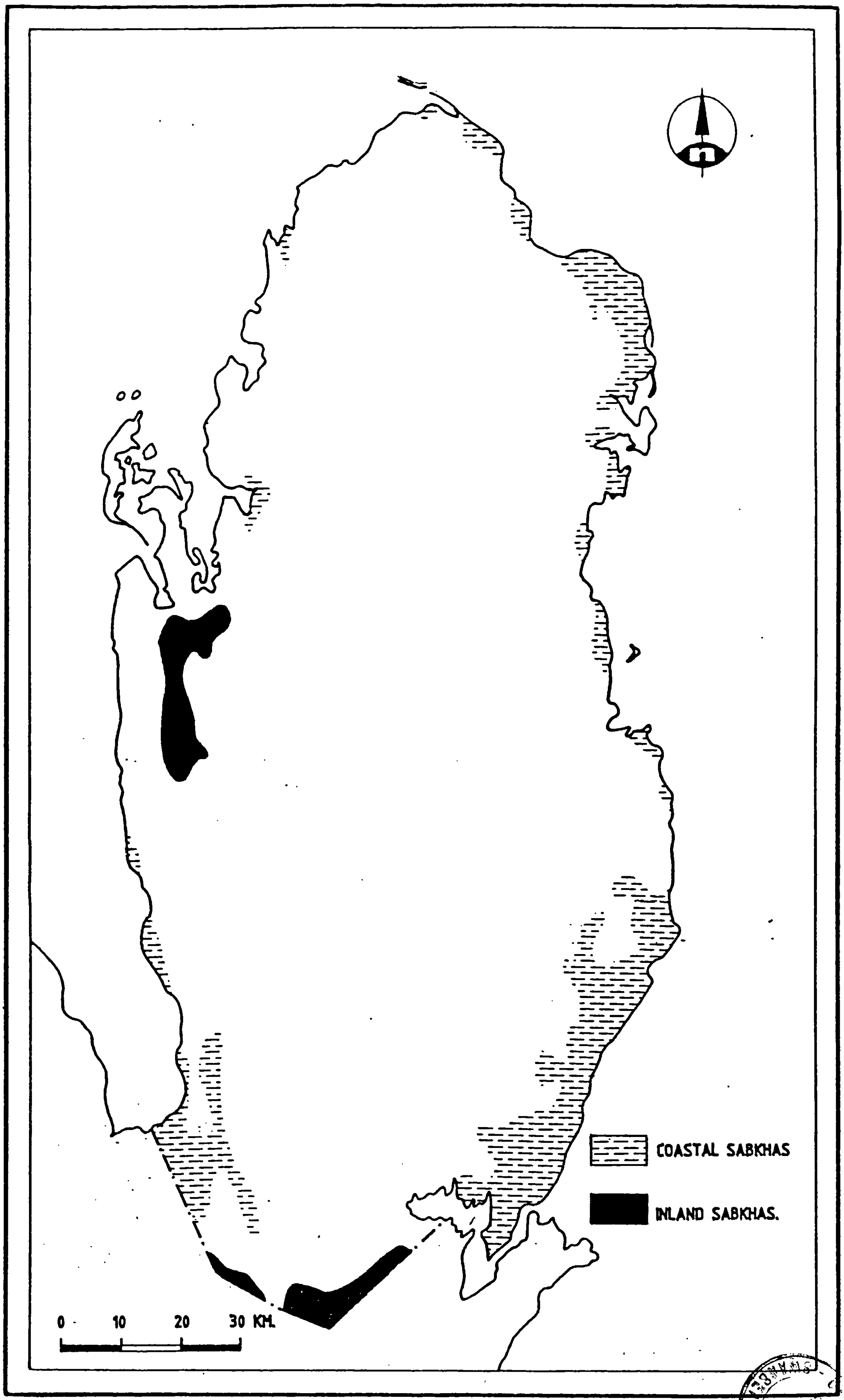


FIG.4.2 THE DISTRIBUTION OF COASTAL AND INLAND SABKHAS AROUND THE COAST OF QATAR PENINSULA.

located along the border between Qatar, Saudi Arabia, and the UAE in three scattered areas, namely the southern part of the Sauda Nathil area, the west part of Jawa al Salama and eastern part of Khufus. The greater part of the surfaces of these sabkhas lies below sea level and covers an area of about 25 km$^2$. The extent of the southern sabkha suggests that the sea at the end of the Wurm maximum glaciation to the end of Late Pleistocene times connected Khor Odaid and Salwa bay, thus spreading across the Qatar Peninsula near the Saudi Arabian border to form an island.

## 4.2 The flooding of Umm Said Sabkha

This sabkha floods frequently when spring tides combine with certain conditions brought about by the prevalent easterly wind and winter rainfall. A photograph taken at high tide (Plate 4.1) provides an illustration of the situation when two surveyed tidal channels in this sabkha penetrated about 40 metres or more to flood the sabkha surface (Fig. 4.3A,B). According to field observation these flooded surfaces drain quickly within a few days or even less, leaving a crust of gypsum salt. Within a few months these salt crusts may begin to suffer deflation or experience loss by the action of rain water dissolving the salts. Such processes can reach a peak in January and then decrease until they cease completely in May.

## 4.3 Pattern of tidal flow within the Sabkha

Owing to low relief and low rainfall, the Qatar Peninsula does not support a ground water system with a strong seaward gradient. The water table in the coastal sabkhas is approximately horizontal at

PLATE 4.1 COASTAL SABKHA FLOODED AT HIGH TIDE, UMM SAID.

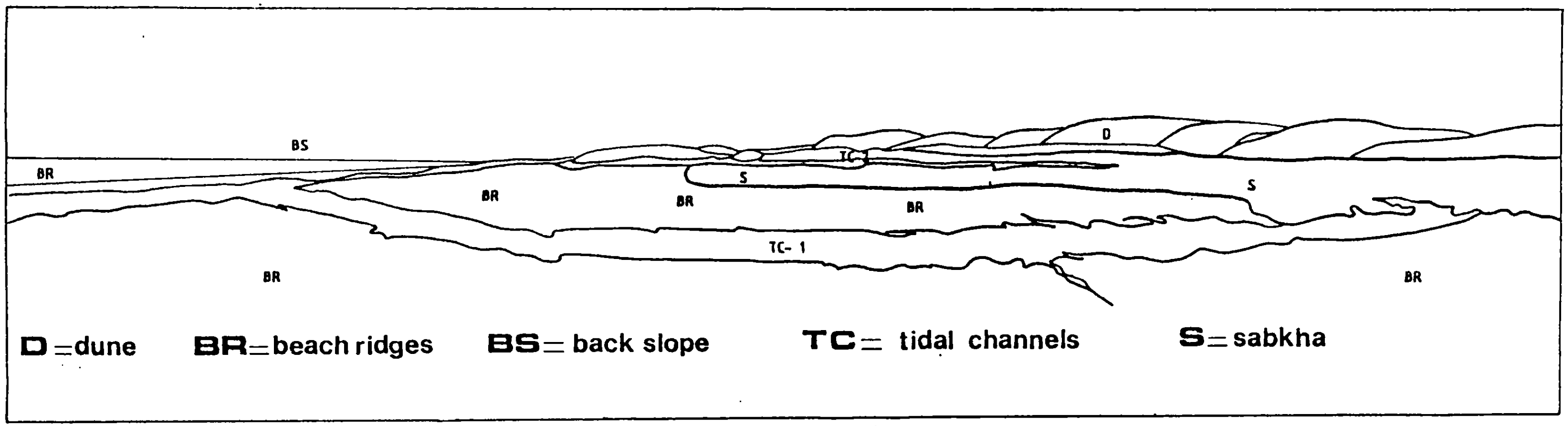


FIG. 4.3 A INTERPRETATION OF GROUND PHOTOGRAPH .

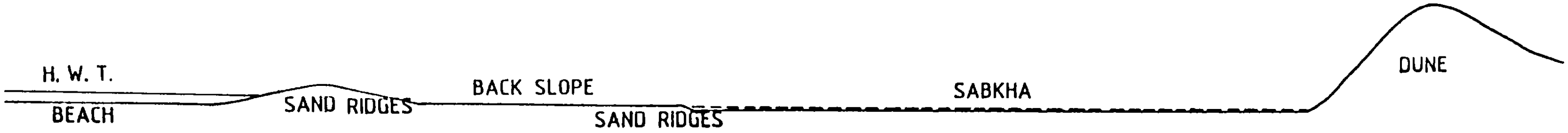


FIG.4.3 B CROSS-SECTION OF THE STUDY AREA.

high tide except near the inland margin, where it falls rapidly in a landward direction. The pattern of ground water flowing through the sabkha to the coastline is illustrated in Figure 4.4 . Some ground water is lost through evaporation from the sabkha, whilst there is recharge due to flooding by wind-driven sea water.

## 4.4 Rate and direction of movement of the sand dunes

The rate and direction of movement of sand dunes to the south of Umm Said have been determined by measurement taken from aerial photographs on three different dates during the last 13 years. The aerial photographs were taken in March 1963 (scale 1:80,000), February 1971 (Scale 1:38,000), and in April 1976 (Scales 1:16,000 and 1:38,000) (Figs. 4.5 and 4.6 ). The sand dunes in the area have moved an average distance of 105 metres between March 1963 and April 1976 in a south or south-easterly direction and at an average rate of 8 $m/yr^{-1}$. The large dunes have prograded somewhat, moving slowly (average rate = 7.5 $m/yr^{-1}$) and the total distance of 265 m was recorded over the 13-year period with an average annual rate of 20.2m. The smallest dune average of up to 40m annually. These particular measurements were taken to the crests of the slip faces, which are unstable and are probably not representative of the movement of the sand dunes as a whole. Some of the smaller isolated dunes appear to diminish in size as they creep away from the protection of the large dune.

(All measurement of sand dune movements have been obtained
by Hunting Survey Data rearranged to show the total
movement of sand dunes during two periods of 1963-1976.

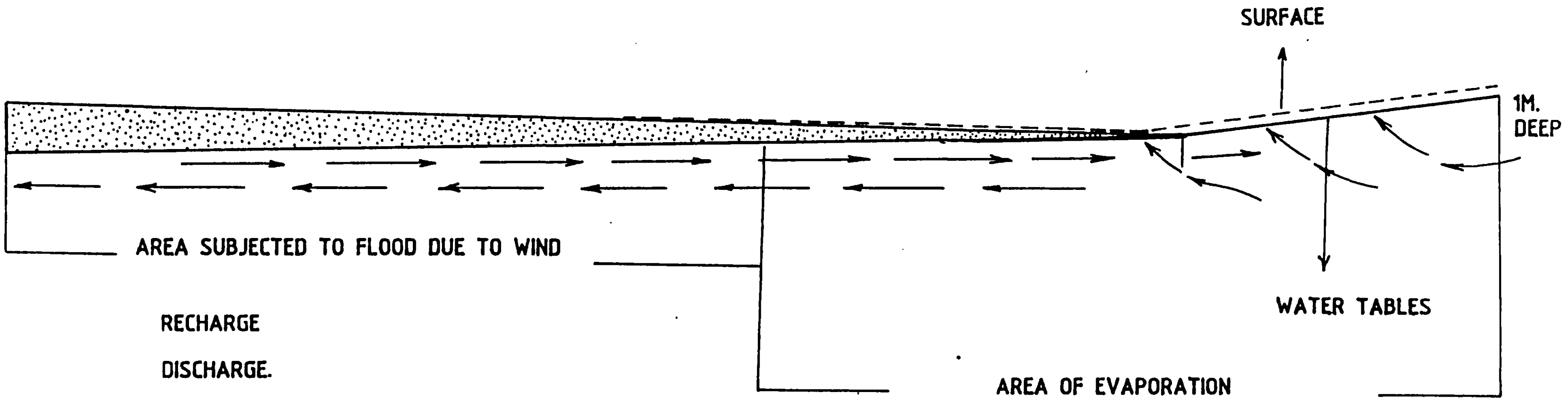


FIG. 4.4 FLOW THROUGH A SABKHA TO THE COASTLINE.

SOURCE ": MODIFIED AFTER PATTERSON AND KINSMON AAPG BULLTIN 1981.

## 4.5 Beach forms

Cross-profiles were surveyed in the study area across the beach, the backing sand dunes and the sabkha (Fig. 4.3B ). Generally, the intertidal part of the beach is characterised by a gentle seaward slope with an angle of 5° with the highest point being about 50cm above high tide level. The beach face is also shown on the profile to have a gradient of 30° giving a steep slope facing the Sabkha zone. The length of this back slope is about 2m. Beyond the reach of waves there is a zone of sand ridges behind the beach slope where dunes are comprised mainly of quartz sand. Beyond these ridges lies the sabkha zone which is flooded along the tidal channel during high tide and during the rainy season (from October to May).

## 4.6 Sediment transfer by wind, waves and tidal currents

An occasional high magnitude, low frequency phase of dune erosion occurs during particularly high tides, with marine erosion processes under-cutting the lower dune slopes. As erosion proceeds, sand slumps down into the erosion void causing further removal and modification of the dune slope profile. During high tides erosion may continue for 2-3 hours and almost all visible damage occurs during this time.

Fig. 4.7 shows how the volume accreted between H.W.M. and wave base with deposition of sand taking place across the near shore zone as swash action intensifies seaward movement, thus bending both to widen and raise the level of the beach. Also, sand is transferred from slumping of the slip face slope of the sand dune under gravity, and most of the material is reworked by the waves and tidal currents.

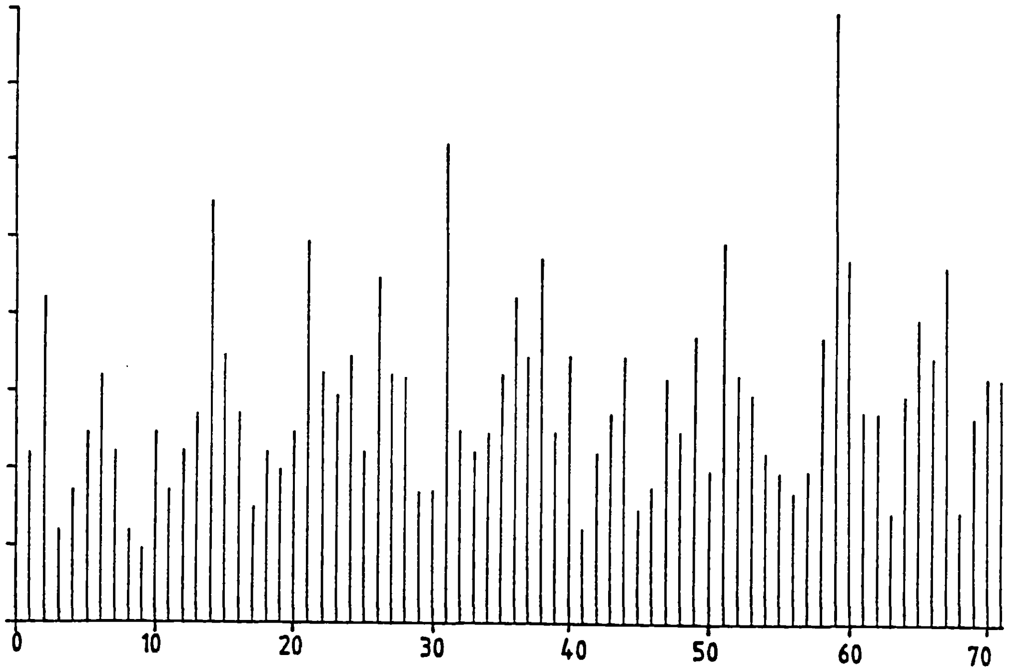


FIG 4.5 TOTAL MOVEMENTS OF SAND DUNES FOR THE PERIOD 1963 - 1971.

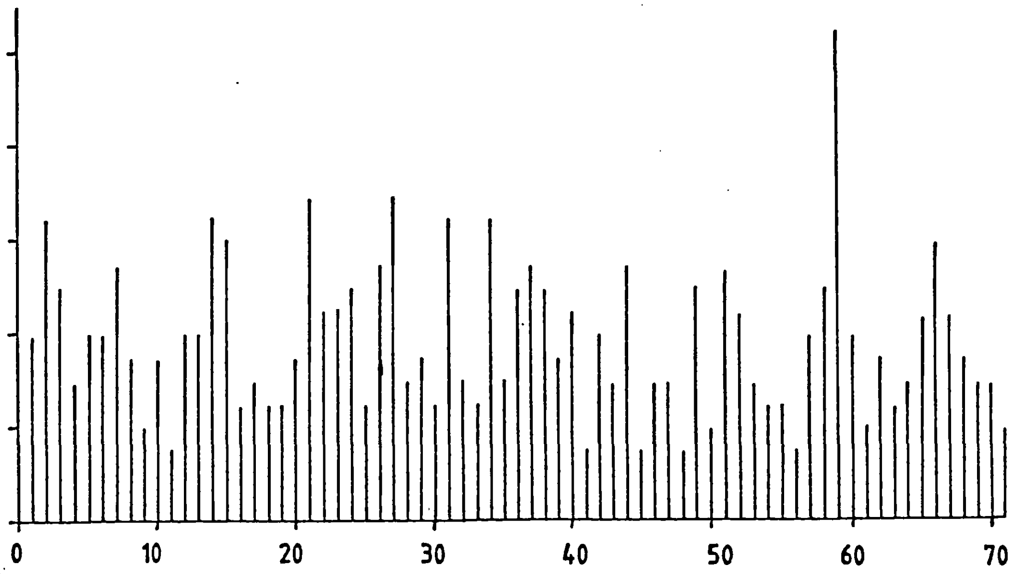


FIG.4.6 TOTAL MOVEMENTS OF SAND DUNES FOR THE PERIOD 1971 - 1976.

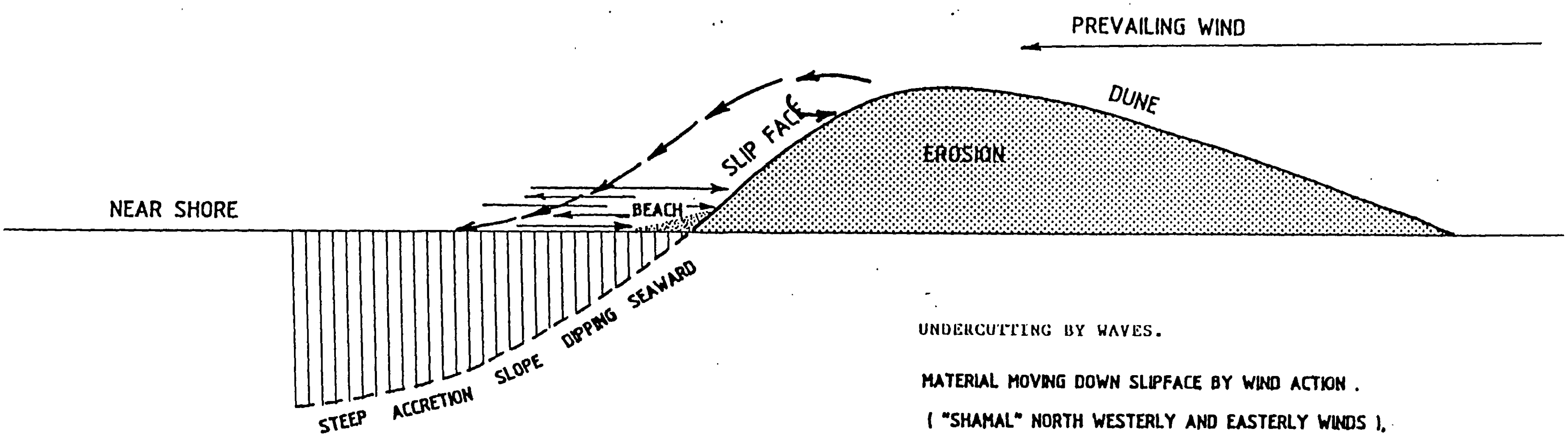


FIG. 4.7 EROSION BY MECHANISMS OF UNDERCUT AND SLIDING.

## 4.7 Chemical analysis of Sabkha sediments

Chemical analysis of the sediments was carried out by the Ministry of Industry and Agriculture. Five samples were taken from different locations on the sabkhas at depths of 1m, 90cm, 80cm, 60cm and 35cm. The location of the five pits is shown in Figure 4.8. In the study area, sand dunes have extended to transgress the saline sabkhas, where broken marine shells and gypsum are commonly found on the surface. The five pits on the area indicated that electrical conductivity increases with depth from 9.17 mmohs at 35cm to 22.6 mmohs at depth of about 1m. Sulphate and chloride are dominant anions (12.21 and 83.34 me/L) in the surface layer and increase at depth to values of 47.06 for sulphate and 22.71 for chloride. Sodium, calcium and magnesium are the major cations and they attain values of 76 (sodium) 4.87 (calcium) and 15.73 (magnesium), me/L in the surface layer, and this increases with depth to values of 210, 22, 53 and 38-64 respectively at a depth of 1m. The analysis also shows that potassium increases with depth from 2.1 units at a depth of 35cm to 5.4 at 1 metre (Table4·1).

A similar study was carried out by FAO workers in (1981) on the same area of Umm Said. It showed that there was a calcium carbonate content of 30%, a pH of 8.0 and progressively increasing elecgrical conductivity (E.C.) with depth from 6.0 mmohs at 30cm to 12.5 mmohs at 1m. Sulphate and chloride are the dominant anions 42 and 39 me/L) in the surface layer and steadily increase through to a depth of 240cm. Sodium, calcium and magnesium are the major cations. Sodium absorption ratio values increase with depth being 5.64 at 30cm, 14 at 1m and 35 at 2m.

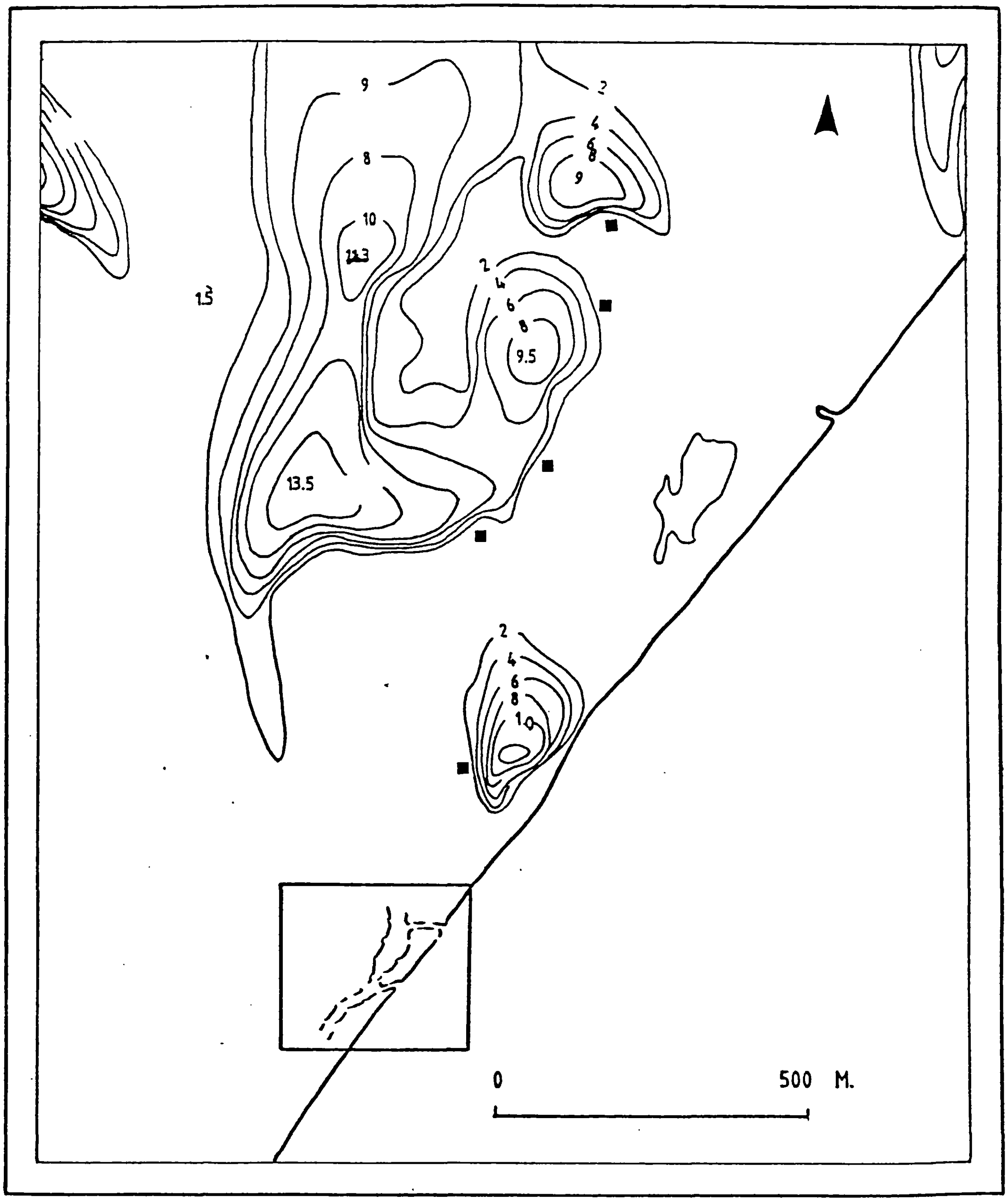


FIG. 4.8 LOCATION OF COLLECTED SAMPLES, UMM SAID AREA.
SOURCE: HUNTING SURVEY SHEET NO. 230/345, 1980.

Table 4.1 Chemical analysis for samples collected from Umm Said Sabkha

| Serial No. | Profile No. | Depth in cm | S.P. | pH | E.C. | Meg/L Anions | | | | Meg/L Cations | | | | $CaCO_3$% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $CO_3$ | $NCO_3$ | CL | $SO_4$ | Ca | Mg | Na | K | |
| 1 | 1 | 100 | 22.14 | 8.05 | 22.6 | - | 2.8 | 226.71 | 47.06 | 22.53 | 38.64 | 210 | 5.4 | |
| 2 | 1 | 90 | 20.18 | 8.31 | 16.16 | - | 2.03 | 154.04 | 31.73 | 13.77 | 25.03 | 145 | 4 | |
| 3 | 1 | 80 | 19.21 | 8.23 | 12.03 | - | 3.87 | 112.85 | 16.51 | 8.51 | 20.38 | 102 | 2.7 | |
| 4 | 1 | 60 | 21.56 | 8.10 | 18.27 | - | 2.74 | 167.88 | 39.10 | 10.12 | 26.80 | 109 | 4.1 | |
| 5 | 1 | 35 | 17.64 | 8.50 | 9.17 | - | 3.12 | 83.34 | 12.21 | 4.84 | 15.73 | 76 | 2.1 | |

### 4.8 Mechanical analysis

Mechanical analysis of the beach sands, sand dunes and sabkha sediments was undertaken. The sediments collected from the beach zone indicated that the grain size ranges from fine to medium sand reflecting the narrow range of grain sizes (Fig. 4.9 ). The cumulative percentage weight curves show that the grain size, sorting ranges between moderate and poorly sorted sands (S = 1.05) (Fig. 4.10 ) and the sediments show a positive skewness (Sk = 0.04) (Fig. 410 ), thus indicating that the differences in particle size between deposits are due to selective sorting (the finer particles carried by almost all currents). Folk & Ward (1957) argued that the sediment usually becomes finer with a decreasing in energy of the transport medium. Thus where wave action is dominant, sediment becomes finer in deeper water because the action of waves on the sea bottom is slight. On the other hand, this turbulence is at a maximum in shallow water in the breaker zone.

Particle size analysis of the sand dunes zone indicates that the grain size ranges between fine and medium fine sands reflecting the narrow range of grain size (Fig. 4.11 ). The sand is moderately sorted (S = 0.74) and the sediments show positive skew (Sk = +0.20) (Fig. 4.12 ). This distribution of sand may be due to wind sorting. A study of sand dunes undertaken by Abolkhair (1985) on the size characteristics of sediment in Al-Hasa Oasis, Saudi Arabia showed that the Al-Hasa dune field has a significant axes of fine grains and a platykurtic to mesokurtic distribution. Abolkhair (1986) discussed the analysis of the statistical parameters of the size distribution of Al-Abaylah barchan dune sands. The results of sieve analysis show that over 90% of sand particles fall in a size range of between 1.500

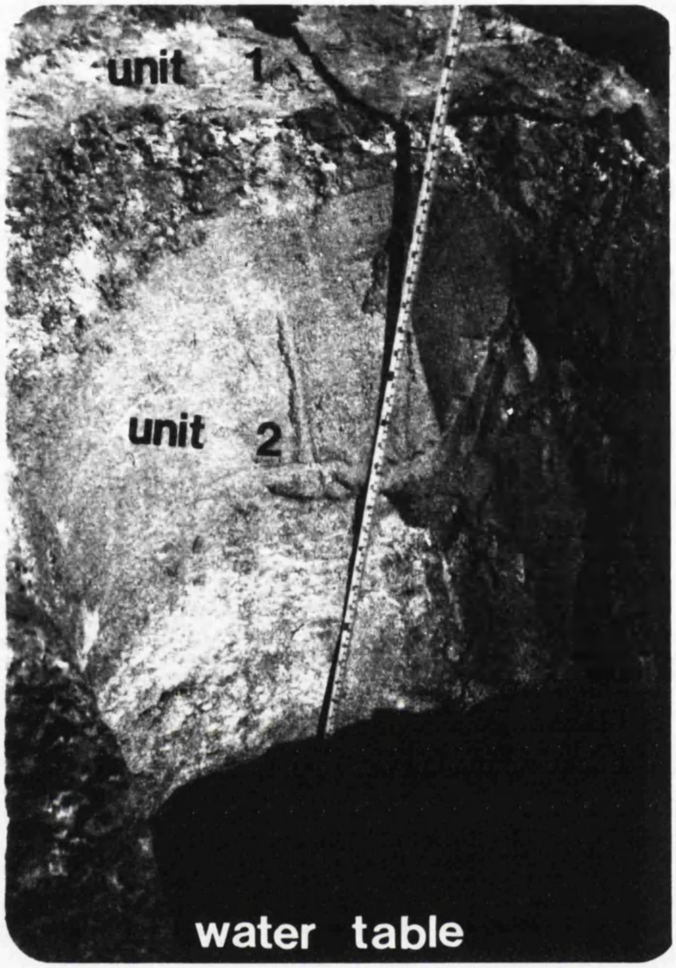


PLATE 4.2 TRENCH, APPROXIMATELY 90cm DEEP IN UMM SAID SABKHA PREDOMINANTLY COMPRISES QUARTZ SAND.

and 3.0. The sand distribution is positively skewed and mesokurtic to leptokurtic in character. Anton and Fuat (1986) indicated that the sand grains collected from Ar-al-Khali, Saudi Arabia come from aeolian dunes which are composed of fine sand. They were well sorted, while samples collected from Dahna, Saudi Arabia were medium to fine grain sands, moderately to well sorted, while samples collected from Jafura, Saudi Arabia showed high medium values and poor sorting characteristics (average S = 1.73). Embabi and Ashour (1985) showed that samples collected from different sand dunes from south-east Qatar are composed of fine to medium-fine sand with a mean of 1.930.

A trench in a sabkha was dug about 90cm deep and about 700 metres inland. Gypsum occurred in unit 1 ( Plate 4.2). Sediments were dominantly comprised of quartz sand grains. Unit 2 showed sediments consisting mainly of cross-bedded aeolian quartz. The water table was found at the base of the trenches. A similar study was carried out by Fryerger _et al._ (1983). It involved the excavation of trenches in a sabkha in the Dhahran area, Saudi Arabia, 10km from the coast. It revealed the dominance of quartz sand in the trenches. Evans _et al._ (1969) and Schneider (1975) showed different units on a sabkha of Abu Dhabi, U.A.E. in the Arabian Gulf. These sediments comprised sands derived from the wind erosion of pre-existing dunes and progradation of subaqueous, intertidal and supratidal carbonate sediments.

The sediment collected from Unit 1 from Umm Said sabkha showed a grain size of fine to medium sand (Fig. 4.13 ). The sand is well sorted (S = +0.36) (Fig. 4.14) and the sediment shows a symmetrical distribution (Sk = 0.00) (Fig. 4.15 ). It is platykurtic (Ku = +0.85) (Fig. 4. 16), the sediment consisting mainly of wind-deposited quartz

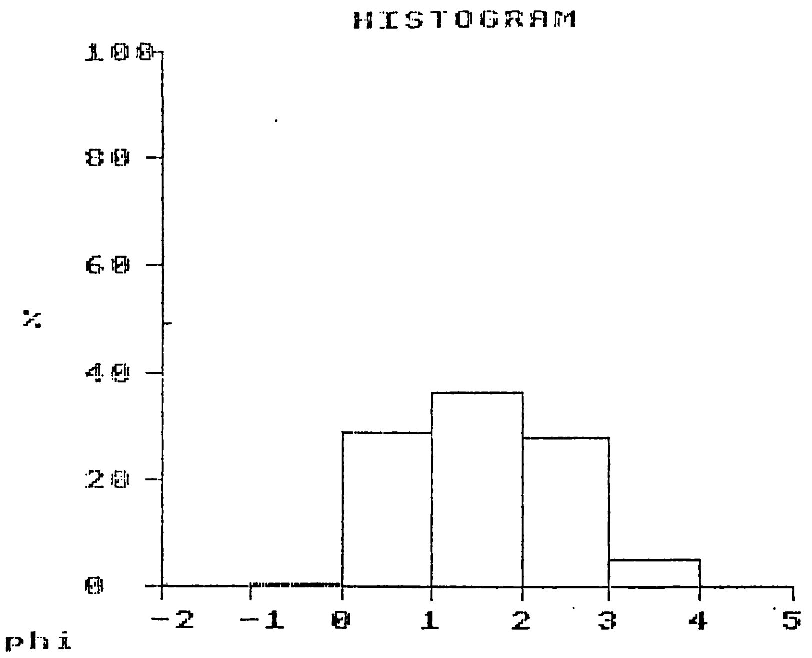


FIG. 4.9 PARTICLE SIZE HISTOGRAM OF BEACHES SEDIMENTS FROM UMM SAID

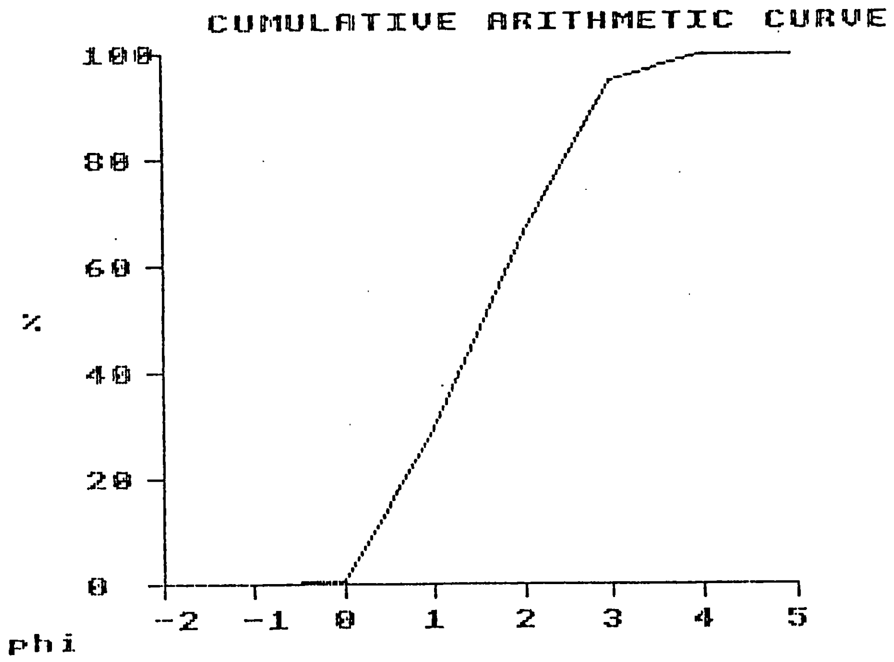


FIG. 4.10 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH SEDIMENT FROM UMM SAID.

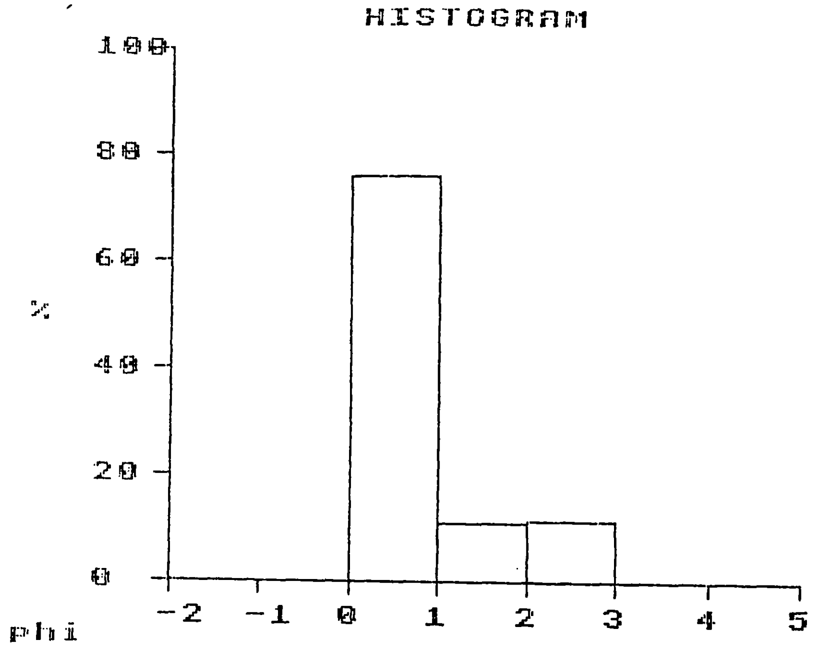


FIG. 4.11 PARTICLE SIZE HISTOGRAM OF SAND DUNES SEDIMENTS FROM UMM SAID.

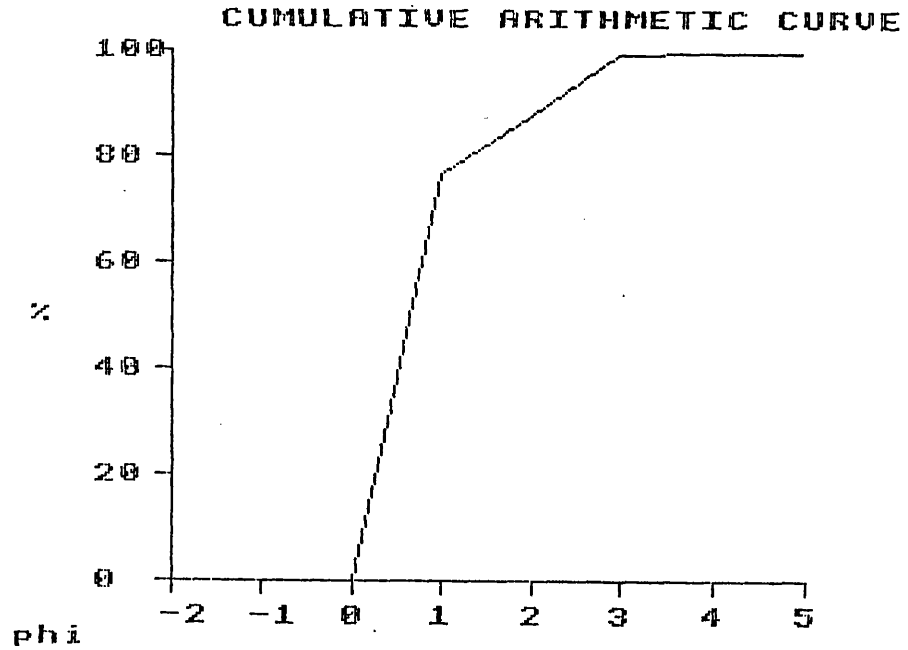


FIG. 4.12 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND DUNES SEDIMENTS FROM UMM SAID.

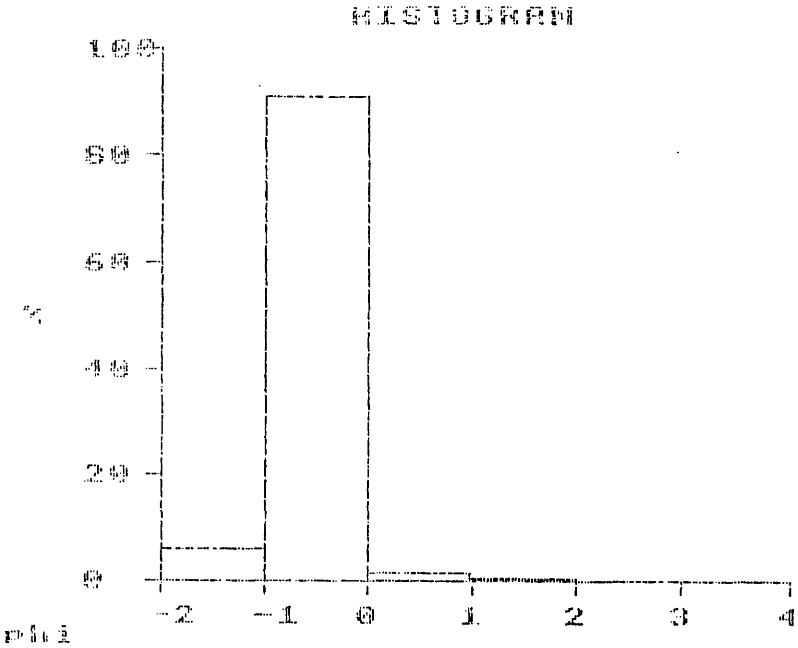


FIG. 4.13 HISTOGRAM OF PARTICLE SIZES FROM UNIT 1 IN TRENCH (SEE PLATE 4).

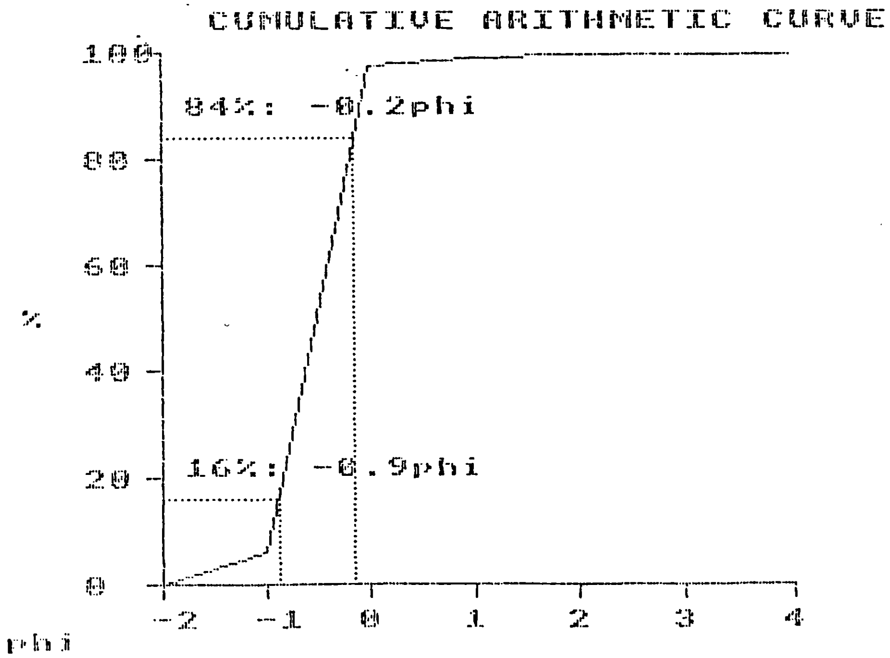


FIG. 4.14 CUMULATIVE PERCENTAGE PARTICLE SIZE: CURVE OF SEDIMENT FROM UNIT 1 IN TRENCH (SEE PLATE 4.2).

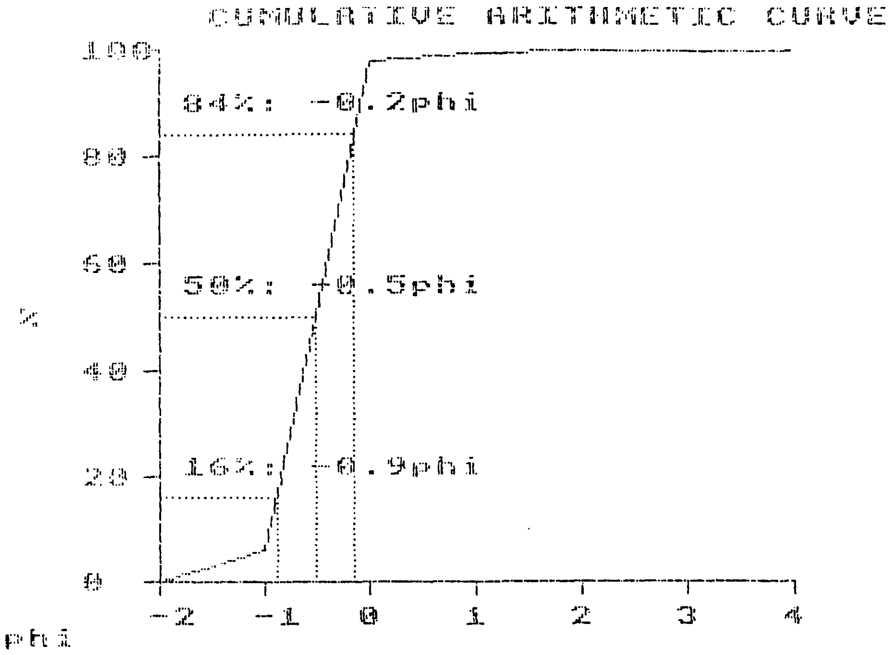


FIG. 4.15 CUMULATIVE PERCENTAGE PARTICLE SIZE: CURVE SEDIMENT FROM UNIT 1 IN TRENCH (SU) (SEE PLATE 4.2).

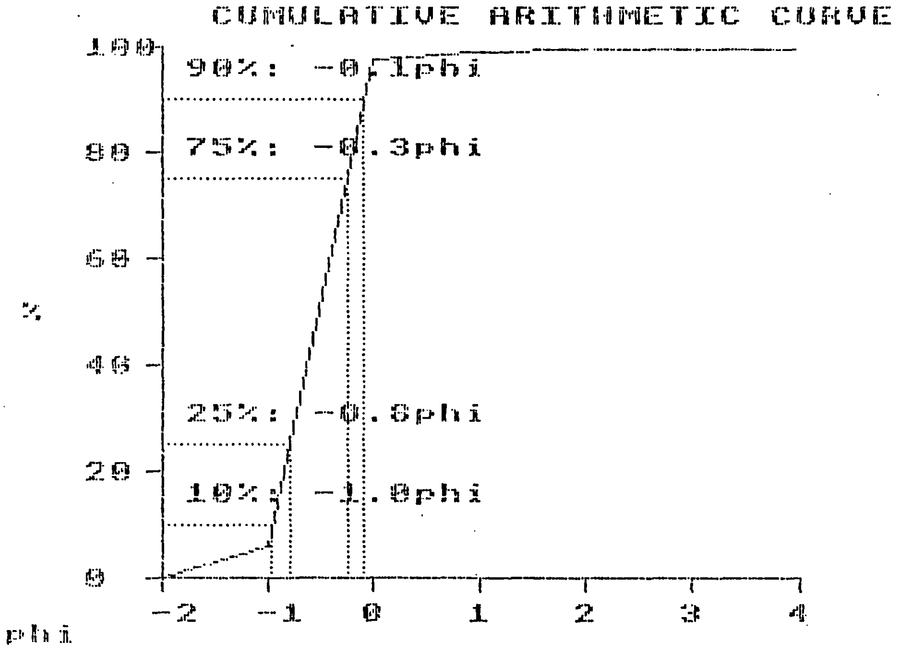


FIG. 4.16 CUMULATIVE PERCENTAGE PARTICLE SIZE: CURVE SEDIMENT FROM UNIT 1 IN TRENCH (KU) (SEE PLATE 4.2).

sand and some halite. Unit 2 comprises fine to medium-fine sand, reflecting the narrow range of grain sizes (Fig. 4.17). The sand is moderately sorted (S = +0.77) (Fig. 4.13) positively skewed (S = +0.07 (Fig. 4.19) and platykurtic (Ku = +0.88) (Fig. 4.20), sediments consist of cross-bedded wind deposited quartz sand.

## 4.9 Future Sedimentation

As a result of examination of the aerial photographs, LANDSAT imagery and field investigations it is clear that under the present climatic regime there will be a continual supply of sand to the Umm Said coastal area. The aeolian lineaments were interpreted from LANDSAT (see Chapter I) including sand sheets and sand dunes and the form of these lineaments has been closely related to the prevailing (NW-SE) wind "Shamal" (Fig. 4.21 and Plate 4.3).

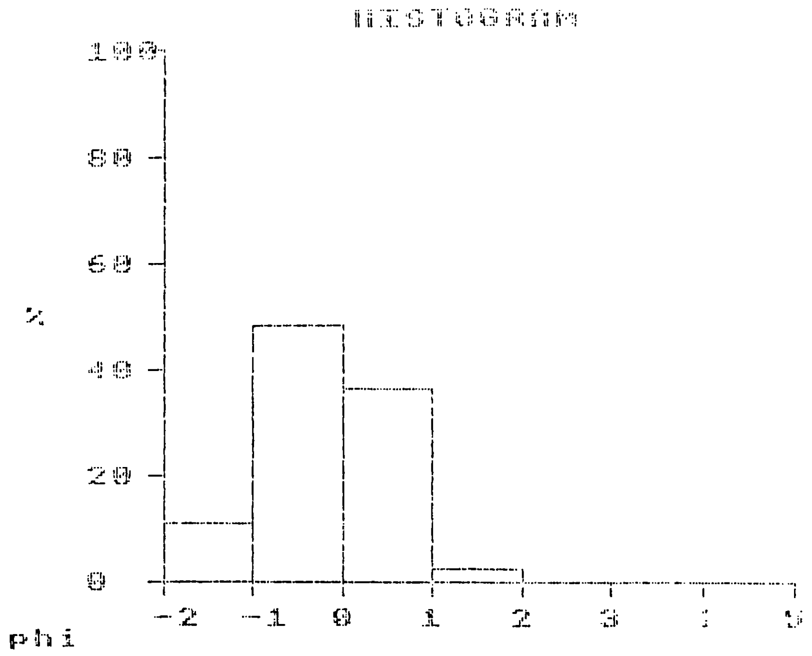


FIG. 4.17 HISTOGRAM OF PARTICLE SIZES FROM UNIT 2 IN TRENCH (SEE PLATE 4.2)

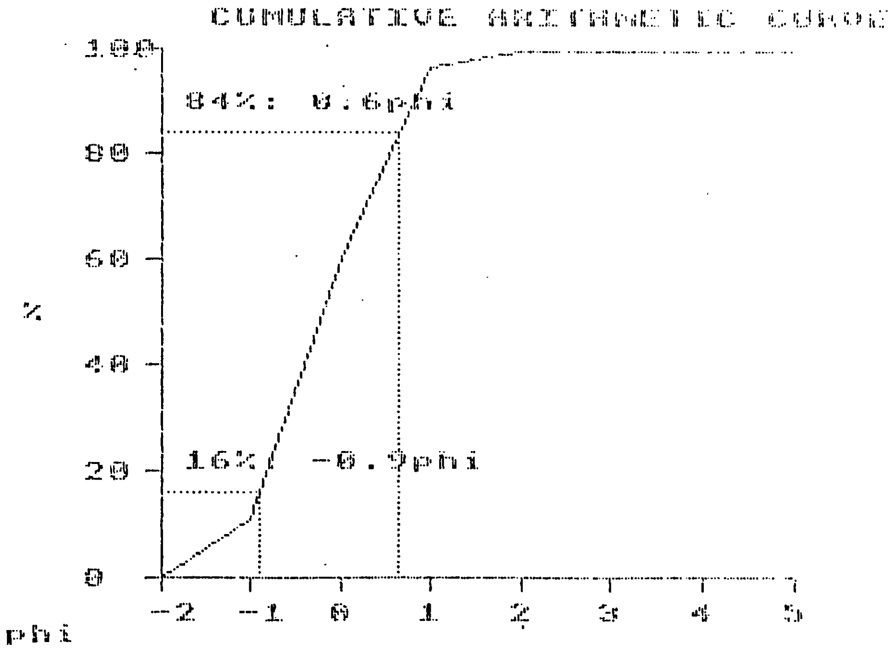


FIG. 4.18 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SEDIMENTS FROM UNIT 2 IN TRENCH (SEE PLATE 4.2).

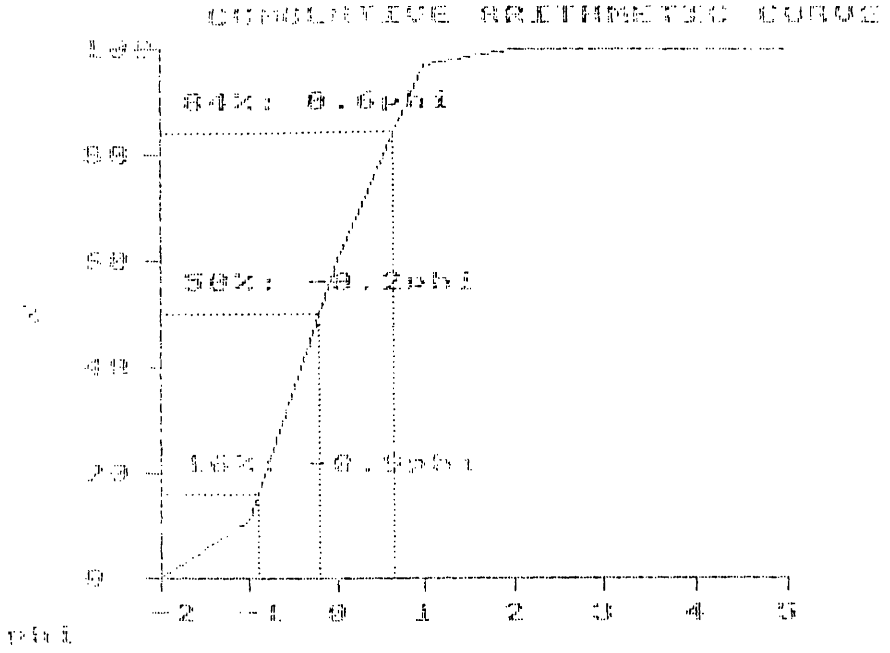


FIG. 4.19 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SEDIMENTS FROM UNIT 3 IN TRENCH (SEE PLATE 4.2) (SK).

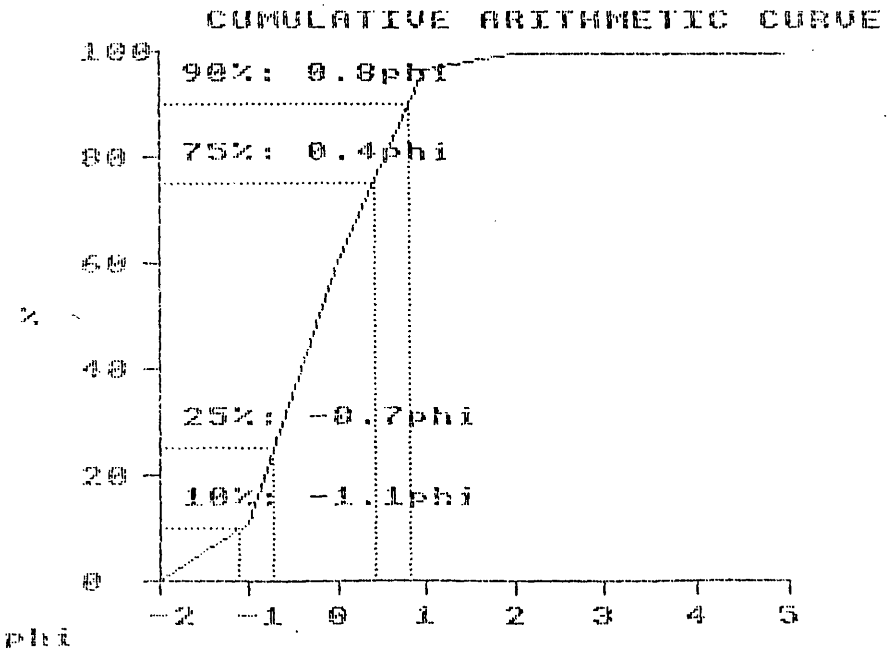


FIG. 4.20 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SEDIMENTS FROM UNIT 2 IN TRENCH (SEE PLATE 4.2) (KU).

## 4.0 Summary

Two types of sabkha can be distinguished.

First, there are coastal sabkhas which are distributed extensively along the east coast, and second, there are the inland sabkhas which are distributed on the western part of the Peninsula of Qatar and the southern part near the border with Saudi Arabia. The sabkha of Umm Said is flooded by high tides and winter rain. Chemical analysis carried out by the Department of Agriculture in Qatar on samples of sabkha sediment showed that these sediments contain mainly sulphate, chloride but also include sodium, calcium and magnesium as the main cations. Thus they contain the most dominant anions and cations. Mechanical analysis was also undertaken on the beach. The grain size ranges (S = +0.07) and platykurtic (Ku = +0.88). The analyses indicate that in Units 1 and 2 the sediments consist mainly of wind deposited quartz sand.

Sediments are transformed in different ways, by wind, waves and tidal currents, which cause undercutting and transport of sediment down the dune slip face. These sands are subsequently reworked by waves and in the tidal channel. Aerial photographs, LANDSAT imagery and field investigation indicate that sedimentation is dependent on the prevailing (NW-SE) wind "Shamal" for their general movement.

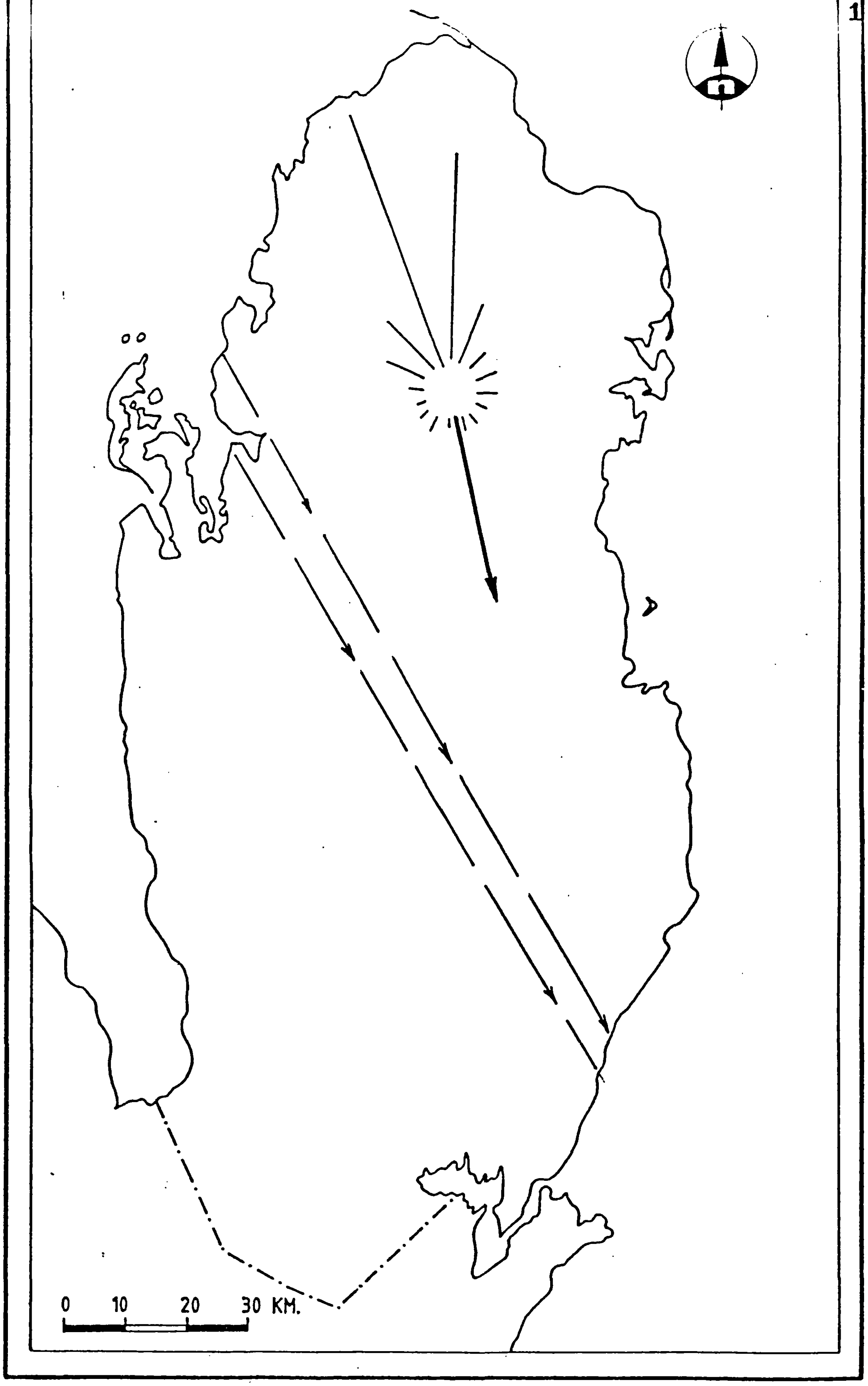


FIG.4.21 DIRECTION OF FUTURE SEDIMENTATION. THE SAND ROSE SHOWS PRINCIPAL DIRECTION FROM WHICH SAND DRIFTS. ARROW ON SAND ROSE INDICATES RESULTANT DRIFT DIRECTION.

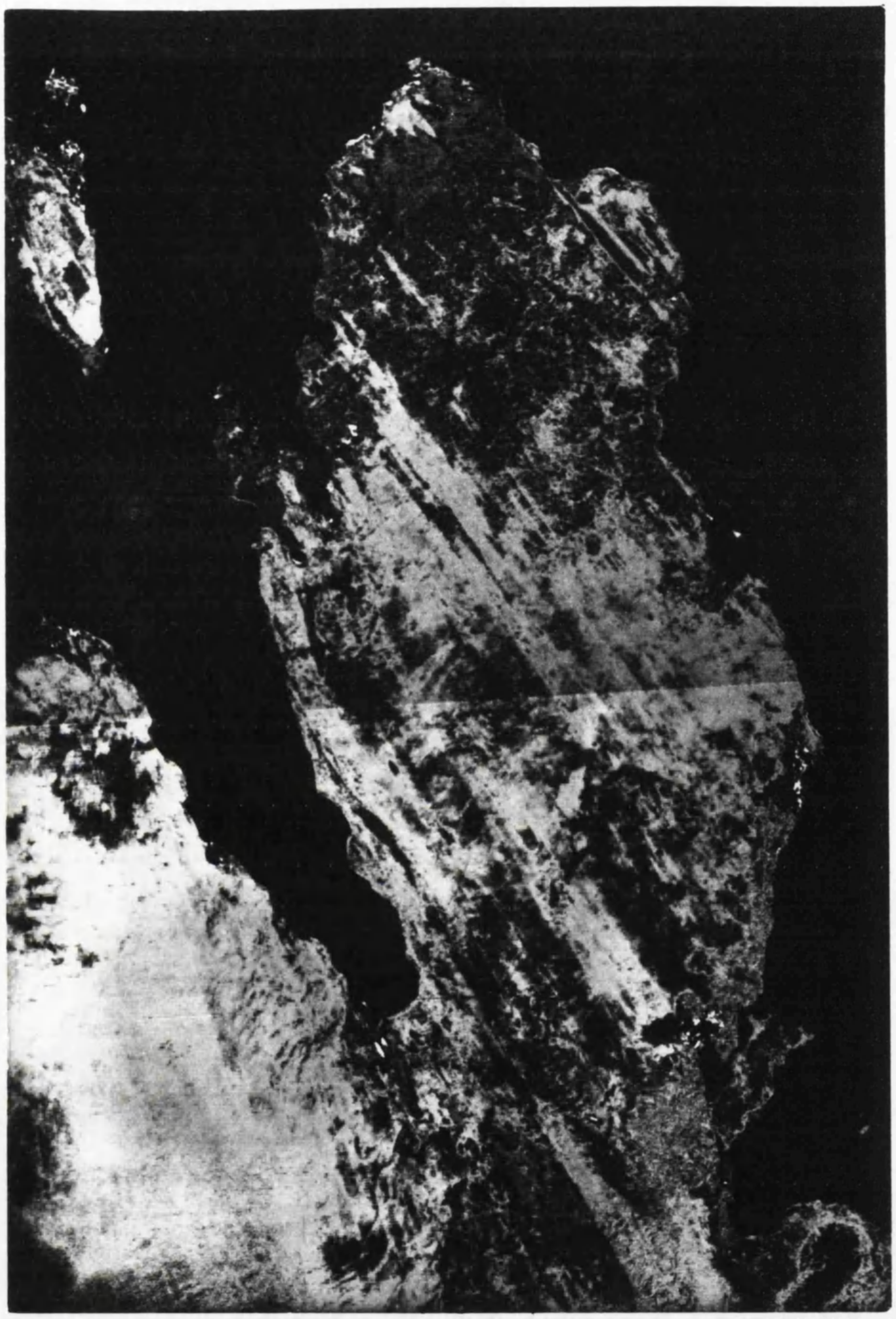


PLATE 4.3 LANDSAT IMAGE SHOWING THE DIRECTION OF THE PREVAILING WIND RESPONSIBLE FOR FUTURE SEDIMENTATION IN THE UMM SAID AREA.

# CHAPTER V

# WAKRA SPIT EAST COAST

# CHAPTER 5

## Wakra Spit : East Coast

### 5.1 Area Description

Wakra sandy spit lies on the east side of the Qatar Peninsula and for the most part is a single spit about 2.5 km long. The spit is joined to the mainland at its northern end, according to the 1963 aerial photographs, but by 1973 it had become cutt off from the mainland. The sandy ridge is now broken by two inlets about halfway along its length. To the west is a lagoon lying between the spit and the artificial coast of the settlement of Wakra Town. Wakra spit is subjected to a tidal range which averages about 0.5 to 1 metre along the east coast of the Qatar Peninsula. The western shore of the spit is subjected to refracted waves and it proved to be an ideal location for a study of beach form related to local wind-generated waves in the relatively shallow and protected water of the lagoon. Spit growth is controlled by the predominant and prevailing north-west wind (the 'Shamal') which accounts for waves for wave fronts moving generally north to south.

The area of study includes offshore sand banks formed mainly by the longshore currents that play an important part in determining the pattern of accretion in the offshore area, which in turn is closely related to the development of the spit. The sediments comprise a mixture of white oolitic sand, shells and coral reef fragments. Occasional waves break through the spit and spread sand over the muddy area in the sheltered lagoonal area (Fig. 5.1 ).

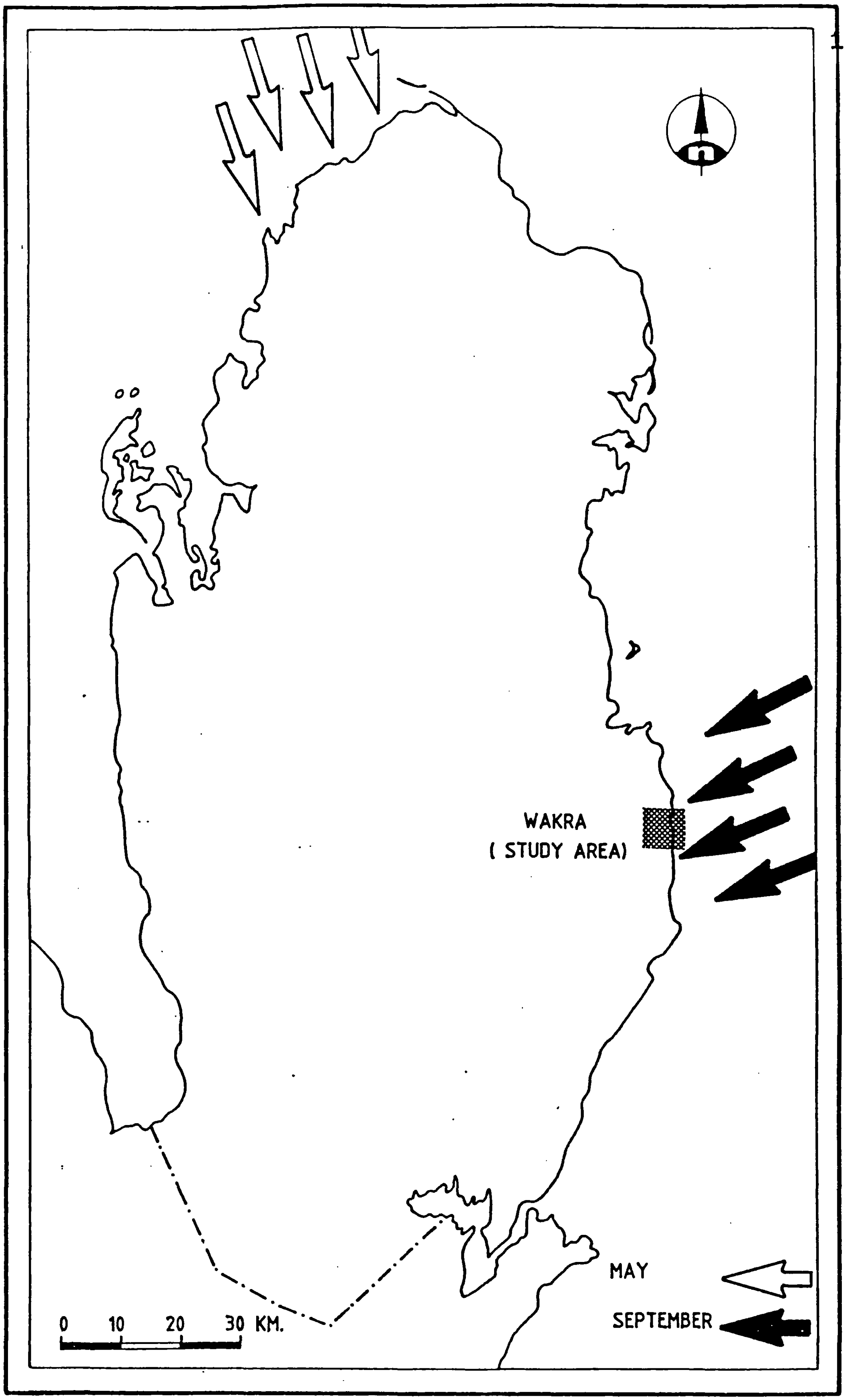


FIG. 5.1 PREDOMINANT NORTH WEST "SHAMAL" AND EAST WINDS THAT CONTROL SPIT GROWTH.

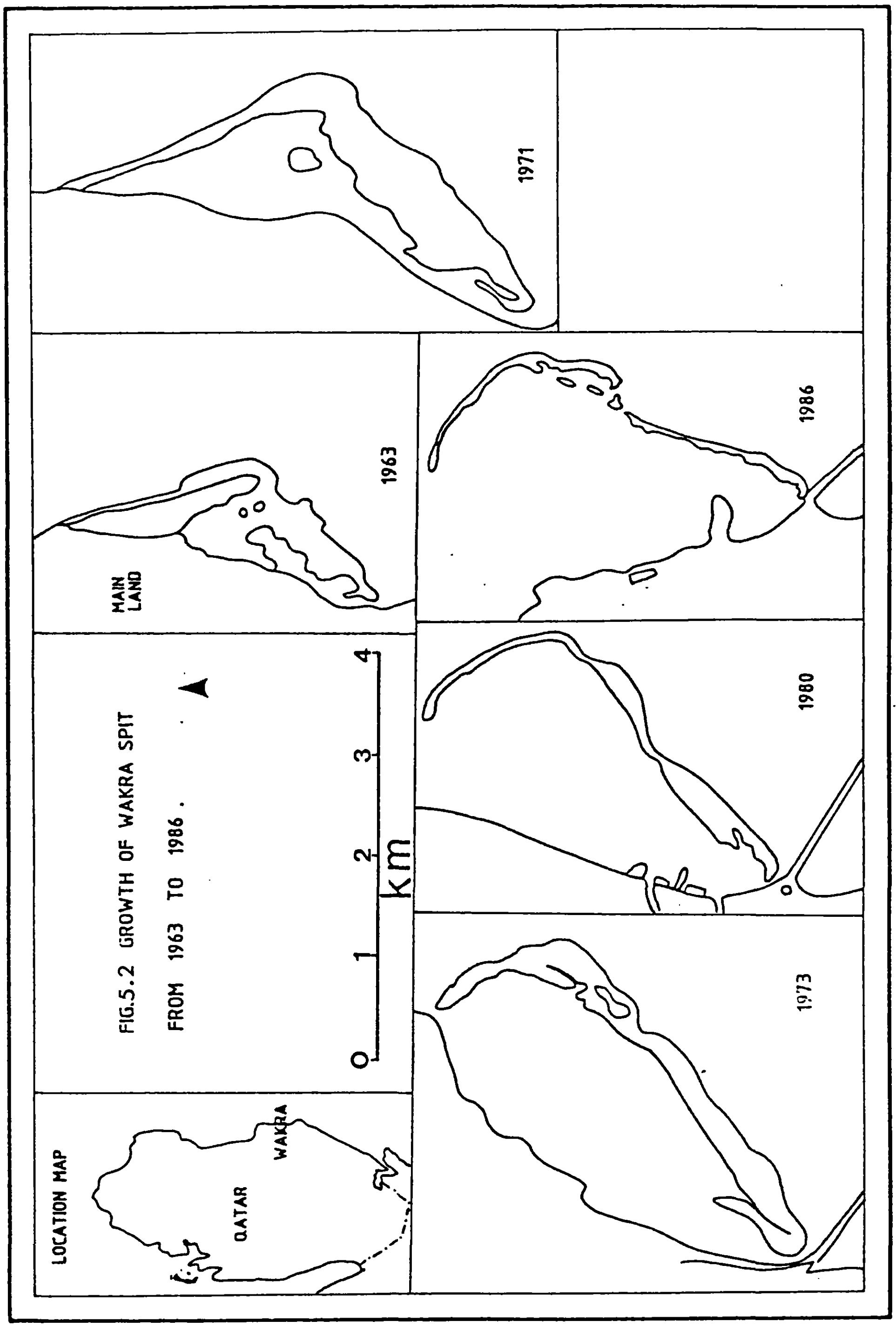


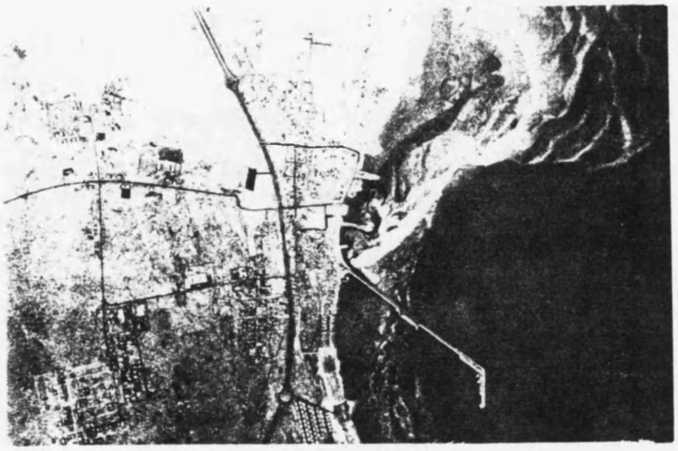
FIG.5.2 GROWTH OF WAKRA SPIT FROM 1963 TO 1986.

PLATE 5.1 WAKRA SPIT FROM 1963-1980.

1963

1971

1973



1980

## 5.2 Aerial photograph interpretation and map analysis

The direction of growth of Wakra Spit has been determined by examining sets of aerial photographs. Four vertical aerial photographs by Hunting Air Survey cover the area of Wakra Spit and allow consideration of the period 1963-1980. The aerial photographs at various scales and at various dates are shown in Figure 5.2 and Plate 5.1. These photographs show the changes in the spit over the 17 year period. The differences in scales and dates of the aerial photographs combined with certain changes in the shape of the spit required particular care in relatively the spit on the older photographs to its appearance on the 1980 photographs (Plate 5.1). The area of Wakra spit is also covered by various topographic maps at two scales of 1:50,000 and 1:50,000 and 1:10,000 and a geological map at a scale of 1:100,000.

Interpretation of the changes in Wakra spit between 1963-1971 (Fig. 5.2 ) shows that slight changes have occurred on the recurved part of the spit (on the aerial photographs for the spit in 1971). Between 1963 and 1971, the spit was still attached to the mainland to the north with formation of a small lagoon behind the spit. Between 1971 and 1973 the spit had decreased in size, but between 1973 and 1980 the spit took on a different shape. The spit has been eroded and cut off from the mainland because of the extraction of the spit sand for building purposes which resulted in a shrinkage in its size. Between 1980 and 1982, the spit was divided by two inlets about half way along its length. The first inlet was about 7m wide and second about 10m wide (Plate 5.2 A and B), and the spit could also be observed to have decreased in size. The reason for this diversion of the spit may have resulted from an alteration in the sediment supply to the spit between 1980 and 1986. It would seem from the 1:10,000 map and photograph

PLATE 5.2 SPIT OF WAKRA HAS BEEN DIVIDED BY TWO INLETS, THE FIRST INLET AND SECOND INLET

taken during the field investigation in 1986 that the spit is building up again because of the formation of the two sand bodies which formed by longshore currents movement (Fig. 5.3 ). According to Bird (1984), waves are essentially a means of transmitting energy through water with relatively small displacement of water particles in the direction of energy flow, and the dimension of waves are determined partly by wind velocity, partly fetch (the extension of open water across which the wind is blowing), and partly by the duration of the wind, and he added that in the coastal waters where fetch is limited the height of the waves is proportional to wind velocity and the wave period is related to the square root of wind velocity. The wind-driven currents and waves along the coast of the Wakra spit are the most important mechanisms of sediment transport along this relatively shallow coast.

The waves and currents are mainly accountable in terms of the 'Shamal' wind and most of Wakra spit and the adjacent coastal environment is exposed to this wind. The tidal currents in this area are developed locally in the coastal water when strong winds are blowing and are oriented approximately parallel to the coast where they attain velocities of 0.5-1m/hr$^{-1}$.

## 5.3 Morphology of the Wakra spit

Wakra spit can be divided into different zones: (1) an offshore zone, extending from the seaward limit of sediment transport by wave action landward to mean low water; (2) a foreshore zone, extending from the mean low water to upper limit of swash and mean high water; and (3) a backshore zone, which extends landward from the upper limit of swash at mean high water to the upper limit of storm swash.

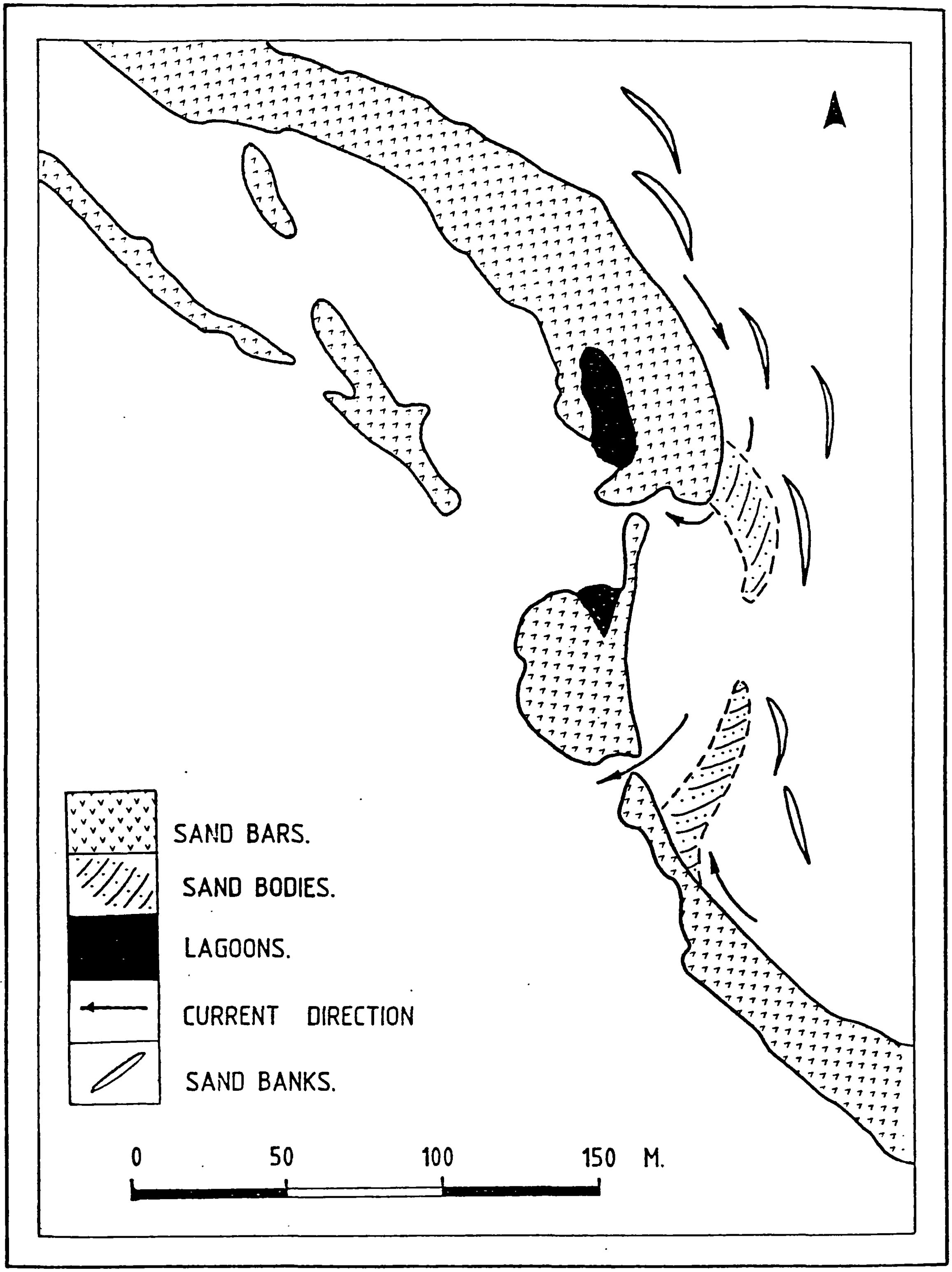


FIG.5.3 MAP SHOWING THE TWO INLETS BREAKING THE CONTINUITY OF THE SPLIT THROUGH THE PERIOD 1980 - 1968 AND THE FORM OF THE TWO SAND BODIES.

The shoreline profile of the spit shows a narrow gently-sloping beach face with a slope ranging from between $9^{\circ}$ to $12^{\circ}$ as demonstrated by Abney level measurement at various times and places (Plate 5.3). The spit has been constructed by local wind generated waves which have induced a southerly movement of sand which rapidly accumulated as a series of ridges. It is suggested from this study that the spit has undergone and probably will undergo a changing of development related to the formation of the beach ridges.

Wave refraction accounts for the distal recurves seen on most spits (Evans, 1942; Holmes;1944; Scheidegger, 1961). Simply stated, on the beach the waves will move onshore with their crest either parallel to the shore or at an oblique angle, depending on the orientation of the beach in relation to wind direction and or fetch. As the waves enter the shallow water, they become subject to refraction. This refraction affects the waves if they approach a straight shore obliquely or move directly on to a deeply intended shore. Refraction also occurs when waves pass the end of an obstacle such as a headland, a shingle foreland or a spit the waves tend to die out gradually. One of the most distinctive features of spits is the growth of the recurve at the distal end (Fig. 5.2, 1986; extreme southern end). In Wakra Spit these recurves formed due to wave refraction which causes the free end of the spit to curve gently round, and once in existence, then it modified local waves approaching from a direction counter to those responsible for the prevailing drift.

The processes of transportation involved in the building of Wakra spit are waves and currents. These result from prevailing north wind direction as well as the slope of the beach and availability, amount, and size of materials. In addition occasional winds blow

PLATE 5.3 NARROW, GENETLY-SLOPING BEACH OF 9° AT WAKRA SPIT.

from an easterly direction and influence the formation of the spit. The growth of Wakra spit shows that the eastward growth of the feature has been marked with the building of new hooked sand bodies, thus indicating waves and currents suitable for their construction, and a suitable site for accumulation . Field observations showed that there is a relationship between the beach profile and sediment size. Five profiles were carried out on different parts of the spit. Beach gradients varied from 9°-12°. Some of these profiles showed the development of a beach berm feature. A berm is a constructional morphological feature resulting from the onshore transport of sediments (King, 1972). This feature is defined as a linear sand body parallel to the shore that occurs on the landward portion of a beach profile. The berms of Wakra spit have a gently-dipping berm top (facing landward) and a more steeply dipping beach face (facing seaward). These two definitions of berm and beach face come from classifications by Wiegli (1953) and Hine (1979). There have been many field investigations and laboratory studies of the relationship between grain size and beach gradient and they are the best summarized in the work of Bascom (1951) carried out at Half Moon Bay, California, where a wide range of sediment sizes and beach gradients were encountered.

## 5.4 Sediment analysis

The spit is formed predominantly of sand but includes some shells, and coral reef fragments. Ten samples were collected from the beach face and berm (top of the berm) and five samples were collected from the sand bodies and from different parts of the spit

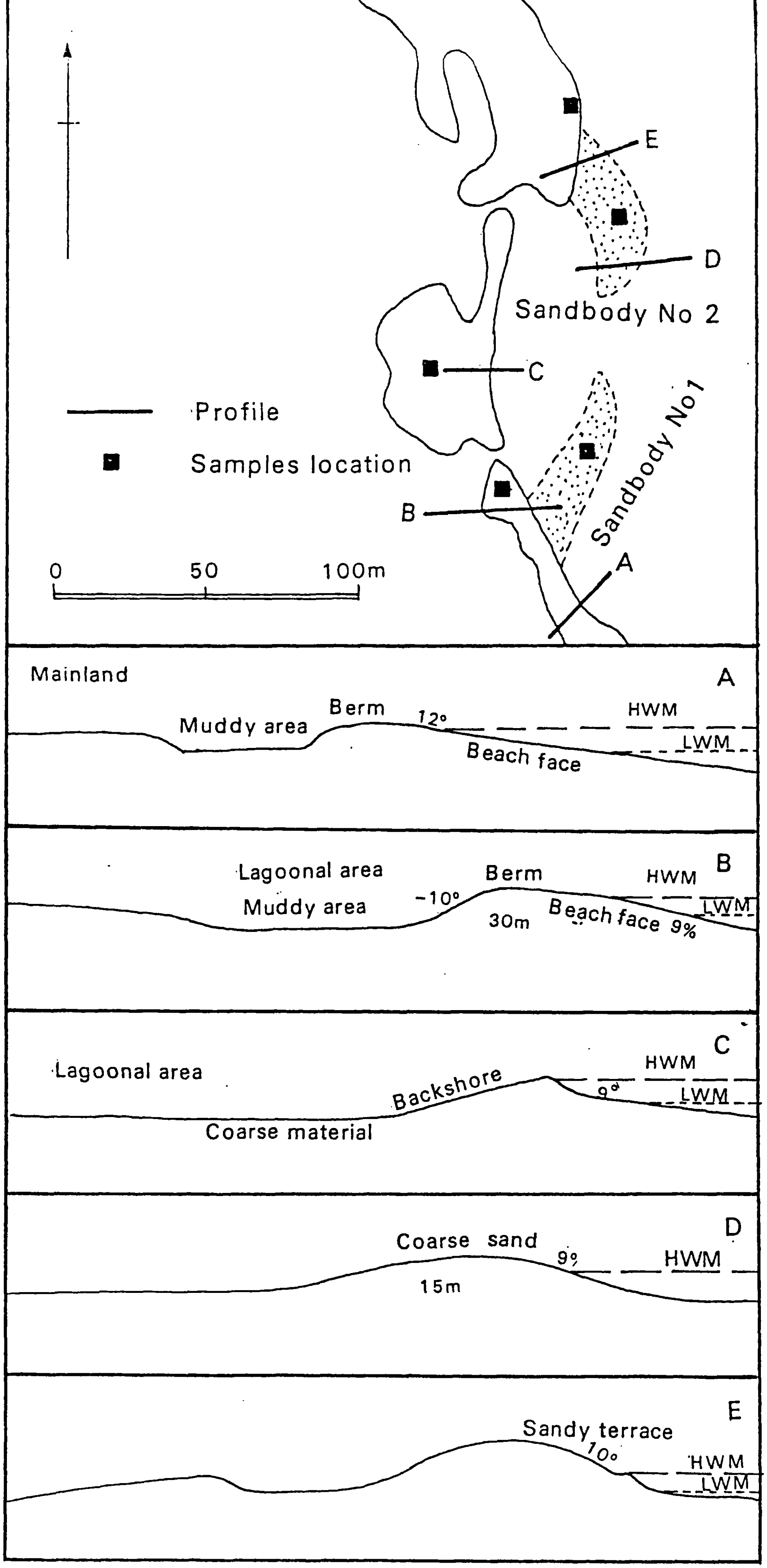


FIG. 5.4 SELECTED PROFILES AND SAMPLE LOCATION AT WAKRA SPIT.

(Fig. 5.4 for sample locations and profiles). These samples indicated that the grain sizes lie between fine and medium-fine sand which is shown in Figure 5.5. The cumulative percentage particle size curve reveals that the sediments are moderately well sorted and well sorted sand with a mean sorting coefficient of 0.70. The sediments are very positively skewed with mean of skewness value of 0.21 and from Figure 5.6 it can be seen that the particle size curve for the beach face and berm tend to have the same shape to the curve for all sand size in the range -1.0 to 20. This distribution of grain size is due to the sorting action of waves and currents and winds along the coast of the Wakra spit. The other samples were collected from 5 sites along the neighbouring beach profiles from the crests of the spits and they have been designated by the letters A to E (Fig. 5.4).

The sample collected from site A has fine to medium-fine sand, reflecting the narrow range of its grain Sizes (Fig. 5.7). The cumulative percentage particle size curves reveals that the sediment is moderately well-sorted (S = 0.66) (Fig. 5.8). The sediment is also slightly positively skewed (Sk = 0.1) (Fig. 5.9) and leptokurtic (Ku = 1.24) (Fig. 5.10). Sediment from the first sand body (site B) comprises fine to medium coarse sand (Fig. 5.11), while the cumulative percentage particle size curve reveals that the sample is moderately well sorted (Fig. 5.12), positively skewed (Sk = 0.21) (Fig. 5.13) and leptokurtic (Ku = 1.20) (Fig. 5.14). Site C is in the middle of the spit (Fig. 5.15). It comprises fine and medium-fine sand. The cumulative percentage particle size curve reveals that the sediment is poorly sorted (S = 1.15) (Fig. 5.16),

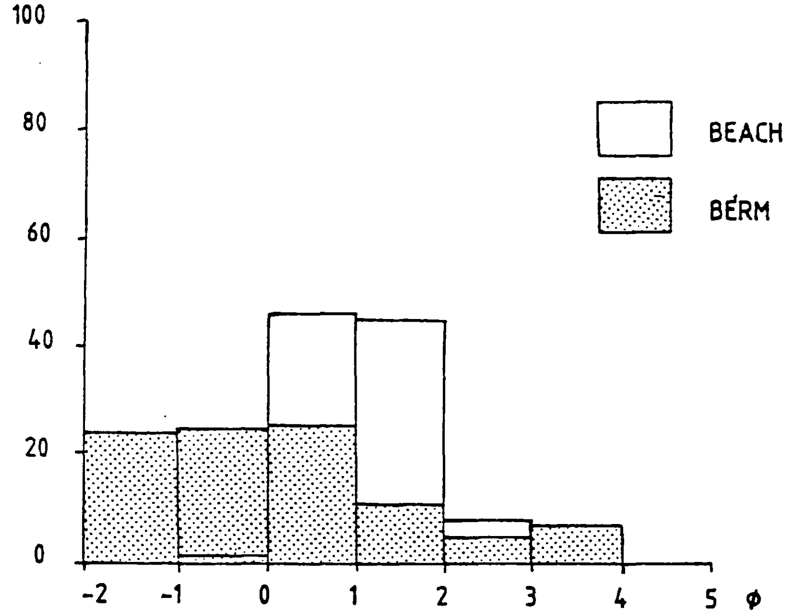


FIG.5.5 SUPERIMPOSED HISTOGRAM FOR THE SAND FRACTION FROM BEACH FACES AND THE BEACH BERMS.

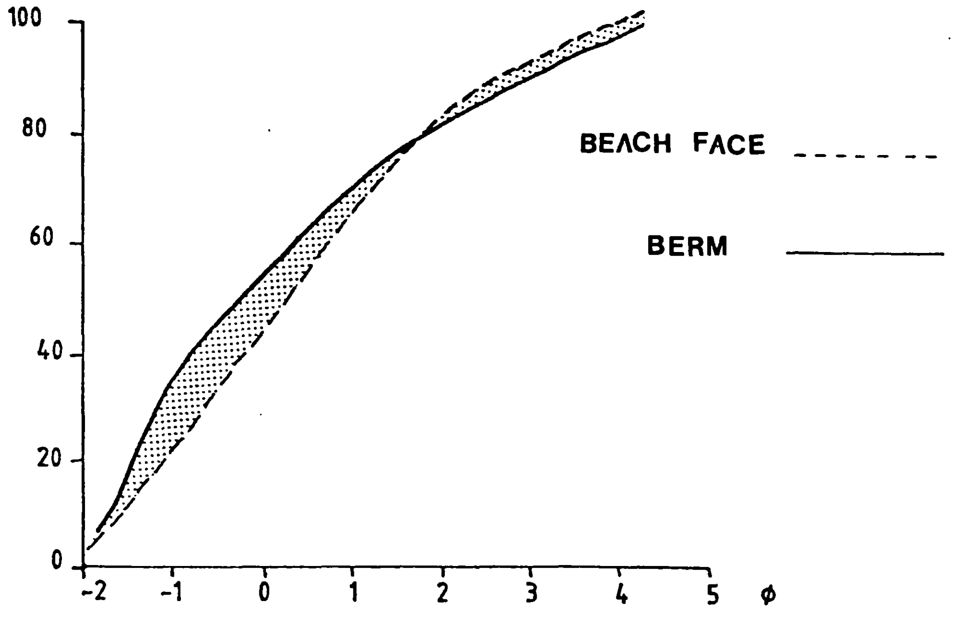


FIG.5.6 CUMULATIVE PERCENTAGE CURVES FOR BEACHES AND BEACH BERMS.

slightly negative skewed (Sk = -0.03) (Fig. 5.17 ), and platykurtic (Ku = 0.84) (Fig. 5.18 ). A sample from the second sand body (site D) shows that the grain size distribution lies between fine and coarse sand (Fig. 5.19 ). The cumulative percentage particle size curve shows that it is moderately sorted (Fig. 5.20 ), slightly positively skewed (Sk = 0.10) (Fig. 5.21 ) and leptokurtic (Ku = 1.15) (Fig. 5.22 ). A sample collected from the spit crest (site E), has a particle size distribution ranging from fine to coarse sand (Fig. 5.23 ). The particle size range is moderately sorted (S = 0.94) (Fig. 5.24), positively skewed (Sk = 0.01) (Fig. 5.25) and mesokurtic (Ku = 0.95) (Fig. 5.26).

## 5.5 Summary

Wakra sandy spit lies on the east coast of Qatar Peninsula and is joined to the mainland at the northern end and is subjected to a tidal range which averages about 0.5 to 1.0m/hr$^{-1}$. The interpretation of the aerial photographs and map analysis has revealed that the spit shows changes in the form over a 17 year period (1963-1980).

The growth of the spit has been controlled by the prevailing 'Shamal' wind which accounts for the predominant waves moving north to south. There are also other processes responsible for the building of Wakra spit. These are the wind-driven currents and the tidal currents which form important mechanisms for sediment transport. Several profiles were surveyed along the spit and the sand bodies. These show a narrow, gently sloping beach face with slope angle ranging between 9$^{o}$ and 12$^{o}$. Some of these profiles reveal the development of a berm reflecting the onshore transport of sediment.

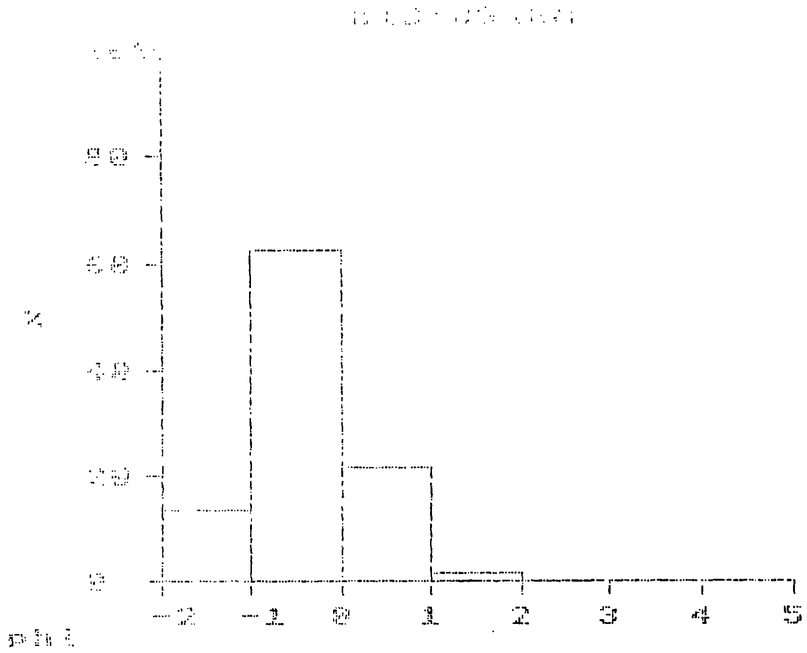


FIG. 5.7 HISTOGRAM PARTICLE SIZE FROM SITE A (SEE FIG.5.5).

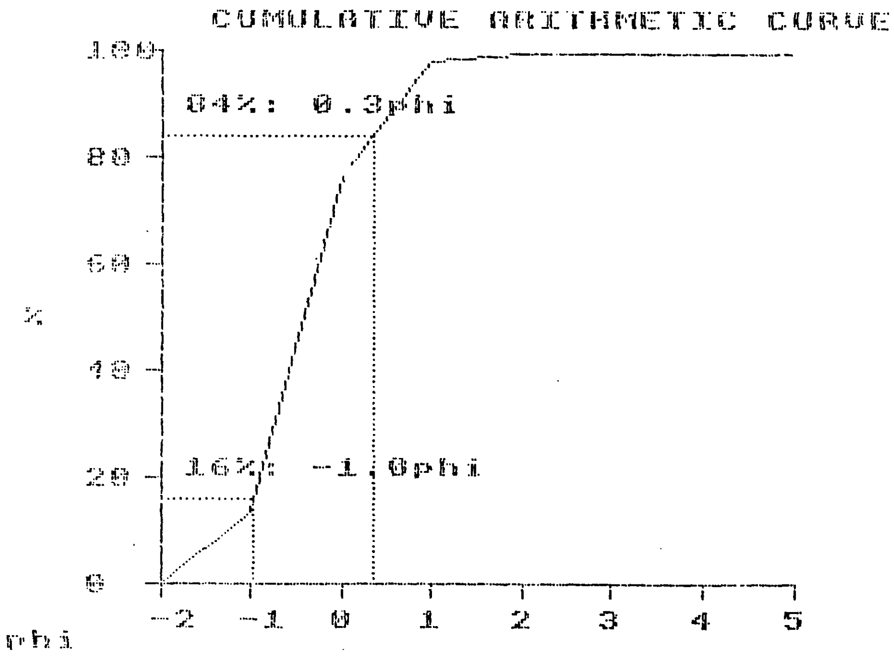


FIG. 5.8 CUMULATIVE PERCENTAGE PARTICLE SIZES OF SITE A, FROM WAKRA SPIT.

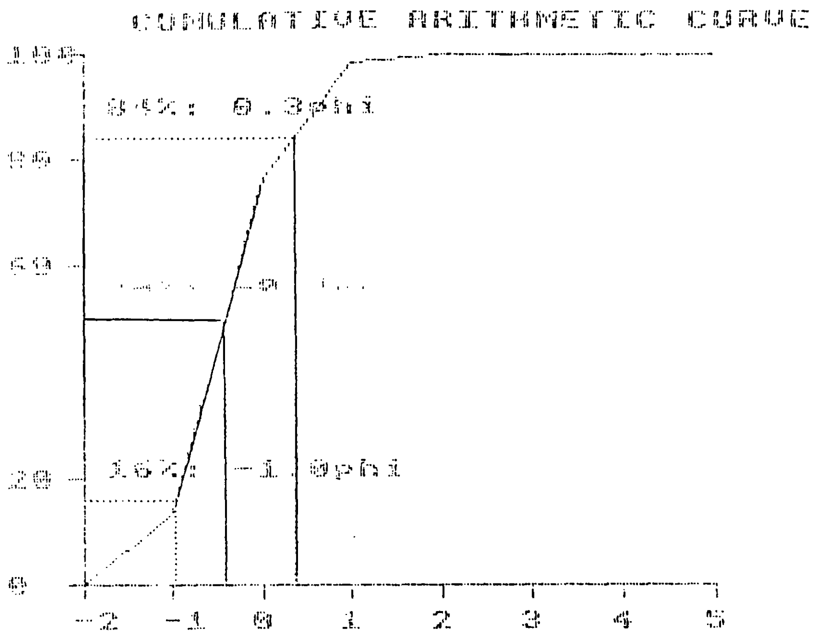


FIG. 5.9 CUMULATIVE PERCENTAGE PARTICLE SIZES OF SITE A, FROM WAKRA SPIT (SK).

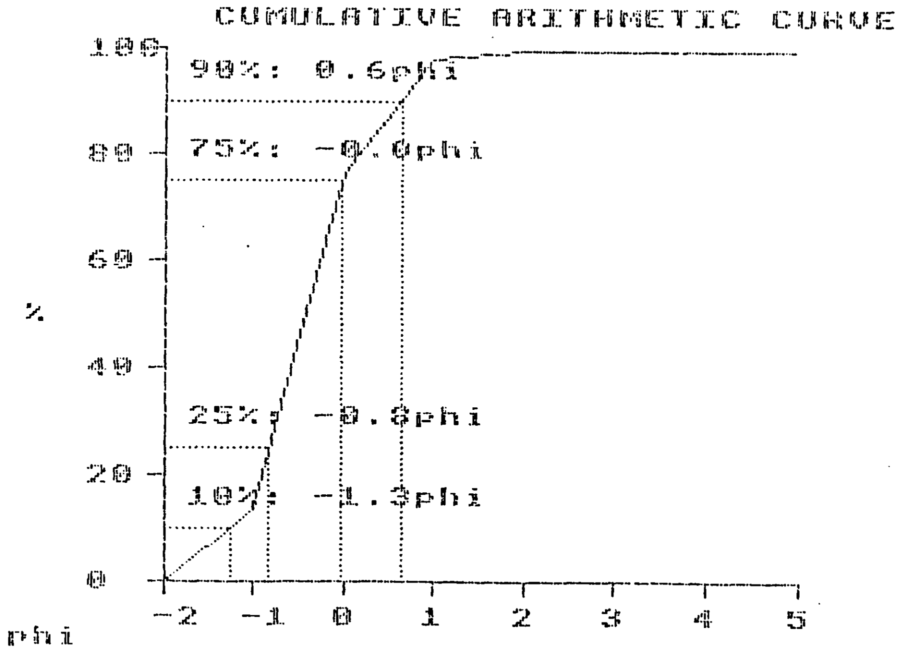


FIG. 5.10 CUMULATIVE PERCENTAGE PARTICLE SIZES OF SITE A, FROM WAKRA SPIT (KU).

Mechanical analysis revealed that sediments collected from the beach face and berm lie between fine and medium-fine sand and are moderately well sorted (S = 0.70) and positively skewed (Sk = 0.21). This analysis indicated that the grain size sorting is due to wave, current and wind action. Samples were also collected from different parts of the spit, and from the sand bodies. Samples A, C and D, indicated that particle sizes lie between fine and medium-fine sand reflecting the narrow range of grain size.

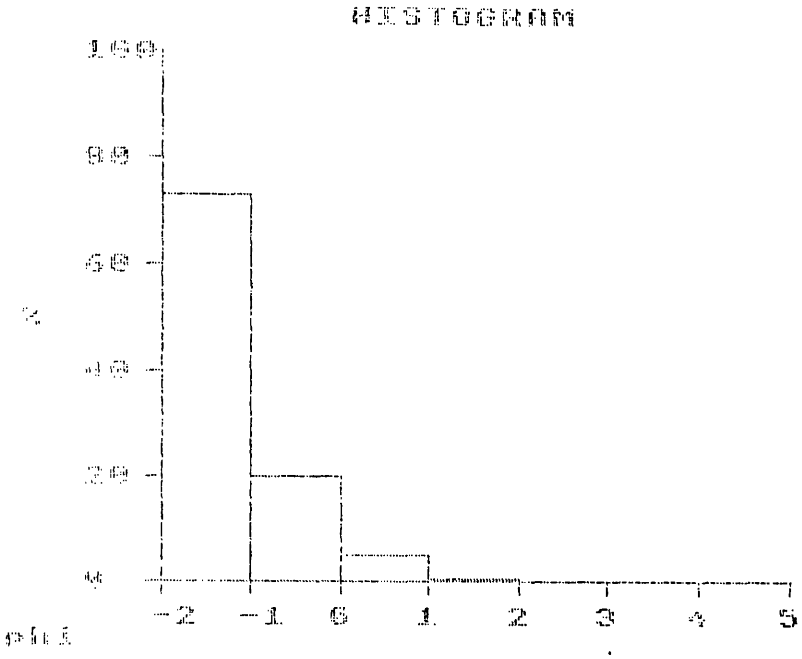


FIG. 5.11 PARTICLE SIZE HISTOGRAM OF SAND BODY FROM WAKRA SPIT (SITE B).

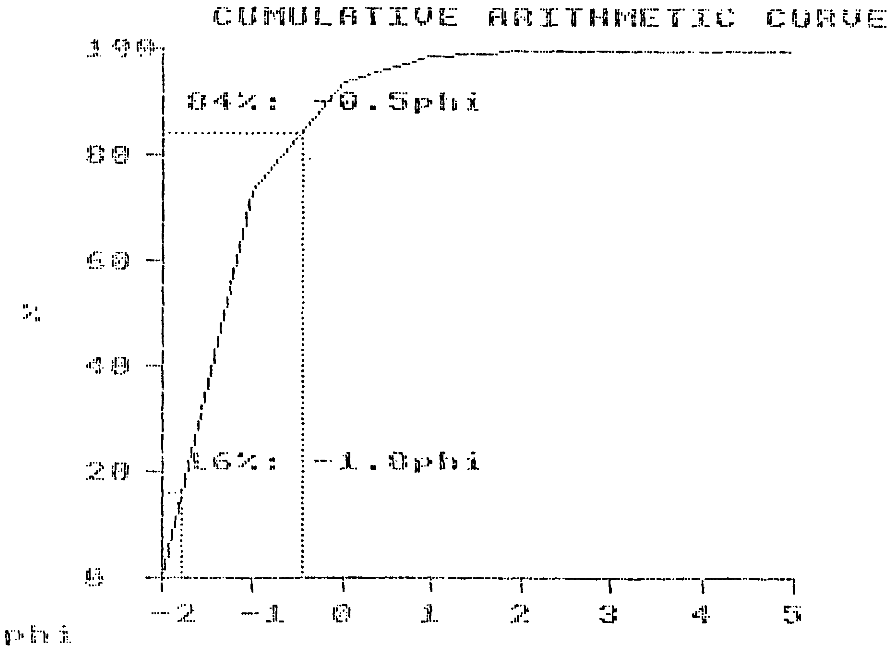


FIG. 5.12 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY FROM WAKRA SPIT.(SITE B).

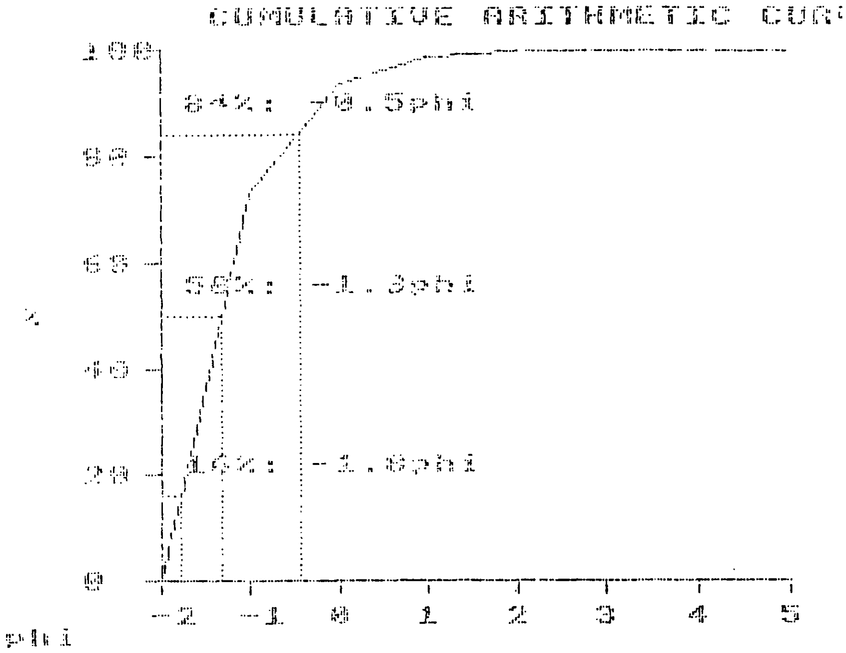


FIG. 5.13 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY FROM WAKRA SPIT (SK).(SITE B).

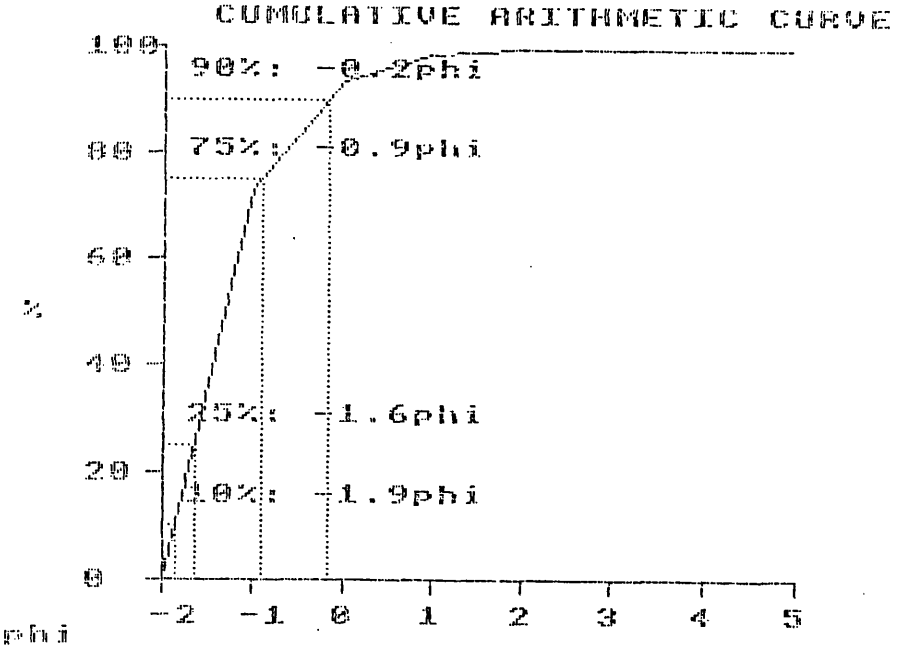


FIG. 5.14 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY FROM WAKRA SPIT (KU).(SITE B).

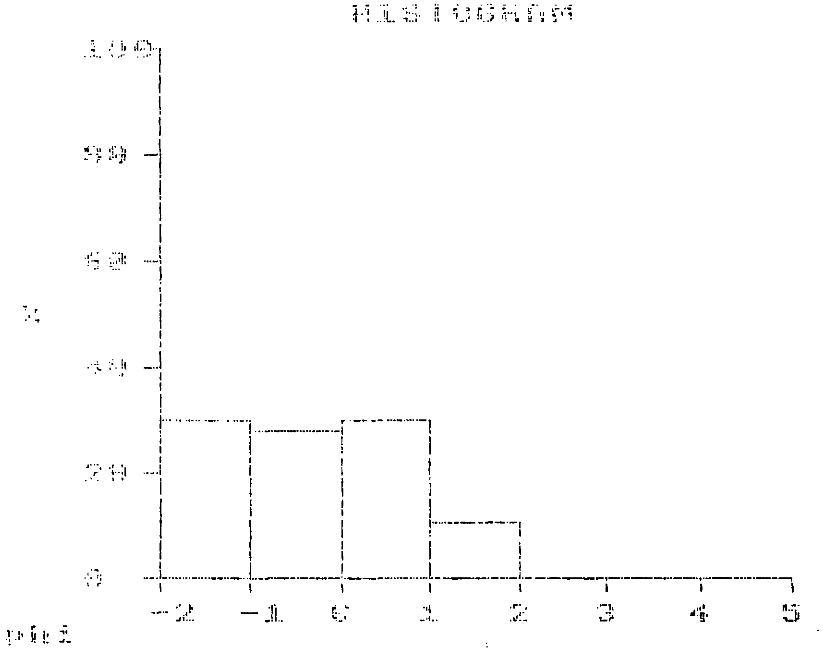


FIG. 5.15 PARTICLE SIZE HISTOGRAM FROM SITE C (SEE FIG. 5.5).

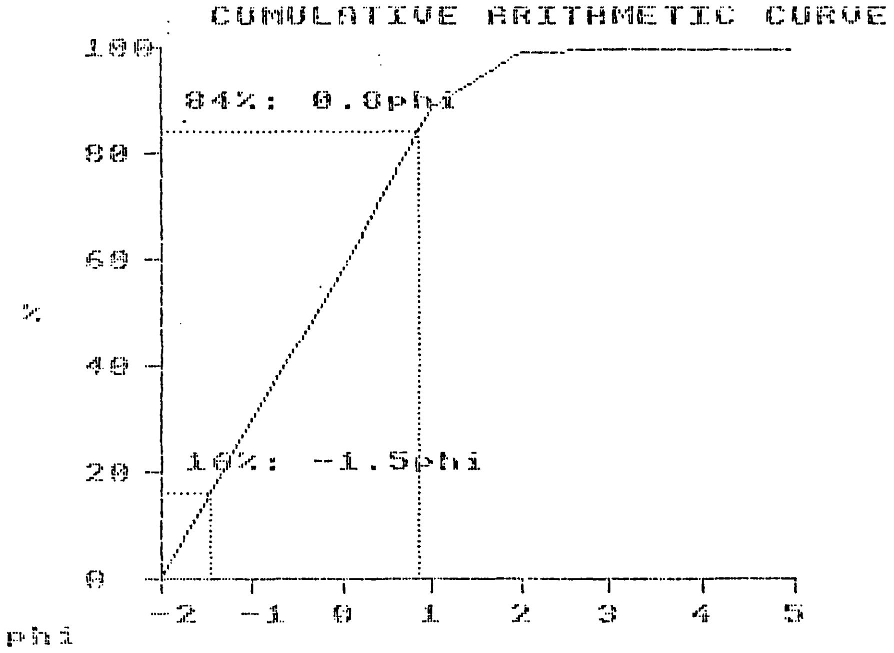


FIG. 5.16 CUMULATIVE PERCENTAGE PARTICLE SIZES OF SEDIMENT FROM SITE C FROM WAKRA SPIT (SEE FIG. 5.5).

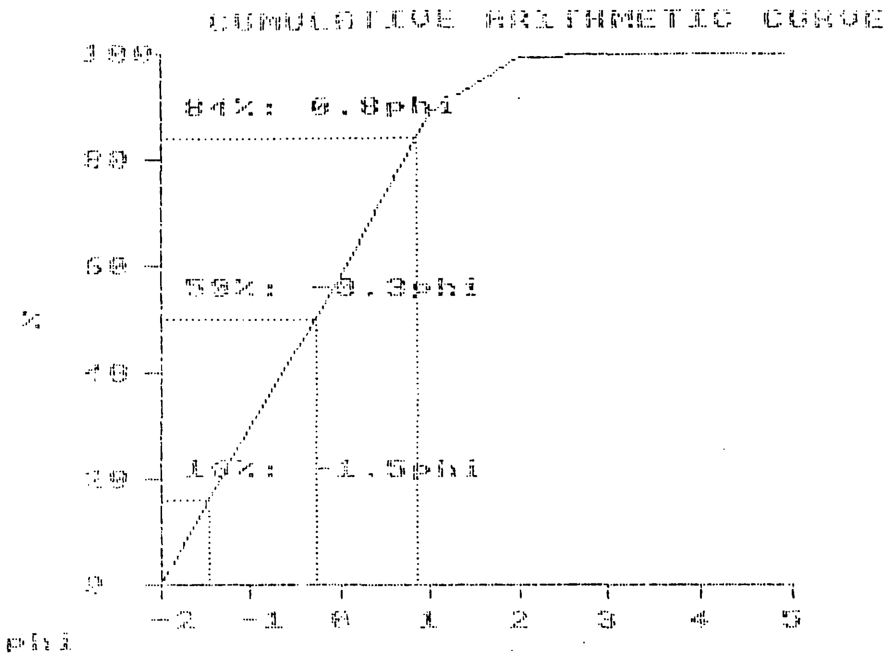


FIG. 5.17 CUMULATIVE PERCENTAGE PARTICLE SIZES OF SEDIMENT FROM SITE C FROM WAKRA SPIT (SK).

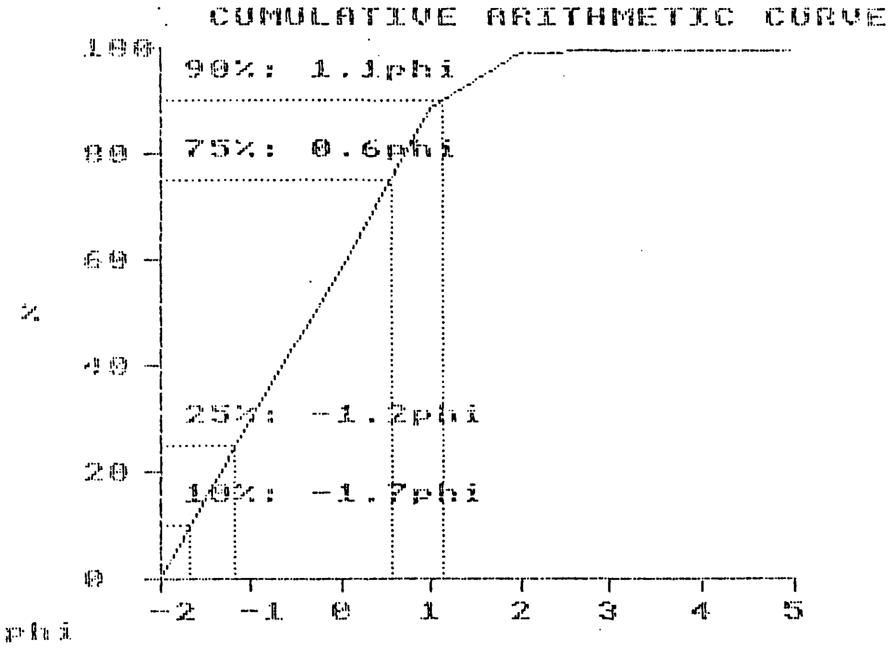


FIG. 5.18 CUMULATIVE PERCENTAGE PARTICLE SIZE: CURVE OF SEDIMENT FROM SITE C FROM WAKRA SPIT.

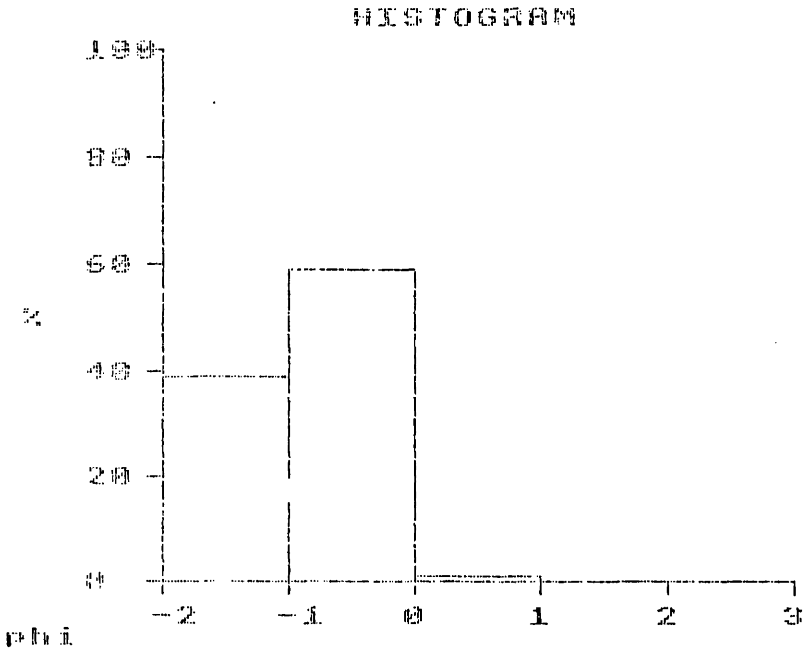


FIG. 5.19 PARTICLE SIZE HISTOGRAM OF SAND BODY, SITE D FROM WAKRA SPIT.

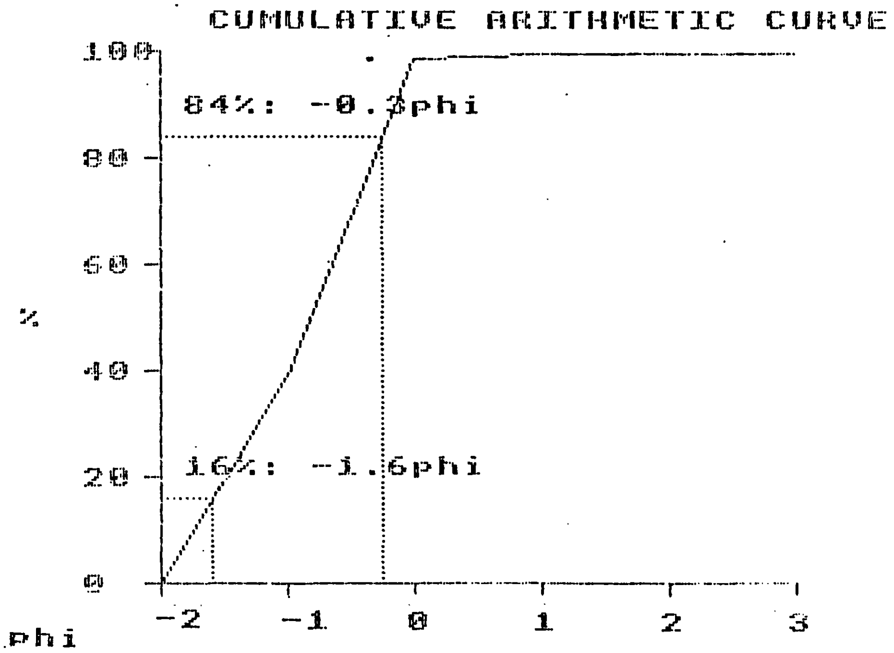


FIG. 5.20 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY, SITE D FROM WAKRA SPIT.

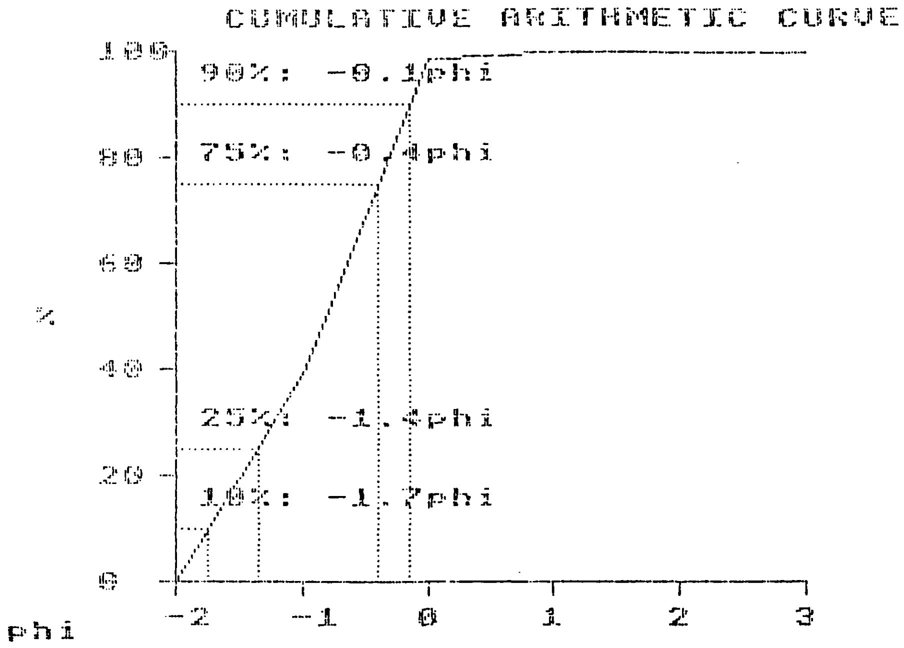


FIG. 5.21 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY, SITE D FROM WAKRA SPIT (SK).

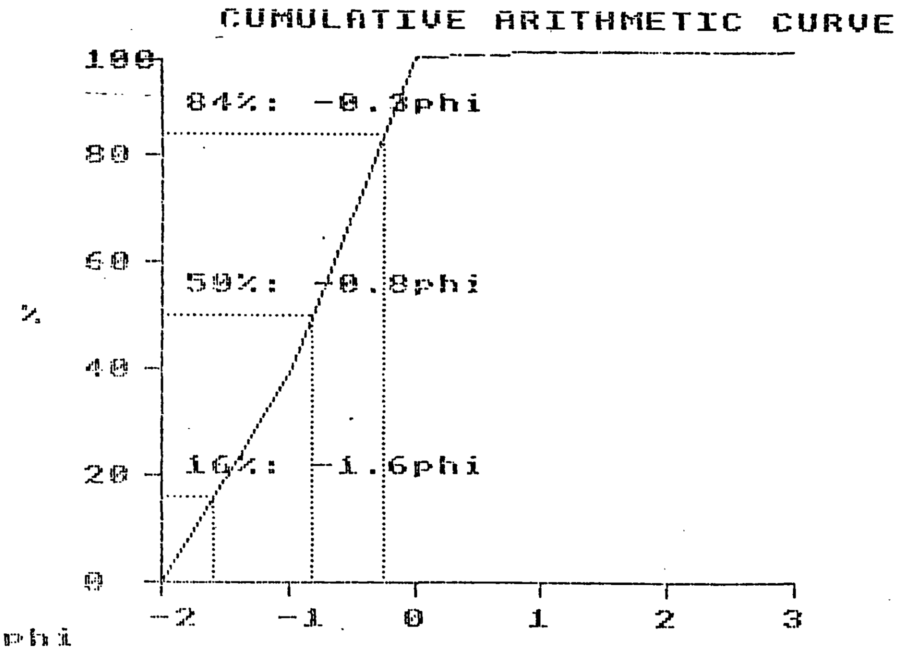


FIG. 5.22 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SAND BODY, SITE D FROM WAKRA SPIT.

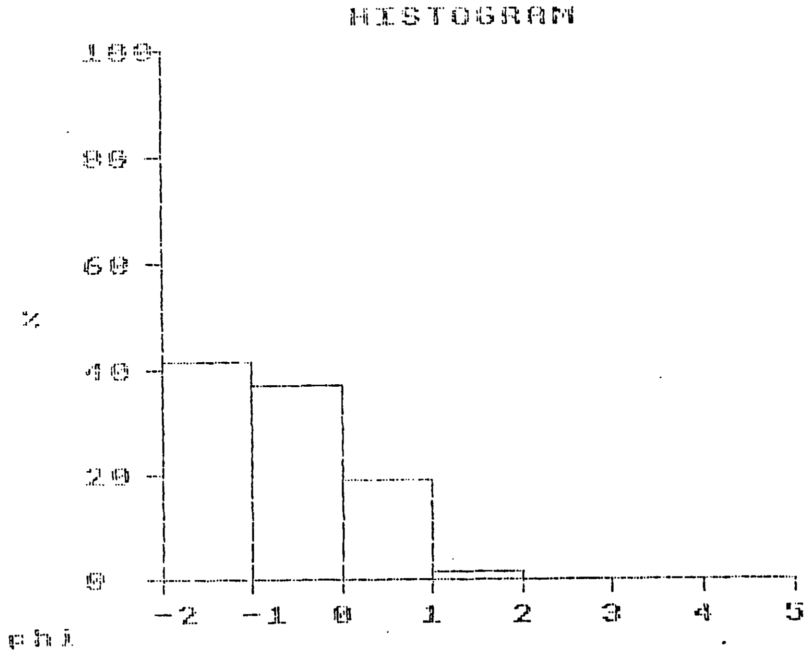


FIG. 5.23 PARTICLE SIZE HISTOGRAM FROM SITE E, WAKRA SPIT (SEE FIG. 5.5)

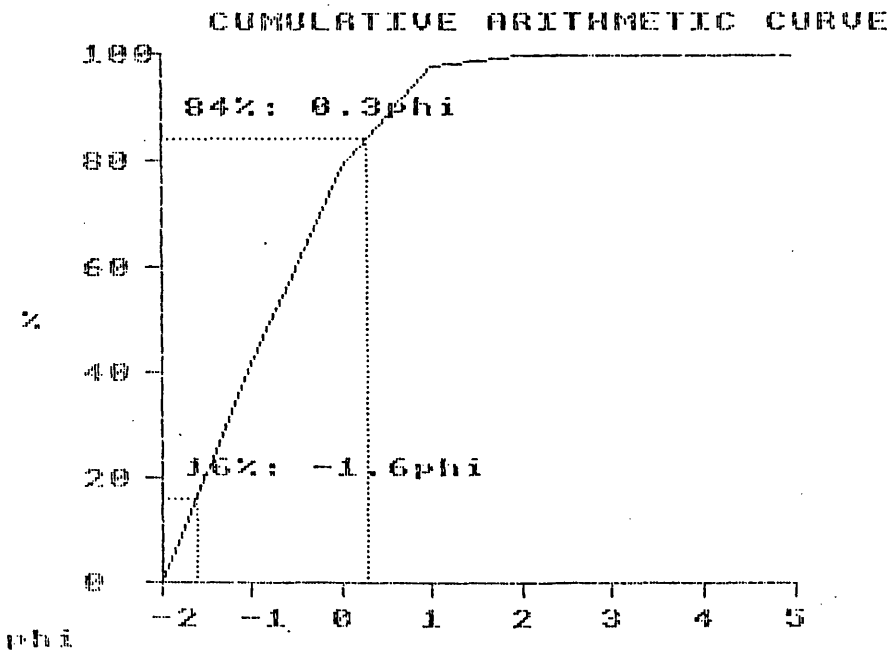


FIG. 5.24 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SITE E, WAKRA SPIT.

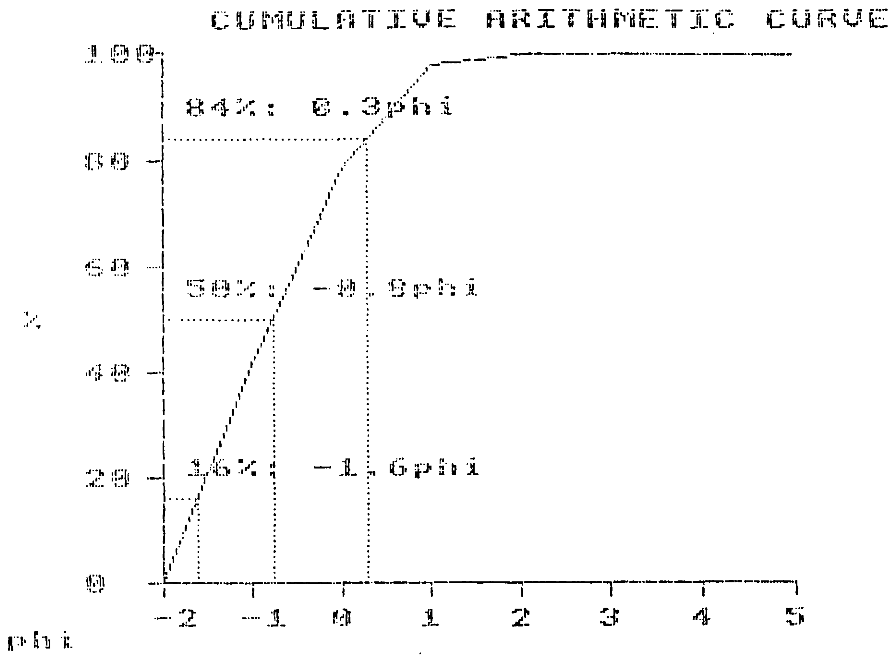


FIG. 5.25 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SITE E, WAKRA SPIT (SK).

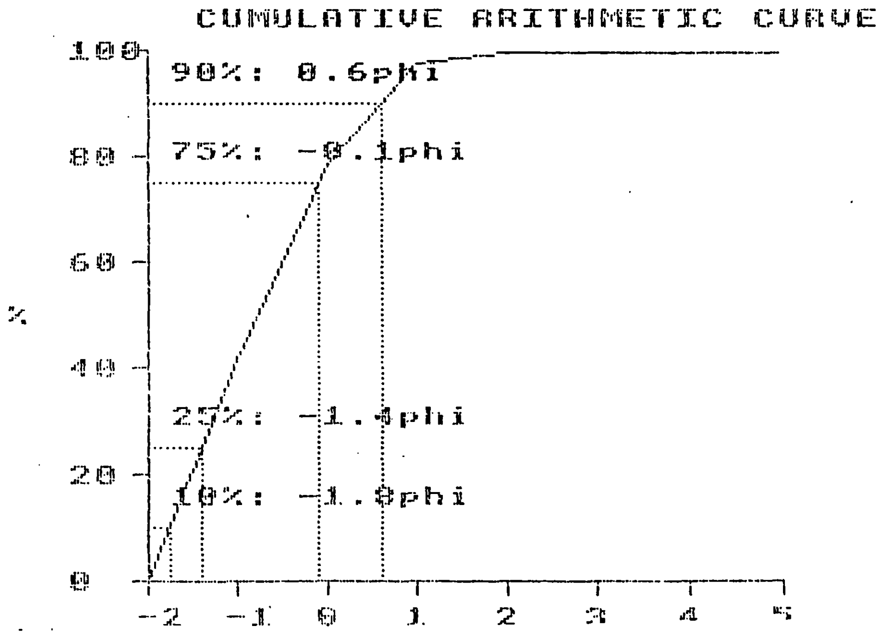


FIG. 5.26 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVE OF SEDIMENT FROM SITE E, WAKRA SPIT (KU).

# CHAPTER VI

# THE COASTAL LANDFORMS AND SEDIMENTS OF THE NORTH-EAST COAST : KHOR AND DAKHERA BAYS

# CHAPTER VI

## 6.1 The coastal landforms and sediments of the northeast Coast: Khor and Dakhera Bays

The coastal embayments of Khor and Dakhera Bays in the northeast of the Qatar Peninsula consist of cliffs and sediment derived from the Eocene Limestone and Dolomite of the Rus formation (Fig. 6.1 ). The plateau surface which extends to the cliff top averages about 20 metres above sea level and extends inland as a more or less level surface for about 8km. Sabkhas have formed which consist mainly of mud with a content of dolomite (10-20%). The thickness of these sediments ranges from 20 to 50cm in Khor and Dakhera. The development of coastal sabkhas results from the constant submergence of a low coast by high tides (1-2m) and these sabkhas extend for several kilometres inland. The water in the bays is generally about 5 metres deep and the salinity attains 41%-39% while the temperature ranges seasonally from 40-50°C. In the shallower water near the shoreline there is a rapid ebb flow between high and low water. Various morphological features have been identified, such as sand bars, spits, muddy surfaces, mangroves and creeks, all of which have been formed in most bays (Figs. 6.2 , 6.3 and 6.4 ). This has been determined by analysis of the aerial photographs for 1963 through to 1977. The tidal range of the area is usually between 0.5 and 1.0m when these sand bars are composed of sand deposit 40% with 40% clay and 20% of silt. Hooked spits were formed in various parts of Khor and Dakhera bays where they can be divided into groups according to their size. The first group of hooked spits comprises large ones,

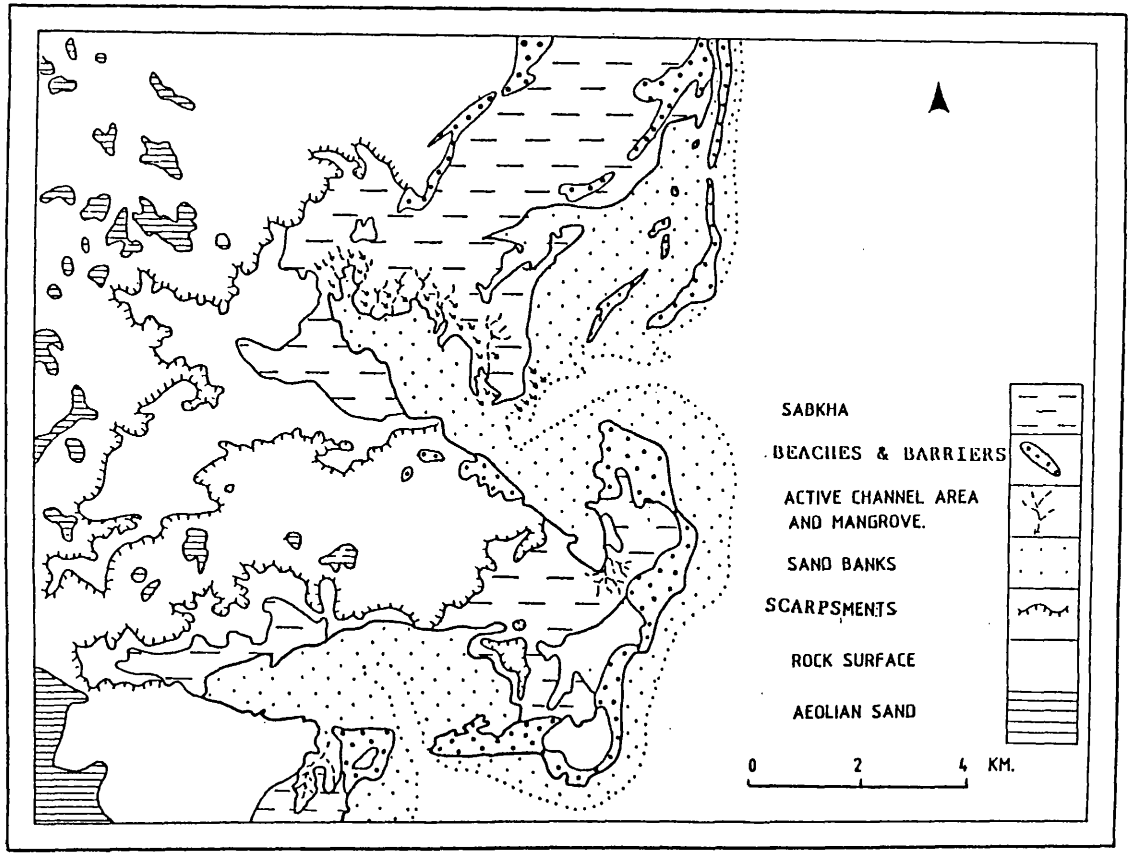


FIG. 6 . 1 GEOLOGICAL MAP KHOR AND DAKHERA .

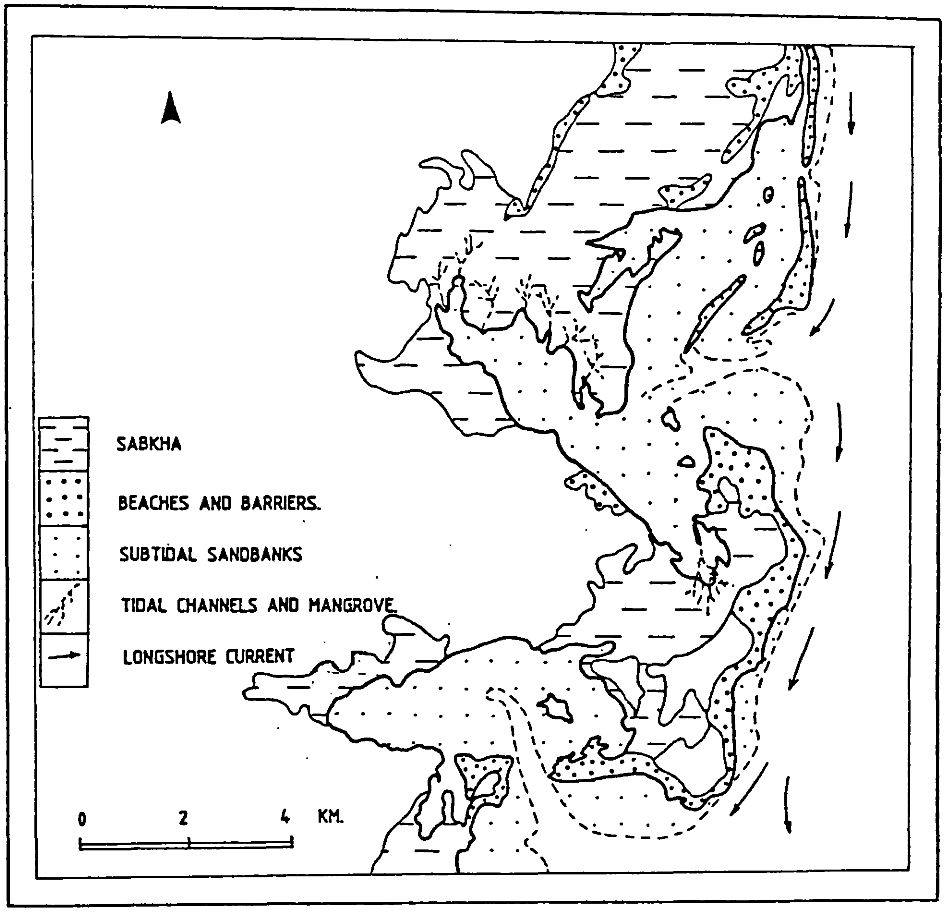


FIG.6.2 COASTAL FEATURES AROUND KHOR AND DAKHERA BAYS.

their lengths ranging between 1.5 and 3km and their breadth varying between 20m to 22m. The second group consists of small hooked spits not exceeding 1km in length.

## 6.2 Tidal-flat sedimentary deposits zonation

On the tidal flats of the study area of Khor and Dakhera bays important geomorphic features have been recognized in the bordering marine areas and in the channel zone, and within each area a series of subdivisions has been recorded.

(1) subtidal flat area; (2) intertidal flat area: (3) supratidal flat area (Fig. 6.5 ).

### (1) Subtidal flat area

This is an area which is composed of the sediments deposited below low-tide level, and it can be divided into adjacent marine, channel, and pond zones. The area of the subtidal flat extends seaward. Sometimes it is referred to as nearshore marine sediments. According to Shin (1973), the subtidal mud and silt constitute the thickest and most extensive deposits in places more than 3m thick in the Dakhera area. Tidal channels form attributory system of curving and winding channels (Plate 6.1A and B), the main channel ranging from 50 to 100m in width. Sand bars may exist in the channel system for 10m near the inner banks of meander bends (Fig. 6.6 ). Levées are another feature which has been formed along the side of the main channel, and built up where the erosion is most active. Across the flooded area a series of cut-off shallow saline ponds has developed as the course of the tidal creeks have changed through time.

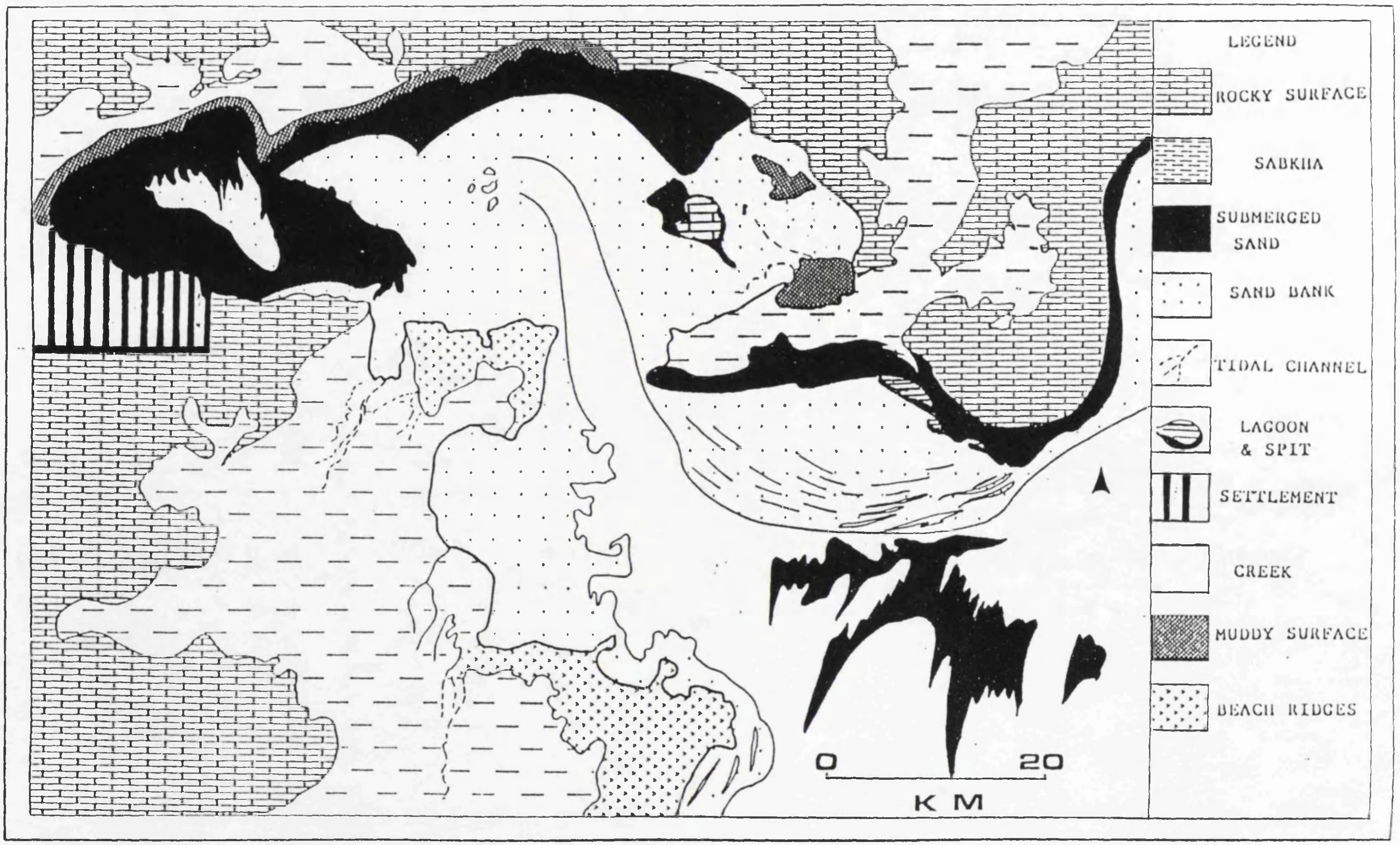


FIG.6.3 KHOR BAY, OVERLAID FROM AERIAL PHOTOGRAPH 1976 (MORPHOLOGICAL FEATURES).

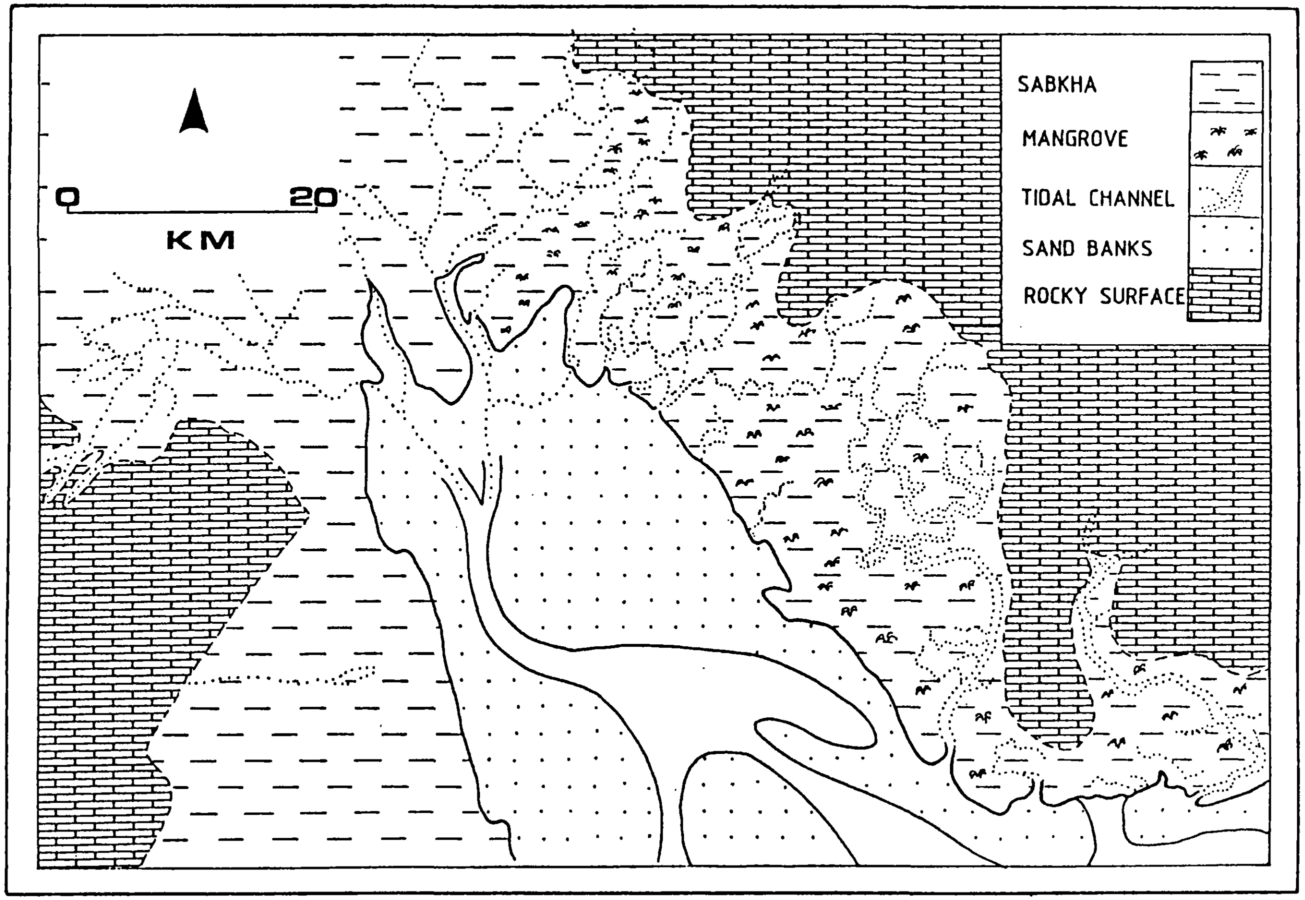


FIG. 6.4 THE MORPHOLOGICAL FEATURES AROUND DAKHERA BAY.

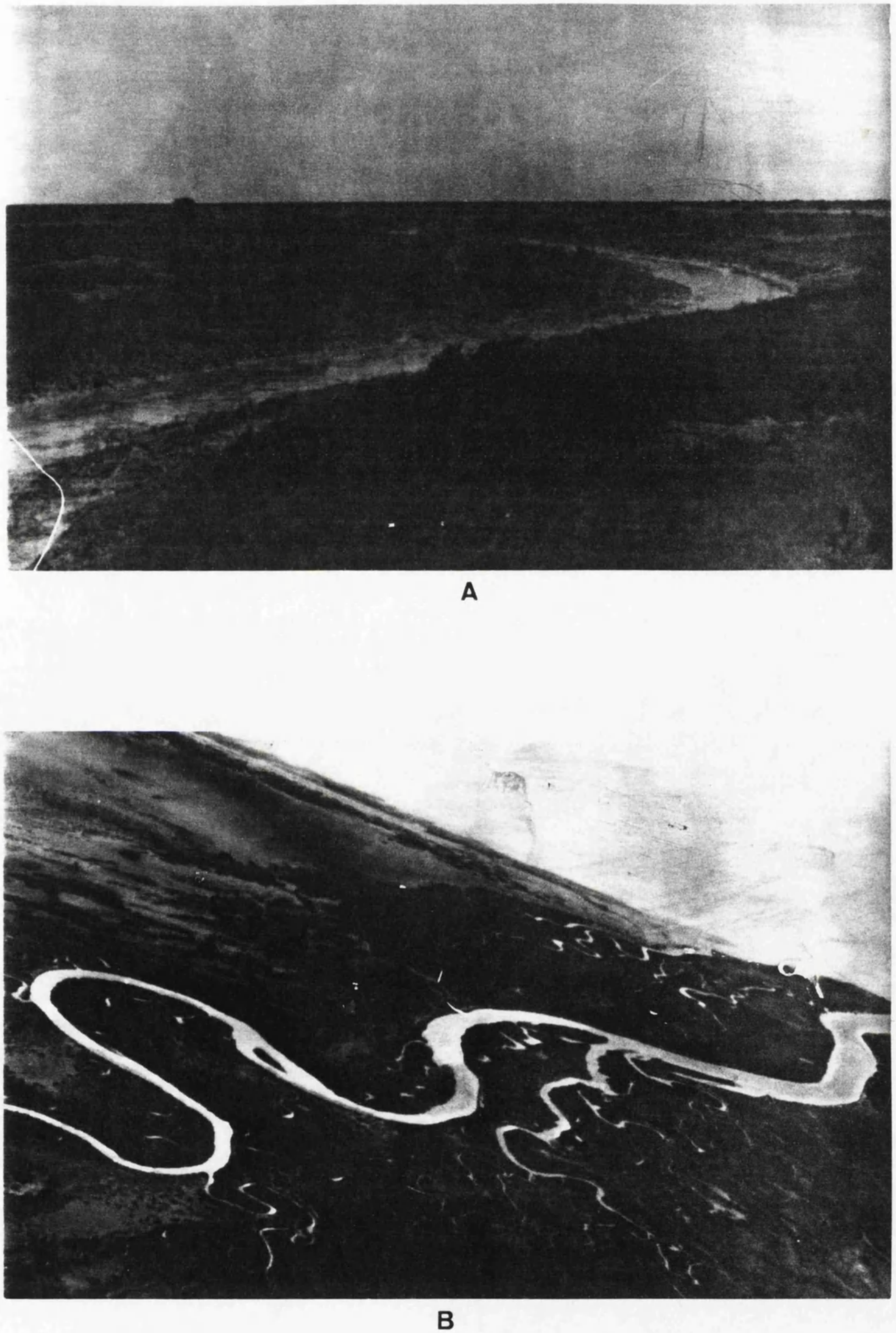


PLATE 6.1 TIDAL CHANNELS FROM A TRIBUTARY SYSTEM OF CURVING AND WINDING CHANNELS, DAKHERA EMBAYMENT. (PHOTOGRAPH TAKEN BY NABIL EMBABI 1980). **A and B**

### (2) Intertidal flat area

The intertidal flat area is located between low and high tide marks. The intertidal flats slope gently at about $1^{\circ}$ with muddy and sandy areas often dissected by meandering channels. They may be partially vegetated on their inner margin to form swamps which can be 5-10km wide and extend for a hundred kilometres along the shoreline. The intertidal areas in the study area have developed in sheltered environments within the coastal embayments of Khor and Dakhera. The sediments comprising the intertidal flats are composed mainly of calcareous sand (50%), silt (30%) and clay (20%). The inter-tidal flats area includes the mangrove areas which can be distinguished on the aerial photographs.

Vegetation such as mangrove (Avicennia marina) plays an important part in the shaping of the deposited forms in the estuaries and of the tidal flats. The extent to which mangrove promotes accretion of mud flats is uncertain but when sediment is deposited mangrove vegetation spreads on the surface and a sheltered environment may eventually be created. Mangrove vegetation encroachment may be impeded by strong wave action or tidal scour while mangrove swamps may become more extensive in sheltered areas, only reaching the open water in low wave energy environment such as is displayed in Plate 6.2A and B. The factor determining whether mangrove vegetation establishes itself and develops in this area is the type of sediment present.(a) Silt, mud and sand are abundant in this area and essential for the development of the mangroves.

As mentioned earlier, the most dominant vegetation in the area of study is the mangrove, found on mud flats on the eastern coast opposite Dakhera and Khor growing on the mud flats. This type of

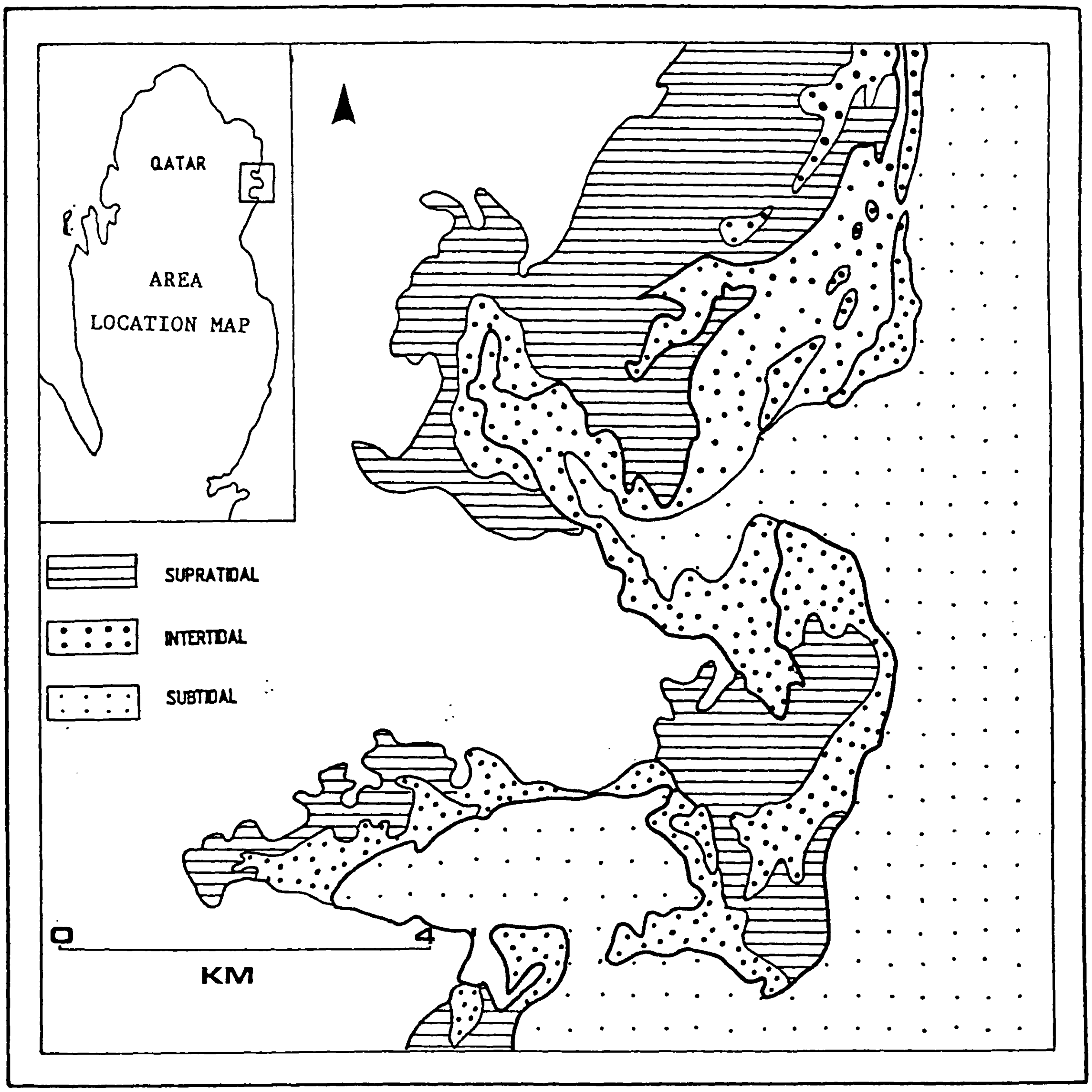
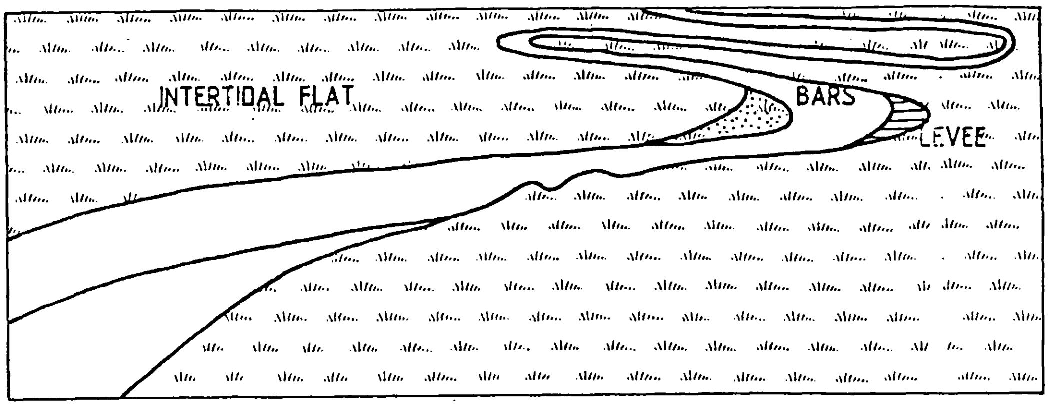
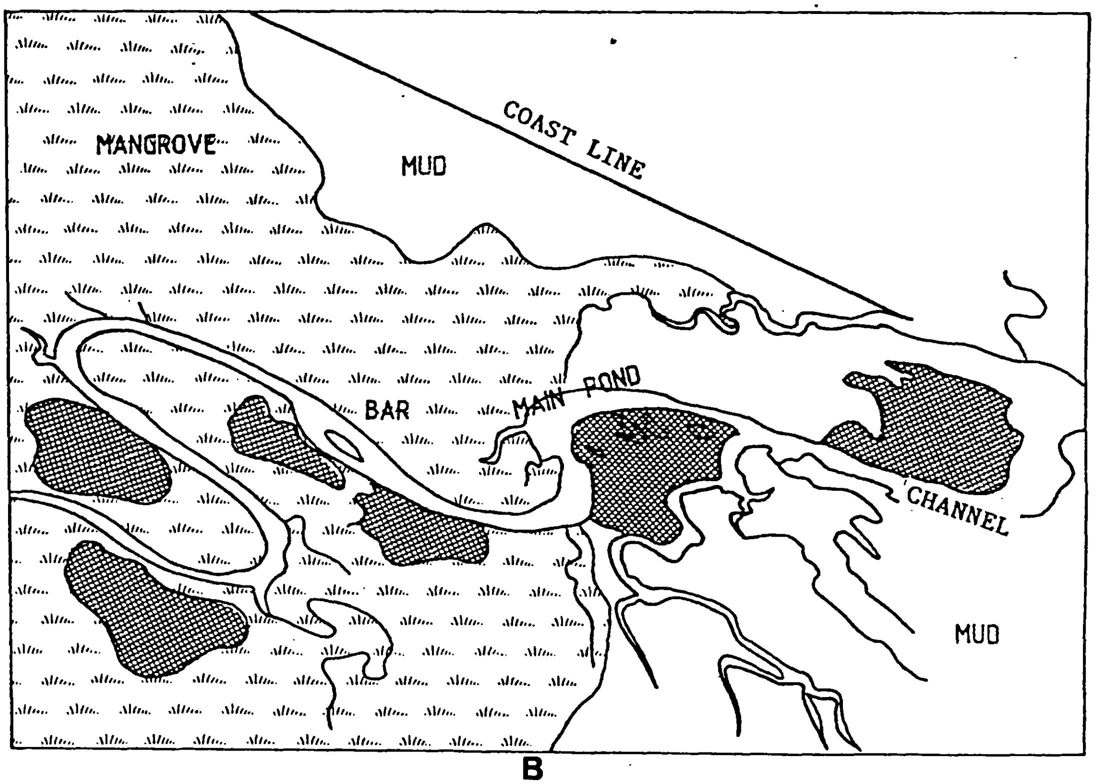


FIG. 6.5 DISTRIBUTION OF THE MAIN SEDIMENTS.



A



B

FIG. 6.6 INTERPRETATION OF FIG. 6.1 A & B SHOWING SAND BARS AND LEVÉE FEATURE FORMED ALONG THE SIDE OF THE MAIN CHANNEL.

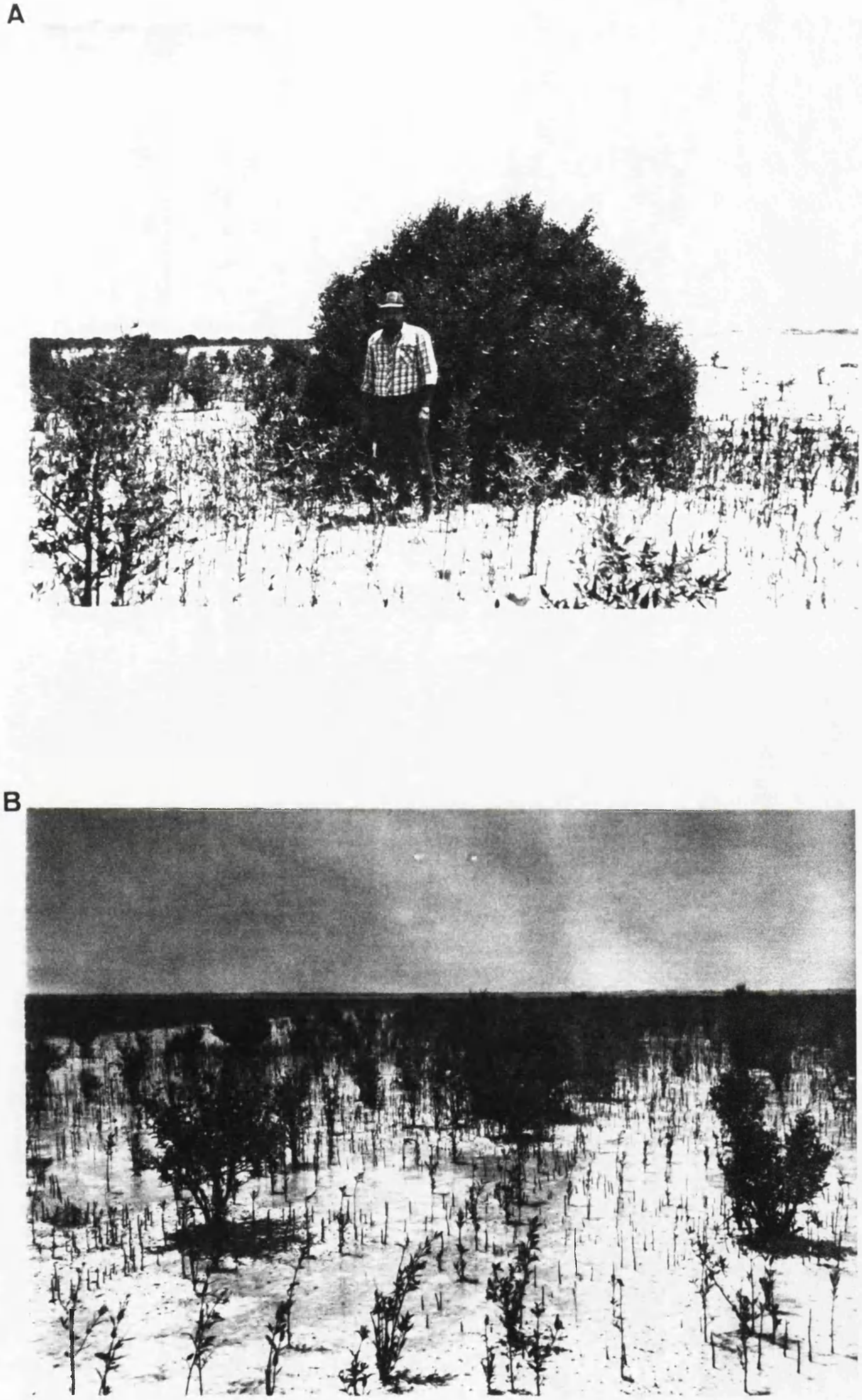


PLATE 6.2 (A & B). MANGROVE VEGETATION ON THE INTERTIDAL FLAT AREA. (AVICENNIA MARINA).

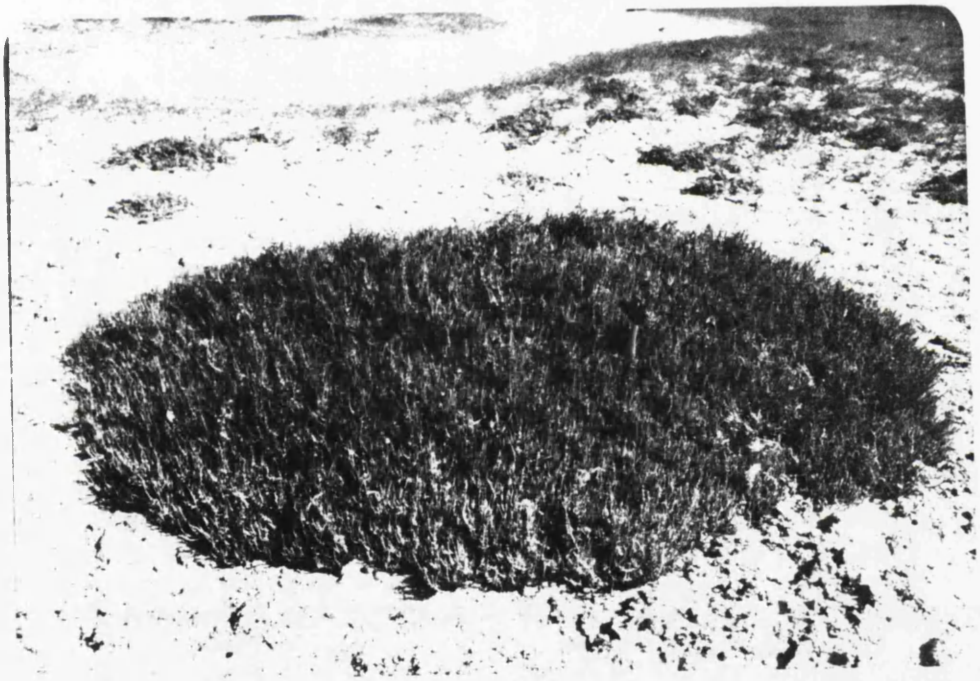


PLATE 6.3 ARTHROCNEMUM GLAUCUM ON COASTAL SALINE SEDIMENT NEAR KHOR.

vegetation has a height of about 2 metres. Another community has been identified by the author and by Batanouny (1981), who identified them as a Archrocnemum glaucum community. The community occurs on saline flats near Dakhera and Khor as individual plants which do not exceed 30cm in height (Plate 6.3).

(b) Low coastal relief

(c) Low coastal wave energy.

### (3) Supratidal flats

Supratidal flats are located above the normal high tide mark and are flooded only during exceptionally high tides and when sea level is raised at times of high water under storm conditions. These tidal flats may attain width of up to 5km and they can be more than 10km long. The thickness of the supratidal sediments may vary from 60cm to 80cm. A content of between 10% and 20% dolomite was recorded in supratidal sediments by Illing, et al. (1965).

## 6.3 Processes

The most important coastal processes noted in Khor and Dakhera bays are the action of longshore currents, tidal currents, wind-driven currents and wave action. Long shore currents are mainly created by the predominant NNW, NW 'Shamal' winds. The bioclastic carbonate and dolomite materials are derived in the main from the extensive offshore coral reefs at the northern tip of the peninsula and are transported southwards, and deposited to form many parallel linear elongated bars and spits. This interpretation was supported by the evidence obtained by digging two trenches, the first being about 65cm deep and located on the beach north of Dakhera (Fig. 6.7 ). The sediments

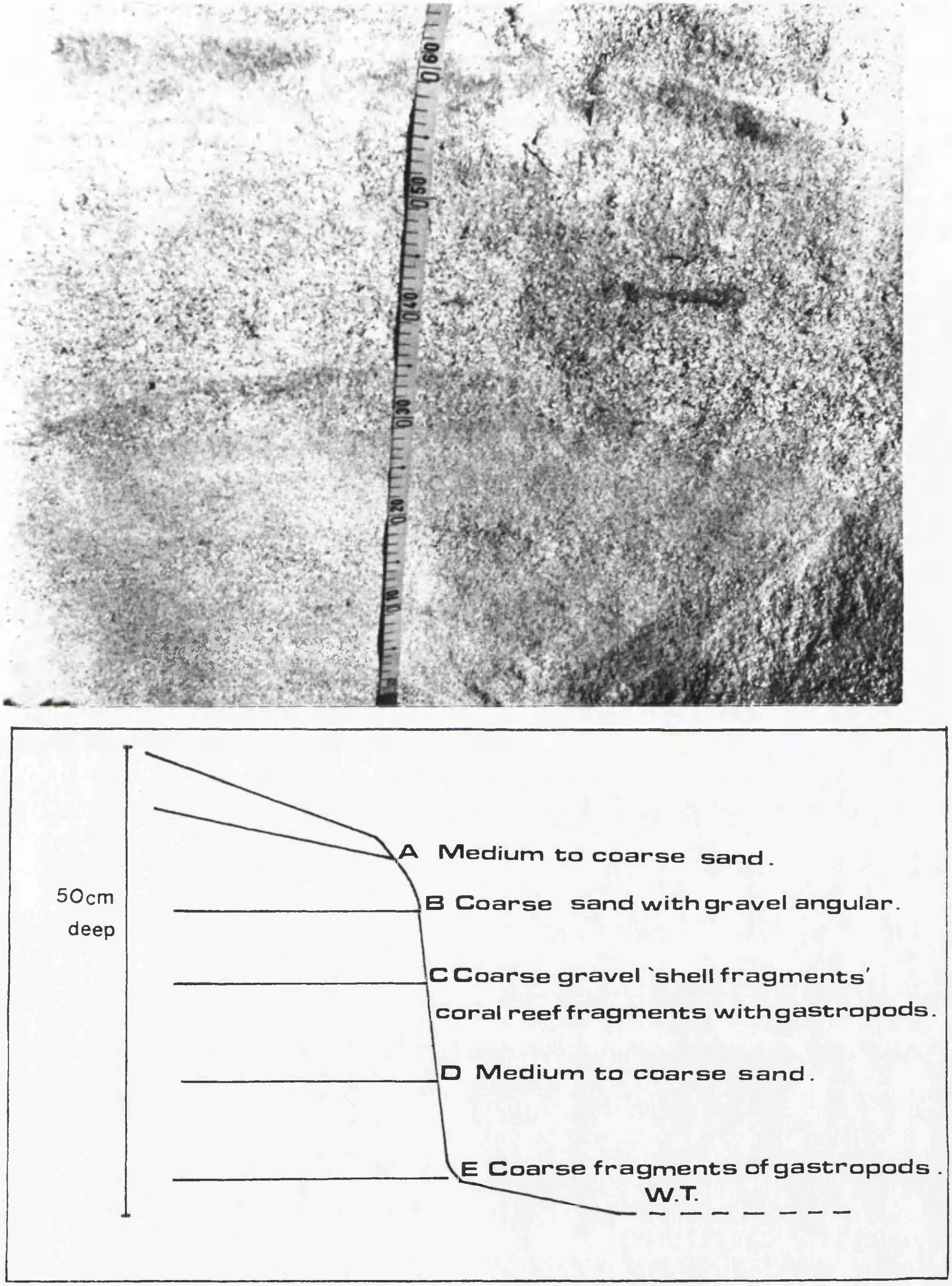


FIG 6.7 BEACH TRENCH SHOWNING MIXTURE OF CORAL REEF SHELL AND SAND LAYERS (TRENCH 1).

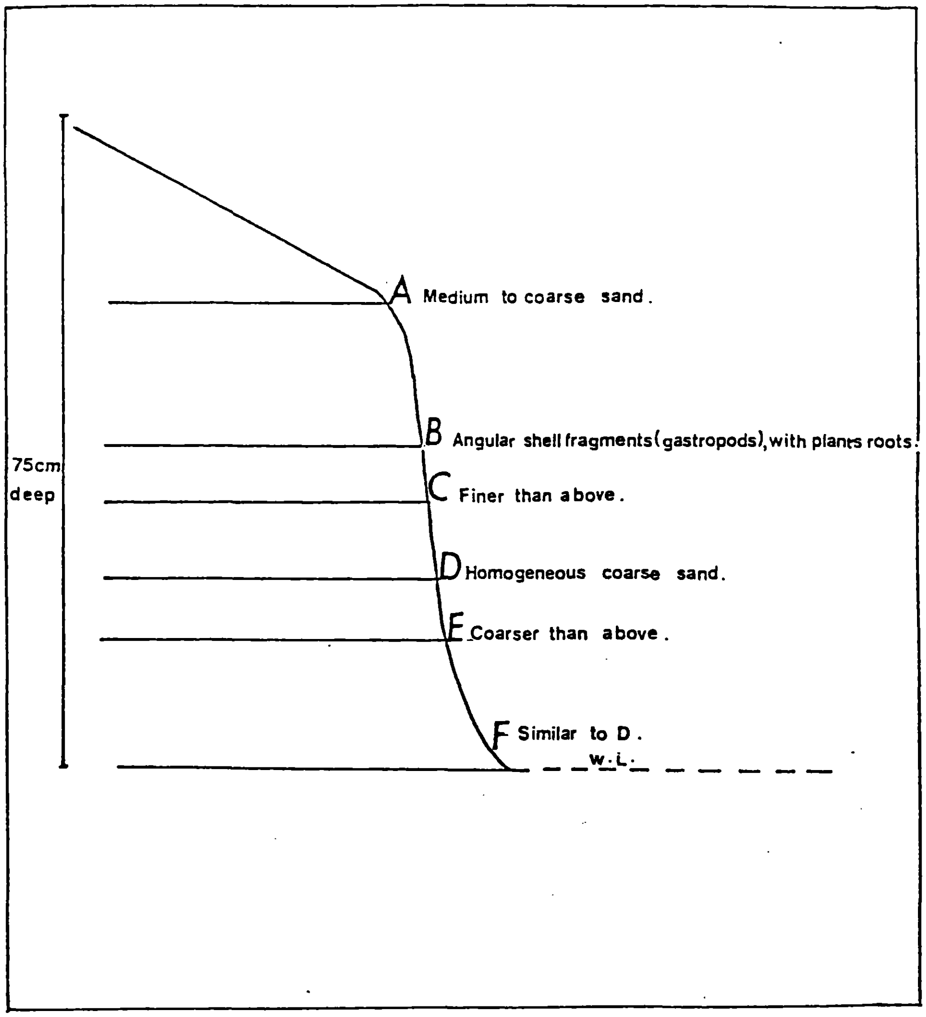


FIG. 6.8 DESCRIPTION OF SEDIMENTS OBSERVED IN TRENCH 2, KHOR BAYS.

exposed consisted of a mixture of coral reef fragments (35%), shells (30%) and sand (35%). The second trench (Fig. 6.8 ) was in the Khor area. It was 75cm deep and the sediments appeared similar to those in trench 1, being composed of a mixture of fine and coarse sand together with a large amount of shell (mainly gastropods fragments).

## 6.4 Sediments

The distribution of various types of sediments is controlled to a great extent by hydrodynamic status, the kinetic energy level of the water body, the nature of the coastal sediments and by the ecological conditions of the bays. The Bays of Khor and Dakhera are affected by the speed of the flood and ebb tidal currents within the two bays (Fig. 6.9 ). Various potential sources of the sediments found in Khor and Dakhera Bays can be identified as follows:

(1) Calcarenite or aeolianite, which forms the coastal ridges (Fig. 6.10 ). Houbolt (1957), who first investigated the marine sediments of offshore areas of the Qatar peninsula, described the greater part of the east and north-east coast as being made of cemented calcarenite. Cavelier (1970) observed that these calcarenites occur today in the shallow areas near the Qatar peninsular coast (from 3.50m - 20m maximum) in close proximity to the coastal zone. This calcarenite is also known as aeolianite, or dune limestone, is a calcareous dune sand that has been cemented or lithified by percolating rain water, following its deposition. According to Russell (1962), pockets of coarse materials or layers somewhat coarser than those above or below become the earliest sites of cementation, probably because they become saturated more readily and dry out more effectively. Bird

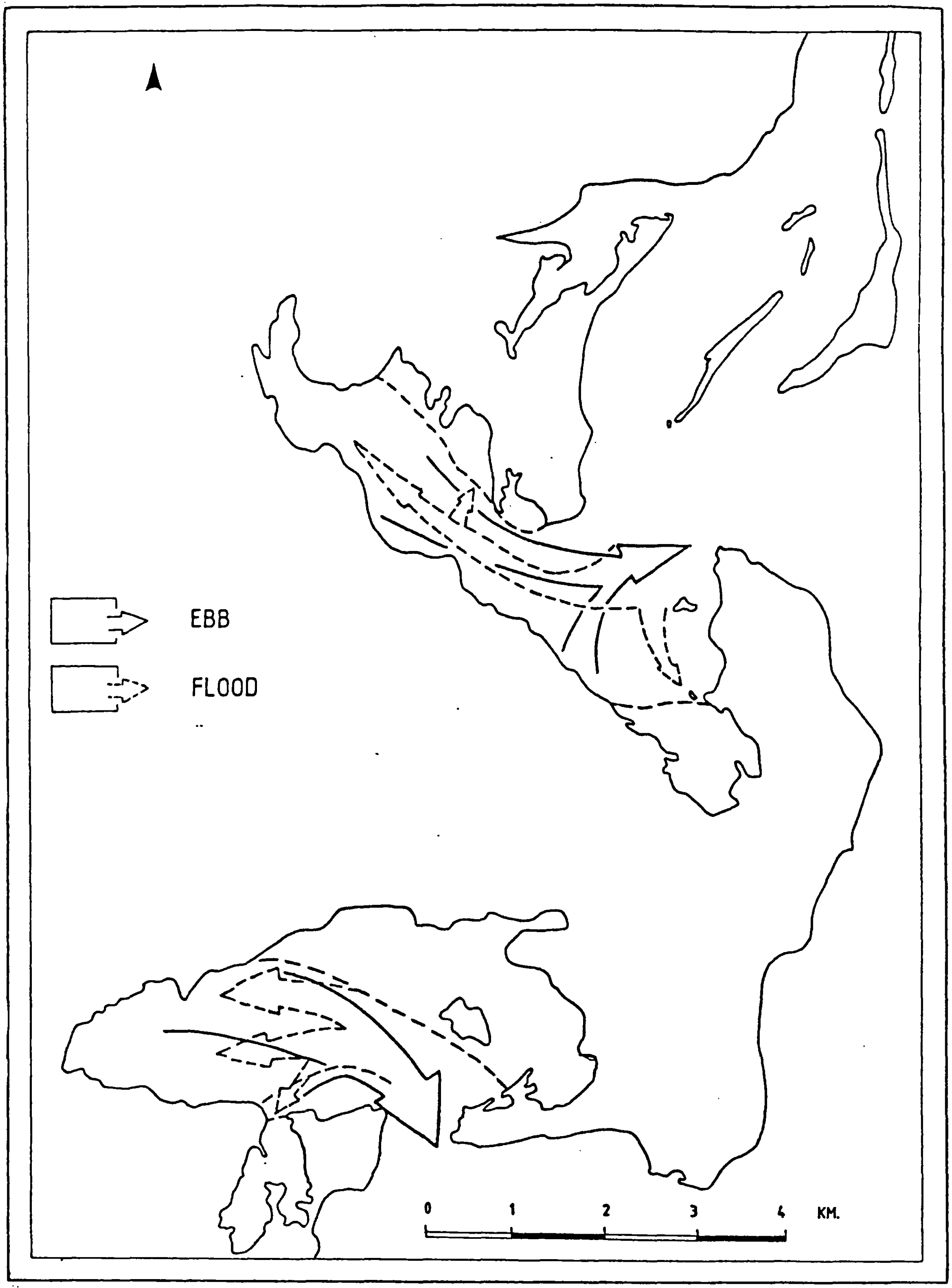


FIG. 6.9 EBB AND FLOOD WITHIN KHOR AND DAKHERA BAYS WHICH COTROL SEDIMENTS MOVEMENT IN THESE LOCATIONS.

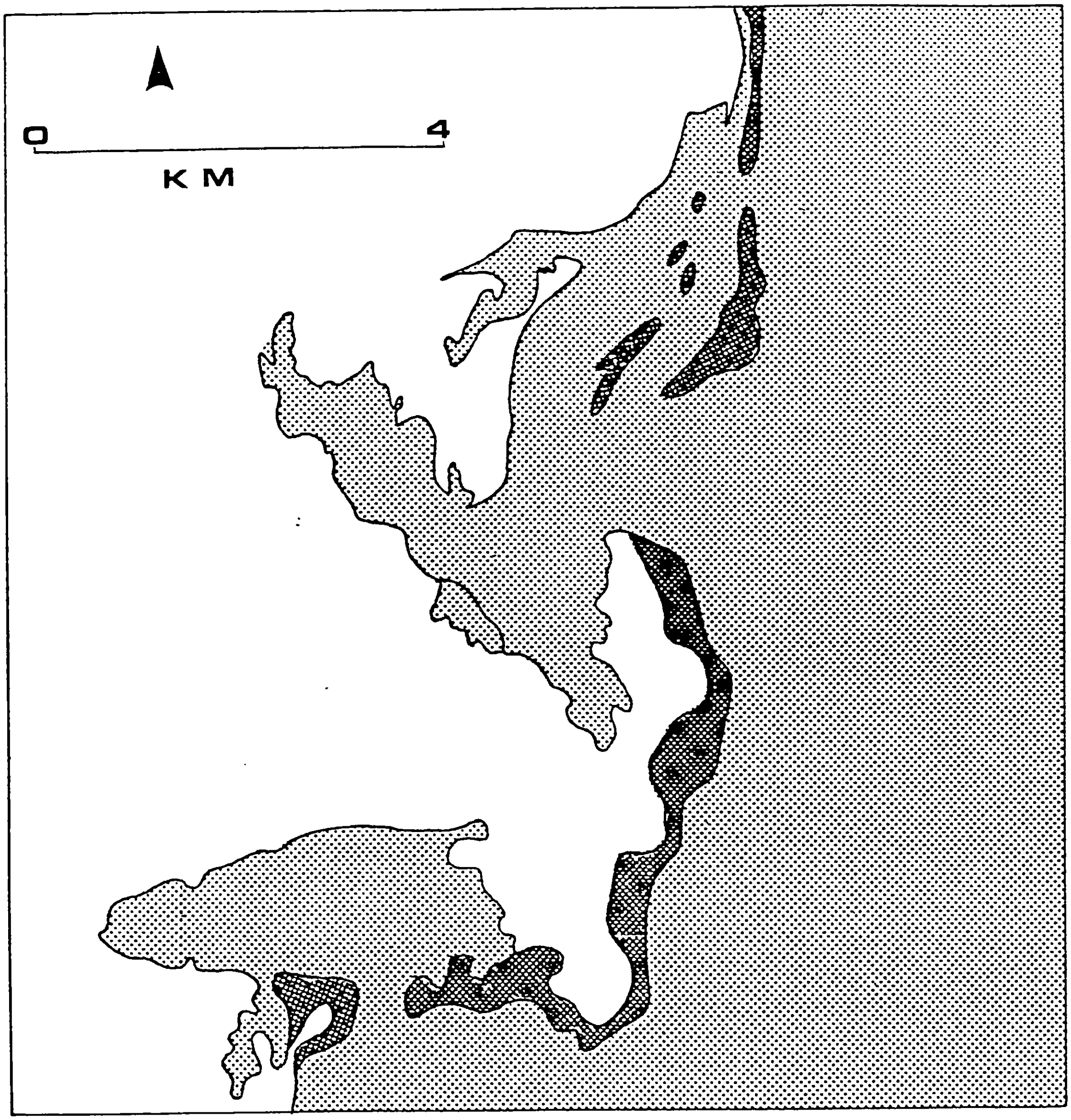


FIG. 6.10 CALCARENITE FORMING COASTAL RIDGES (DENSE SHADING) AROUND KHOR AND DAKHERA EMBAYMENTS.

(1984) recorded similar features along the South Australian coast lying at successive levels up to more than 60 metres above present sea level. Gill, E.D. (1982) studied calcareous deposits of aeolian origin covering thousands of square miles of the southern Australian coastal region, ranging in thickness from a few feet to over 200 feet (c. 70m) in extent. Some of these calcarenite ridges represent relict or fossil dunes of Pleistocene age and they extend for at least 5 to 10km along the coast. In the area of the Khor and Dakhera Bays, such ridges achieve heights of 3 metres above sea level. As a result of present-day weathering they contribute to the sediments of the bays, and are thus responsible for the relative abundance of sandy (medium to coarse sands) sediments here.

### (2) Aeolian sand

Aeolian sands are derived mainly from the surface desert deposits and transported by the prevailing 'Shamal' wind to contribute to the sediments in the bays. Clearly the percentage of winds blowing off the mainland which are capable of carrying sand will affect the volume of sediment derived from this source.

### (3) Coral reefs

Along the north-east coast of the Qatar peninsula, coral reefs are located between low water mark and about 2-3 metres below this level. Surface and shallow sea-water temperature range seasonally from a minimum of 16°C to a maximum of over 40°C. At greater depths (more than 4-5 metres), the seasonal temperature ranges from about 20°C to 36°C. Surface temperatures from May to October are about 30°C. The area of Khor and Dakhera Bays receives a large quantity of coral reef fragments that have been drifted by coastal long shore currents,

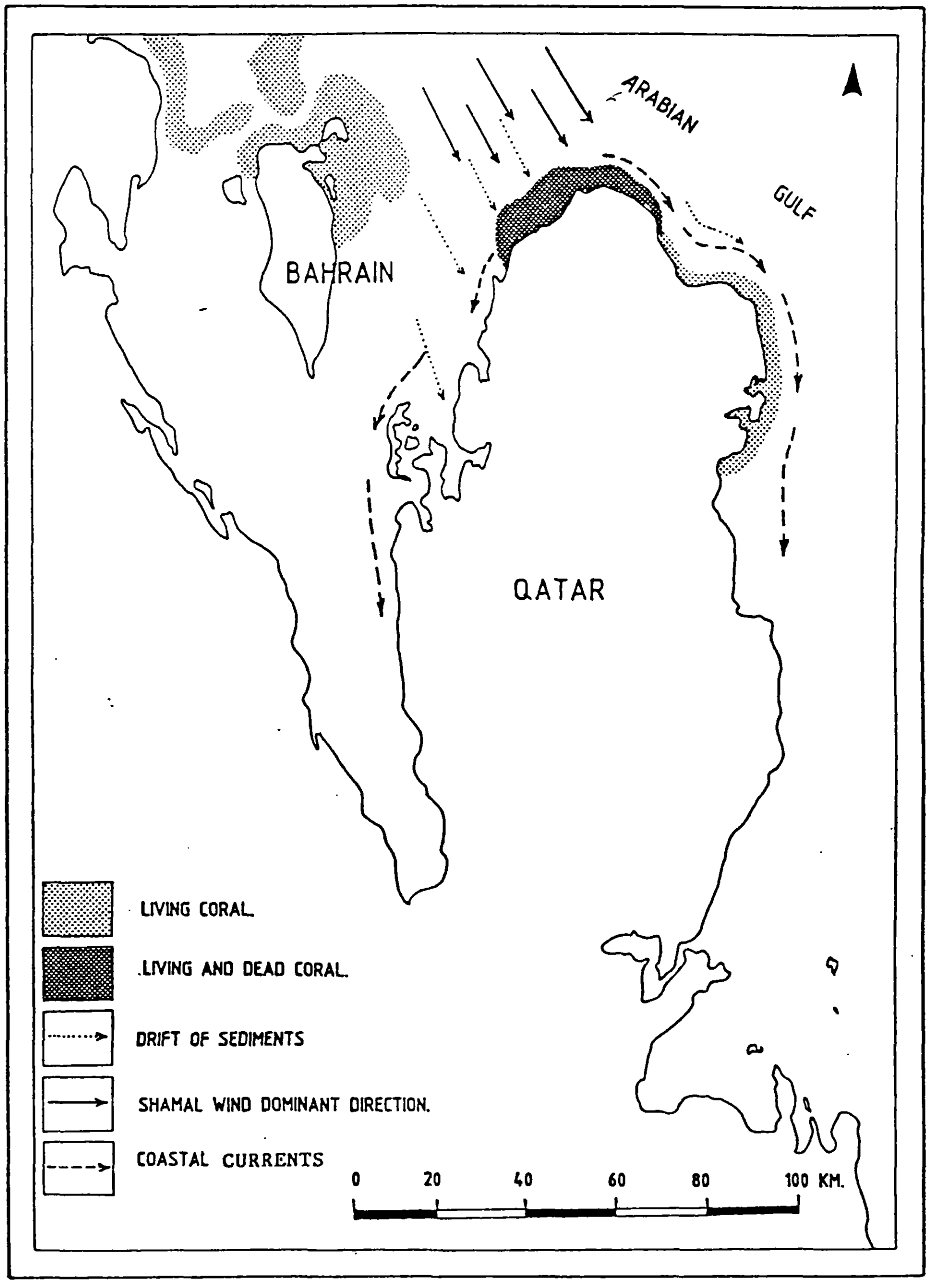


FIG.6 11 SOURCE OF CORAL REEF SEDIMENTATION.

around the coast of the peninsula from north-south (Fig. 6.11). The sediments are moved from the live coral areas around Bahrain Islands in the north-west and from the northern part of Qatar.

### (4) Beachrock

Beachrock is formed when a layer of beach sand becomes consolidated by secondary deposition of calcium carbonate at about the level of the water table (Russell, 1962).

Beachrock has been found throughout the tropics, for example, on the shores of the Caribbean, around the Mediterranean, the Red Sea, Arabian Gulf, and coasts of Brazil, South Africa and Australia. An adequate supply of calcium carbonate is needed in addition to a high temperature ($>20^{\circ}C$) to permit a precipitation of calcium to achieve cementation of sand, algae, coral and shell fragments. Ginsburg (1953) studied beachrock in South Florida and found that marine beachrock is produced by the intertidal precipitation of interstitial aragonite under the influence of increased temperatures and the rate of beach drainage. The restriction of beachrock to coral seas is due to its temperature dependence and its localised distribution is revealed in beach stability and structure. Russell (1959) and (1962) described the distribution and physiographic significance of intertidally cemented beach sands on inter-tropical shores and developed a theory of their origin based on studies of beachrock from islands between Puerto Rico and St. Lucia in the Caribbean Sea. Russell states (1963, p.24):

> "..beachrock is beach material that has been cemented by calcite deposited from ground water. Cementation of beachrock takes place along the water table under a beach. The ground water must have a high content of calcium carbonate which is precipitated as a calcitic cement in beach sand following upward capillary movement"

PLATE 6.4 BEACHROCK DIPPING SEAWARD IN THE KHOR AREA.

According to Russell's theory (1962) cementation takes place along the water table. Beach sands above the water table are typically polished, since percolating sea water is super-saturated with calcium carbonate, and unable to dissolve calcareous material; beneath the water table circulation fresh water is able to cause chemical weathering of sands, whose surfaces are typically pitted and unpolished, and at the water table itself, sand grains are coated with calcium carbonate. Stoddart (1970) studied the origin of beach rock in British Honduras. This work appears to be incompatible with general hypotheses put forward by Russell and co-workers. Stoddart (1970, p.246) reached a conclusion that in British Honduras, any explanation of beachrock formation must take into account:

> "(1) two stage cementation involving initial aragonite bonding with no solution of grains followed by void-filling with calcite and the disappearance of original structures; (2) initial bonding within the beach, and subsequent secondary lithification on exposure following beach retreat; (3) initial bonding in location where fresh water appears to be absent; (4) the patchy and discontinuous distribution of the beach rock, which is difficult to explain on water table hypothesis, and also in terms of derivation from sea water".

Good examples of beachrock can be found on the east coast, in the Khor and Dakhera embayments, and on the west coast on Abrug peninsula where the beachrock is about 1.5 above high water mark and the bedding places dip seaward at 4°-6°. The upper limit of the beachrock differs from place to place. For example, in Barrier Islands on the north coast, the beachrock is found about 1 to 1.5 metres above sea level.

## 6.5 Beach profiles

Geomorphologically, the beaches around the bays of Khor and Dakhera display low angle ($6^{\circ}$-$8^{\circ}$) beach profiles. A set of schematic diagrams show the general geological and geomorphological characteristics of the coastline of these two bays and the location of the selected profiles (Fig. 6.12 ).

The bays are characterized by a simple low relief formed mainly of semi-consolidated oolitic limestone of Pleistocene age. No continuous measurements or quantitative data of the force direction and type of wave attack are available for different periods and places around the bays of Khor and Dakhera.

### *Profile A*

This profile is characterized by simple low relief along the southern part of the Dakhera bay, showing evidence of wave action and weathering, at high tide level. The profile shows a series of beach rock layers lying between 50cm to 1m above sea level. The profile extends to the tidal mud flat zone (Fig. 6.13 , profile A , and Plate 6.5).

### *Profile B*

This profile extends from the cliff to the area of mud flat and on to the active channel area and to the area of mangrove on the shores of Dakhera bay. The coast profile shows a cliff where weathering and wear abrasion are clearly evident, with a sabkha forming on the foreshore beach slope (Fig. 6. 13, profile B , and Plate 6.6).

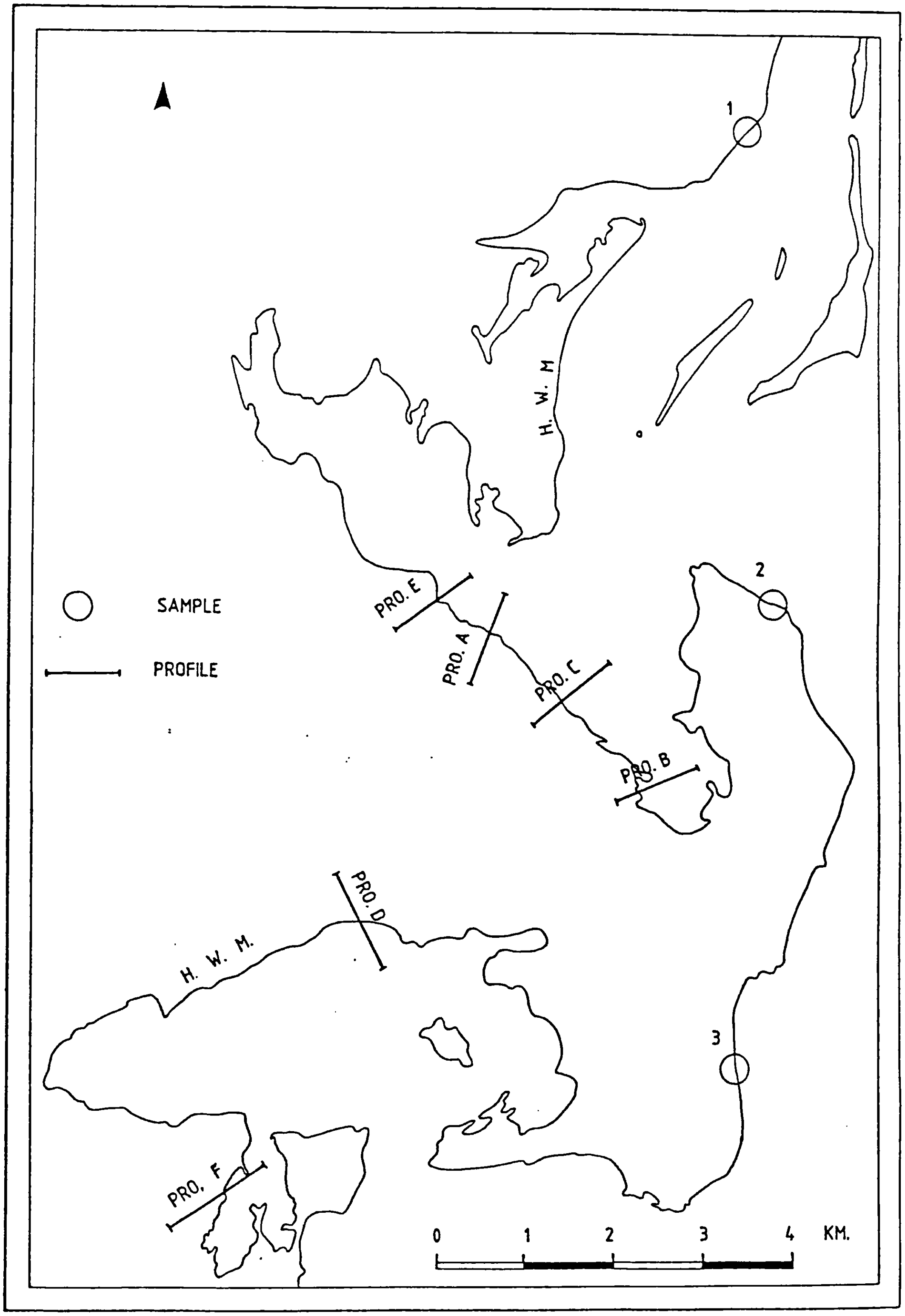


FIG 6.12 LOCATIONS OF SELECTED PROFILES AND SAMPLES, AT KHOR AND DAKHERA BAYS.

PLATE 6.5 LOCATION OF PROFILE A, DAKHERA BAY.

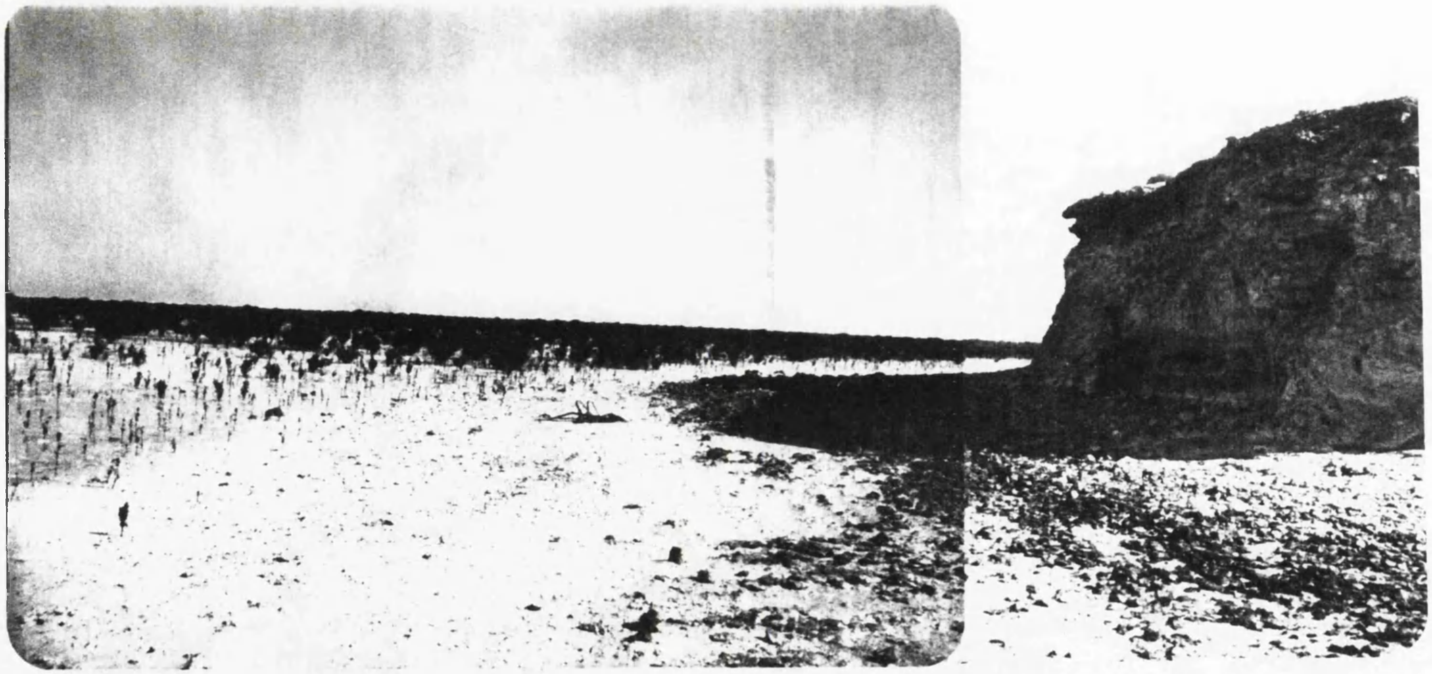
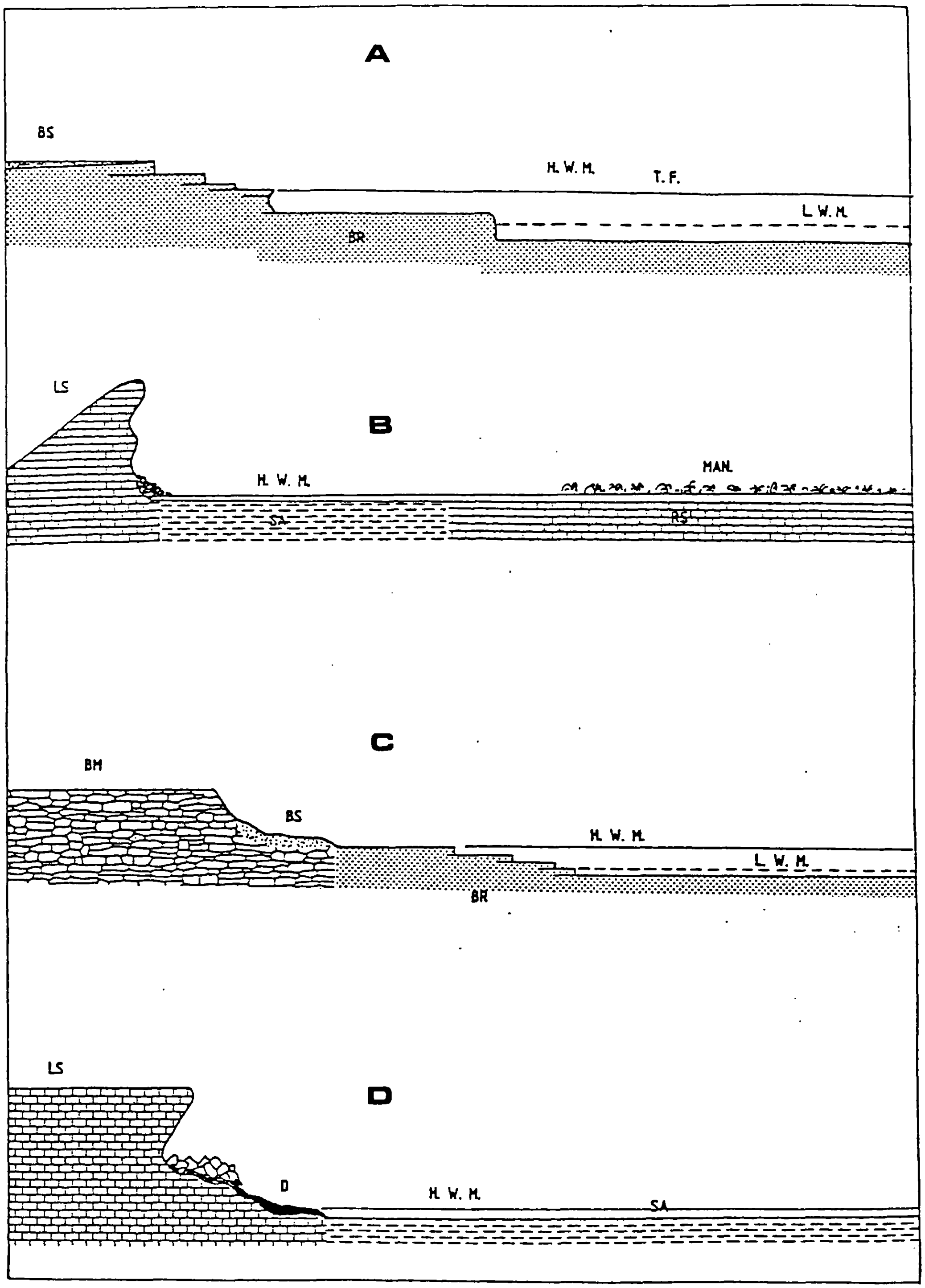


PLATE 6.6 LOCATION OF PROFILE B, CLIFF BACK MANGROVE.



BR = BEACH ROCK
BS = BEACH SLOPE
SA = SABKHA
BM = BERM
TF = TIDAL MUD FLAT
LS = LIMESTONE
MAN = MANGROVE
D = DEBRIS

FIG. 6.13 PROFILES ACROSS THE COASTLINE IN KHOR AND DAKHERA BAYS.

*Profile C*

This profile shows a very low relief profile with beach rock ridges dipping seaward and ranging in height from 50cm to 80cm above sea level. The foreshore forming the beach slope is (Plate 6.7).

*Profile D*

This profile displays undercutting which has resulted in the developing of an 'overhang' to the cliff and this will lead ultimately to the collapse of part of the overlying limestone. Such displaced blocks apparently disintegrate rapidly in the highly saline conditions where the debris mantling the bedrock surface in front of the overhang is exposed to wetting and drying by salt water.

*Profile E*

This profile is similar in some respects to profile D but the main difference is that this profile crosses two beach rock platforms, ranging in height between 50 and 70cm above sea level. This profile also shows an undercut notch about 1m in height in the limestone cliffs, resulting from wave action.

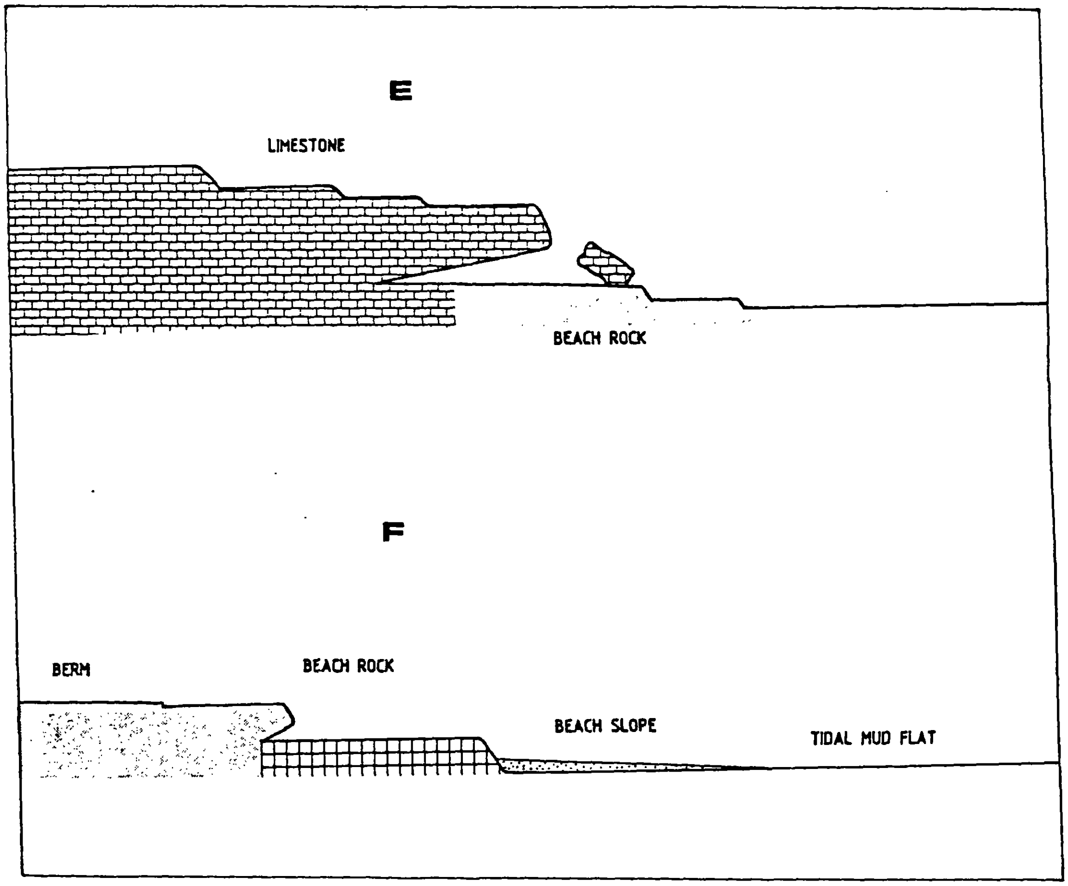
*Profile F*

This profile is also characterized by low relief. The foreshore is characterized by a swash bar forming the beach slope. Beach rock is present, ranging from 50 to 70cm in height above sea level.

## 6.6 Grain size analysis

Mechanical analysis was undertaken of sand from the beaches and subtidal, intertidal and supratidal flat areas. Twenty samples from

PLATE 6.7 LOCATION OF PROFILE C, KHOR BAY.


E
LIMESTONE
BEACH ROCK
F
BERM
BEACH ROCK
BEACH SLOPE
TIDAL MUD FLAT

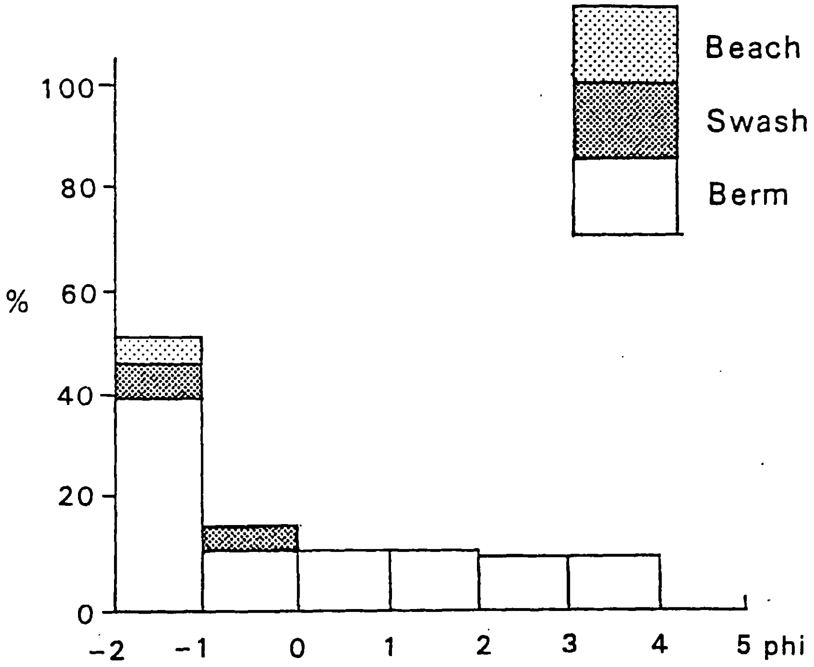


FIG. 6.14 COMPOSITE HISTOGRAM OF SEDIMENT FROM BEACHES, SWASH BERMS AROUND KHOR AND DAKHERA.

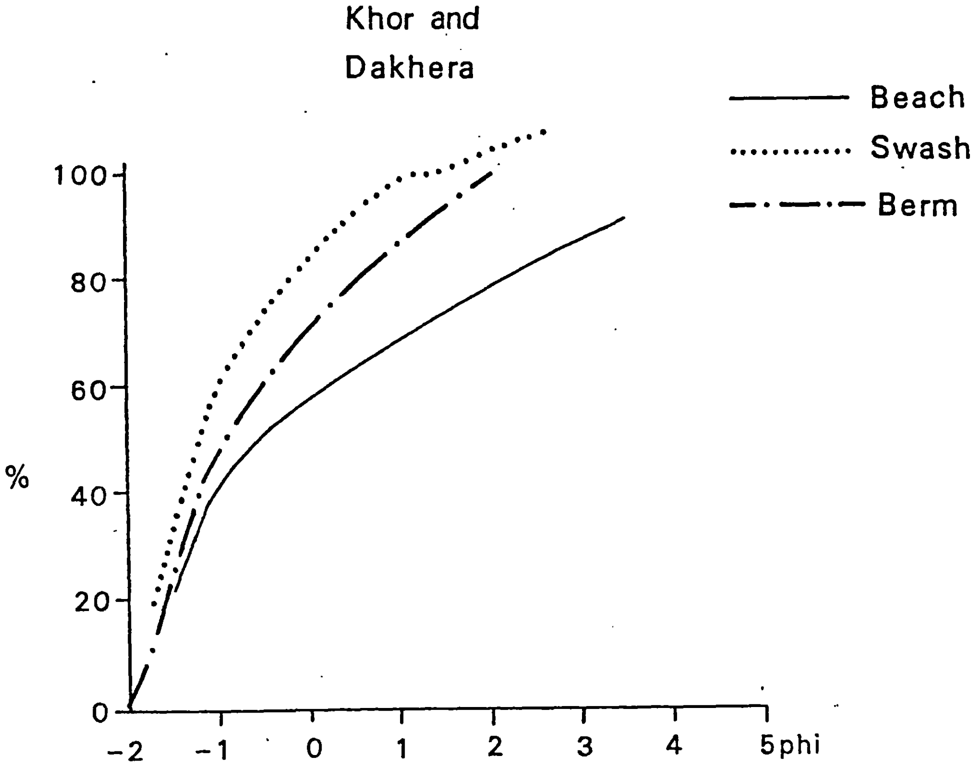


FIG. 6.15 CUMULATIVE CURVES OF BEACHES, SWASH AND BERM SAMPLES FROM DAKHERA AND KHOR.

each site were collected from various locations in Khor and Dakhera Bays. Sample locations are shown in Figure 6.12. Sand beaches are controlled by several major factors including wind direction and velocity, mean size of sand, as well as currents, waves, and an abundance of sediments.

Komar (1976) discussed the main factors that control the mean size of beach sediment, while Friedman (1967) attempted to distinguish beach sands from sand in other environments on the basis of two-dimensional plot parameters such as sorting and skewness. The grain size analysis for sediment collected from the beaches (beach face, swash and berm) indicated that the grain sizes fall between fine and coarse sand (Fig. 6.14). They are poorly moderately well-sorted with a mean sorting coefficient of +0.86. The sediment is positively skewed (Sk = +0.58) and mesokurtic to platykurtic with a mean of +0.95 sediment from beach, swash bern (Fig. 6.15).

Analysis of the sediments collected from the subtidal zone indicated that grain sizes lie between fine to coarse sands (Fig. 6.16). They are moderately sorted (S = +0.74), positively skewed (Sk = +0.25) and leptokurtic (Ku = +1.17), and the sediments collected from intertidal flat areas reveal that the sediments lie between fine and medium-fine sand reflecting the narrow range of grain size (Fig. 6.17). They are moderately sorted (S = 0.82), positively skewed, (Sk = 0.37) and very leptokurtic (Ku = 2.42). Sediments collected from the supratidal zone comprise fine to coarse grain size sand which is very poorly sorted (S = 1.72), negatively skewed (Sk = -0.77) and platykurtic (Ku = 0.87). This particle size distribution of the sand grains is due to the efficient sorting mechanisms provided by the currents, tides, and waves within the embayments of Khor and Dakhera.

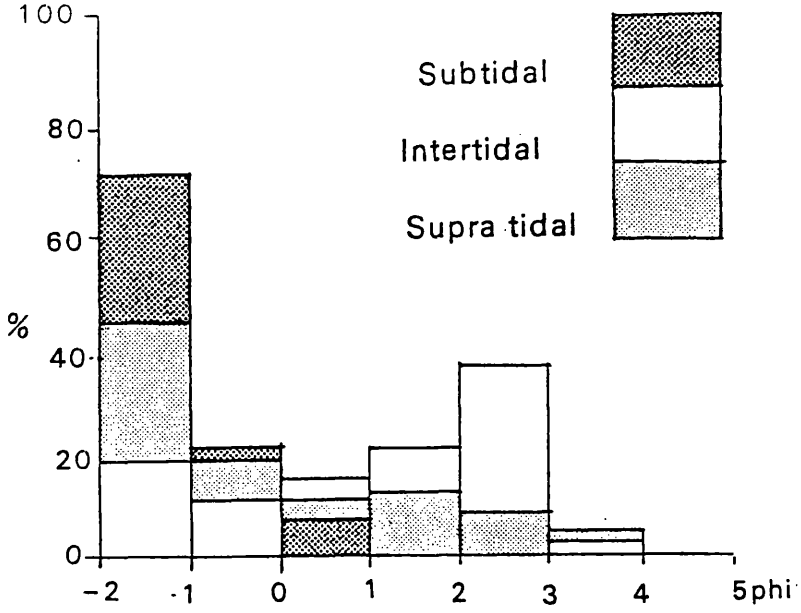


FIG. 6.16 COMPOSITE HISTOGRAM OF SEDIMENT FROM SUBTIDAL, INTERTIDAL, SUPRATIDAL FLAT AREAS IN KHOR AND DAKHERA BAYS.

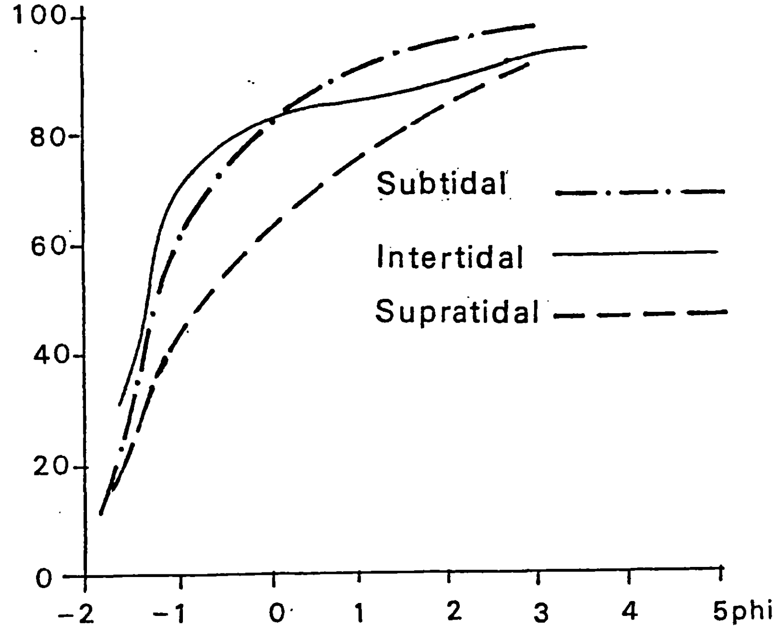


FIG. 6.17 PARTICLE SIZE OF CURVES OF SEDIMENT FROM SUBTIDAL, INTERTIDAL AND SUPRATIDAL AREAS IN KHOR AND DAKHERA BAYS.

## 6.7 Summary

The bedrock underlying the embayments of Khor and Dakhera located on the north-east coast of the Qatar peninsula is composed of Eocene limestone and dolomite. The embayments occupy about 8 kilometres of the coastline, with a water depth averaging about 5 metres and a tidal range of between 0.5-1 metres. Morphological features identified from the field investigations and interpreted from the aerial photographs range from sand bars, spits and lagoons, to sabkhas. The shallow bays of Khor and Dakhera are characterized by a sedimentary zonation that includes subtidal, intertidal and supratidal flat areas. The bays receive sediments from various sources such as the 'fossil' calcarenite around the coast and from the aeolian sands that have been transported by the 'Shamal' wind from the north or north-west. Coral reef fragments have been transported from the northern tip of the Qatar peninsula by longshore currents to this coastal location. Grain size analysis of samples from the beaches indicated mainly fine to coarse sands which are poorly to moderately sorted, poorly skewed and mesokurtic to platykurtic. These characteristics are due to the sorting of the grains by marine processes. The sediments collected from the subtidal zone are fine to coarse sands which are moderately sorted, positively skewed and leptokurtic. Sediments from the inter-tidal zone are fine to medium fine sands which are moderately sorted, positively skewed and leptokurtic. Supratidal sediments comprise fine to coarse sediments which are very poorly sorted, negatively skewed and platykurtic. These characteristics are the result of action by currents, tides, and waves.

# CHAPTER VII

# THE BARRIER ISLANDS OF THE NORTH COAST OF QATAR

# CHAPTER VII

## 7.1 Barrier Islands of the North Coast of Qatar Peninsula

### 7.1.1 Theories of barrier islands formation

The term barrier island was used by Gilbert (1890), but these landforms were also defined and analysed by De Beaumont (1845) who suggested that barrier islands formed from the accretion of materials. The theory was supported by Johnston (1919) who termed these features 'off shore bars'. Other terms used to described these features included barrier beaches, barrier bars, sand reefs, sand bars, and sand banks. Gilbert (1885) proposed that a barrier was formed from the transportation of materials rather than erosion and that spits were converted to barriers by subsequent breaching of former continuous ridges. Pierce (1963) observed small barriers forming a short distance from the shore during high water associated with storms. Zenkovitch (1963) suggested two methods of barrier formation. The first involved the sinking of a wave-built terrace and the second submergence of an alluvial plain. Fisher (1968) provided a historical basis of the development of the barrier island formed from sediments derived from offshore as De Beaumont had previously suggested. Hail and Hoyt (1968) studied barrier development on a submerged coast off the Atlantic coast plain of Georgia, U.S.A., and parts of the East Australian coast. The theory of formation of barrier islands given in their study is based on the following considerations:

(1) beach sediments accumulate adjacent to the shoreline;

(2) once formed, the island may prograde, erode or remain stationary depending upon the sediment supply, wave and current action. They

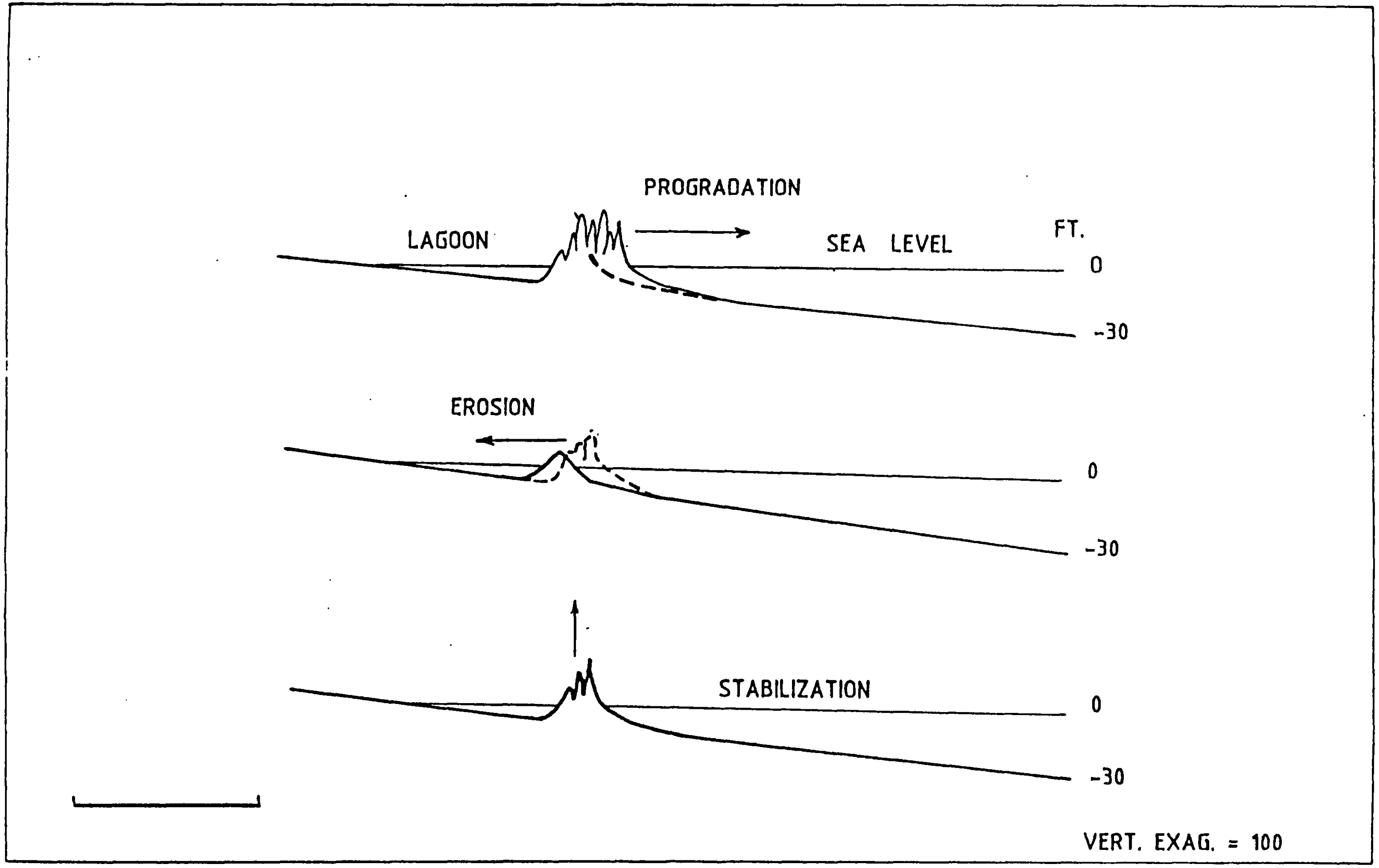


FIG. 7.1 BARRIER ISLAND 1) PROGRADING 2) ERODING AND 3) STABILIZATION DEPENDING ON (A) SEDIMENT SUPPLY (B) RATE OF SUBMERGENCE AND (C) HYDRODYNAMIC FACTOR. (FROM J.H. HOYT, 1969).

They considered that movement of materials was predominantly onshore during the formation of the barriers (Fig. 7.1 ). Fisher (1968) pointed out inconsistency in Hoyt's theory concerning the dating of surface barrier sediments. The diagram (provided by Hoyt, with numbers added by Fisher) indicates that probable sequence of development. According to Hoyt's theory, a prograding dune or beach ridge develops with a sequence of ridges becoming gradually younger in a seaward direction (ridges 1-3). Later following submergence, the dune ridge becomes a barrier island and grows upwards and seawards by developing a second set of prograding ridges (ridges 4-5). (Fig. 7.2). Hoyt (1967) suggested that barrier islands form from spits in the direction of longshore sediment transport (Fig. 7.3 ). Fisher (1967) argued that the well-known barrier islands of the middle Atlantic states from New York to North Carolina have developed in just such a manner. Purser and Evans (1973) studied a barrier island along the Trucial Coast, SE Persian Gulf, and argued that this barrier developed due to the effective longshore transport, aided by "Shamal" winds and associated waves and surface currents. Evans et al. (1972) also studied the oceanography ecology, geomorphology and sedimentology of the barrier island complex along the Trucial Coast, indicating that their development depended upon the longshore transport of sediments, moving parallel with coastline of the Trucial coast. Hoyt (1968) provided an abundance of evidence from the New South Wales and Queensland coasts in Australia to support his views. The origin of barrier islands and spits has also been subject to a number of geomorphological studies (e.g. Leatherman,1979-1981) who argued that the sand barriers on the Gulf and Atlantic coasts of the United States are continuing to move landward as the outcome of storm over-

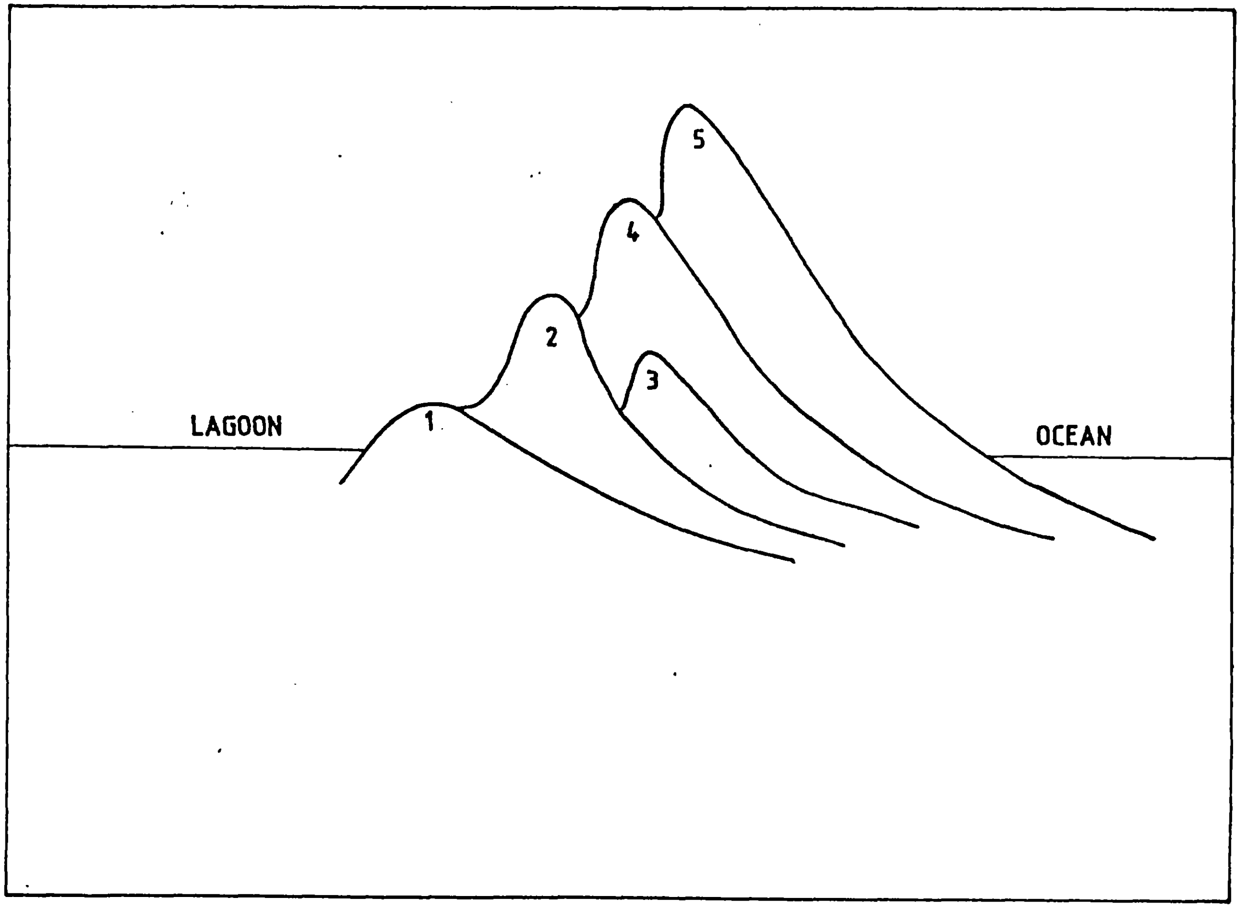


FIG. 7.2 BARRIER ISLAND FORMATION (FROM J.J. FISHER 1968).

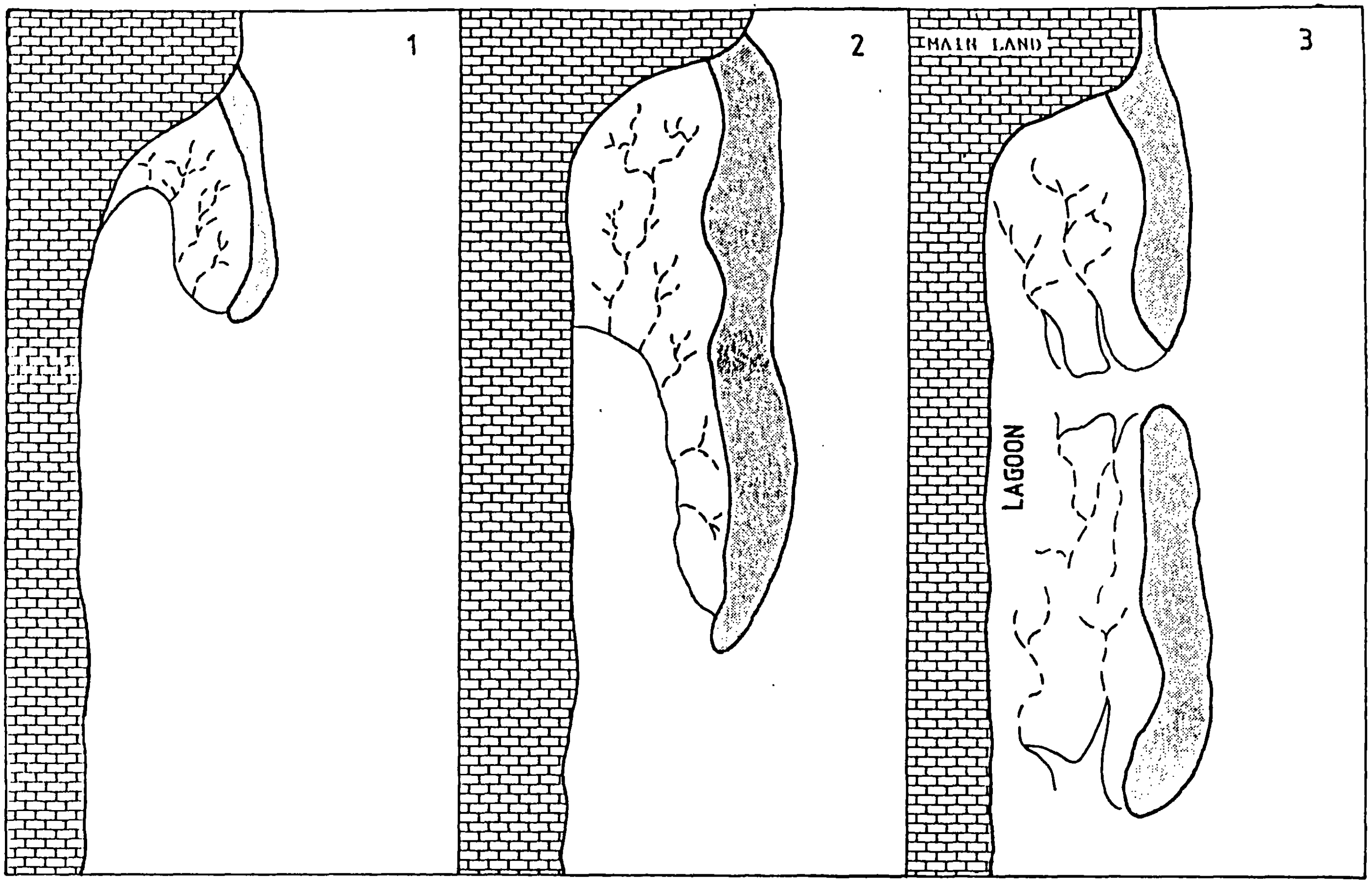


FIG.7. 3 1) BARRIER ISLAND FORMATION FROM SPIT .

2) SPIT DEVELOPS IN DIRECTION OF LONGSHORE SEDIMENT TRANSPORT .

3) SPIT FORMING BARRIER ISLAND . FROM J. H. HOYT 1969 .

wash and the drifting of dunes by onshore winds. Elsewhere, barriers, thus initiated, have remained in a position parallel to the pre-existing coastline resulting from the deposition of further sediment arriving on their shores. In south-eastern Australia a history of intermittent progradation is shown by the numerous successively-formed beach and dune ridges parallel to the coastline of the ninety mile beach (Bird, 1978), and on sectors of the New South Wales Coast at Disaster Bay where Thom *et al.* (1978) have dated stages in Holocene accretion on the broad barrier that encloses Lake Wonboyn.

Sandy barrier islands are located at the northern tip of the peninsula of Qatar. They are elongated islands lying parallel to the coastline and separated from the mainland by a series of small lagoons. The width of these barrier islands reaches about 200 metres and the length reaches 8.5km. These barrier islands form a chain-like series of small islands with only part of these barriers submerged during high tides. Wave action and current movement are dominated by the 'shamal' winds which blow parallel to this segment of the coastline. The wind-generated waves result in considerable turbulence and wave activity with the result that sediments are distributed in the lagoon area. The tidal range lies between 0.5 and 1.4 metres and the water depths are between 1 and 3 metres (Fig. 7.4 ). The platform of the barrier islands is related to the pattern of the refracted swell and the growth has been attributed to longshore drifting. The main source must be materials eroded or collected from the algal coral reefs and shoals which occur 1-4km offshore, and from materials from the seafloor of the Arabian Gulf.

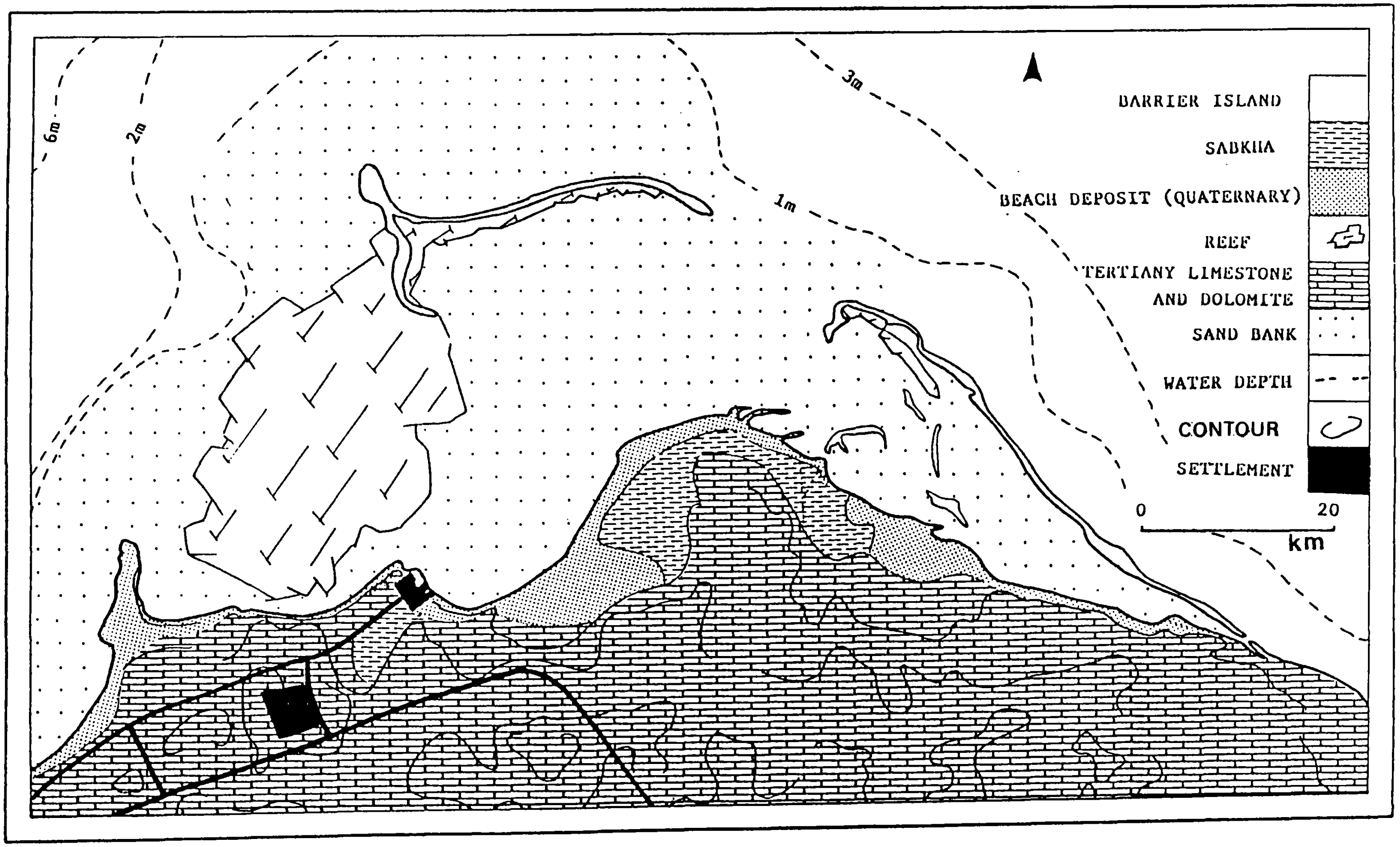


FIG.7.4 LOCATION MAP

The sandy barriers off the north of the Qatar Peninsula appear to be anchored in places. They have prograded on their seaward side and contemporary erosion is not driving them landward. It is possible that the swell approaching the coast has been moving sand into the nearshore zone from where it is redistributed and redeposited as the shore prograded.

The field investigation indicates that barrier islands are likely to have formed during the Holocene marine transgression and they are considered to have attained their present position and height within the past 6000 years. It is possible that a phase of slight emergence aided coastline progradation with the addition of beach ridges and dune ridges, while intervening phases of submergence led to the trimming back of these deposits. Separation of beaches and dune ridges would thus be related to sea level oscillations. The latter would also have been brought about by sequence of slight tectonic disturbance within the Arabian Gulf for the movement of the precise cause is unknown.

## 7.2 Field observation and aerial photo-interpretation

Examination of the aerial photographs dated 1963-1977 show the barrier islands over the fourteen year period. Some changes have taken place on the spit (Fig. 7.5 and Plate 7.1) and the barrier islands have brought about modification in the configuration of the lagoon. A new prograded spit (Fig. 7.6 ) has built up as a result of wind, wave activity, velocity and direction of movement of the water along the north coast from the north and north-west. These factors worked together to build up this new spit. This spit became increasingly

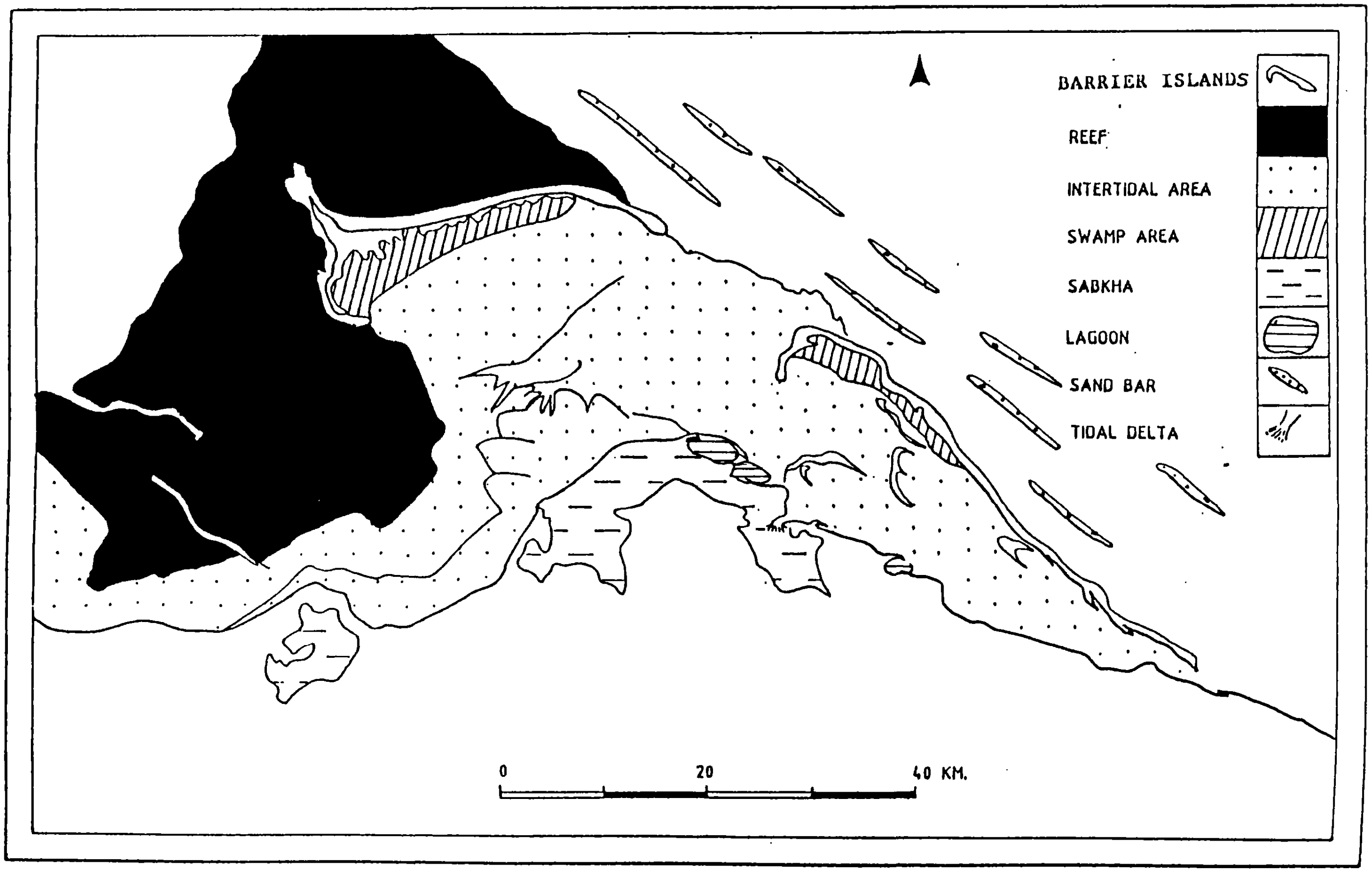


FIG.7.5 INTERPRETATION OF THE AERIAL PHOTOGRAPH 1963.

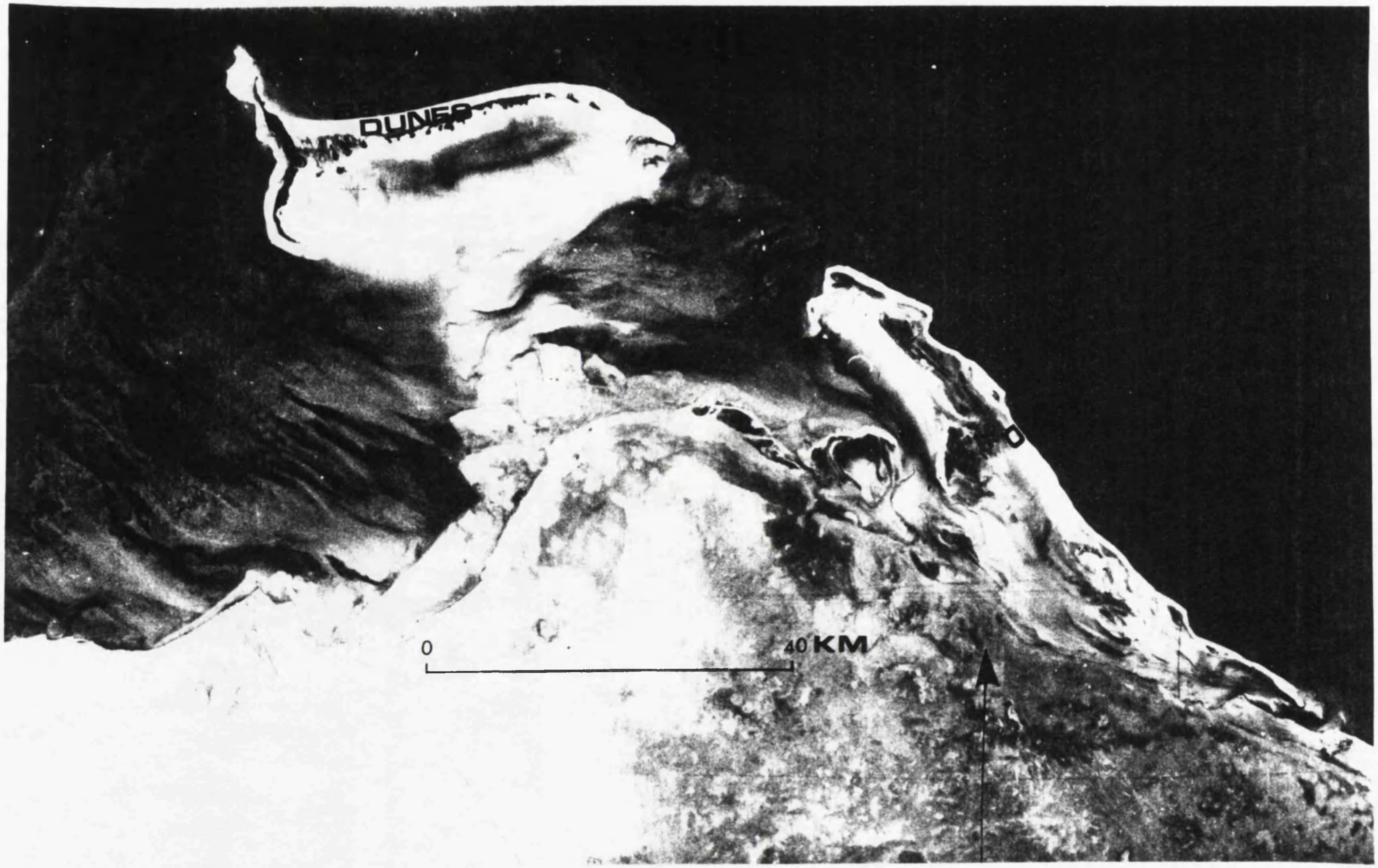


PLATE 7.1 BARRIER ISLANDS, 1963 (AERIAL PHOTOGRAPH TAKEN BY HUNTING SURVEY 1963).
D= DUNE.

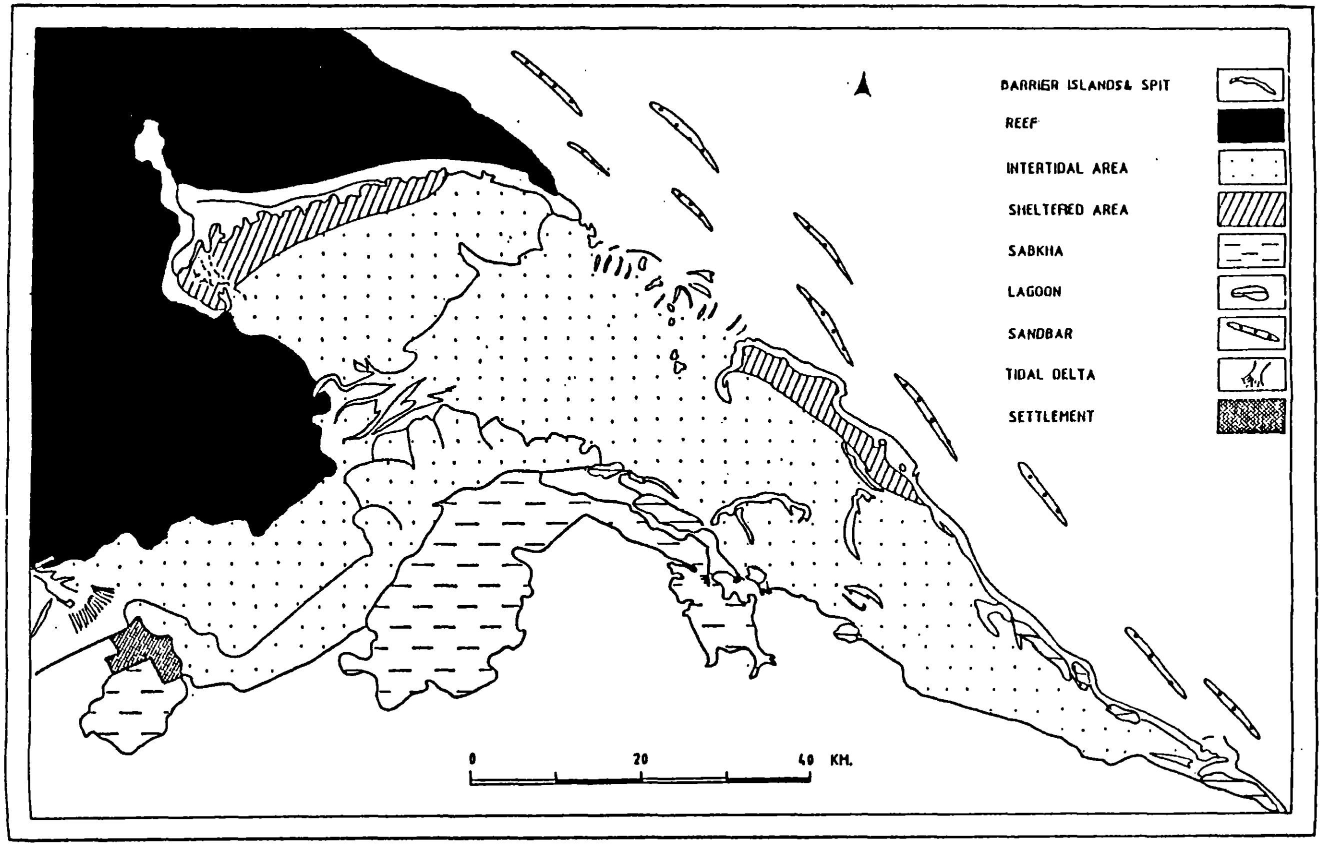


FIG.7.6 INTERPRETATION OF THE 1977 AERIAL PHOTOGRAPH.

unstable as it grew between 1963 and 1977 and through until today. Small spits have been seen (Fig. 7.7 & Plate 7.2) developing parallel to the coastline, while the lagoon itself has been divided into a series of small lagoons. This process has been called segmentation by Price (1947) who described it in association with lagoon development on the Texas coast and it has been observed in S.Africa (Zululand coast). Zenkovitch (1959) also described a similar process at work in some Russian coastal lagoons. Orme (1978) described segmentation as a process whereby a large lagoon is converted into a series of smaller, round or oval lagoons by means of spits, barriers and cuspate forelands building out at intervals from lagoon margins. The efficiency of this process depends on (1) the geometry of the initial lagoons, (2) the direction and strength of wind and related waves and wave-generated currents operating within the lagoon.

## 7.3 Processes

The wave and tidal currents generated by the predominant 'shamal' winds are considered largely to control the development of the coastal morphology of the barrier islands and lagoons, transporting materials from the bordering environments (e.g. the shoal and algal coral reefs developed 1-4km offshore) with deposition taking place for the most part on the northern part of the barrier islands. Wave action is sufficiently strong to maintain a considerable volume of sediment in suspension and thus allow it to be transported by the local currents. These waves are also generating slow-moving currents which move sediment transported by saltation and traction. Most of these movements take place across a series of sand bars and

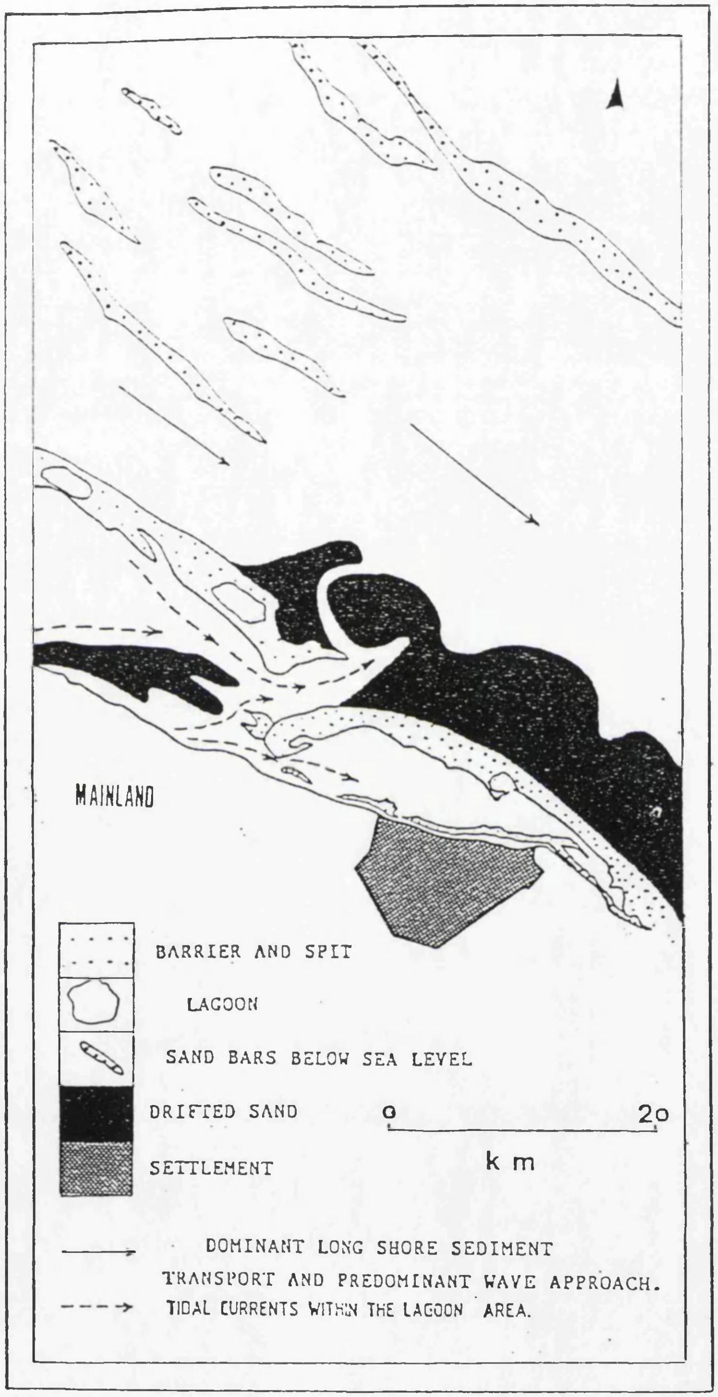


FIG. 7.7 FORMATION OF A NEW SPIT ON THE SOUTHERN PART OF THE BARRIER ISLANDS

PLATE 7.2 FORMATION OF NEW SPIT ON THE SOUTH PART OF THE BARRIER ISLANDS (HUNTING SURVEY, 1977).

offshore shoals. Scour action along the tidal channel tends to keep the lagoon area free from the fine materials except the most sheltered area (Fig. 7.6 ). Elsewhere, the waves distribute sand and coarse materials (shells, coral fragments and gastropod shells) which accumulate around the lagoon margins.

Two profiles were surveyed using a Dumpy level, tripod and staff across the barrier islands from the low tide mark on the north side of the barrier islands to the south side (Figs. 7.8 and 7.9 ) to the lagoon margin. The first profile extends for about 800 metres and the second for about 1000 metres. The maximum height of the Barrier Islands is about 2.6-3.0 metres above sea level in the northern part where beachrock is exposed. Taylor and Illing (1969) studied Holocene intertidal calcium carbonate cementation in Qatar and they identified beachrock about lm thick at the surface. These cemented Holocene deposits are close to the present sea level extending from below low water to a little above high water (+0.5 to 1.0m). Beachrock is exposed in front of the beach ridges and typically consists of several cemented layers which tip seawards at 5°-10° and form a low rampart, with a bed composed of coral reefs and sands. If it is accepted that beachrock is formed between high tide and low tide level, then the emergence of beachrock recorded here may be a useful indicator of a previous higher sea level (Plate 7.3). Levelling was continued to the sand dune ridge system in the middle of the barrier island where there are single dune ridges which attain heights of about 3 metres above sea level in some localities. The surveying was continued from the lagoon (water depth about 1.5-2 metres) to the mainland for a distance of 500m. Behind the

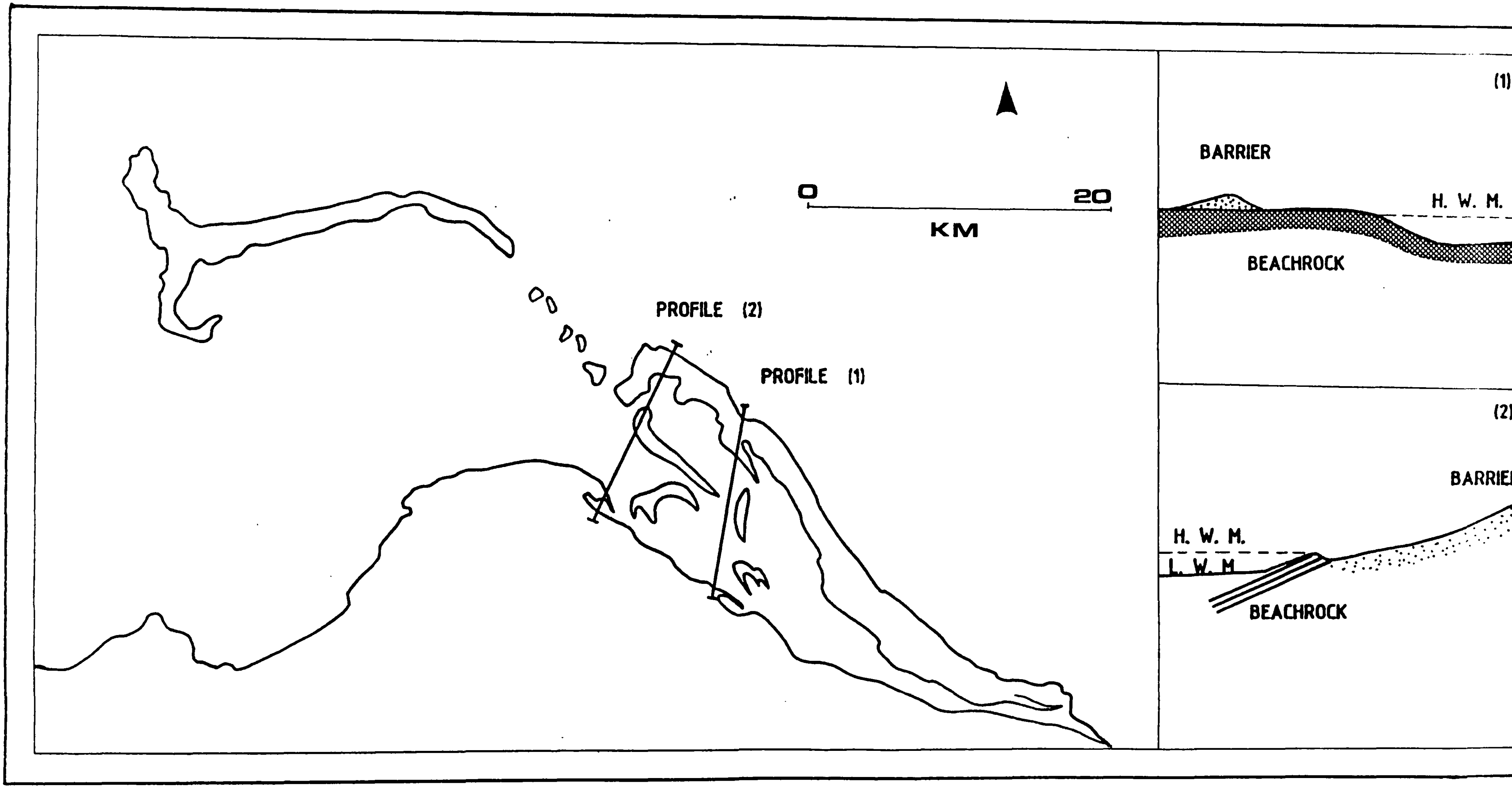
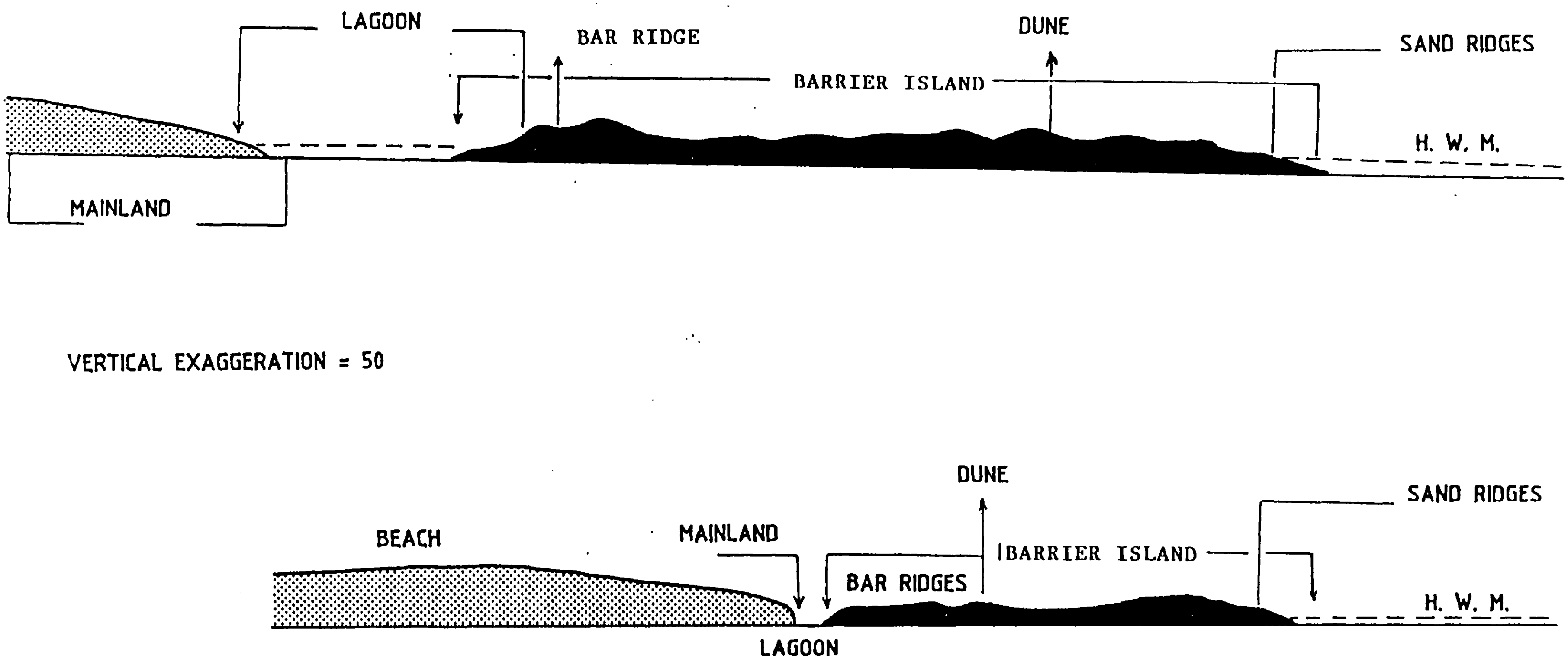


FIG. 7. 8 LOCATION OF PROFILES AND BEACHROCK LOCATION .



VERTICAL EXAGGERATION = 50

FIG. 7.9 PROFILES SHOWING THE MORPHOLOGY OF THE BARRIER ISLANDS OF RAS RAKAN.

barrier, the lagoon becomes the site of deposition. In the lagoon area, despite its protected nature, a carbonate mud has been found, and other sediments there consist mainly of sand, as well as small patches of broken fragments derived from coral reefs. It seems that wave action and tidal currents have managed to accumulate various materials all over the lagoon area, except the small area of swamp colonized by the black mangrove (Avacinnia marina) and other halophitic plants. Surveying was continued to the mainland where small cliffs attain a height of about 1m above sea level in limestone bedrock.

## 7.4 Sediments and their sources

The barrier islands are fronted by beaches in which the beach face developed with a slope leading upward to a berm. The berm is a constructional morphological features (see Chapter 4) resulting from the onshore transport of sediments (King, 1972). These features are defined as linear sand bodies oriented parallel to the shore that occur on the landward side of the beach profile. The beaches are composed of oolitic sand (60%). The remaining 40% comprises a large accumulation of coarse transported shells and coral debris which are concentrated on the berm and on the beach face of the barrier islands. The continuity of the beaches attest to the abundance of beach-forming materials and powerful onshore constructive action and longshore movement of these materials in the coastal zone.

The beaches are composed mainly of materials in the medium to coarse sand range with most of the beaches about 7 metres wide with a berm reaching to 1-2 metres above sea level. Behind the

PLATE 7.3 BEACHROCK DIPPING SEAWARD AT 5° + 10° THE BED COMPOSED OF CORAL REEFS AND SANDS. BARRIER ISLANDS, SEA TO THE RIGHT.

berm, surficial materials are finer and have a slope inland towards the lagoon of $3^o$.

The outline of the barrier islands are related to the pattern of refracted Arabian Gulf swell (Fig. 7.10 ) and growth has been influenced by longshore drifting. The main source of sand comprising the barrier islands is provided by the reef flat, coral reef and shoal which extend for 1-4km around the north coast of the Qatar Peninsula. The sediments from these coral reefs are eroded by waves and carried by the longshore currents to the barrier and lagoon. The analysis of beach of barrier islands and lagoon deposits shows that about 40% of the materials are composed of coral.

## 7.5 Analysis of samples

Mechanical analysis has been carried out on ten samples collected from beach, dune and berm zones on the barrier islands. Particle size curves were constructed and the usual formulae (see chapter 9) were used to calculate the median (md), the mean (M2), the sorting coefficient (Ql), the skewness $SK_1$) and kurtosis ($KG_1$) of the sediments. The particle size histogram shows that the particle size of all the samples lies mostly between fine and medium fine sands with a small amount of coarse sand.

The results of the analysis reveal that the sand is characteristically well sorted with a mean sorting coefficient of +0.61. The sand is moderately skewed (Sk = 0.21) and platykurtic (Ku = -0.90) (Fig. 7.11 ).

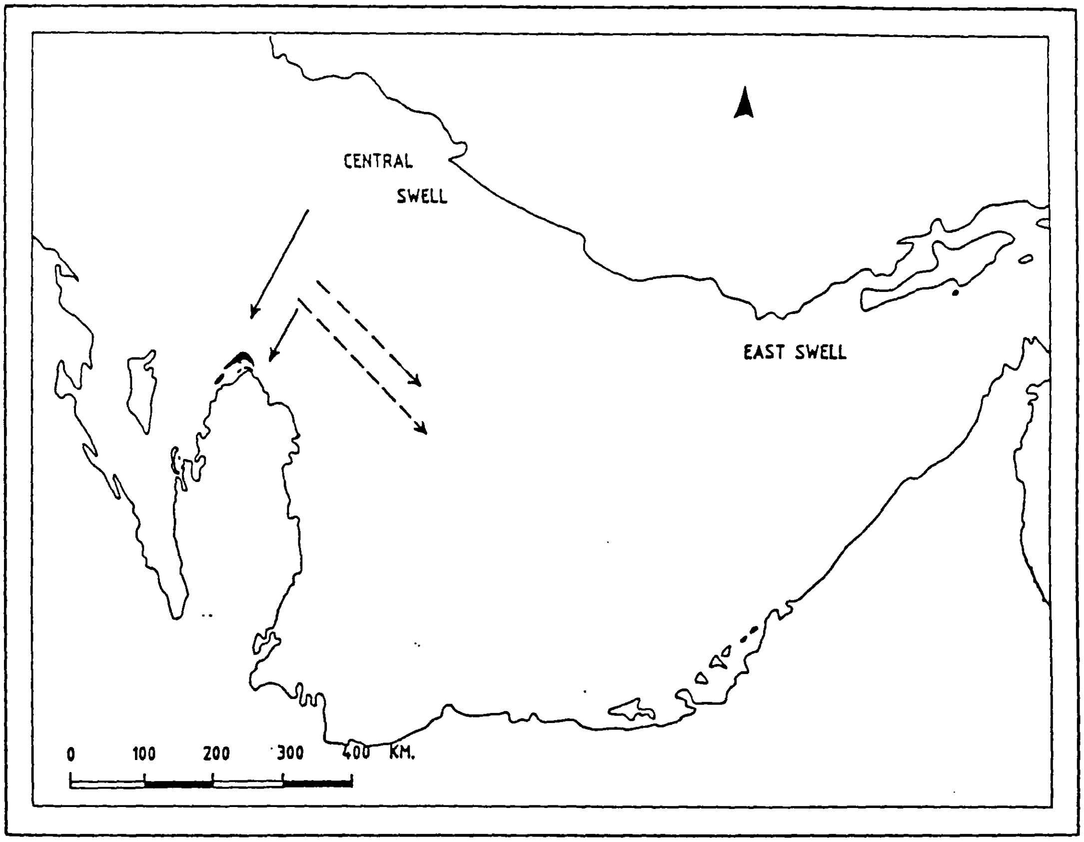


FIG.7.10 MONTHLY MEANS OF WIND SPEED AND DIRECTION AND CURRENT SPEED AND DIRECTION (DEUTSCHES HYDROGRAPHISCHES INSTITUT PILOT CHART 1960), DASHED ARROWS REFER TO MARCH AND SOLID ARROWS REFER TO MAY. CENTRAL AND EAST SWELL WITH ARABIAN GULF (FROM PURSER 1973) ARE SHOWN ABOVE.

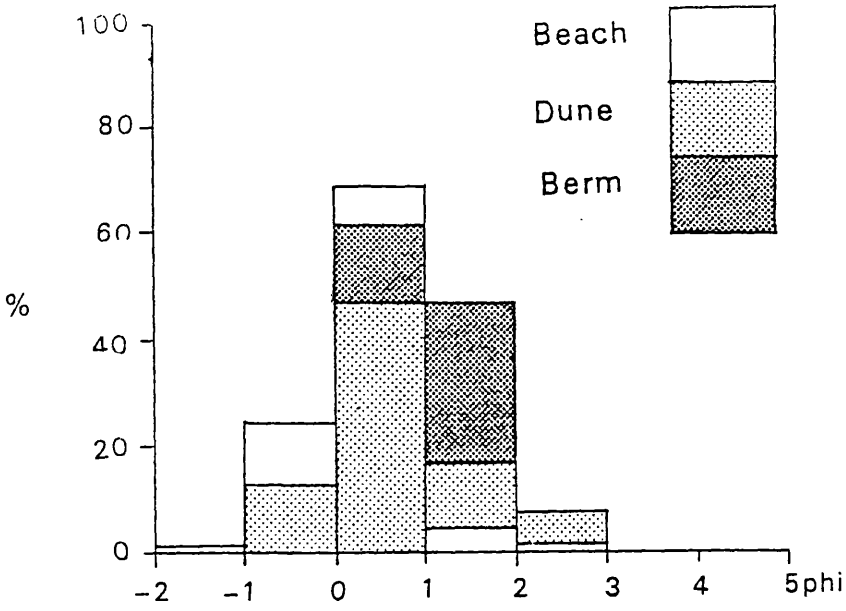


FIG. 7.11 COMPOSITE HISTOGRAM FROM THE SAND FRACTION FROM THE BEACH, DUNE AND BERM, BARRIER ISLANDS.

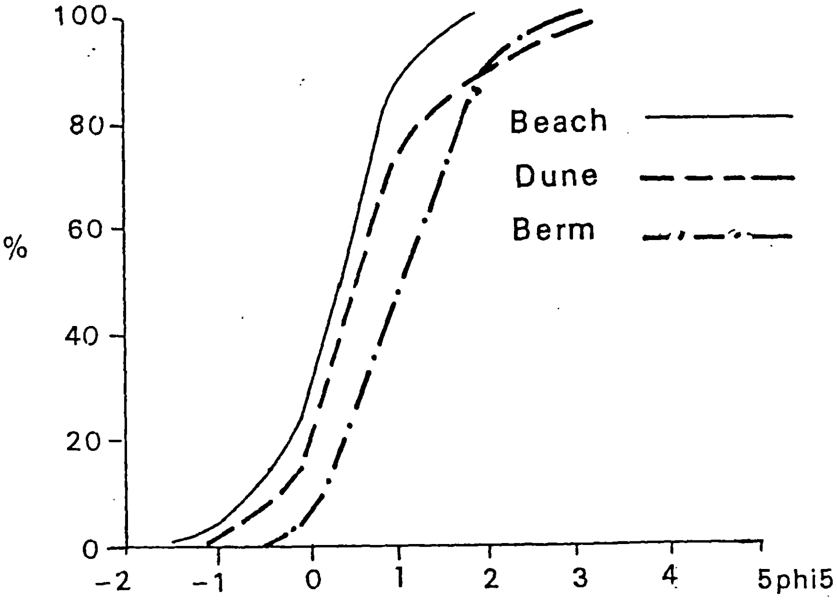


FIG. 7.12 CUMULATIVE PERCENTAGE PARTICLE SIZE CURVES OF BEACH, DUNE AND BERM.

These values indicate that the barrier islands comprise a large proportion of fine to medium sand which is platykurtic to mesokurtic. The particle size distribution of the sand is almost certainly due to sorting by wind, wave and current action along the barrier islands coast. It can be seen that the particle size curves for beach, dune and berm tend to be similar, all lying within the sand grain range (between -1Ø and 2Ø) (Fig. 7.12 ).

## 7.6 Summary

The sandy barrier islands located parallel to the north coast of the Qatar Peninsula are about 200 metres in width, and extend for about 8.5km along the coast. Processes in this area are dominated by the 'Shamal' wind which blows parallel to coastline and is chiefly responsible for the resulting sediment distribution. The barrier islands are separated from the mainland by lagoons which attain a depth of 1-2 metres, the floors of which are composed of a variety of sediments. The most notable change through time in the barrier island has resulted from the growth of the southern part of the spit (Fig. 7. 7). The two profiles surveyed across the barrier island to the mainland revealed low sand dunes attaining heights up to about 3m above sea level, beach rock ramparts composed of cemented shells and coral reef fragments dipping seaward $5^{o}$-$10^{o}$, and possibly representing a formation developed under conditions of a higher sea level.

The barrier islands receive sediments from various sources, such as the offshore coral reefs, and the floor of the Arabian Gulf.

Particle size analysis reveals that sediments on barrier islands mainly comprise fine to medium sand and they are platykurtic to mesokurtic. The form of the particle size curves for the beach, dunes and berm is due to the sorting action of waves and winds along the coast of the barrier islands.

# CHAPTER VIII

# THE COASTAL LANDFORMS AND SEDIMENTS OF THE WEST COAST

# CHAPTER VIII

# THE COASTAL LANDFORMS AND SEDIMENTS OF THE WEST COAST

## 8.1 Introduction

The west coast of the Qatar Peninsula extends for about 250 km from Bin Rahal bay to the Gulf of Salwa. A variety of coastal landforms are displayed, such as embayments, active cliffs, shore platforms, and sand beaches. The topography of the west coast is dominated by the local anticlinal ridges, such as Dukhan and Sauda Nathil, and the syncline which controls the location of the Gulf of Zekreet. The study is based mainly on the analysis of aerial photographs at a scale of 1:16,000 to 1:38,000 and on a geological map at a scale of 1:100,000, together with field investigations. The coast forms of the west coast can be divided into structural and related landforms (related to structure) and depositional and lithified landforms.

A coastline is rarely straight for any distance, but usually has more or less defined curves and often an intricate pattern of bays of various shapes and size. In most cases an embayed coast is formed as a result of submergence and the sea penetrates into depressions produced by non-coastal processes. The development of coastal embayments was first analysed in general by Davis (1919) and later by Johnson (1919) and Zekovtich (1967). The embayments on the west coast are considered to be the most notable features which identify a very different coastline from that of the rest of the Qatar Peninsula.

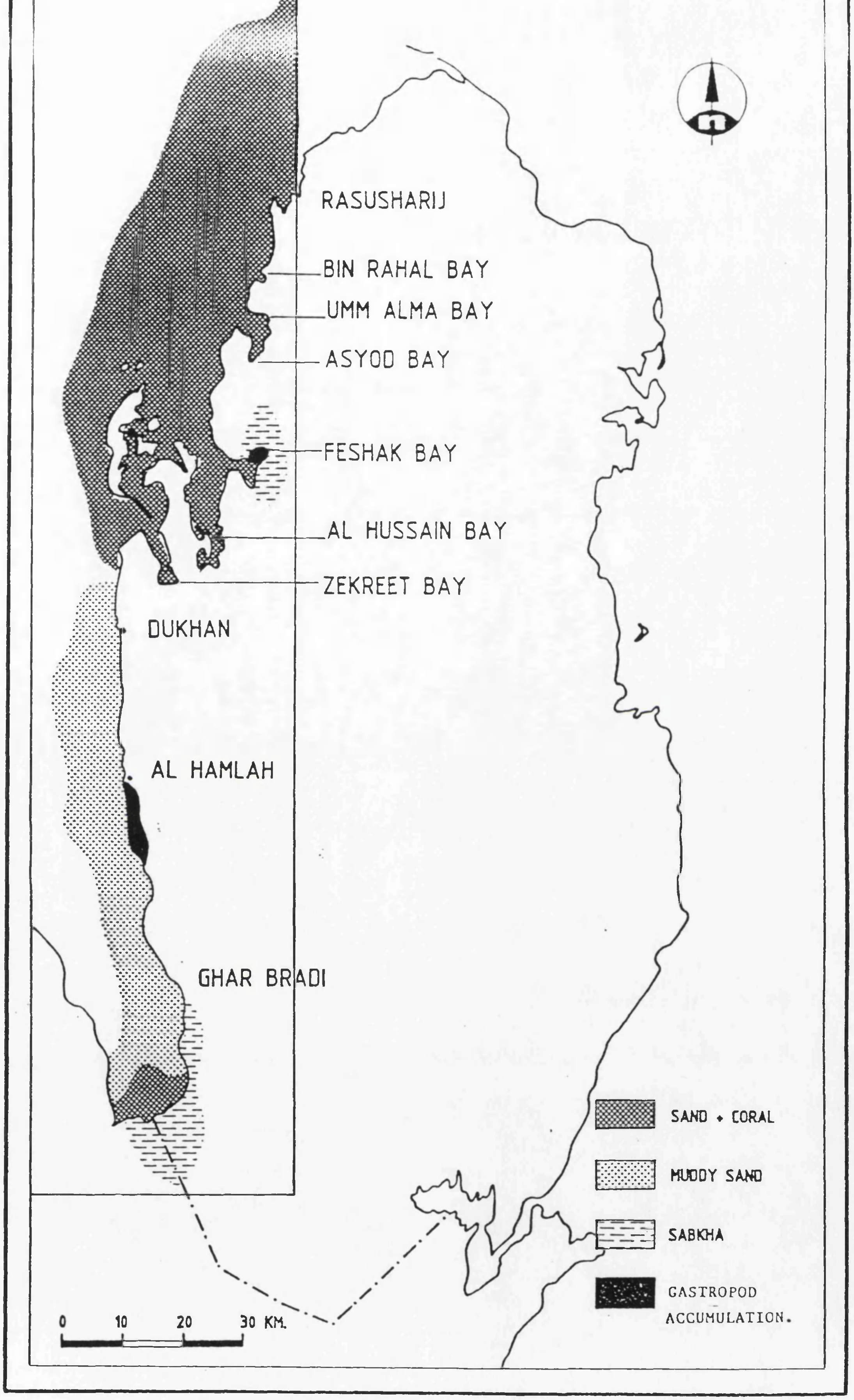


FIG.8·1 DISTRIBUTION OF THE LANDFORMS AROUND THE WEST COAST OF QATAR PENINSULA. THE LOCATION OF SITES MENTIONED IN THE TEXT ARE ALSO SHOWN.

The morphology of the coastal area is influenced by low relief, geological structures, tidal currents and sea currents, all of which have contributed to the creation and shaping of the embayments.

## 8.2 Geological framework

The structure and the rock types contribute to the form of the bays, where it has been able to establish that erosion is concentrated on the 'soft' rocks. The embayments were affected to a general degree by the geological situation and by the variation of sea level during the Tertiary, and especially during the Quaternary. Climatic conditions have affected wave condition (see chapter 1, Fig.1.19, for geological structure of the area), and particularly the strong unidirectional prevailing winds have aided the formation of the embayments. The north-west winds and the north-east winds blow for most of the year against the coastline, and generate the southward movement of sea currents parallel to the coastline. These contribute to the distribution of the marine sediments (sands, gastropods, and coral reef fragments) which contribute to barrier forms lying parallel to the present coastline, and these barriers are backed by the lagoonal zones. Five large embayments are found along the west coast (Fig. 8.1 ). Bin Rahal Bay, Umm alma and A Syod Bays; Feshakh Bay; Hussain Bay and Zekreet Bay.

### 1. Bin Rahal

Bin Rahal is a small bay only 1 km in width from north to south. It is characterized by a shallow water depth (2-4m) as sediments have accumulated as a result of wave and current action and the extension of the coral reef formation located at its entrance.

They later act as partial barriers and supply some materials, such as broken fragments of coral to sediments found within the embayments, FIG.8 2.

2. Umm alma and Asyod Bays

These bays are shallow (water depth 2-4m) and extend for 12 km from north to south. There are extensive marine depositional features around the two bays, including beaches, sand banks and spits. The sand banks cover almost the whole floor of the bays and tend to be oriented perpendicular to the west clast (Fig. 8.2 ).

3. Feshakh Bay

This bay lies north-east of Hussain bay and is semi-circular in form, extending for 4 km in both east-west and north-south directions with a water depth of 2-4 metres. It is connected to Hussain bay through a relatively narrow outlet which is no wider than 1.5 km. Sabkha mud flats surround Feshakh bay with the northern sabkha extending for 5-6 km in an east-west direction. There are some elevated shoreline features along the eastern and western margin of this sabkha. It seems that the whole of Feshakh bay will be transformed eventually into a sabkha because of the constant deposition on its floor which has been significantly shallowed by the formation of extensive sand bars (Fig. 8.3 and Plate 8.1).

4. Hussain Bay

This bay is about 17 km long from north to south with a maximum width of nearly 7 km and a water depth of 2 to 4m. It lies between the Abrug Peninsula in the west and the mainland in the east. It is comprised of several small bays (A, B and C). The largest bay

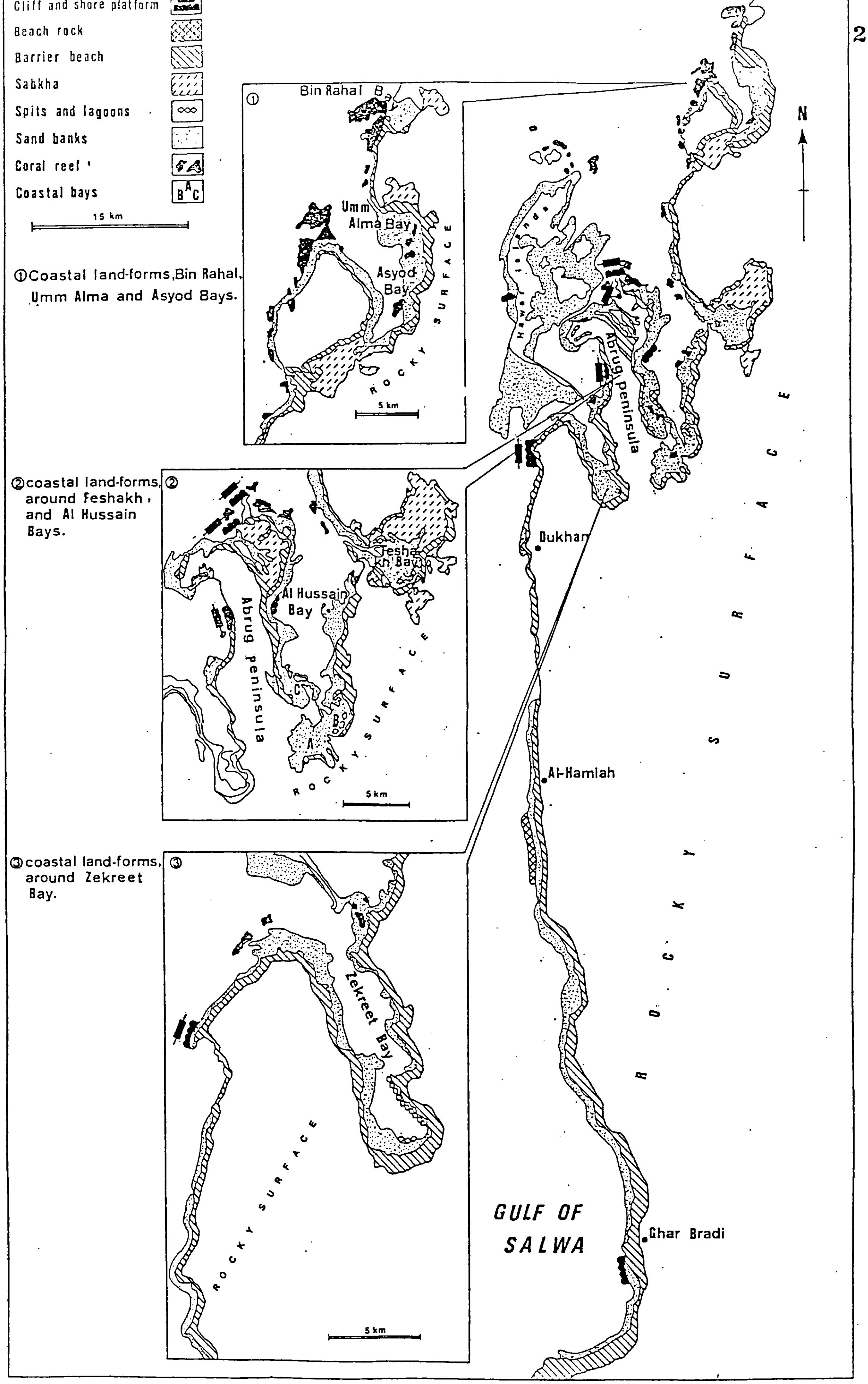


Fig.8.2 Main coastal land-forms around the west coast of Qatar peninsula

PLATE 8.1 (A) AERIAL PHOTOGRAPH FOR FESHAKH BAY . HUNTING SURVEY, RUN 4.3098, 1977.

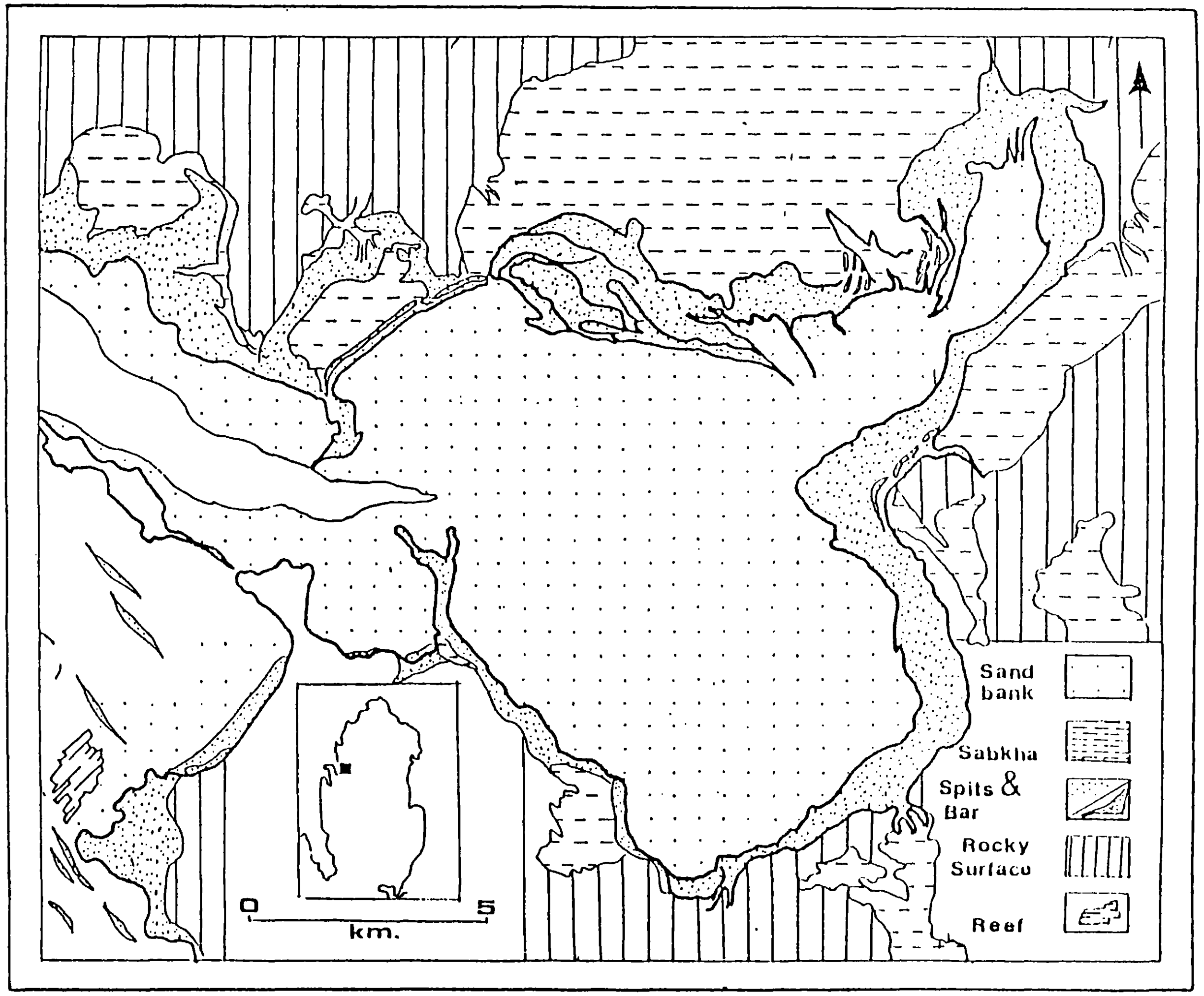


FIG. 8.3 FISHAKH BAY, OVERLAID FROM AERIAL PHOTOGRAPH, 1977.

(A) has a maximum width from east to west of about 4 km and about 3.5 km from north to south. Its floor is covered by sand bars with a substantial content of mud, varying from 40-60% of total volume, the sea currents responsible for delivering the sediment to the bay are mainly controlled by the prevailing north-west (Shamal) wind. To the north-east, bay (B) has a direct outlet to Hussain bay through a relatively wide outlet of about 1.5 km. Bay (C) has an elongated shape in an east-west direction extending for 3 km but is only 1.5 km wide from east to west. It is connected to Hussain bay through a narrow outlet. This bay is also characterized by having a shallow water depth of 2-3m, and its floor is also covered by extensive sand bars.

## 5. Zekreet Bay

This bay is located between Abrug peninsula in the east and the headland of Dukhan in the west. The bay is 9 km long and 5 km wide with a water depth reaching 2.5 metres. This bay occupies a synclinal formation, with a geological structure closely controlling the overall shape of the inlet. The coastline around Zekreet bay is generally low-lying but 1-3 metres high cliffs in limestone are present on the east coast of the bay. According to the aerial photographs taken in 1977, and with reference to Figure 8.2 , Zekreet Bay can be divided into two parts. The southern part is characterized by the dominance of marine deposition due to the 'Shamal' (north-west) wind which drives waves carrying sediment southwards into Zekreet Bay. The northern part of the bay is characterized by extensive marine deposition which includes sand barriers and sand banks that have accumulated at the entrance. The waves are driven by the north wind

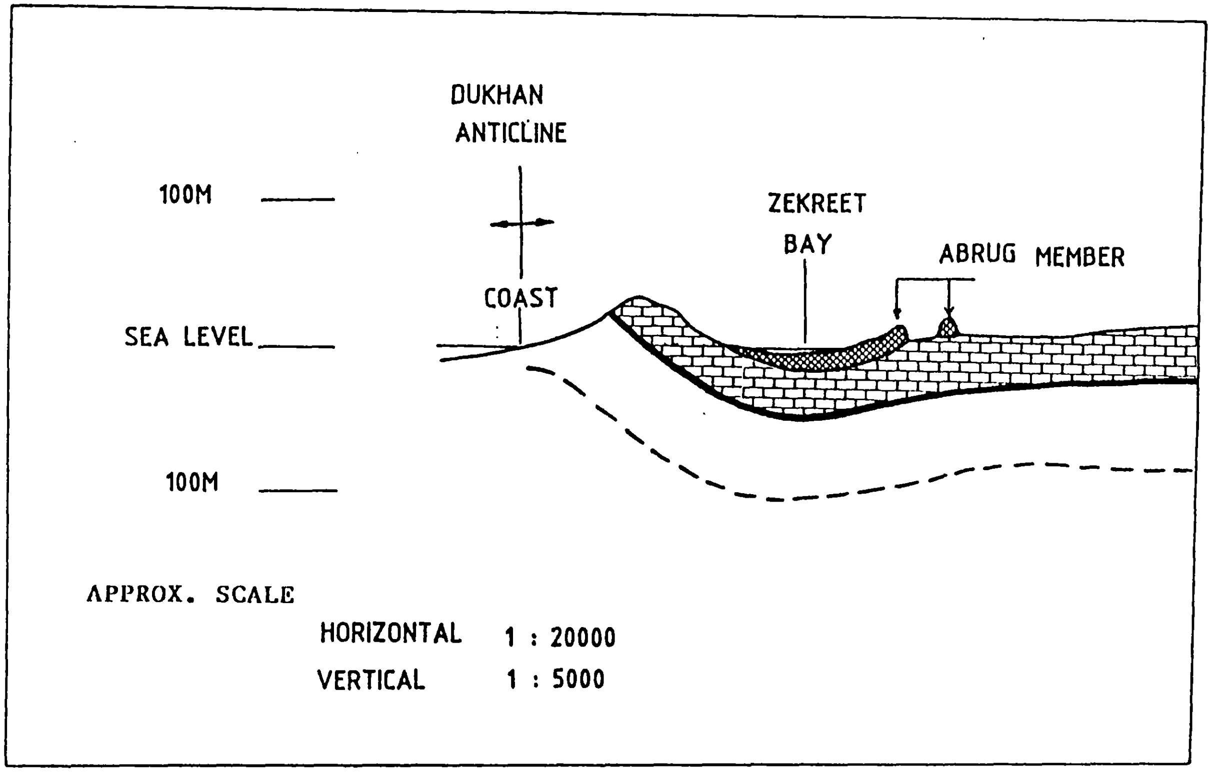


FIG.8.4 THE SYNCLINAL FORM OF ZEKREET BAY.
SOURCE: IDTC. SELTRUST ENGINEERING LTD. (1980).

and the accompanying sediments have been deposited where the water depth is 2 to 4 metres. Thus Zekreet Bay has formed and gained its present shape due to the geological structures (Fig. 8.4 ) which have been exploited by marine action. We can see clearly that the bay occupies the breached synclinal form, while the outer coastline intersects the anticlinal limb.

## 8.3 Shore platforms

### 8.3.1 Introduction

Erosion of the coastal slope and the successive removal of the debris by near-shore currents cause increasing recession of the shoreline leaving behind shore platforms which are normally gently sloping or quasi-horizontal (1:100 gradient is common according to Pethick (1984), although angles between $0^{o}$ and $3^{o}$ are common, and these values can exceed according to location (Flemming, 1965; Trenhaile, 1980). Platforms are very variable in width, but tend to reach a maximum of about 100m (Flemming, 1965) and the profile normal to the shore varies from linear to concave in form. Some authors describe composite profiles which are convex overall (e.g. Bradley and Griggs, 1976). The elevation of these platforms seem to depend more on the definition adopted by various authors rather than on any real morphological variation. Bird (1984) suggested that groups of platforms could be identified, and similar features have been found on the west of Qatar lying between high and low tide marks.

### 8.3.2 Shore platforms profiles

The purpose of this section is to present profiles in order to identify the shore platforms and to examine their development and that of related features. Three sites have been chosen and the platforms carefully surveyed using an optical level and staff. The first two sites are located on Abrug Peninsula and the third in the Dukhan area. The mean sea level for those profiles has been estimated from the data available from field observations and the tide tables for 1986 supplied by the Meteorological Department, Qatar. In each case the profile has been drawn from levelling data and additional information derived from geological maps and aerial photographs taken in 1977.

These intertidal and low tide shore platforms (as termed by Clowes, A. 1982) occur at various levels between high water level (+1.2m and +2m) and the majority of these platforms extend outwards from the foot of the low cliffs. In figs. 8.5 and 8.6 it can be seen that two platforms cut across different rock lithologies and structures.

Around the west coast of Qatar peninsula the tidal range is 1.5m and the platforms have gentle slopes between low and high tide limit, and end in wave cut notches at the base of low cliffs in limestone. These intertidal platforms are clearly abrasion features and are covered with venner of pebbles formed from the erosion of the cliffs. The shore platform on the west coast of Abrug peninsula is backed by an 11m high cliff, with pronounced notch at its base. However, solution of the limestone is observed to be active at the base of the cliff and has undoubtedly aided cliff recession and extension of the

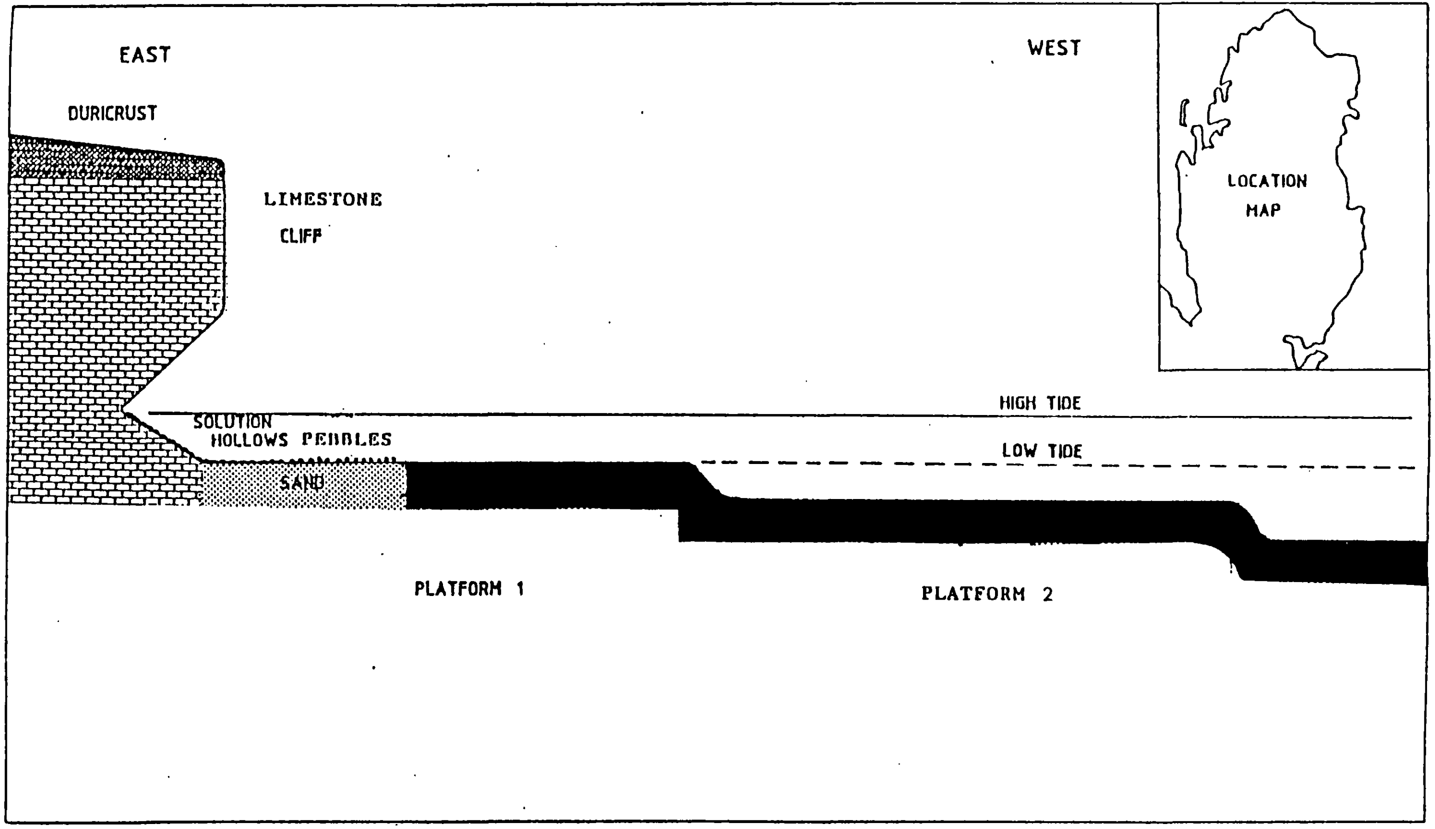


FIG.8.5 SHORE PLATFORM , WEST COAST OF ABRUG PENINSULA , QATAR .

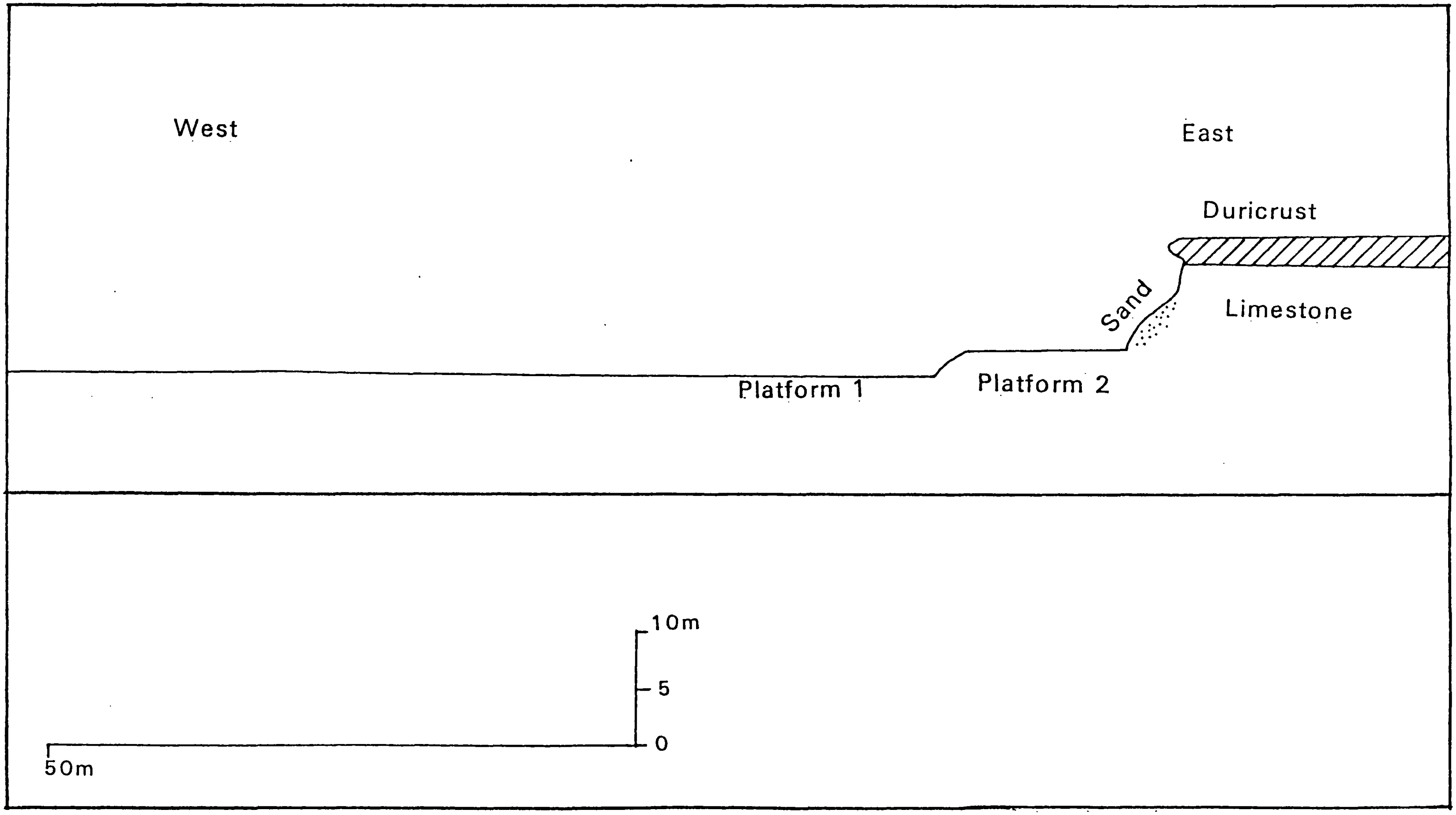


FIG. 8.6 SHORE PLATFORM FORMATION, DUKHAN AREA, WEST COAST, QATAR.

platform. These platforms showing the formation of solution hollows and a pronounced micro-relief are discussed in a later section. The Abrug platform extends seawards for 30-35 metres and the surface is developed on dolomitic limestone. It was surveyed in the intertidal zone between high and low tide level where the surface gradient was found to vary with lithology and structure. The shore platform exhibits two distinct levels of platform which appear to present the interaction of various factors, such as rock structure, exposure to the wave action and possibly to changes of sea level (Fig. 8.5 ). It is impossible to be certain whether or not the latter may result from either eustatic change or slight tectonic warping on this coast.

The second platform on Abrug Peninsula extends seaward over 40-50m (Fig. 8. 6 ). It is inclined towards the sea at an angle of 5° one of the steepest slopes recorded. In the upper part of the profile, there is an accumulation of sand which could have been derived from the weathered cliff. The profile shows a series of two levels extending up to 20m above sea level. The Figure 8.6 shows two platforms : the microcliff separating them may also have resulted in either eustatic change or slight tectonic action.

The third platform in the Dukhan area represents the low tide platform (as termed by Clowes, A, 1982 and Bird, 1984), which displays various interesting features as shown in figure 8.7. The platform has gentle slope between low and high tide limits. The surface is inclined at 3° and the width of the surface of the platform exceeds 20m. Mushroom rock features occur. These are created by a combination of wave action and solutional activity. They are about

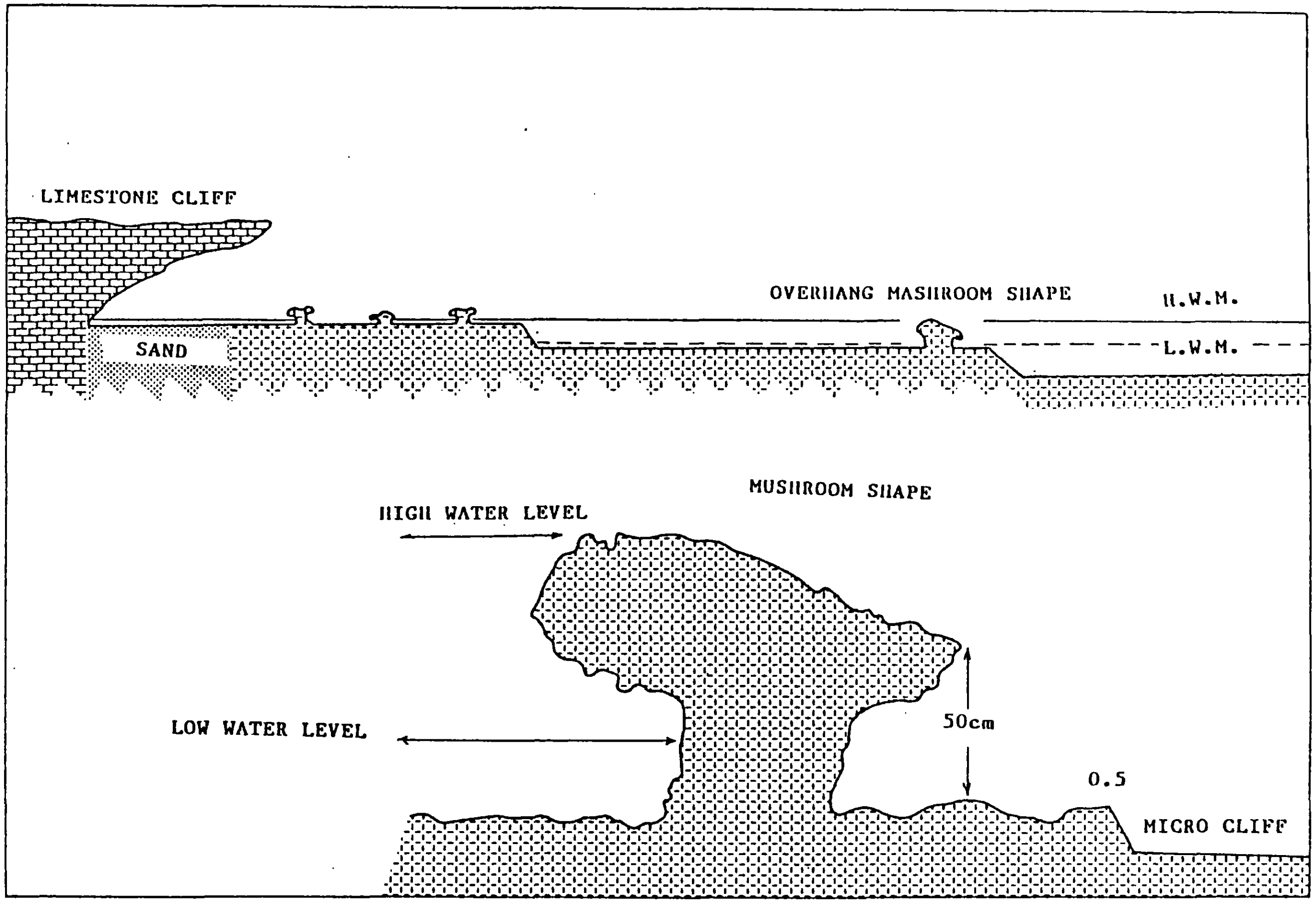


FIG.8.7 SHORE PLATFORM FORMATION, DUKHAN AREA, WEST COAST, QATAR. FORMATION OF MUSHROOM SHAPE BY WAVE ACTION AND SOLUTIONAL ACTIVITY.

1 metre high and 50cm in diameter (Plate 8.2A and B). The pronounced notches at the base of the 'mushroom' features are coincidental with low tide level, while the top of the 'mushroom' features on the lower platform coincides with high tide level. Other upper platforms, the notches at the base of the 'mushroom' features occur at high tide level. Flemming (19[illegible]5) stated that these low-tide platforms are associated with low wave energy, warm waters and carbonate-rich rocks, and are frequently accompanied by notches in the cliff behind. Notches are taken by many to be morphological evidence of solution despite the saturation of sea-water with calcium carbonate.

Thus the 'mushroom' features appear to represent stages in the reduction in height of a sequence of shore platforms, brought about by a combination of wave abrasion and chemical activity. They are best developed on a limestone coast like that of Dukhan area where high salinity values of the sea water may be more important than solutional activity. Wetting and drying of the rock surfaces combined with the generation of the salt crystals in the intertices of the limestone, may well account for substantial weakening and hence retreat (lowering the rock surface and thus solution *sensu stricto*) is not the main process.

## 8.4 Cliff profiles

The cliffs are a function of the processes of weathering and erosion both marine and subaerial, and the concavities or convexities present are due to a combination of these two processes.

A

B

PLATE 8.2 A & B MUSHROOM FORMS ON THE DUKHAN SHORE PLATFORM. THEY ARE FORMED BY SOLUTIONAL ACTIVITY ACCOMPANYING WAVE ACTION.

Marine processes attack the base of the cliff leading to the undermining of the limestone strata, resulting in structural collapse and maintenance of a vertical or under-cut profile. Subaerial processes are operating on the upper part of the cliff leading to the creation of a convex or seaward sloping profile. If marine processes are dominant, the rate of under-cutting is such that the convex upper profile rarely developed in this area, and normally the cliffs have under-cut or vertical profiles. When marine processes are weak and subaerial processes are active a composite profile develops. This is composed of a vertical under-cut part of the base of the cliff, and a convex or seaward sloping section above. Cliff profiles in the Abrug peninsula, Dukhan, and Ghar Bradi are all formed in limestone (Fig. 8.8 A,B,C). The cliff profiles are generally vertical, although under-cutting commonly takes place, resulting in rock falls, as seen at Ghar Bradi (Fig. 2.4 chapter 2). The location of these marine cliffs corresponds with the zone of maximum marine attack where the prevalent and dominant north or north-west wind blows directly on-shore for much of the year. There can be no doubt that this environment factor, together with the geological structure clearly controls of the development of the profiles (Fig. 8.8 ). Some of these cliffs terminate upwards in a hard duricrust which leads to the production of a substantial 'overhang' as seen in Figure 8.8 and illustrated in profiles 1-2-4-6-5-7-12-13. Elsewhere the cliffs display wave-cut notches and overhangs which have developed mainly by solution and wave activity on the limestone (Fig. 8.8 , profiles 12-13). Some cliffs have debris fans masking their base and the old wave-cut notch, the rock debris being gradually reduced by solution and salt weathering and removed by wave action until the cliff base is again

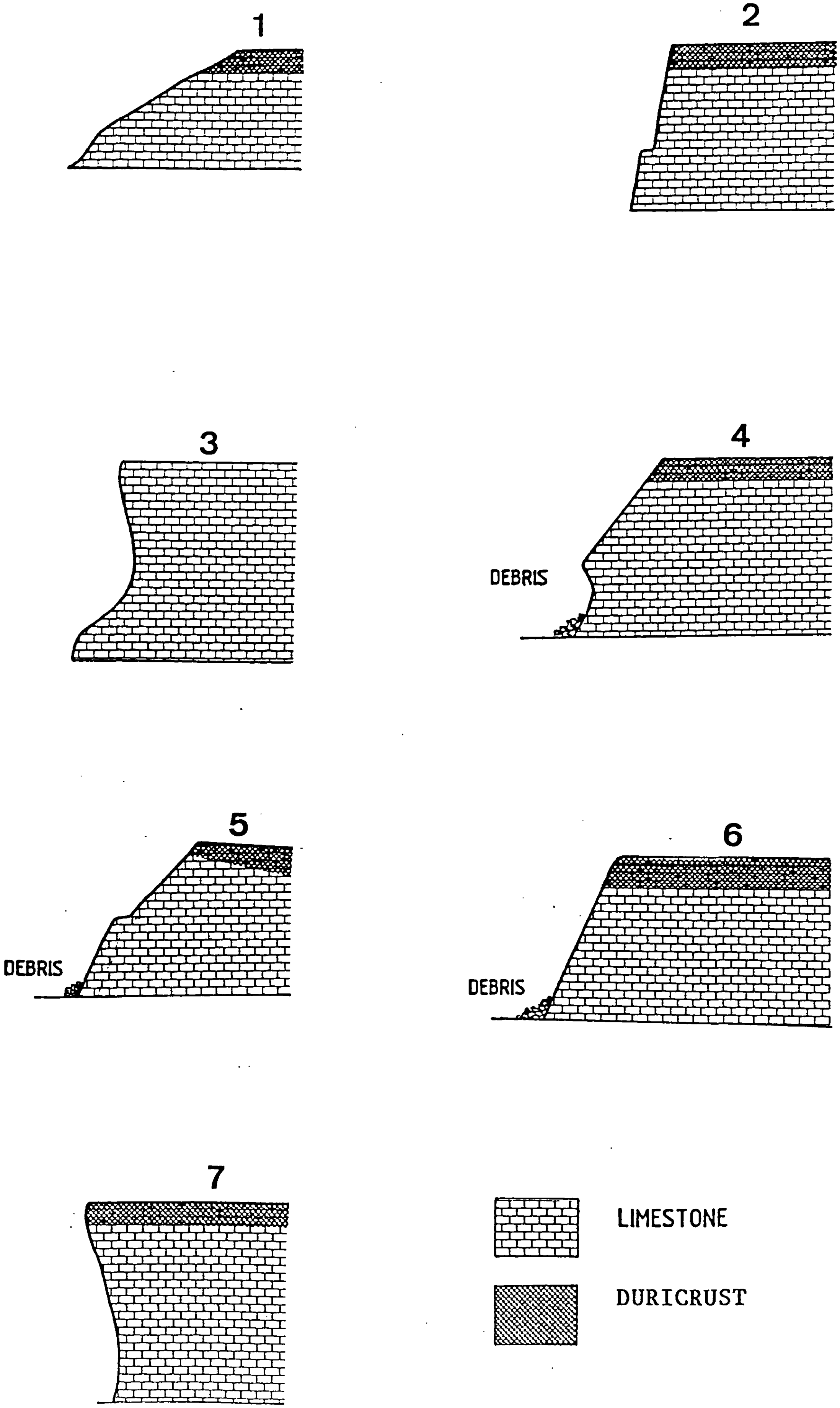
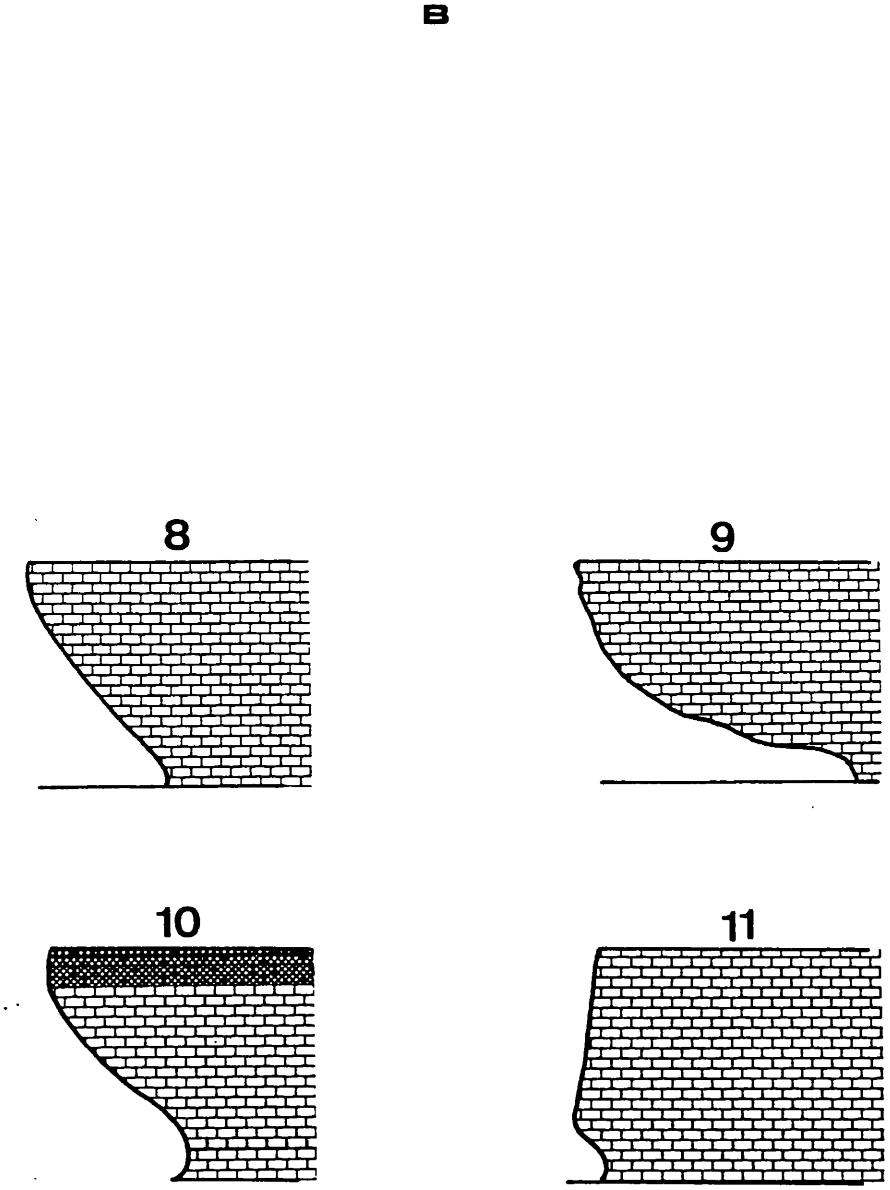


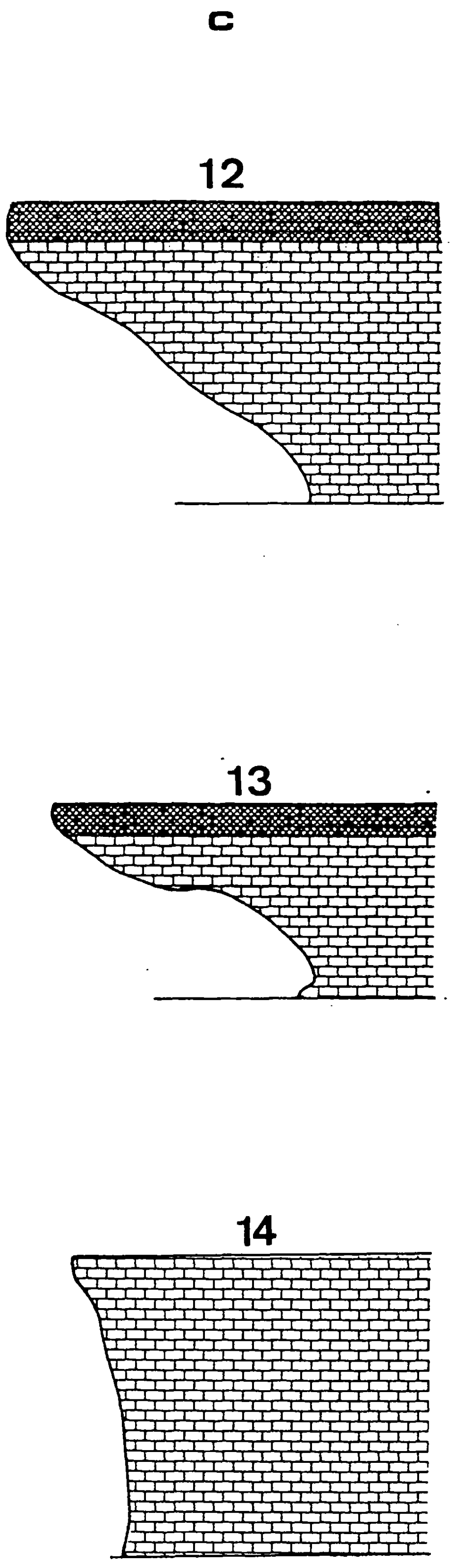
FIG.8.8 CLIFF PROFILES IN ABRUG PENINSULA.



▩ DURICRUST

▦ LIMESTONE

FIG.8.8 CLIFF PROFILES IN DUKHAN .



▦ LIMESTONE

▩ DURICRUST

FIG. 8.8 CLIFF PROFILES GHAR BRADI

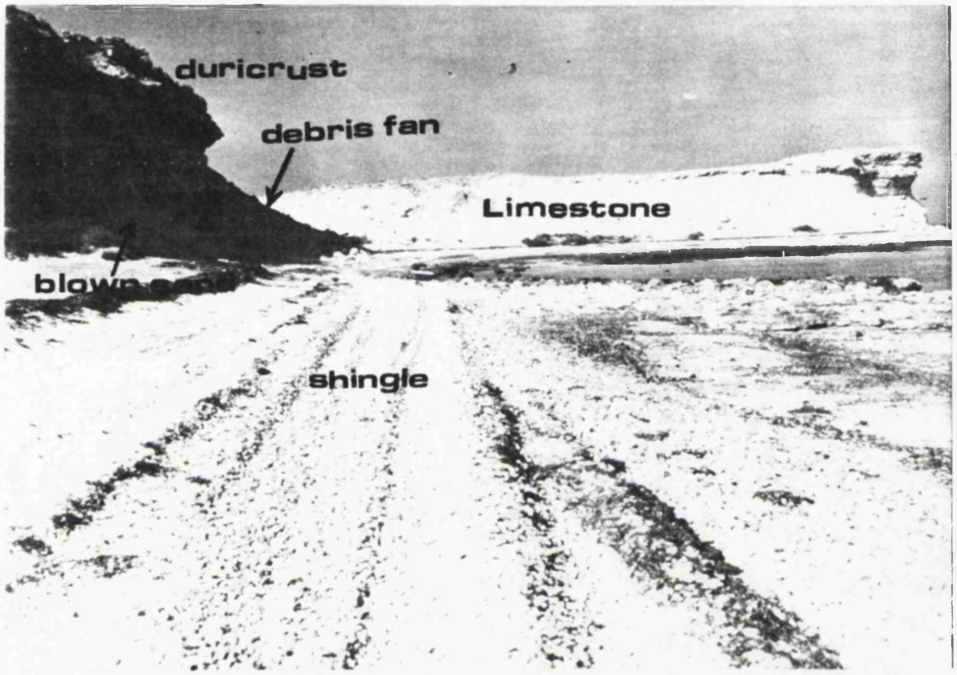


PLATE 8.3 PROFILE NO. 6. ARROWS INDICATING DEBRIS FAN RANGES BETWEEN 42 - 43 ON ABRUG PENINSULA.

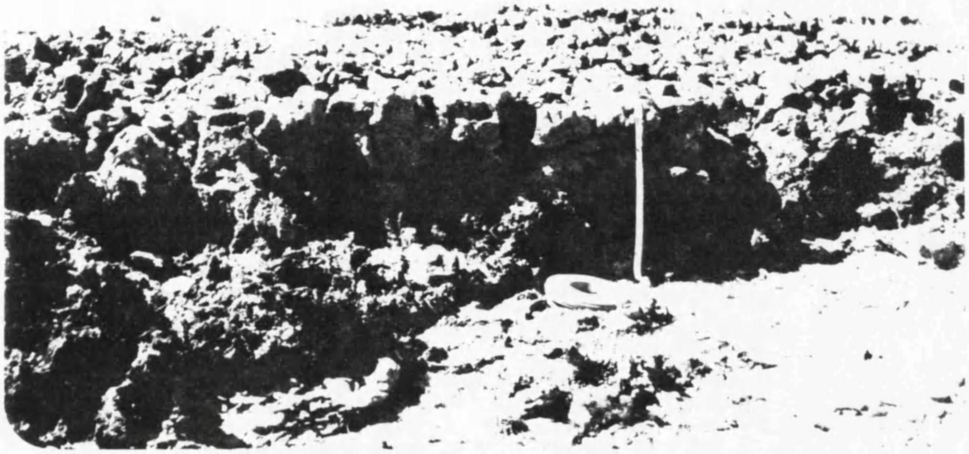
exposed to wave attack. Undermining then produces further rock falls so that the cliff retreats intermittently. The debris fan has been measured in different locations ranging between 42°-43° (Plate 8.3) (Profile No. 6). Therefore in the Abrug peninsula ,Dukhan and Ghar Bradi the cliff profiles illustrate the relative efficiency of marine versus subaerial processes, but also the result of geological control which may enhance the rate of profile development.

## 8.5 Coastal processes

The processes of shoreline development are different in importance in each coastal area. The purpose of this section is to show the importance of individual processes upon the cliffs and shore platforms.

### Solution:

Solution on the coast is particularly important on the extensive coastal exposures of limestone bedrock. The morphological effect of solution is to produce sharp, fretted, pinnacles or lapiés on the limestone (Plate 8.4). Solution hollows commonly develop on some of the shore platforms where waves breaking on the vertical scarp face throw up quantities of spray, constantly maintaining pools of stagnant highly saline water (Trenhaile, 1969). The pools are actually deepened by solution attaining a maximum of 25-28cm (Plate 8.4) and widening of the hollows continues until original surface is totally destroyed. Subsequently, extension wears down the wall between adjacent hollows reducing the local micro-relief and as a result of the destruction of the hollows, small projections are produced on the surface of the shore platforms. Notice too that in Plate 8.4 solution has reduced a higher level platform to new lower level (in



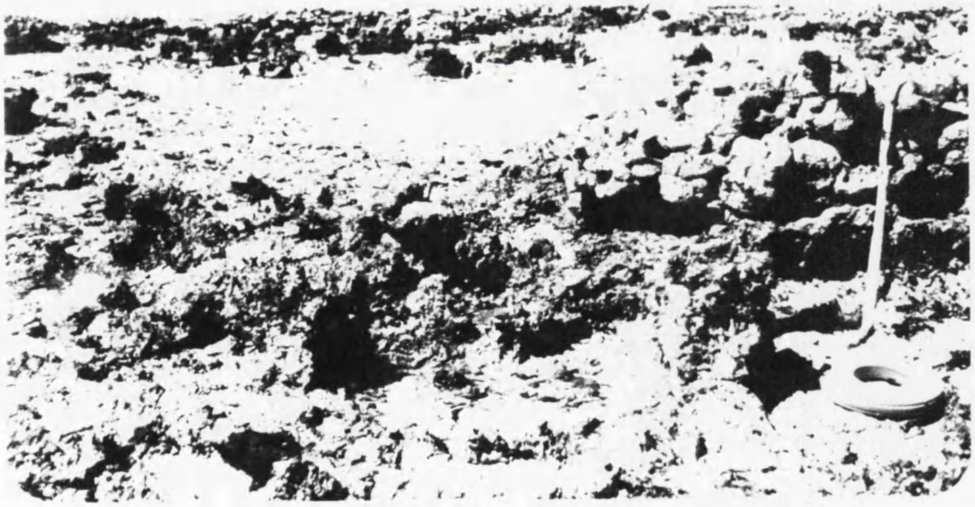


PLATE 8.4 A& B, THE FORMATION OF LAPIES ON LIMESTONE, ABRUG PENINSULA. TYPICAL SOLUTION LIMESTONE SURFACE AT DIFFERENT LEVELS CAN ALSO BE SEEN.

the foreground). In Plate 8.4 an isolated small pillar of limestone can be seen to the left of the measuring tape, illustrating the manner of rock reduction. Solution hollowing is, however, considered to be a secondary process, which adds detail to the platform surface, but it is unlikely to have been responsible for the development of the complete platform.

### Abrasion

Abrasion is a process that is important to development of the cliff and shore platform in the Abrug peninsula , Dukhan and Ghar Bradi. Abrasive materials are abundant along the shoreline where wave action effects erosion and long shore drift transports materials southward because of the prevailing north-west winds. However, it is particularly difficult to ascertain the relative importance of abrasion and solution in this area. That the two processes combine to bring about lowering of the rock surface is not in doubt, but it has not proved possible to measure solution rate.

## 8.6 Marine depositional forms

Various morphological features have been formed by marine deposition along the west coast of the Qatar peninsula. These include beach barriers, spits and sand banks. The nature of these depositional features is a function of several constructional components, the most important of which includes the type and amount of material being moved, the wave generation area, wave refraction, wave approach direction determined largely by the prevailing winds, longshore movement, platform gradient and tidal range. The shoreline sediments comprise mainly quartz sand, coral reef fragments and gastropods, and there is a general north to south movement of the sediments along the coast, as already explained.

The morphological features include:

## 1. Barrier Beaches

The construction of barrier beaches has been of interest to many authors in several parts of the world (for example, eastern USA, Kraft 1971), the Gulf of Mexico (Otves, 1970) and eastern Australia (Thom, 1978; Swift, 1975). It has been postulated that certain barrier beaches had become detached from mainland beaches by flooding of the low-lying area behind the outer barriers when submergence was initiated. In shallow embayments such as those around the west coast of Qatar peninsula, other factors are important. These include the gentle relief, low tidal range, abundance of sediments derived from the adjacent cliffs, the presence of materials eroded from the headlands and moved into the bay, and the moderate wave energy. These processes combine to produce large accumulations of sediment in the off-shore areas, sufficient to allow barrier beach construction.

## 2. Spits

Spits are forming around the east coast of Zekreet Bay. They do not usually exceed 300m in length and some of them are backed by coastal lagoons. The spits in Hussain Bay extend along the west and east shores of this bay (B) and are oriented generally in a north-south direction. The spits are also linked to the mainland at their northern end showing that longshore drift is from north to south. The largest spit is found on the east shore at the entrance of the bay: its total length is 2km and its greatest width is approximately 600 metres. Along the west coast of Bay (B) small spits have formed which are connected to each other, some at their southern ends and others at their northern ends. Spits have also formed along the west coast of Bay (C) and they are connected to the mainland at their northern ends which demonstrated that longshore drift within this bay is also from north to south. Spits also formed within Feshakh bay where they are small compared to those in Zekreet Bay, their length ranging between 300m -1.5m and their breadth from 40m -55m.

### *Sandbanks*

These features occur along almost the whole west coast, their formation controlled by the same factors that formed the barrier beaches and spit, primarily the wave and current action involving the southward drift of sediments along the coast. Sand banks that formed along the east coast of the Umm Alma and Asyod Bays tend to be wider due to the movement of the water within the bay.

## Lithified beaches (Beachrock

On the west coast south of the Al Hamlah area lithified beaches have been found. This 'beach rock', as it is known in the literature, is in the form of a 'pavement' 10 metres or more in width. Some of these beack rock features resemble wide, nearly flat 'platforms'. The presence of limestone undoubtedly influences beach rock cementation through the availability of warm sea water. In the presence of high concentrations of calcium carbonate cementation takes place. Davies (1973) argued that beach rock may be closely associated with 'old'

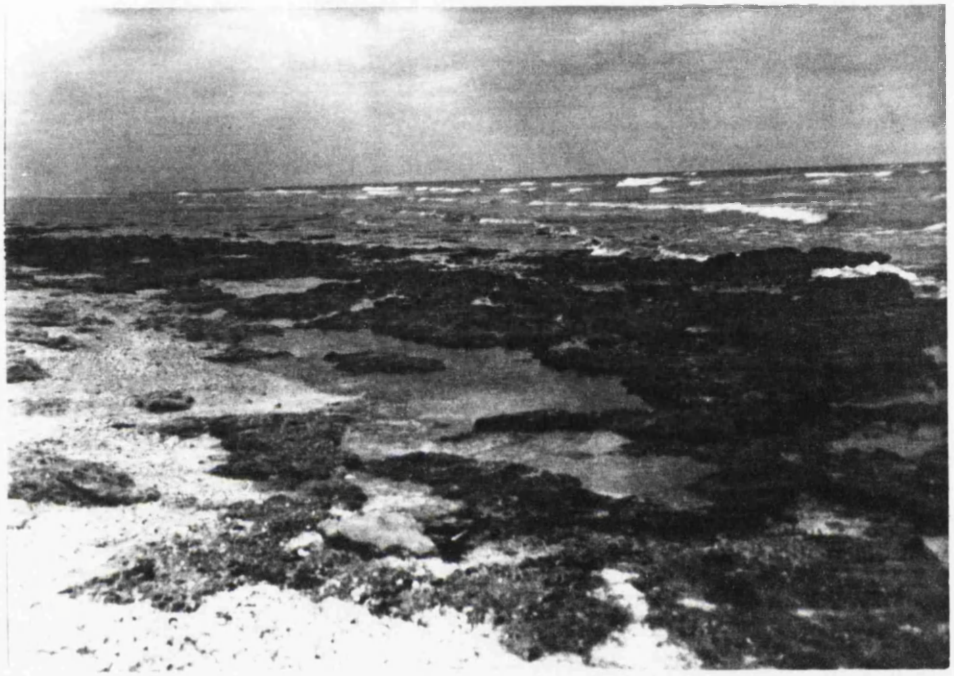


PLATE 8.5 BEACHROCK, SOUTH OF AL-HAMLAH ON THE WEST COAST.

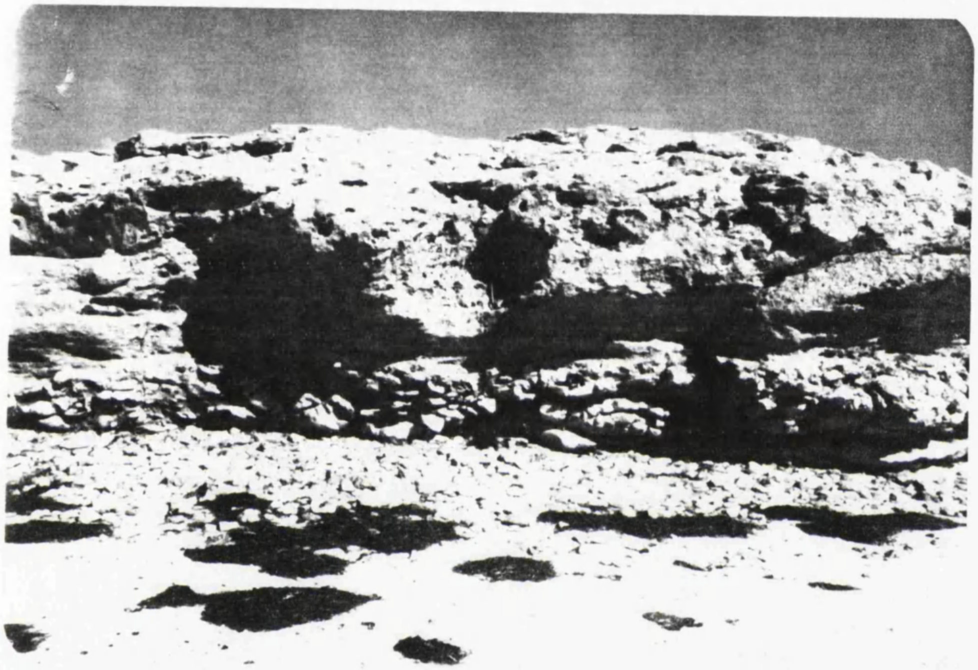


PLATE 8.6 AEOLIANITE ON RAS ABU OMRAN NORTHWEST OF QATAR.

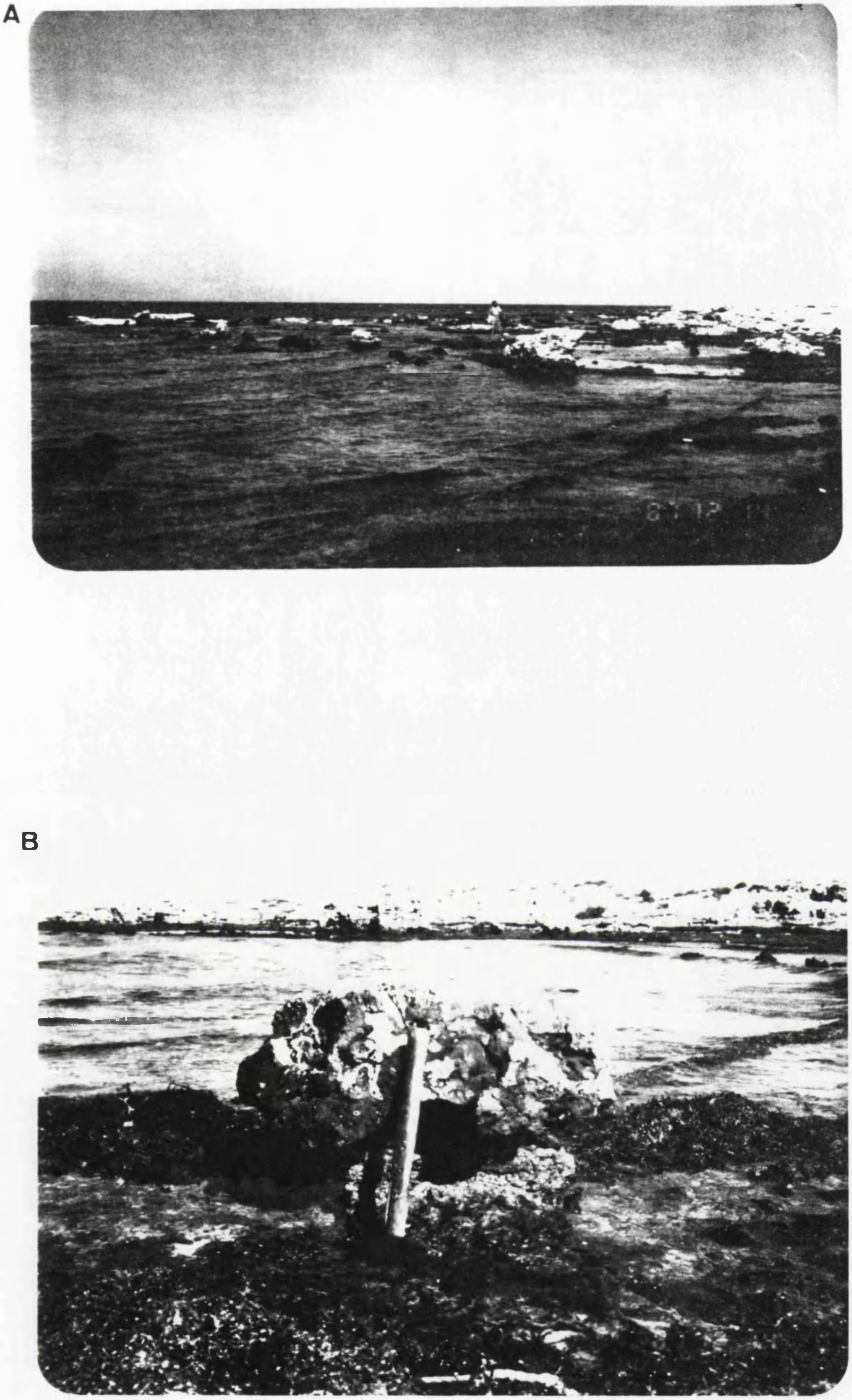


PLATE 8.7 A&B.PROFILE 2A LIMESTONE CLIFF AND 'MUSHROOM' ROCK FEATURES FORMED BY SOLUTIONAL ACTIVITY TO THE NORTH OF BIN RAHAL BAY.

cemented dune sands called aeolianite as mentioned in Chapter II (Plate 8.5) and this may also be true in places in Qatar. The beach rock provides a protective skin at the lower part of the beach where it occurs absorbing wave energy until it too suffers abrasion and solution.

A group of profiles have been measured showing the general geological and geomorphological features of the west coast, running from Ras Abu Omran to Hussain bay (Fig. 8.9).

I. The profile measured at Ras Abu Omran illustrates the typical cliff profile. There is a bed of rounded beach shingle ranging in thickness of 60-80cm at the base of the cliff while the aeolianite is seen to be horizontal bedded and about 1m thick (Plate 8.6).

## II Bin Rahal Bay profiles

Two profiles have been measured in the northern part of Bin Rahal Bay (2A and 2B, figure 8.9) where Middle Eocene limestones and marls have been eroded into a dissected plateau, limited on the seaward side by steep cliffs exceeding 2 metres in height. The profile indicates the presence of 'mushroom' rock features about 50cm high which are believed to have formed mainly by solutional activity accompanied by wave action (plate 8.7). Profile 2B is characterized by the development of an extensive sabkha (salt mud flat) where sediments occupy an area of Bin Rahal, with gradients across the sabkha of only $1^{\circ}$-$2^{\circ}$ (Fig. 8.9 and plate 8.8).

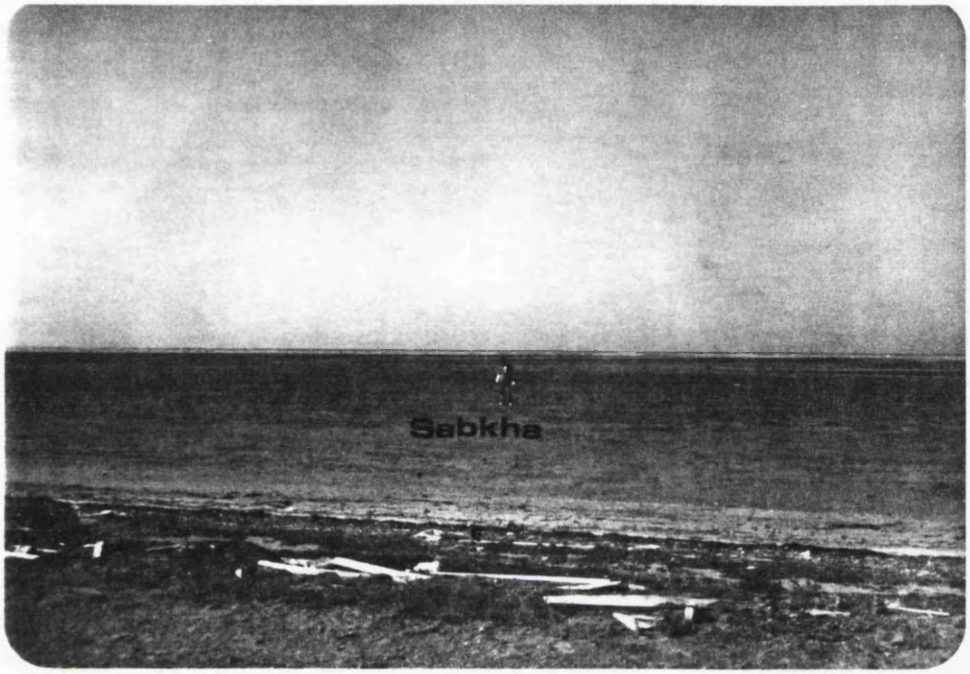


PLATE 8.8 **AN** EXTENSIVE SABKHA IN BIN RAHAL BAY (B2).

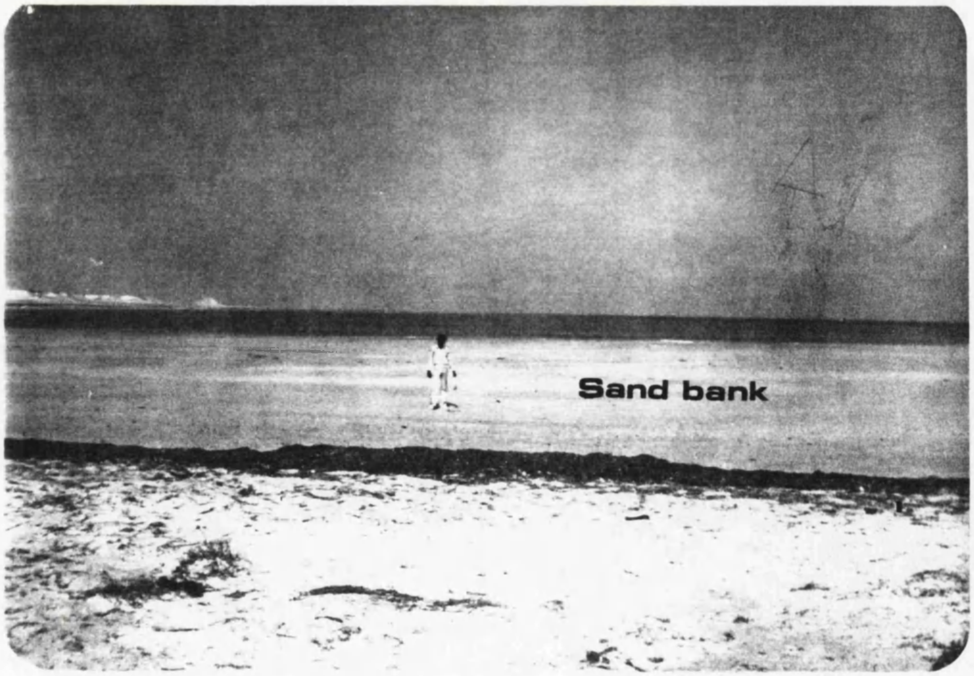


PLATE 8.9 SHOWING EXTENSIVE DEPOSITS OF SAND BANKS IN HUSSAIN BAY.

### III Umm Elma Bay profile

This profile was surveyed north of Umm Alma Bay and is characterized by simple low relief showing evidence of the deposition of sand barriers. At high tide level the profile extends to the bedrock that is mainly covered by sand banks in the bay.

### IV Feshakh Bay profiles

Two profiles have been surveyed on this coastal segment and they are characterized by low relief. Profile A4 shows the accumulation of pebbles, the latter indicating evidence of wave and tidal current deposition, while in B4 the profile shows the formation of a sabkha lying between two sand barriers formed by wave and tidal currents action. These sand barriers are fronted by the extensive surface of the sand bank of Feshakh Bay (Fig. 8.9 ).

### V Hussain Bay profile

This profile shows extensive deposits making up sand banks and sand barriers formed by wave and tidal action within the Bay of Hussain (Fig. 8.9 and Plate 8.9).

## 8.7 Sediment analysis

The objective of this section is to determine the mechanical characteristics of the coastal sediments on the west coast. Mechanical analysis has been made of nine samples collected from beach swash zones and beach berm sites on the West Coast from Dukhan area to Ghar Bradi; samples were also collected along a profile from Bin Rahal Bay and Hussain Bay across the barrier beaches and sand banks.

Studies such as those of Friedman (1967) attempted to distinguish beach sands from other sedimentary environments on the basis of two-dimensional plots of parameters such as sorting and skewness, obtained from grain size distribution. Greenwood (1969) also attempted to differentiate between dune, beach backshore and beach foreshore sands based on grain size analysis. Kolvan (1966) applied the same approach to samples from Barataria Bay, Louisiana and determined three different sedimentary environments. The first determined represented beach surface dominance, the second current deposition, and the third a protected area where gravitation settling of sediments occurred. There appear to be three main factors that control the mean grain size of beach sediments. These are: (1) the sediment source; (2) the wave energy; and (3) the general slope on which the beach is constructed. The relationship between the source and the grain size of sediments available to the beach is more apparent in carbonate beaches than in quartz-felspar dominated beaches.

Grain size analysis indicated that sediments collected from the beach fall between coarse and medium coarse sand (Fig. 8.10). Cumulative percentage particle size curves for samples collected from the beaches along Dukhan, Hamlah and Ghar Bradi (Fig. 8.13) indicated that the sediments are well sorted to moderately-sorted with a mean value for S of +0.60. Also the sands are strongly to moderately skewed with a mean value of S = 0.22 and they are platykurtic (Ku = 0.90) (Fig. 8.13). Considering the skewness and kurtosis characteristics of the studied beaches, it can be concluded that the coarse fraction of these sediments comprises mainly coral reef fragments and shells.

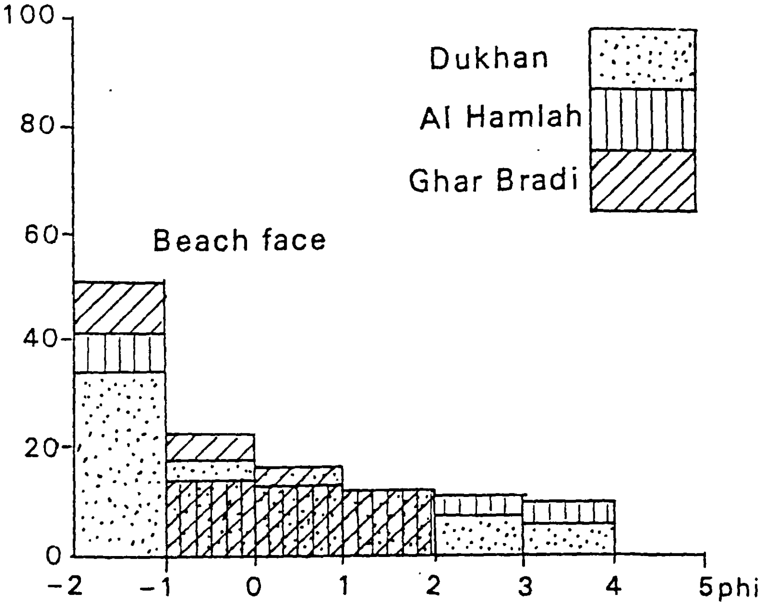


FIG. 8.10 SUPERIMPOSED HISTOGRAM FOR BEACH FACE SEDIMENTS FROM DUKHAN, AL HAMLAH AND GHAR BRADI.

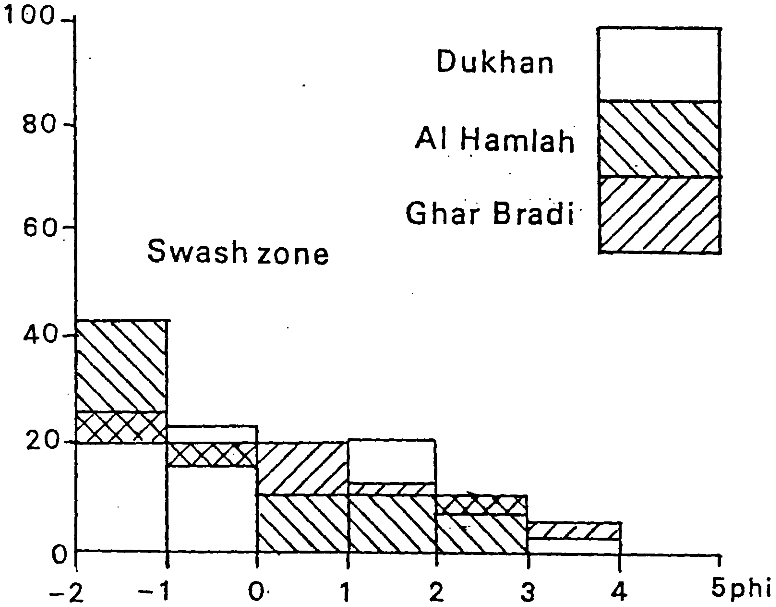


FIG. 8.11 SUPERIMPOSED HISTOGRAM FOR SWASH ZONE SEDIMENT FROM DUKHAN, AL HAMLAH AND GHAR BRADI.

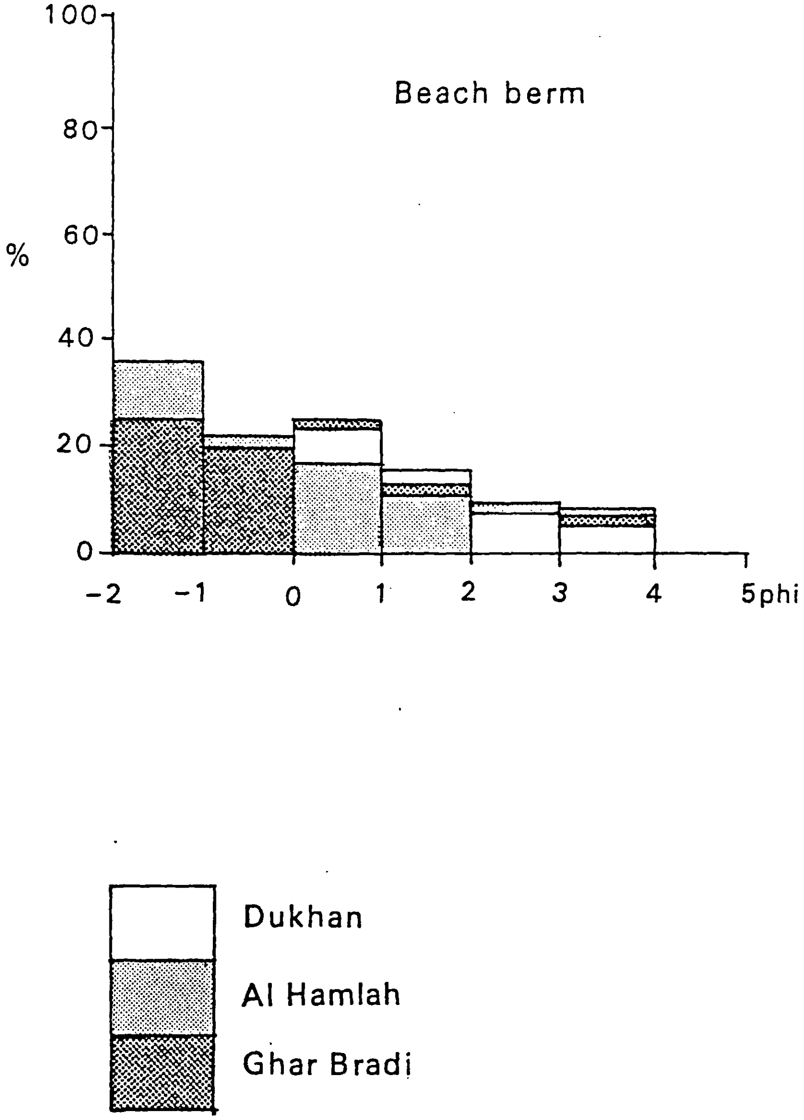


FIG. 8.12 SUPERIMPOSED HISTOGRAM FOR SEDIMENT COLLECTED FROM BEACH BERMS FROM DUKHAN, AL HAMLAH AND GHAR BRADI.

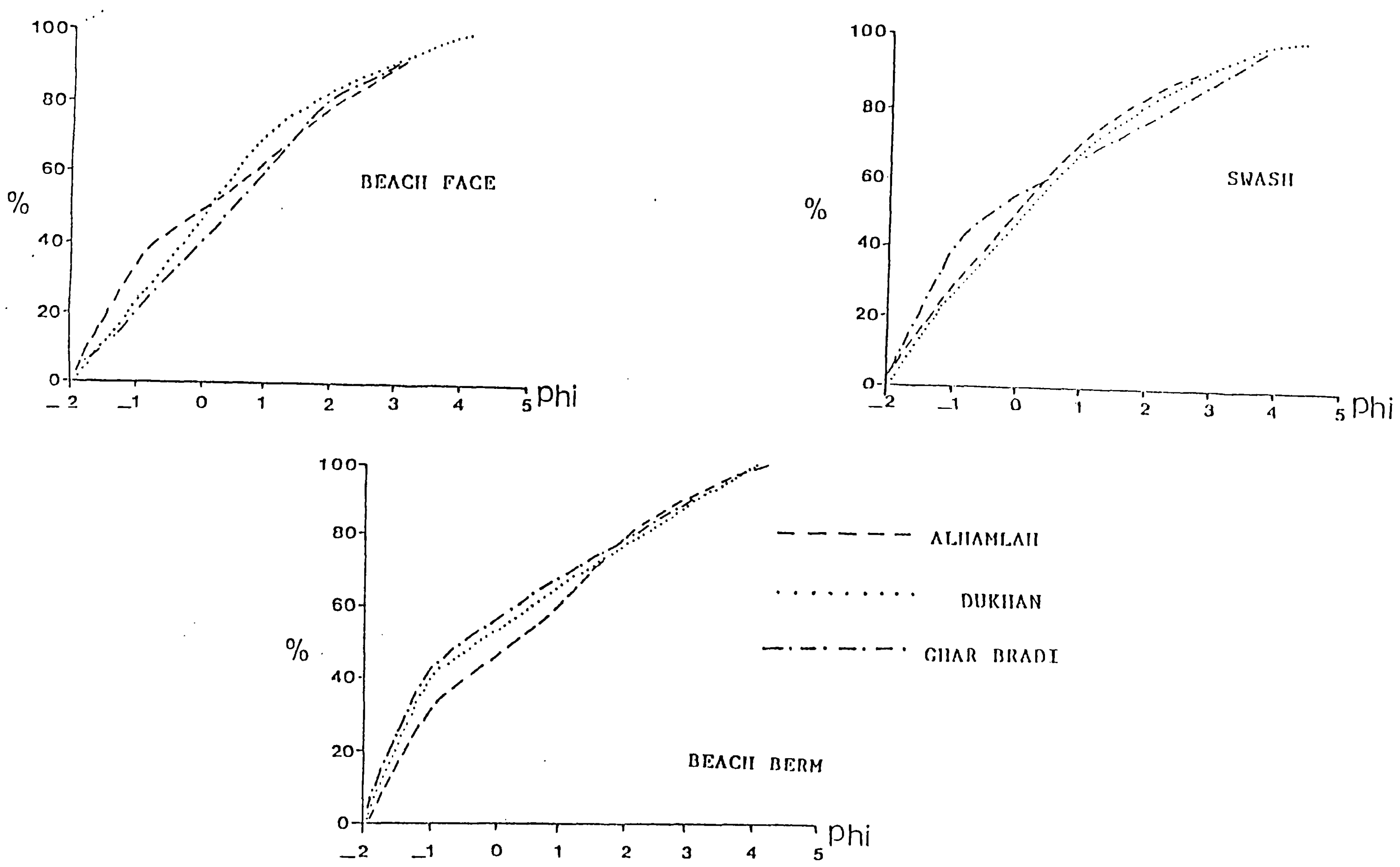


FIG. 8.13 CUMULATIVE CURVES FROM SAMPLES COLLECTED FROM BEACH FACE, SWASH AND BEACH BERM FROM DUKHAN, AL HAMLAH AND GHAR BRADI.

The sand grains collected from swash zones are characteristically coarse to medium fine sand (8.11). They are well sorted with a mean value for S of +0.60. They are moderately skewed (Sk = 0.20) and platykurtic (Ku = +1.11) (Fig. 8.13). This suggests this is an area in which coarse lag deposits accumulate due to their progressive removal of fine by wave action.

The samples collected from the beach berm zone reveal that the sediments are coarse to fine sands (Fig. 8.12 ), well sorted with a mean sorting value of +0.51. They are moderately skewed (Sk = 0.22) and platykurtic (Ku = 0.61) (Fig. 8.13 ). These analyses indicate that the grain size distribution on the west coast of Qatar peninsula are the result of the sorting mechanisms of currents and waves driven by the "Shamal" wind along the west coast.

The mechanical analysis of ten samples collected from the barrier beaches at Bin Rahal bay, indicated that they comprise fine and medium-fine sand reflecting the narrow range of grain sizes (Fig. 8.14 ). The sediments are poorly sorted with a mean sorting value of +1.56 (Fig. 8.15 ), negatively skewed (Sk = 0.54) (Fig. 8.16 ) and are mesokurtic (Ku = +0.92) (Fig. 8.17 ). Samples were collected in Hussain Bay from beach barrier. Particle size analysis reveals that the sediment consists of coarse to fine sands (Fig. 8.18 ). These sands are poorly sorted with a mean sorting value of +1.70 (Fig. 8. 19), negatively skewed (Sk = -0.35) (Fig. 8.20 ) and platykurtic (Ku = 0.77) (Fig. 8.21 ). This indicates that the sands are relatively fine, but contain a coarse fraction that consists of coral reef fragments, which have drifted from the nearby coral reef along the west coast.

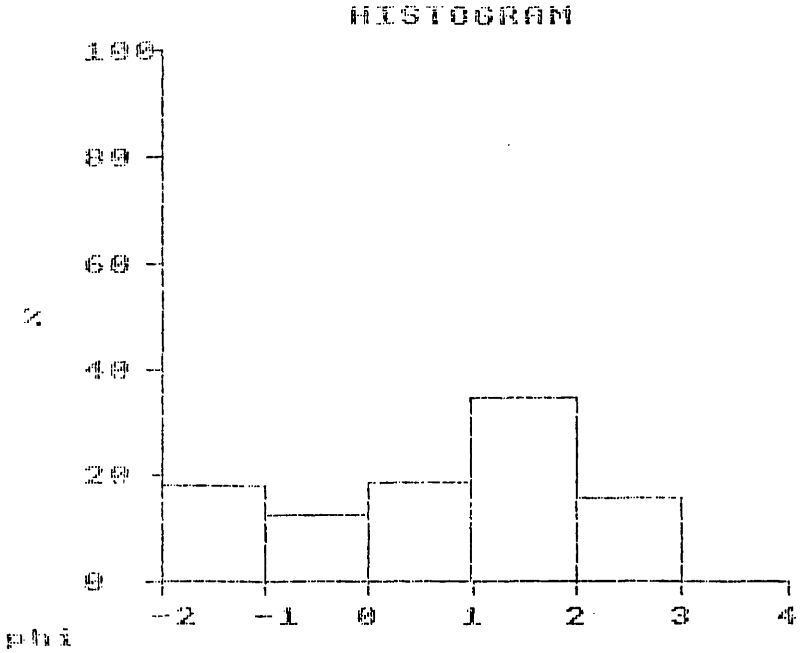


FIG. 8.14 PARTICLE SIZE HISTOGRAM OF BEACH BARRIER SEDIMENTS, BIN RAHAL BAY.

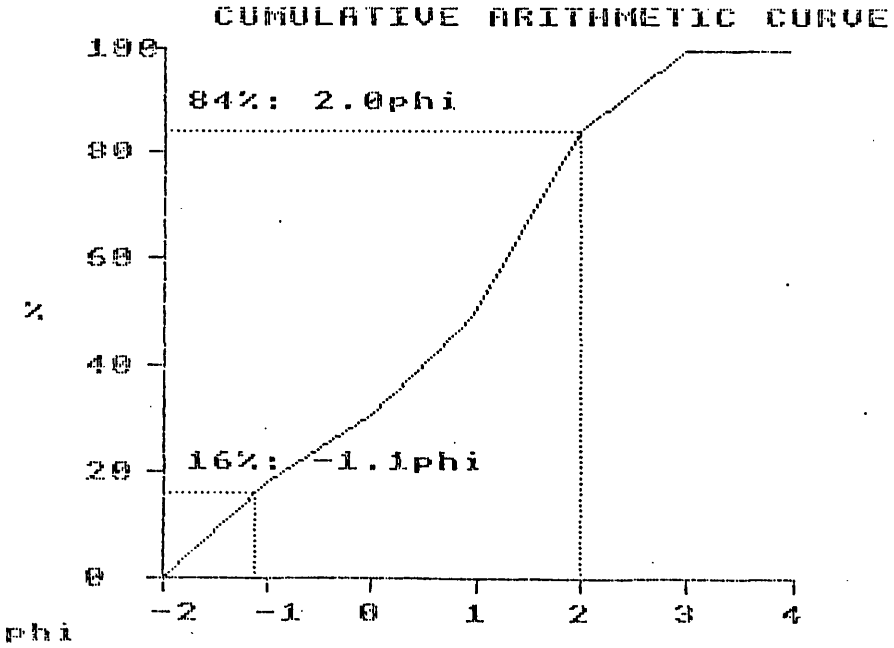


FIG. 8.15 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, BIN RAHAL BAY.

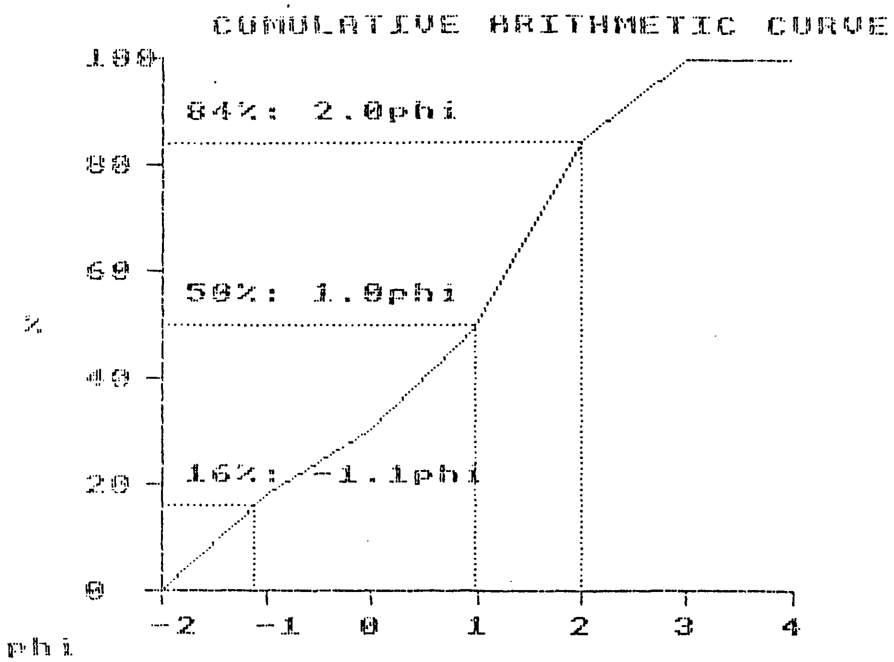


FIG. 8.16 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, BIN RAHAL (SK).

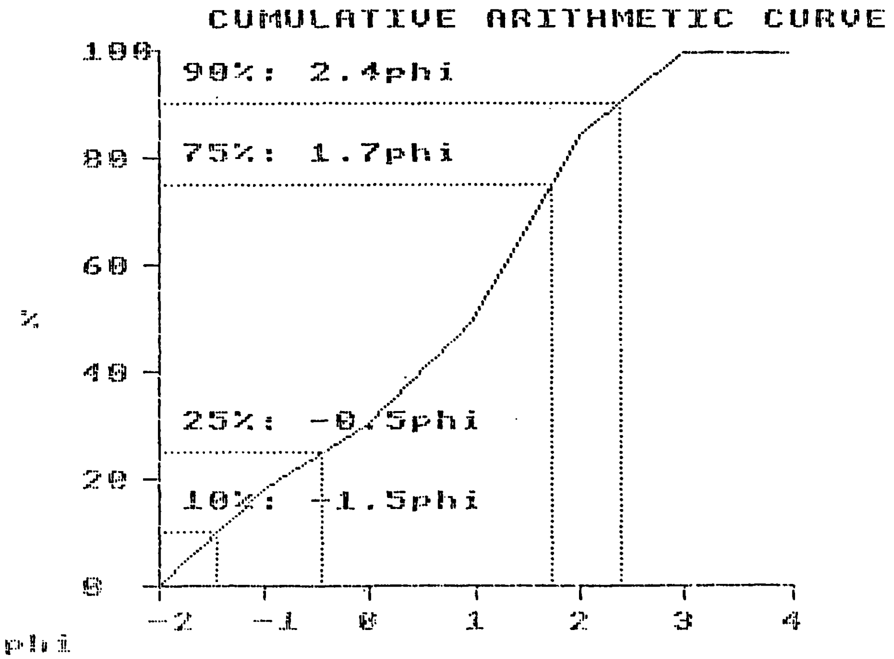


FIG. 8.17 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, BIN RAHAL (KU).

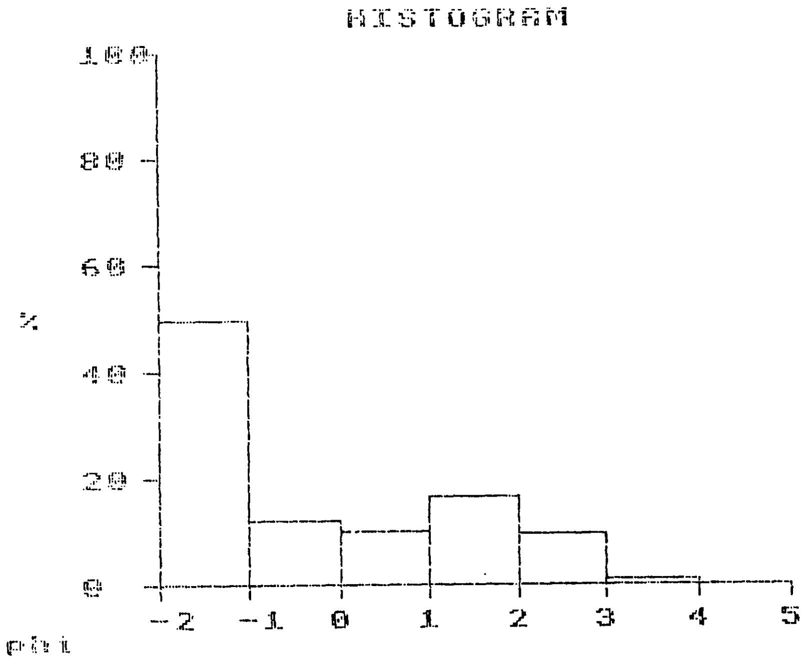


FIG. 8.18 PARTICLE SIZE HISTOGRAM OF BEACH BARRIER SEDIMENTS, HUSSAIN BAY

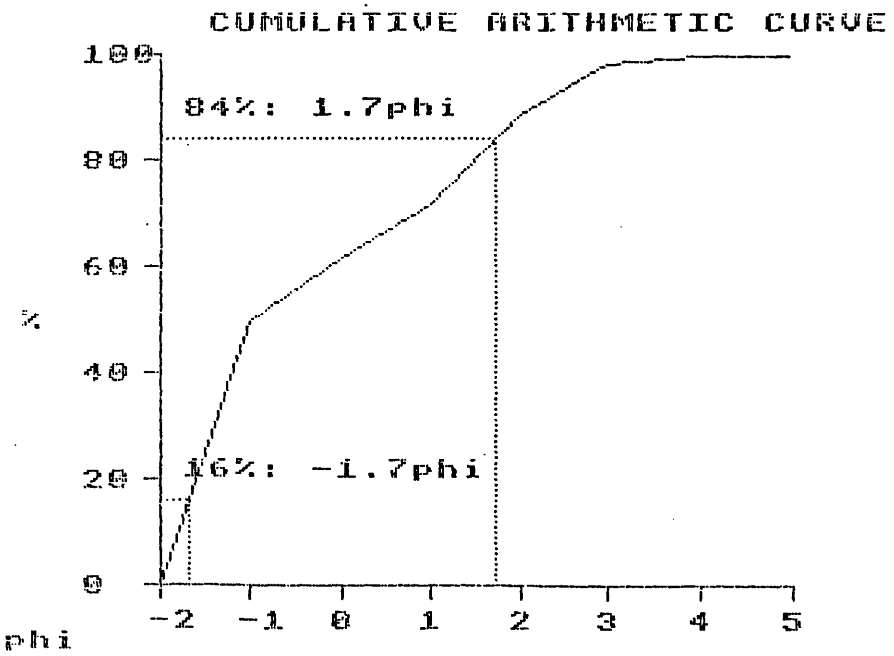


FIG. 8.19 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, HUSSAIN BAY.

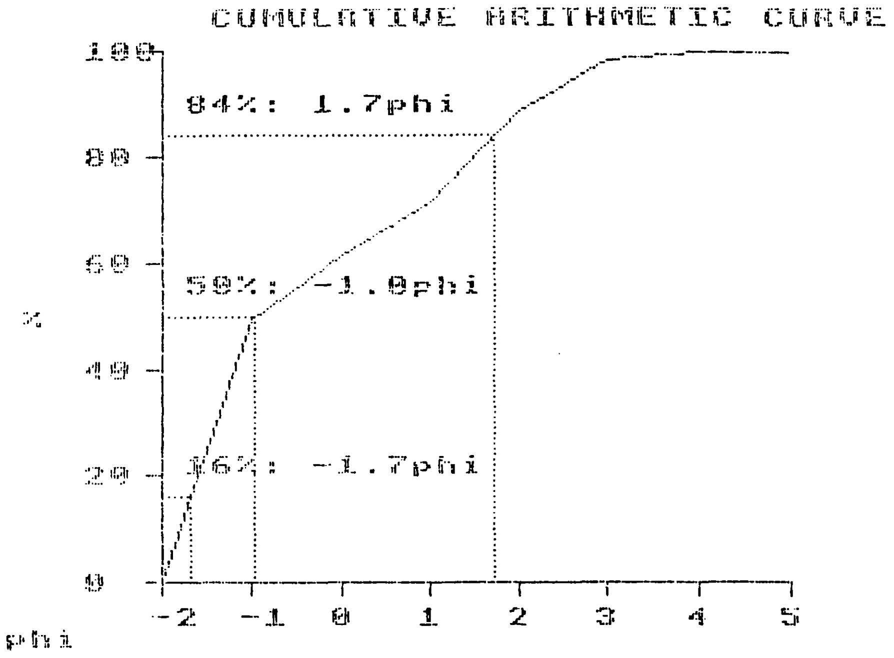


FIG. 8.20 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, HUSSAIN BAY (SK).

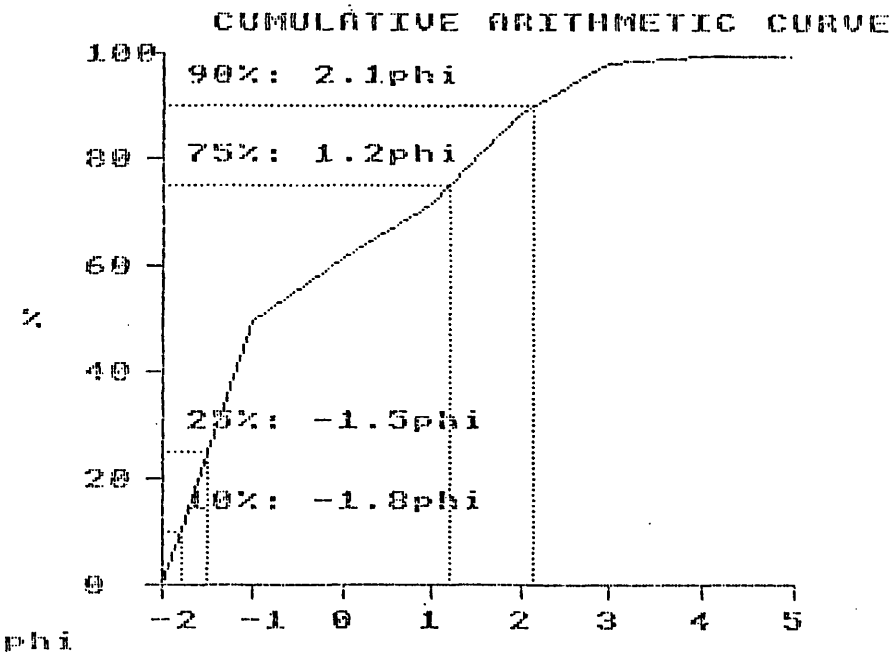


FIG. 8.21 CUMULATIVE PERCENTAGE PARTICLE SIZE OF BEACH BARRIER SEDIMENTS, HUSSAIN BAY (KU).

Analysis of the sand from sand banks in Bin Rahal bay indicates that the grain size lies between coarse and medium fine sands (Fig. 8.22). They are poorly sorted with a mean sorting value of +0.75 (Fig. 8.23). They are positively skewed (Sk = 0.33) (Fig. 8.24), and leptokurtic (Ku = 0.75 (Fig. 8.25) Sediment was also collected from sand banks in Hussain Bay (10 samples) and analysis reveals that grain sizes lie between coarse and fine sand (Fig. 8.26). The sediment is poorly sorted with a mean value sorting of 1.87 (Figure 8.27). They show little tendency towards skewness (Sk = 0.02) (Fig. 8.28) and are platykurtic with a mean kurtosis value of +0.75 (Fig. 8.29). The analysis indicates that the grain size distribution of sediment around Bin Rahal and Hussain Bays on the west coast of the peninsula are due to the sorting action of marine processes, such as waves, currents and wind mechanisms. Coral reef and shell fragments make up most of the coarse action.

## 8.8 Summary

The west coast of the Qatar peninsula extends for 250km and a variety of coastal landforms and shoreline features have formed here because of the low energy conditions, limited fetch, shallow water depth and the influence of the north or north-west "Shamal" wind which is responsible for southward moving waves and currents.

The landforms of the west coast result from geological factors and geomorphological processes, with structural conditions, depositional environments and relic (lithified) sediments contributing to the coastal landforms. The embayments are the most notable features along the west coast and several factors are responsible for their formation: low relief, geological structures, tidal currents and prevailing winds. Five large embayments are identified: (1) Bin

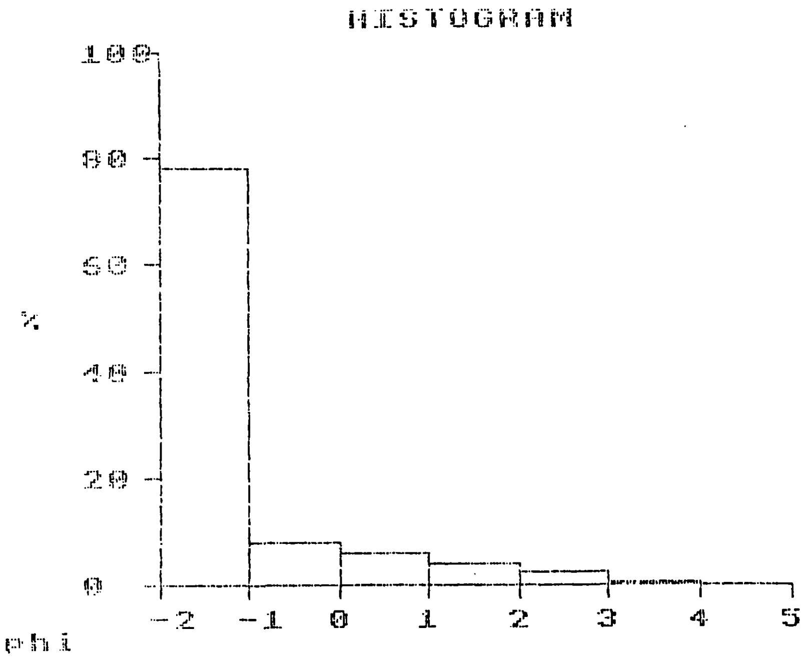


FIG. 8.22 PARTICLE SIZE HISTOGRAM OF SAND BANK SEDIMENTS FROM BIN RAHAL BAY.

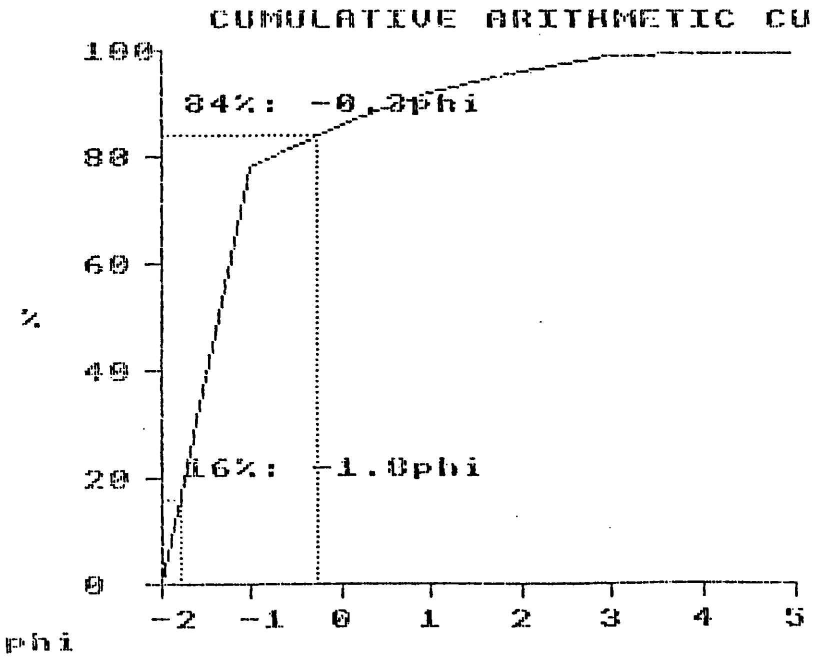


FIG. 8.23 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM BIN RAHAL BAY.

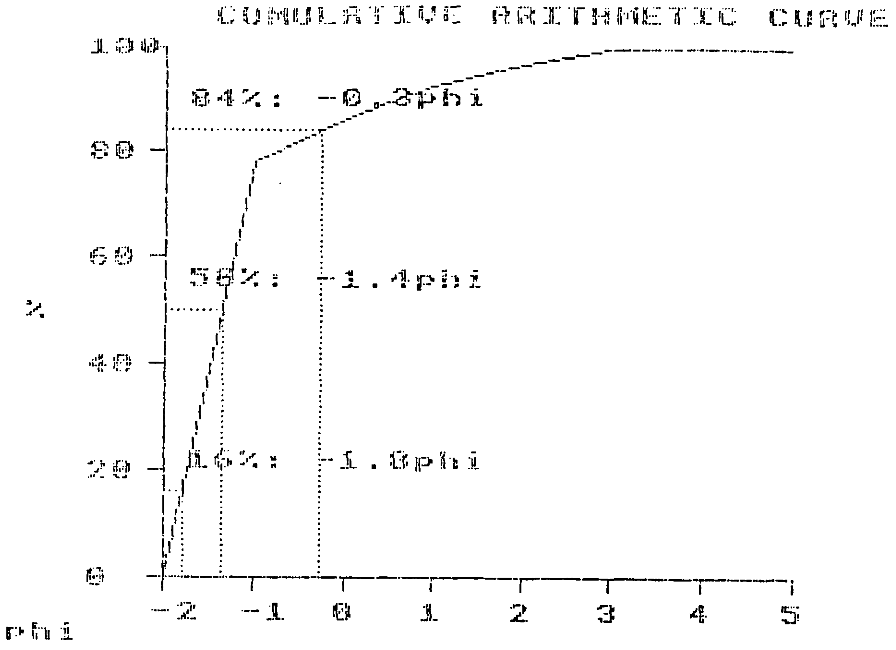


FIG. 8.24 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM BIN RAHAL.

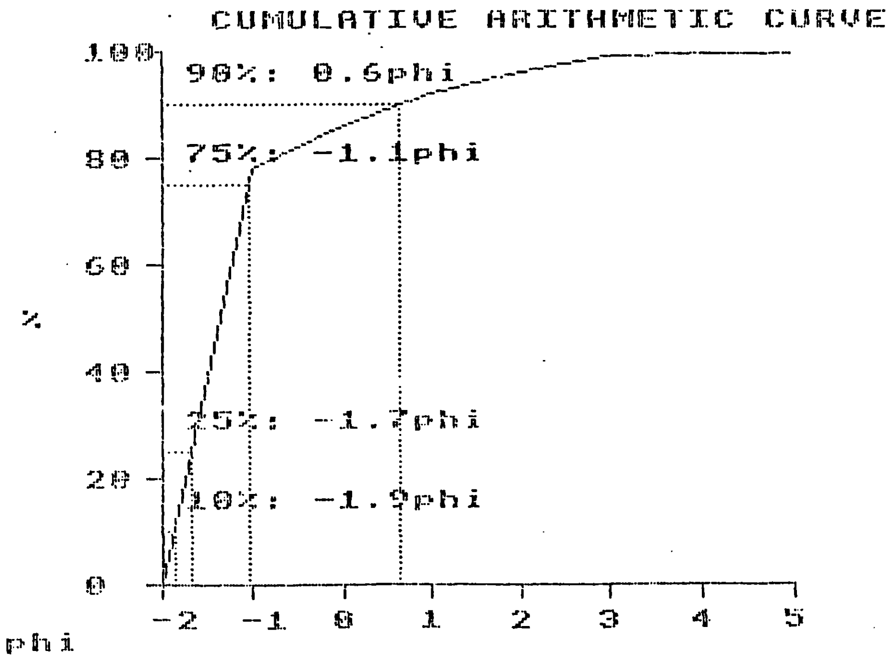


FIG. 8.25 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM BIN RAHAL BAY.

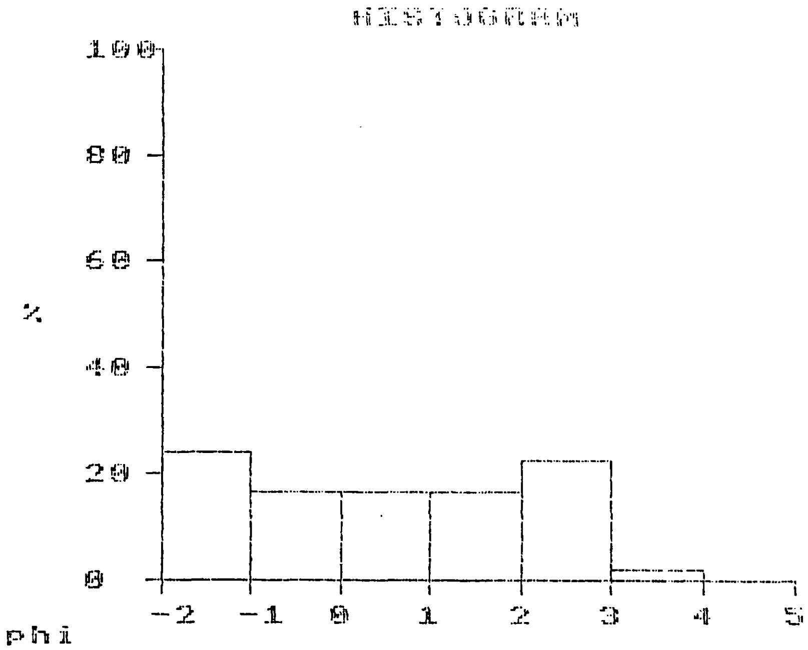


FIG. 8.26 PARTICLE SIZE HISTOGRAM OF SAND BANK SEDIMENTS FROM HUSSAIN BAY.

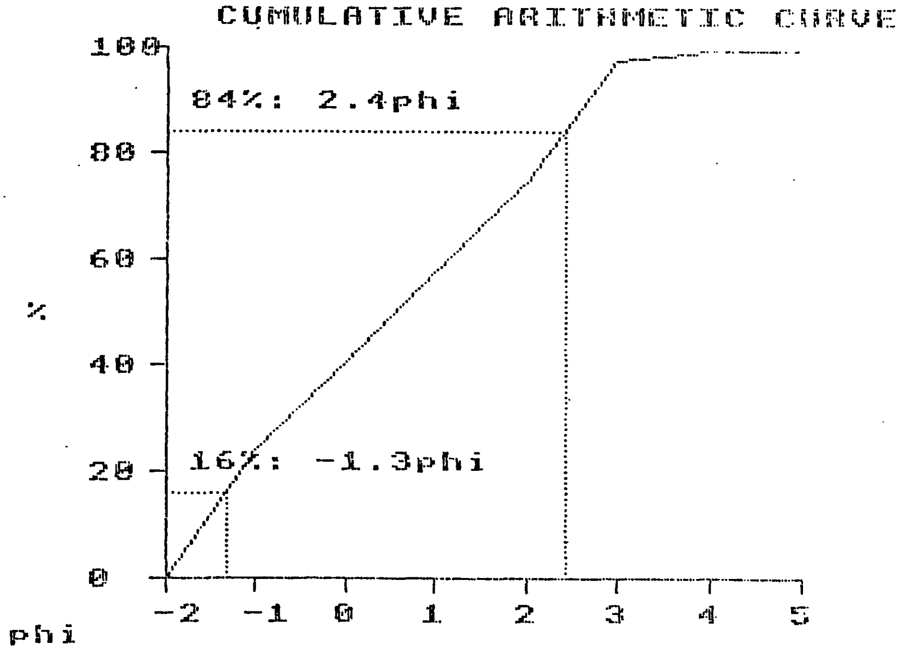


FIG. 8.27 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM HUSSAIN BAY.

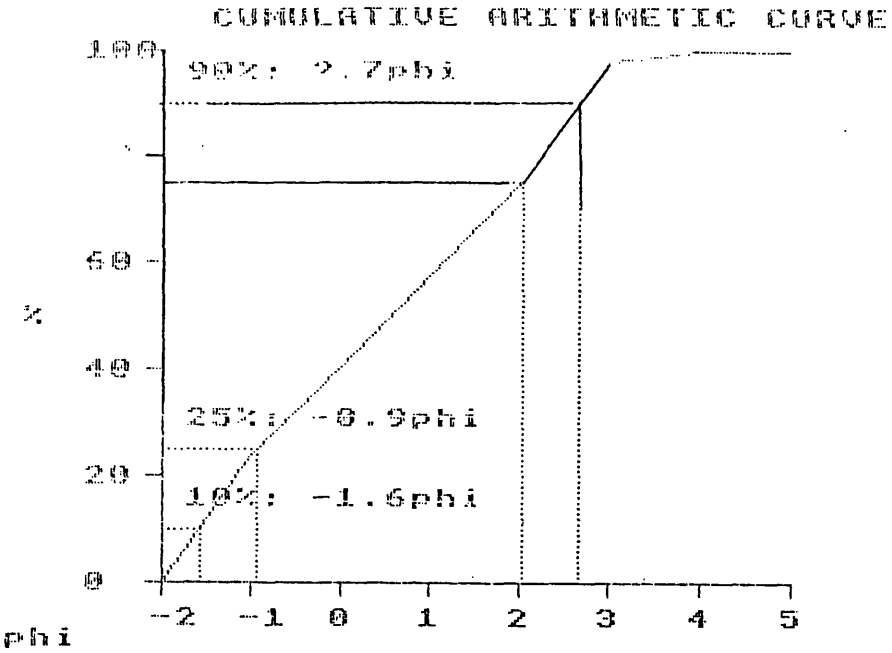


FIG. 8.28 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM HUSSAIN BAY (SK).

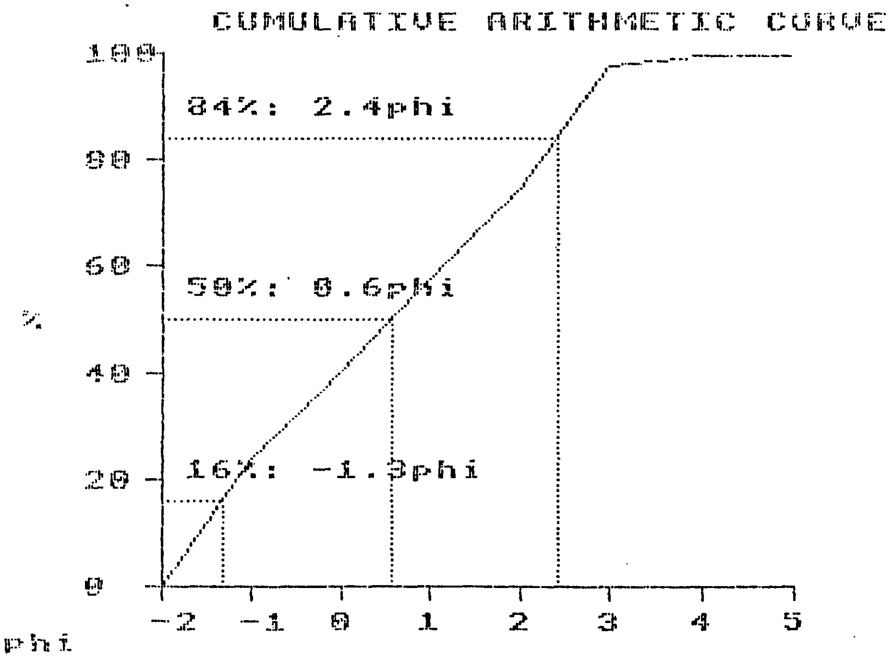


FIG. 8.29 CUMULATIVE PERCENTAGE PARTICLE SIZE OF SAND BANK SEDIMENTS FROM HUSSAIN BAY (KU).

Rahal Bay; (2) Umm Alma and Asyod Bay; (3) Feshakh Bay; (4) Hussain Bay; and (5) Zekreet Bay.

Shore platforms have been identified in the Abrug Peninsula and in the Dukhan area. The Abrug Peninsula platforms are classified as inter-tidal shore platforms backed by cliffs. There is evidence that the base of the cliff is being actively attacked by wave action. The platforms around the Dukhan area have been classified as low tide shore platforms exhibiting rugged relief and exceeding 20m in width. 'Mushroom'-shaped pedestals occur on the surface of many of the platforms. Cliffs are also present around Dukhan, Ghar Bradi and the Abrug Peninsula where they are developed in limestone. Some of the cliffs are capped by a duricrust and their morphology is closely controlled by geological structures and a variety of sub-aerial and marine processes. Three main coastal processes are important in shoreline development: solution, abrasion as well as salt weathering. Extensive depositional features include barrier beaches, spits and sand banks which are widely distributed along the west coast due to the low relief, low tide range and abundance of sediments. Lithified beaches ('beachrock') are found to the south of Al-Hamlah due to the abundance of sediments, calcium carbonate and warm coastal waters.

Analysis of samples collected from beaches, swash zones, beach berms, barrier beaches and sand banks comprise mainly coral reef fragments, and shells with an amount of fine sand drifted by the different marine processes that act along the west coast.

# CHAPTER IX

# ANALYSIS OF THE COASTAL SEDIMENTARY DEPOSITS

# CHAPTER IX

# ANALYSIS OF THE COASTAL SEDIMENTARY DEPOSITS

The purpose of the analysis of the sediments is to determine their depositional environments. This in turn will help in understanding the processes involved in the development of the coastal features. The methods of investigation were applied to: (1) particle size analysis, and (2) the analysis of the quartz grain surface texture using a JEOL 35C Scanning Electron Microscope.

## 9.1 Particle size analysis

### Introduction

Particle size analysis or the mechanical analysis of sediments is an important technique, which has been widely used for the interpretation of sediments. It can provide information about the agent of transport responsible for the origin of the sediment, distinguishing between marine, aeolian and other deposits, as well as giving a possible indication of the physical properties of the transporting agent (e.g. stream capacity, current velocity and intensity of wave action). Krumbein (1934), Otto (1938) and Keller (1945) have all used the technique, the latter being the first to discriminate between beach and dune sands. All these workers used particle size analysis as a correlative and discriminative method. Folk and Ward (1957) studied the grain size parameters of point bar on the Brazos River, Texas. By plotting skewness against kurtosis, they were able to interpret the genesis of the sediments. Mason and Folk (1958) showed that grain size analysis was useful in distinguishing beach sands, dunes and aeolian flats on Mustang Island, Texas. Skewness and kurtosis are the best parameters for identifying transporting environment because these properties are reflected by the changes in the tails of the grain size distributions. Beach sands were found to have a normal curve while dune sands were positively skewed and mesokurtic. Friedman (1961) analysed samples from dunes, rivers, sea beaches and lake shores in a number of countries and found that there are three modes of transport that tend to lead to characteristic particle size curves. These are, according to Reineck and Singh (1973):

(1) Transport in subaqueous suspension. This is the subaqueous suspension of small particles entrained by moving water in the form of turbulent currents and eddies. The resistance of water through which a particle is sinking by gravity combined with turbulence helps to keep the finest materials in suspension for a long time. In general, the grain size of such sediment is usually less than 0.1mm.

(2) Transport in saltation, Reineck and Singh (1973) quoting data of the U.S. Waterways Experiment Station (1939), showed that grain sizes of up to 1.0mm in diameter were transported 60cm above the bottom of a channel. The maximum size transported by saltation depends upon different factors, such as velocity and water depth.

(3) Transport by rolling. The coarsest grains in a sediment are mostly transported by rolling along the bed channel. Inman (1949) pointed out that there were three fundamental modes of subaerial transport, surface creep, saltation and suspension.

## 9.2 Methods of analysis

Samples were collected along the Qatar coastline from Umm Said to Ghar Bradi (Fig. 9.1) at eight locations. At each locality three samples were collected to represent various lithotypes and different coastal environments (lower beach, swash zone and beach berm). The samples were taken from the original sample bags, spread on a metal tray, and oven-dried out at 105°C. Half of each of the dried samples was taken for grain size analysis and the other half was kept as reference material for further investigation. About 100 grms of each sample was used for sieve analysis, each sample being placed on a net of sieves of decreasing mesh size ranging from 2$\phi$ to 4$\phi$ at 1$\phi$ intervals. The net of sieves was then placed on a sieve shaker and shaken for 10-15 minutes. The amount of sediment retained on each sieve and in a receptacle placed beneath the 4$\phi$ mesh sieve was then accurately weighed. Data from the grain size analysis was plotted using a package micro computer programme and the various phi percentiles needed for the calculation of grain size parameters were determined.

The grain size parameters used are those suggested by Folk and Ward (1957). These are graphic mean size (Mz$\phi$), inclusive graphic standard deviation ($\sigma$ 1), inclusive graphic skewness ( Sk ) and graphic Kurtosis (Kg). These four parameters are given by the following formulae:

$$\mathrm{MZ}\phi = \frac{\phi 16 + \phi 50 + 84}{3}$$

$$\sigma_1 = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

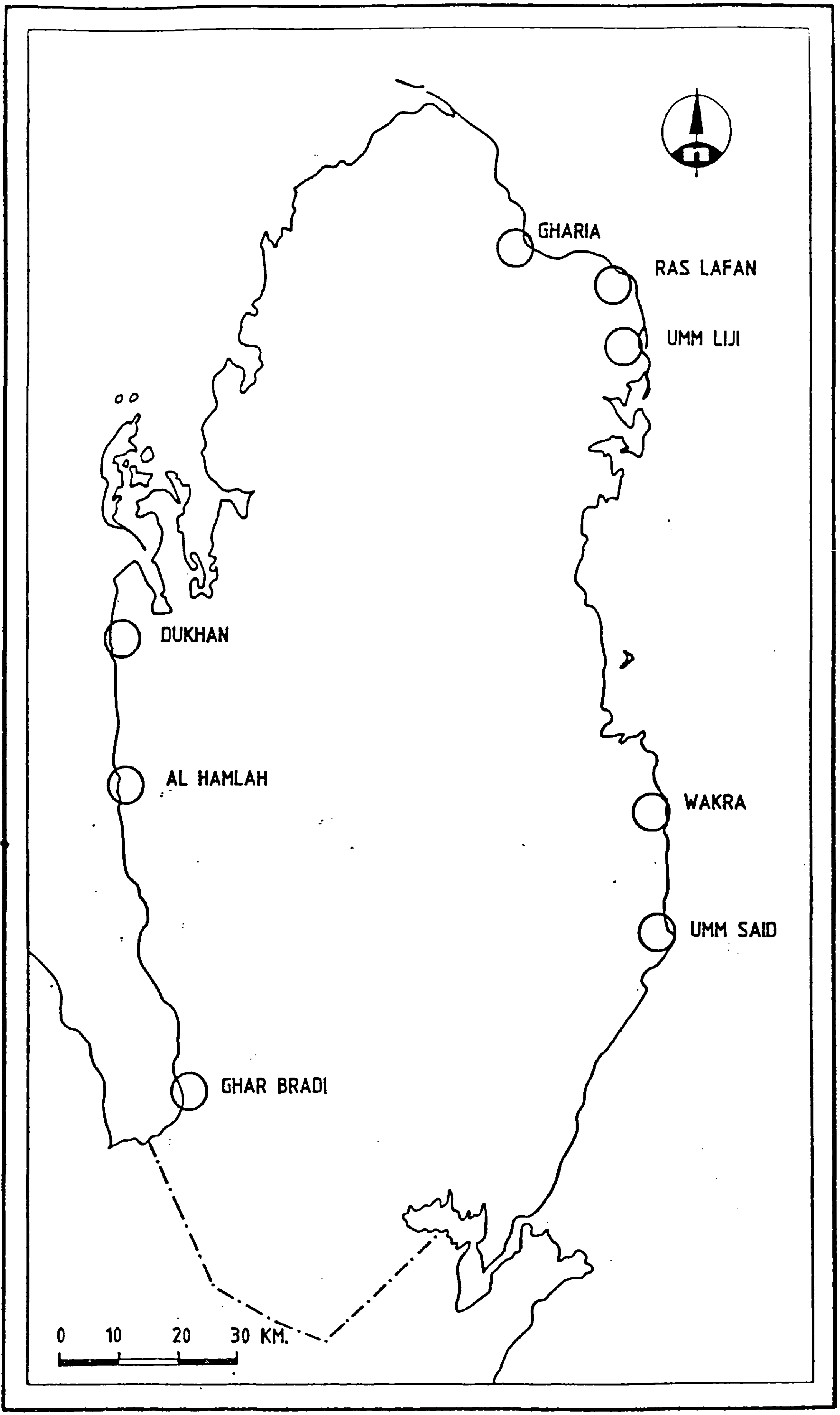


FIG.9.1 SAMPLE LOCATIONS

$$Sk = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} \qquad \frac{\phi5 + \phi95 - 2\phi50}{2\ (\phi95 - \phi5)}$$

$$Kg = \frac{\phi95 - \phi5}{2.44(\phi5 - \phi25)}$$

## 9.3 Results

The beach deposits of the Qatar peninsula range in mean size from 0.46Ø (coarse sand) to 2.30Ø (fine sand) with an average of 1.14Ø (medium sand). The mean size of the majority of the samples (56%) lies between 2Ø and 1.5Ø. The phi graphic standard deviation (an expression of the degree of sorting) from the transition zone, the area between the inner nearshore zone and the beach berm, range between 2.06 (moderately sorted) and 1.99 (poorly sorted), and phi standard deviation (sorting) between 2.08 (very poorly sorted) and 0.91 (moderatley sorted). The phi standard deviation (sorting) for the samples collected from the beach berm crests average 1.89 (poorly sorted) and the phi standard deviation for the samples collected from the swash zone range between 0.86 (moderately sorted) and 2.08 (very poorly sorted).

Folk and Ward (1957) suggested a scale which can be used to describe sorting and this is shown in Table9.1. Folk and Ward (1957) also suggested a set of verbal descriptions for ranges of the skewness value (Table9.2). A negative value indicates that the sample has a tail of coarse grains whereas a positive value indicates a tail of finer grain sizes. The skewness of sediments can be independent of size and sorting, being a measure of the asymmetry of frequency. Curve values of skewness of the Qatar samples are mostly from 1.12 (very positively skewed) for samples collected from the beach to 0.89 (very positively skewed) for samples collected from the swash zone to 0.58 (very positively skewed) for samples collected from the beach berm crest. Kurtosis (KU) is a measure of the distribution curve with respect to the sorting of the tail. If the central portion is better sorted than the tail, the curve is said to be excessively peaked or leptokurtic. If the tails are better sorted than the central part, then the curve is said to have a flat peak or is platykurtic, and if the two portions are equal then it is mesokurtic. The verbal limits suggested by Folk and Ward (1957) for kurtosis are shown in Table 9.3.

The samples from the coastal areas of the Qatar peninsula range in kurtosis from platykurtic (0.90) to mesokurtic (1.08). The cumulative curve for beaches, swash zones and beach berms in Qatar all have a similar shape and most of them tend towards coarse grades (Fig. 9.2 ). In the superimposed histogram of sand fractions each sample has been divided into groups to avoid confusion in interpreting the histograms. The histograms show that the samples comprise sediments mostly between coarse and medium coarse sand as a result of the fact that they are largely composed of coral reef fragments and shell fragments (Fig. 9.3 A and B) (Fig. 9.4 A-B) (Fig. 9.5 A-B).

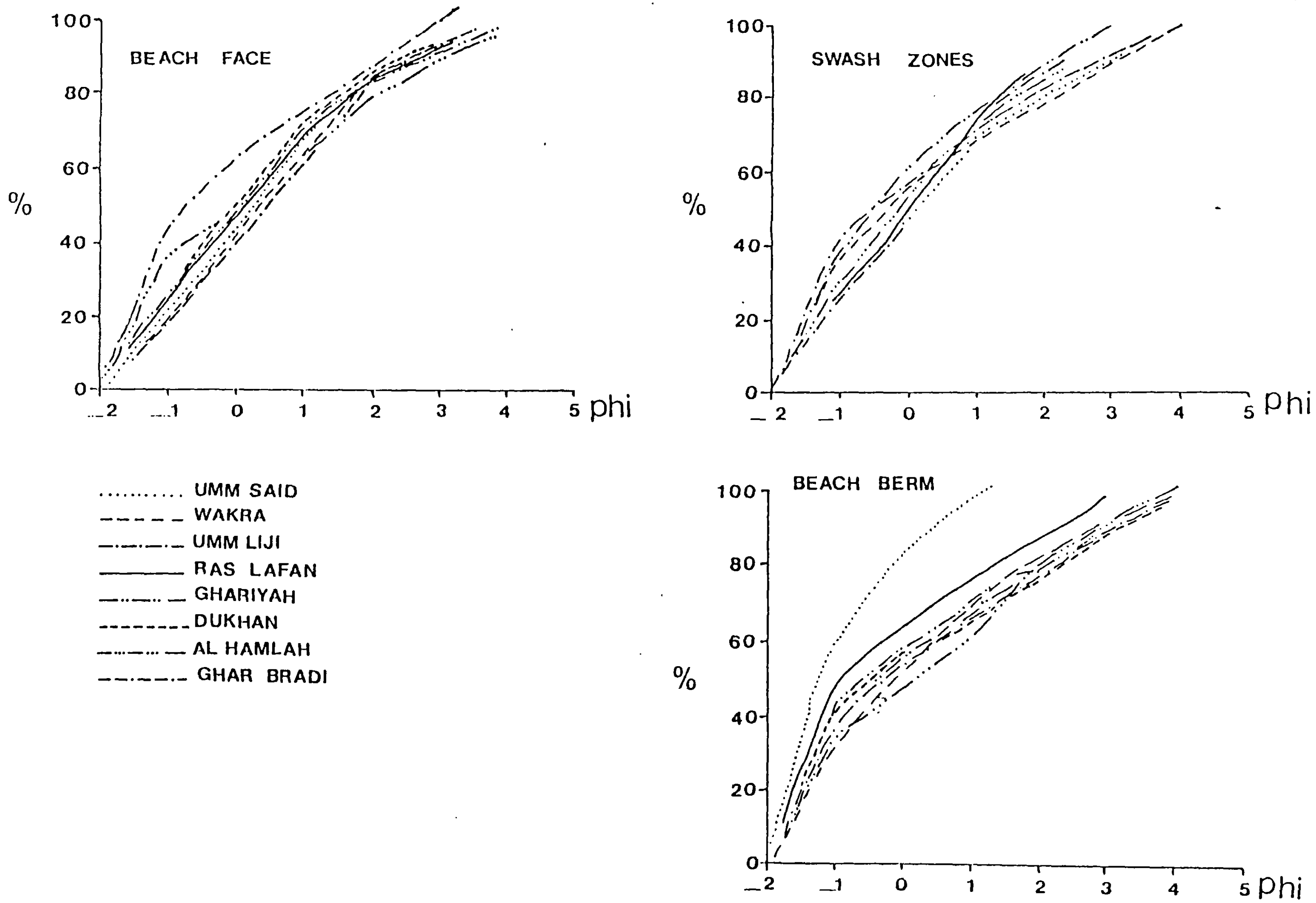


FIG.9.2 CUMULATIVE PERCENTAGE CURVES FOR BEACHES, SWASH ZONES AND BEACH BERMS, QATAR.

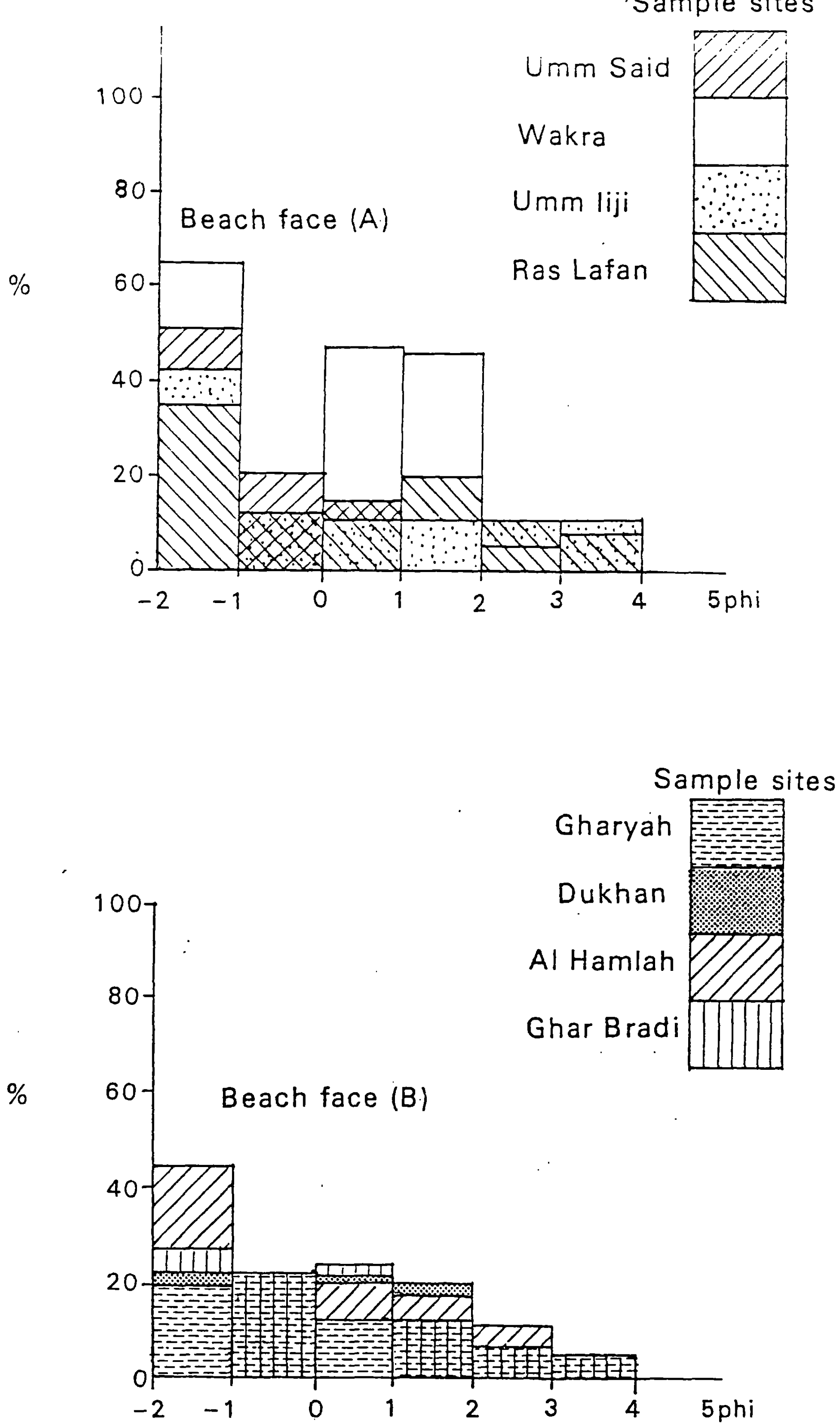


FIG. 9.3 SUPERIMPOSED HISTOGRAMS FOR THE SAND FRACTION FROM BEACH FACES.

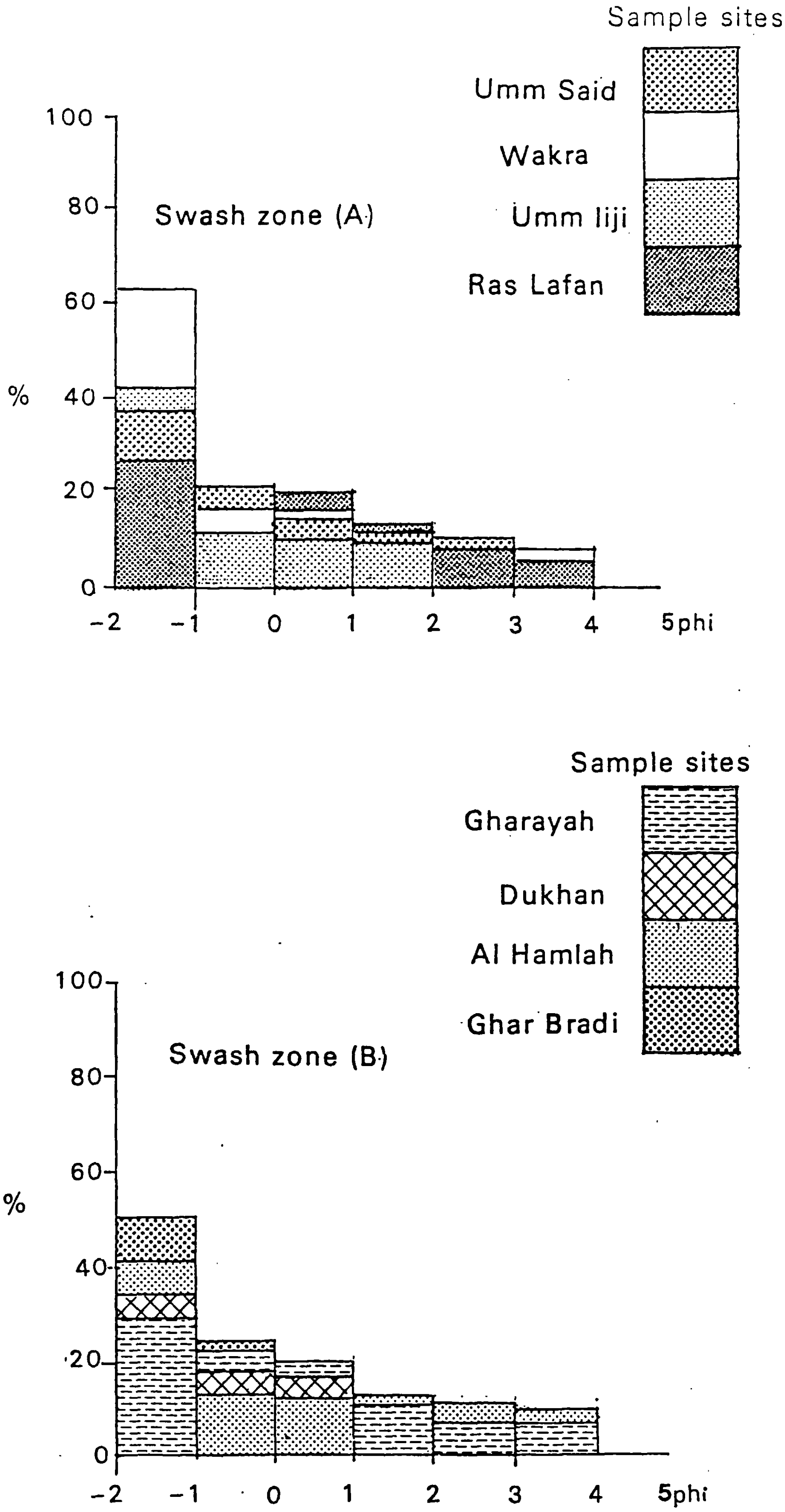


FIG. 9.4 SUPERIMPOSED HISTOGRAMS FOR THE SAND FRACTION FROM SWASH ZONES.

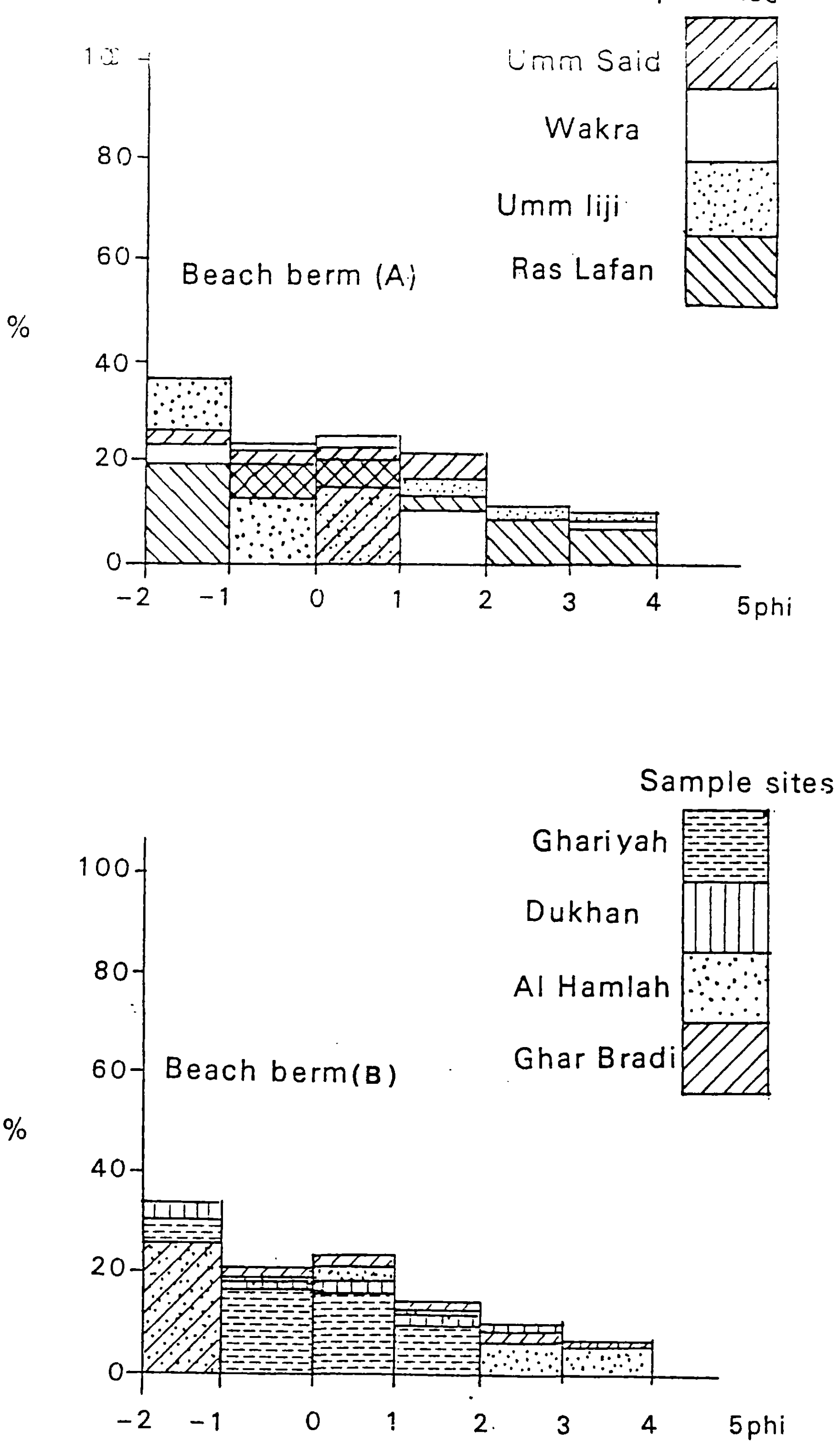


FIG. 9.5 SUPERIMPOSED HISTOGRAMS FOR THE SAND FRACTION FROM BEACH BERMS.

Table 9.1 Sorting coefficients and descriptions (Folk & Ward 1957)

| | |
|---|---|
| 1 under 0.35 | Very well sorted |
| 0.35 - 0.5 | Well sorted |
| 0.5 - 1.0 | Moderately sorted |
| 1.0 - 2.0 | Poorly sorted |
| 2.0 - 4.0 | Very poorly sorted |
| Over 4.0 | Extremely poorly sorted |

Table 9.2 Skewness values and descriptions (Folk & Ward 1957

| | |
|---|---|
| Sk from -1.00 to 0.3 | Very negatively skewed |
| -0.3 to 0.1 | Negative skewed |
| -0.1 to +0.1 | Nearly symmetrical |
| + 0.1 to 0.3 | Positively skewed |
| + 0.3 to 1 | Very positively skewed |

Table 9.3 Kurtosis values and descriptions (Folk & Ward 1957)

| | |
|---|---|
| Under 0.67 | Very platykurtic |
| 0.6 to 0.90 | Platykurtic |
| 0.90 to 1.11 | Mesokurtic |
| 1.11 to 1.50 | Leptokurtic |
| 1.50 to 3.00 | Very leptokurtic |
| Over 3.00 | Extremely lepokurtic |

## Analysis using the Scanning Electron Microscope

### 9.4 Introduction

The Scanning Electron Microscope (SEM) was used to investigate sediments and has been widely used in recent years for solving problems of environmental reconstructions by examining the surface textures of quartz sand grains (Krinsley and Doornkamp, 1973; Al Asfour, 1978; Bull, 1981).

Surface textures of certain sand grains were examined using the Transmission Electron Microscope (TEM) in the early 1960s (e.g. Krinsley and Takahashi, 1962; Beideman and Porter, 1962; Kuenen and Perdok, 1962). These authors conclude that the mechanisms of transport and condition of the environment are often characterised by the nature of the quartz grain surface textures. Schneider (1970) and Krinsley and Doornkamp (1973) noticed the advantage of using the SEM rather than TEM, because from the SEM, the grain surface can be observed directly without duplication. Soutendam (1967) noted that the number of well-rounded, frosted grains in sediments tend to be correlated with the intensity of wind action the sand grains have undergone. For example, in desert sands about 98% of the grains are well rounded whereas sand derived from coastal dunes near sand beaches contain an average 81% rounded grains (Al Asfour 1978). This percentage decreases to about 0% when the sands are thin and/or deposited on a rocky coast. Krinsley and Smalley (1973) studied the shape and nature of quartz particles and they reached the conclusion that these become flatter with decreasing size. A cleavage mechanism may operate below the critical size of about 100 microns, when the flat particles would tend to form a more open packing than spherical particles. Brown (1973), also studied the depositional history of Pleistocene sand grains of controversial origin using surface textures. He concluded that if grains are found bearing apparent "glacial" textures it is possible to say that these grains have been subjected to a 'high energy', especially where there is a wide range of particle size present. Stoffers and Ross (1979) studied Late Pleistocene and Holocene sedimentation in the Persian Gulf and the Gulf of Oman. They identified the source of the sediments and demonstrated that sedimentary environments and transport mechanisms could be interpreted. The interpretation of the lithology and stratigraphy of the sediments deposited during the last 30,000 years in the Persian Gulf showed that the sediments are clearly related to environmental changes. The most important of these changes has been the supply of sediments from rivers and eustatic changes in sea level. Geogiev and Stoffer (1980) have studied the surface texture of quartz grains deposited in the Persian Gulf and the Gulf of Oman during the last 30,000 years using the SEM technique. The quartz grains studied in the Gulf of Oman revealed a mixture of different surface textures (beach, aeolian, and high salinity environments with post-depositional chemical activity) to those observed in the Persian Gulf samples. Al-Asfour (1978) has used the surface features of quartz grains for defining the various sedimentary environments of coastal terrace deposits in northern Kuwait, while Saleh and Khalaf (1980) used quartz grain surface textures for defining the various sedimentary environments from the desert plain and coastal areas, also in northern Kuwait. Imabi and Ashour (1985) studied the sand grain surface textures of samples from sand dunes in south-east Qatar investigating the relationship between the old and recent depositional environment. Ly Cheng (1978) examined surface textures of quartz grains of modern sand sediments from the New Castle - Post Stephens area of Eastern Australia.

The results show that beach sands are characterized by mechanical features while chemical action is of comparatively minor importance.

## 9.5 Methodology

The coast of the Qatar Peninsula is generally covered with a layer of recent (i.e. Holocene) sediments and various sediment types can be recognized, comprising coastal sand dunes and sandy beaches. Thirty samples were collected from the east/&the west coast chosen to represent the various types of recent deposits that are characteristic of east coast environment (Fig. 9.6). The procedures used for cleaning the quartz sand for SEM examination involves using dilute hydrochloric acid to remove the $CaCO_3$ and any iron staining.

The samples were washed in distilled water, dried and placed under a binocular microscope so that a number of the quartz grains could be extracted. Between 15 and 20 grains from each sample were selected for SEM investigation. The grains were arranged on aluminium stubs covered with double-sided sticky tape. The quarz grains were coated with a thin (150$^{o}$A thick) layer of gold and then viewed with the SEM. Each quartz sand grain was studied individually on the characteristics of the quartz surface recorded; the features were photographed with a magnification varying from 80 to 1000 times.

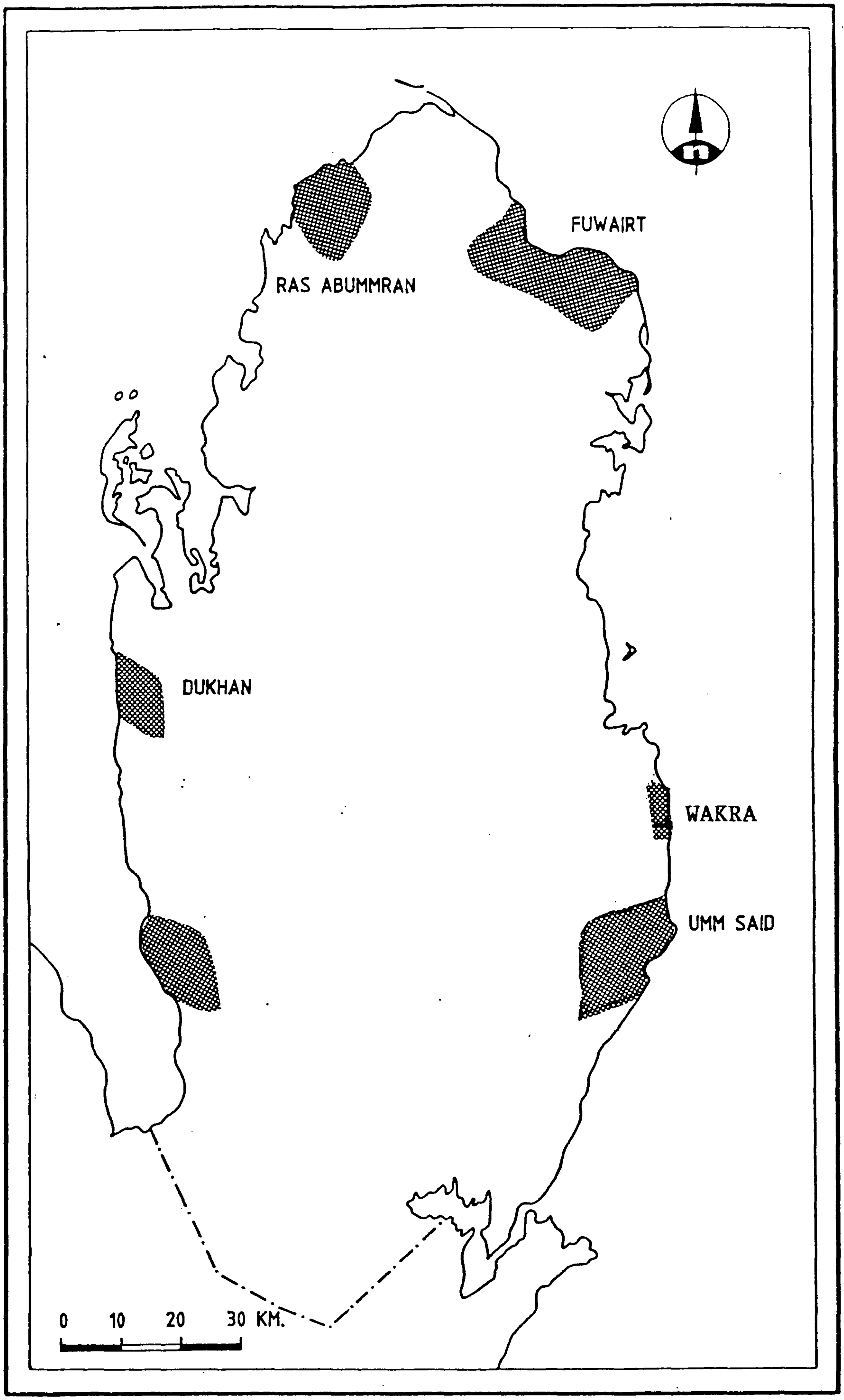


FIG.9.6 SITES OF COLLECTED SAMPLES FROM THE EAST AND WEST COASTS.

## 9.6 Results

The quartz grains were mixed in shape varying from rounded to angular and there are frosted and smooth grains. The grains from the Qatar sediments show the effects of mechanical action upon these quartz grains. Mechanically affected grains usually have features such as dish-shaped concavities, grooves and upturned plates, while chemical action is revealed by etching and silica precipitation with features such as irregular solution pits, precipitation plates and deep grooves being present.

*Coastal dunes*

The quartz grains derived from the modern mobile coastal dunes are characteristically well-rounded (Plate 9.8), have V-shaped pits (Plate 9.4 ), upturned plates (Figs. 9.2 and 9.5 ) and dish-shaped concavities (Plates 9.3 , 9.5 , 9.8 , and 9.9 ). These surface textures represent two different transporting environment: aeolian and subaqueous. This is in accord with the view that the sands undergo both wind transport by the 'Shamal' wind and then undergo reworking by wave action. All grains showed modification by chemical action in the form of solution and precipitation (Plate 9.11 and 9.12 ).

*Beach sands*

The beach sand quartz grains are dominated by mehanical V-shaped pits (Plates 9, 2 , 9.4 and 9.6 ), and curved grooves (Plate 9.10 & Plates 9.2 , 9.9 and 9.8 ). Some of these quartz grains are sub-angular with low relief; they have irregular breakage patterns and some have high relief. Such breakages are relatively common in grains

PLATE 9.1 SUBANGULAR BEACH SAND, GRAIN WITH ORIGINAL ROCK CHARACTERISTICS, (SCALE BAR REPRESENTS 100µm). A CERTAIN AMOUNT OF SOLUTION AND PRECIPITATION OCCURS ON THE SURFACE.

PLATE 9.2 TYPICAL SURFACE TEXTURE OF BEACH ORIGIN. THE SURFACE OF THE GRAIN IS ALMOST COVERED BY MECHANICALLY-FORMED V-SHAPED PITS. CURVED GROOVES ARE SCATTERED ON THE SURFACE WITH SOME V-SHAPED PATTERNS ORIENTED ALONG THE AXIS OF THE GROOVES. (SCALE BAR = 10µm).


25KV X100 0001 100.0U UCS85

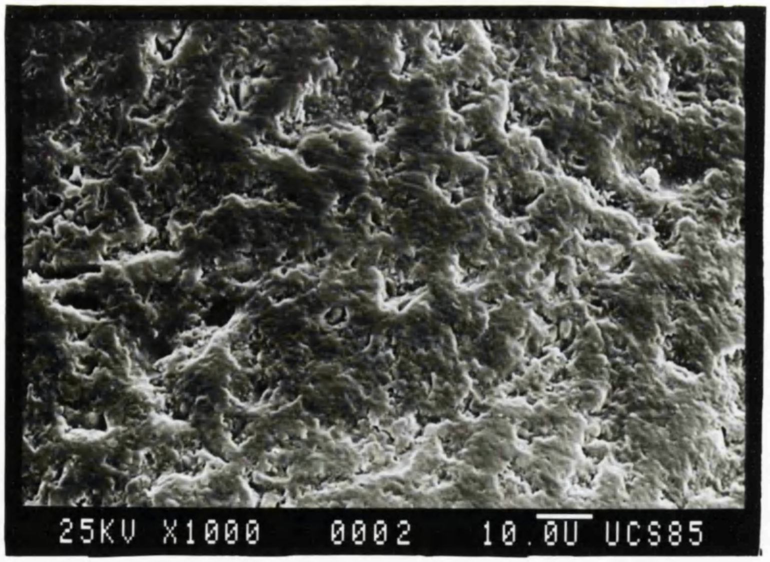
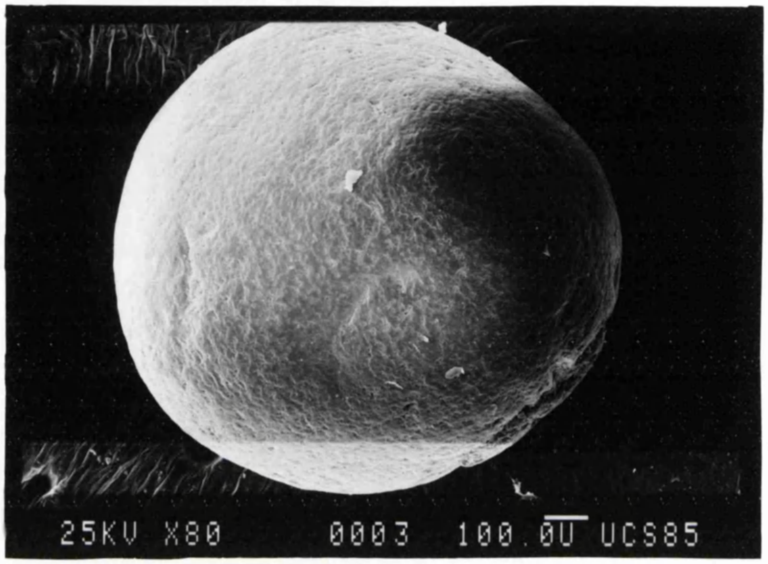

25KV X1000 0002 10.0U UCS85

PLATE 9.3 DUNE SAND GRAIN. IT IS WELL ROUNDED WITH DISH-SHAPED CONCAVITIES UPTURNED PLATES AND LOW RELIEF TYPICAL OF AEOLIAN TRANSPORT. (SCALE BAR = 100µm.)

PLATE 9.4 BEACHGRAIN WITH NON ORIENTED V-SHAPED PITS, INDICATING BEACH PROCESSES (SCALE BAR = 10µm).


25KV X80 0003 100.0U UCS85

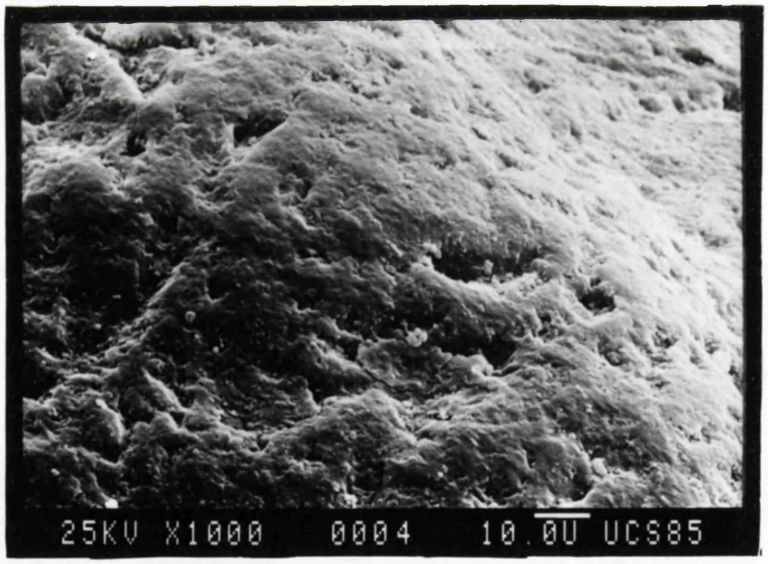

25KV X1000 0004 10.0U UCS85

PLATE 9.5 SAND DUNE GRAIN. WHOLE GRAIN WITH DISH-SHAPED CONCAVITIES AND UPTURNED PLATES. (SCALE BAR = 100µm).

PLATE 9.6 BEACH SAND GRAIN. WHOLE GRAIN WITH V-SHAPED PITS AND DISH-SHAPED CONCAVITIES. THE GRAIN HAS LOW RELIEF. (SCALE BAR = 100µm).


25KV X100 0005 100.0U UCS85

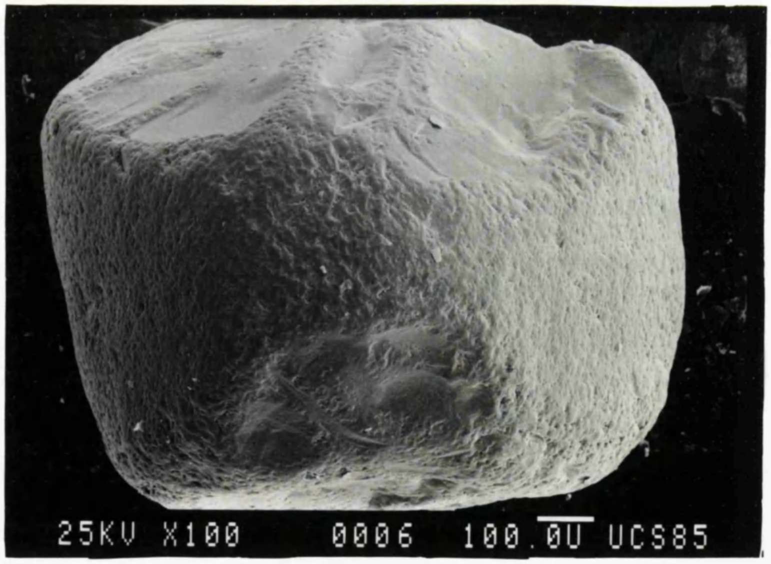

25KV X100 0006 100.0U UCS85

PLATE 9.7 BEACH SAND GRAIN. IT HAS SOME CHARACTERISTICS OF AN AEOLIAN ENVIRONMENT WITH ITS DISH-SHAPED DEPRESSIONS. CHEMICAL ACTION HAS, HOWEVER, DESTROYED SMALLER CURVED GROOVES (ARROWED). (SCALE BAR = 100µm).

PLATE 9.8 BEACH SAND. PART OF THE SURFACE OF A BEACH SAND GRAIN WITH UPTURNED PLATES AFFECTED BY SOLUTION. (SCALE BAR = 100µm).


25KV X100 0007 100.0U UCS85

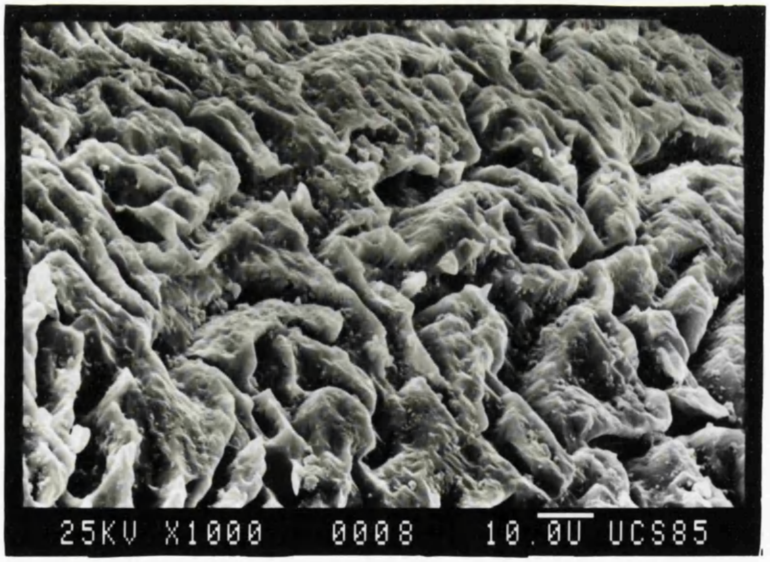
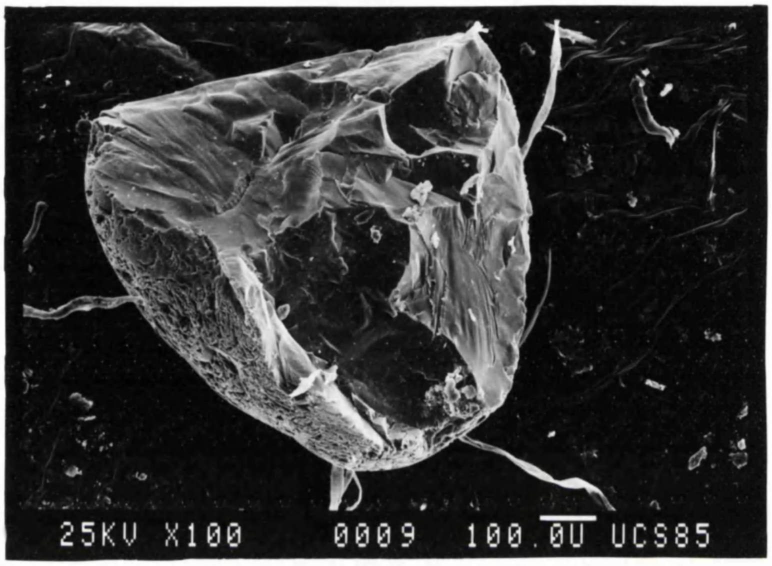

25KV X1000 0008 10.0U UCS85

PLATE 9.9 A WHOLE BEACH SAND GRAIN THAT HAS BEEN BROKEN. THE OLDER SURFACE HAS V-SHAPED PITS. SUCH BREAKAGES ARE RELATIVELY COMMON IN A MARINE ENVIRONMENT. THE GRAIN IS FAIRLY ANGULAR, HAS VERY HIGH RELIEF AND DISPLAYS MANY ARCUATE PARALLEL FRACTURE PATTERNS. (SCALE BAR = 100μm).

PLATE 9.10 A BEACH SAND GRAIN WHICH IS WELL ROUNDED AND COVERED WITH CHEMICALLY, ALTERED V-SHAPED PITS. (SCALE BAR = 100μm).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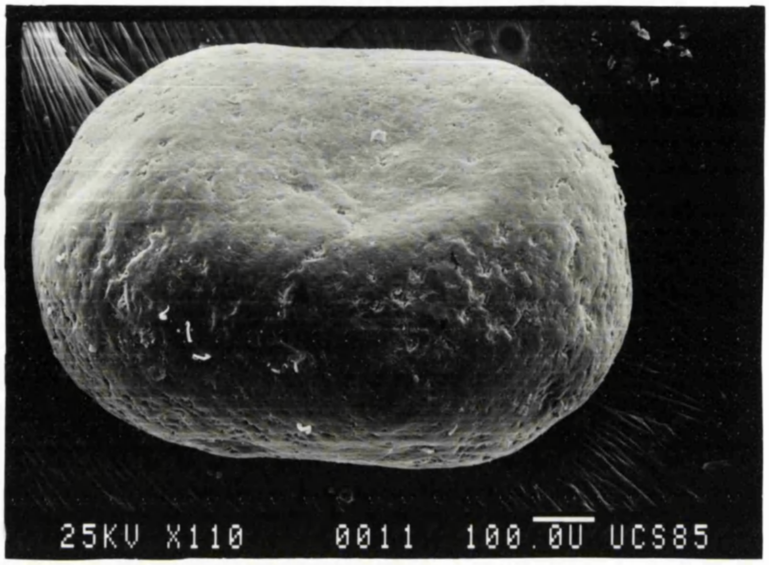
25KV X120 0010 100.0U UCS85

PLATE 9.11 A WELL SHAPED DUNE SAND GRAIN WITH SEVERAL DISH-SHAPED CONCAVITIES AND LOWER RELIEF. (SCALE BAR = 100µm).

PLATE 9.12 A SUBROUNDED DUNE SAND GRAIN WITH DISH-SHAPED CONCAVITIES AND LOW RELIEF. (SCALE BAR = 100µm).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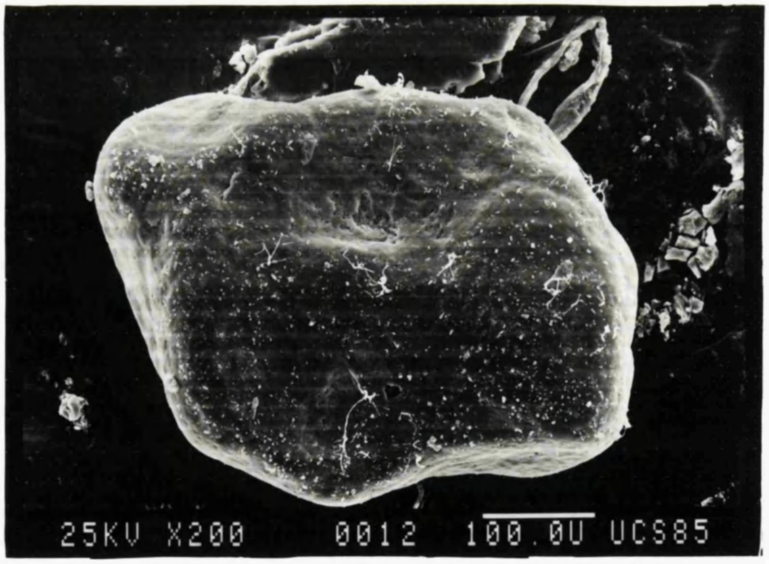

25KV X200 0012 100.0U UCS85

derived from a marine environment (Plates 9.1 and 9.7). The presence of these features on quartz grains from beach environments has led to the belief that they are caused by impact in a turbulent, high energy environment.

Investigation of the surface textures of quartz sand grains from beach and sand dunes environments in the Qatar Peninsula reveals the occurrence of two main sets of processes, mechanical and chemical. The mechanical surface features are mainly generated by aeolian transportation of the sand from north-west of the Qatar Peninsula under the effect of prevailing north-west "Shamal" wind and by beach processes. Most of these sands are characterized by upturned plates which have been affected by chemical action, while subsequent beach reworking has given rise to the addition of the V-shaped pits. Thus this preliminary investigation of quartz sand grains from the Qatar coastal environment has proved a valuable tool in separating depositional origins and has also confirmed the presence of a mixture of grains in the east coast sediments where aeolian action from inland has contributed to beach formation.

## 9.7 Salt weathering experiments

### 9.7.1 Introduction to previous work on salt weathering processes

Wellman and Willson (1965) identified the main mechanisms by which salt may lead to rock disintegration. The necessary conditions include a supply of salt, and a cyclic change in humidity or temperature. An agent of transport is then required to provide a means of 'exporting' the products of the salt weathering. Salt weathering is a particularly important process in arid areas and especially in coastal areas of the Middle East where there is a ready availability of saline solutions. Where both conditions prevail as in Qatar, salt weathering is particularly important. On the coast, salt is provided at a rapid rate by splashing of waves and from sea spray. The rocks most at risk are those that frequently become wet and then dry out, that is, in general rock surfaces in the zone immediately offshore, the whole zone above the low water mark is also subjected to wetting and drying and thus where rock is exposed, this too will suffer salt weathering. Goudie, et al. (1970) showed that wetting and drying of fresh black shale in distilled water caused the rock to disintegrate. Ollier (1969) reported that fine grained rocks such as shale, disintegrated by flanking and splitting when repeatedly wetted and dried. Cooke (1973) suggested that in the desert the surface may be wetted by rainfall or dew (Figs 9.7 & 9.8).

In some areas wetting by dew may be most important, permitting a daily wetting and dry cycle. Cooke and Smalley (1968) identified the main mechanisms by which salt may lead to rock disintegration. The processes identified in desert and coastal areas included: (1) crystal growth from solutions; (2) volume changes accompanying hydration; (3) volumetric expansion of crystalline salt as a result of temperature change. Goudie et al. (1970) studied the disintegration of the sand stone samples which were immersed in saturated salt solution and subjected to temperature comparable to the Central Sahara daily temperature regime for 40 days (60°C for six hours and 30°C for the remainder of each 24 hour cycle.

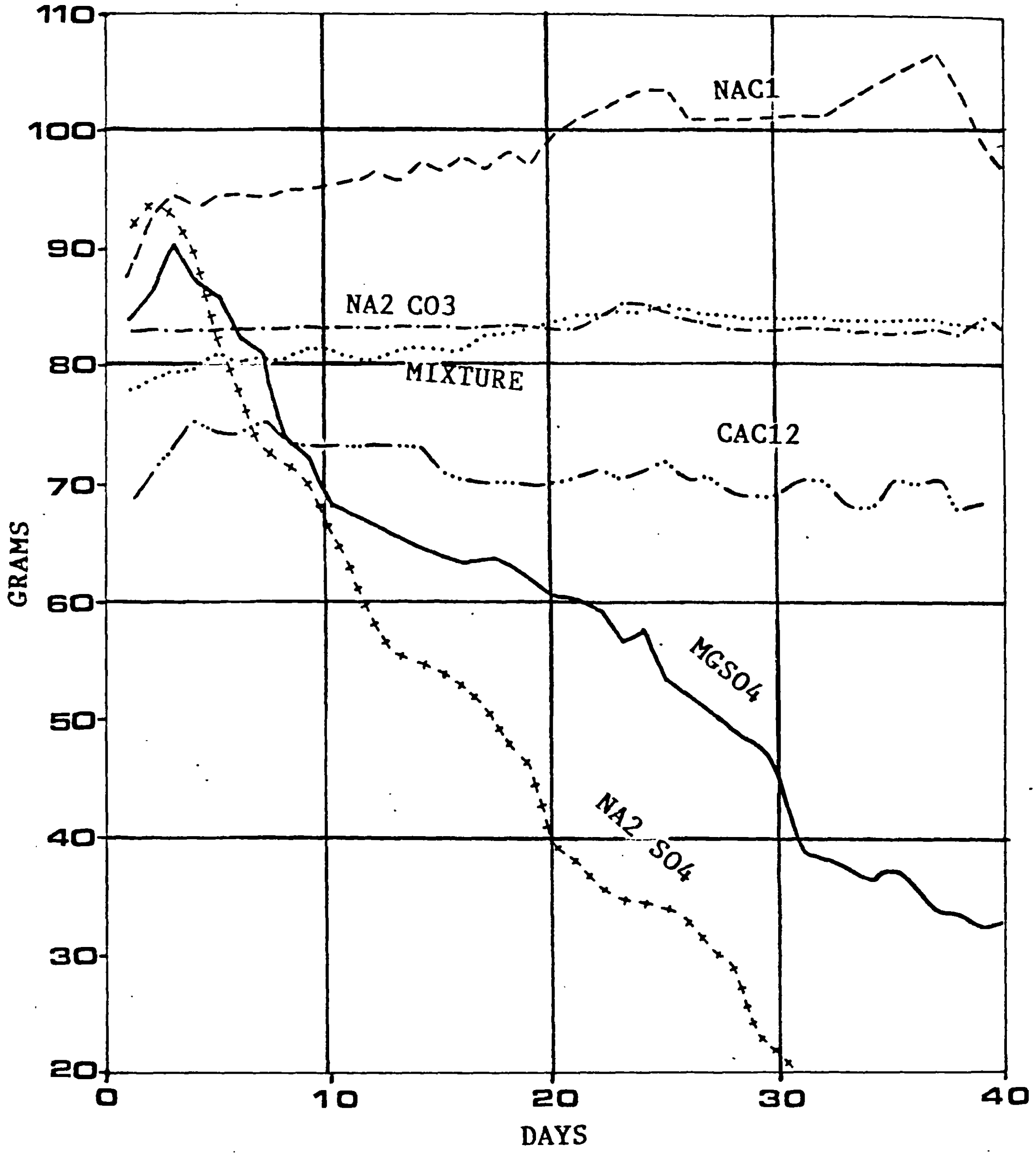


FIG.9.7 CHANGE IN WEIGHT OF SANDSTONE SAMPLES ON TREATMENT WITH DIFFERENT SALTS (AFTER GOUDIE et al.1970 AND COOKE 1978).

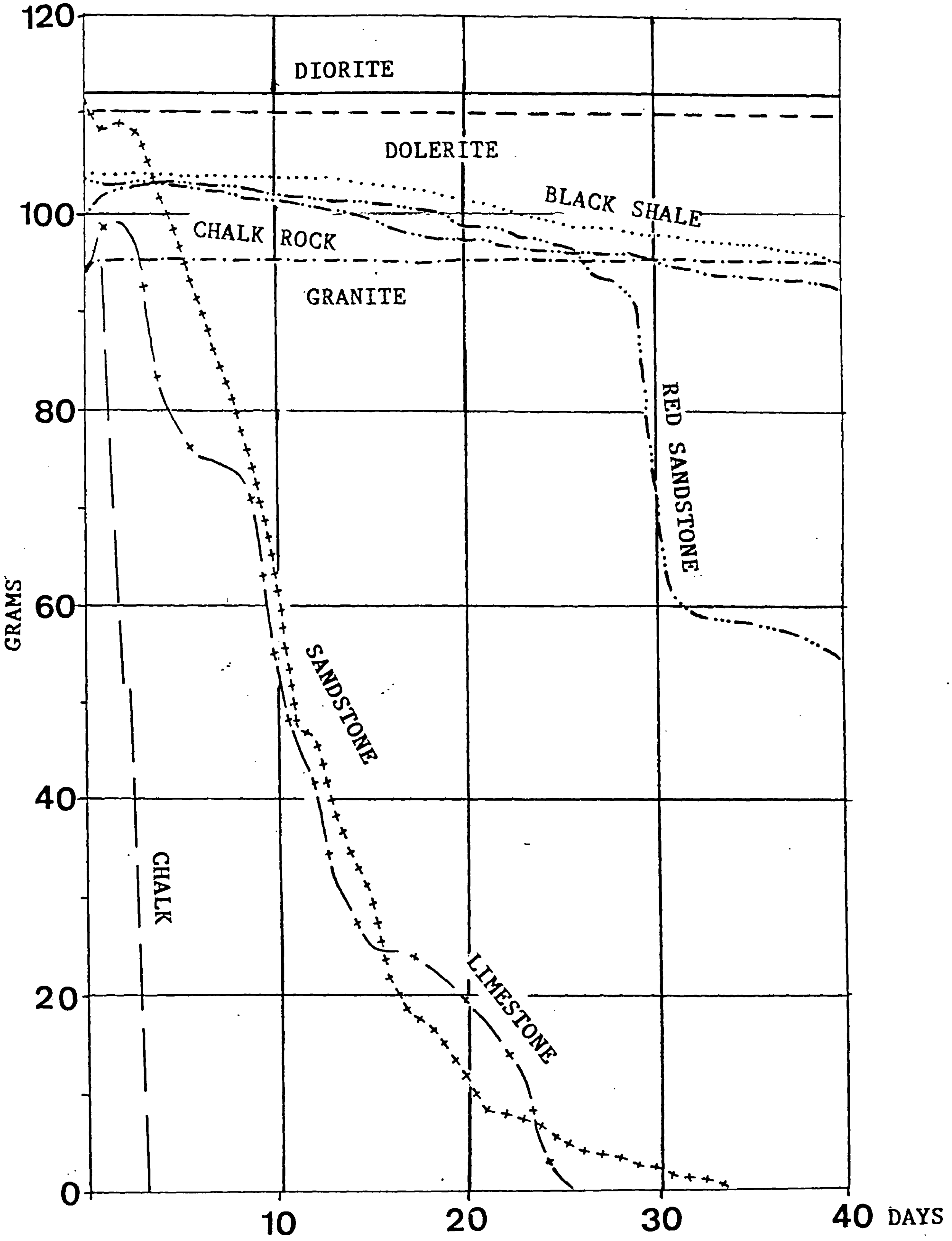


FIG.9.8 CHANGE IN WEIGHT OF DIFFERENT ROCK TYPES FOLLOWING TREATMENT WITH SODIUM SULPHATE (AFTER GOUDIE et al.1970 AND COOKE 1978).

The experiments demonstrate that:

(1) the ability of salt to lead to the disintegration of rock by growth crystal; (2) the effect of salts on different types of rocks; (3) the significant factors determining rock susceptibility on the rate of water absorption (rank correlation of weight loss after 40 cycles, and (4) the fact that sodium sulphate ($Na_2SO_4$) was the most effective substance in causing disintegration of sandstone samples. Goudie (1974) also showed that salt crystallisation using natural cycles and salt found in nature under arid conditions, is a highly effective cause of rock disintegration in comparison with other mechanical processes. Progressive breakdown occurred using salts such as $Na_2SO_4$, $Cacl_2$, $NaNO_3$ and $MgSO_4$ for sandstone and $Na_2SO_4$, $Na_2CA_3$, $NaNO_3$ amd $CaCl_2$ for chalk. From the results it seems that sodium sulphate ($Na_2SO_4$) is the most effective of these salts (Fig. 9.9 ). Goudie (1976) also showed the efficiency of sodium sulphate as an agent of disintegration in comparison with other mechanical weathering processes in Mohenjo-Davo, Pakistan. Cooke (1978) conducted a laboratory experiment to simulate salt weathering processes under desert conditions. The majority of salt being used caused no significant rock disintegration during the 40-day cycle, but it was recognised that they may operate very slowly. The experiment revealed the response of three rock types with different salts in a simulated desert environment. It showed that the rate of destruction seems to be related to certain rock properties, and once again the sodium sulphate ($Na_2SO_4$) was the most effective salt used (Fig. 9.10 ). A study of salt weathering was made by Doornkamp *et al.* (1980) in Bahrain using sodium sulphate, calcium sulphate and distilled water. They used sodium sulphate because it is one of the most important salts in Bahrain and the experiment

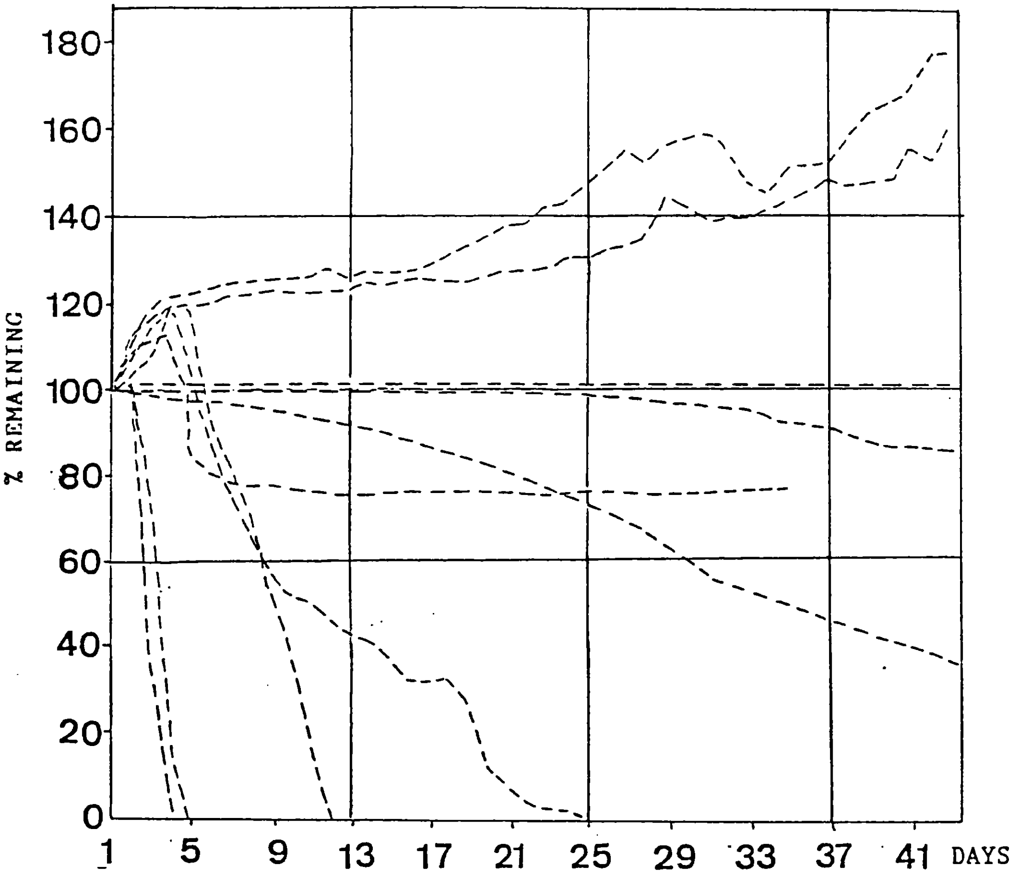


FIG. 9.9 SALT WHEATHERING EXPERIMENT, BY GOUDIE(1974).

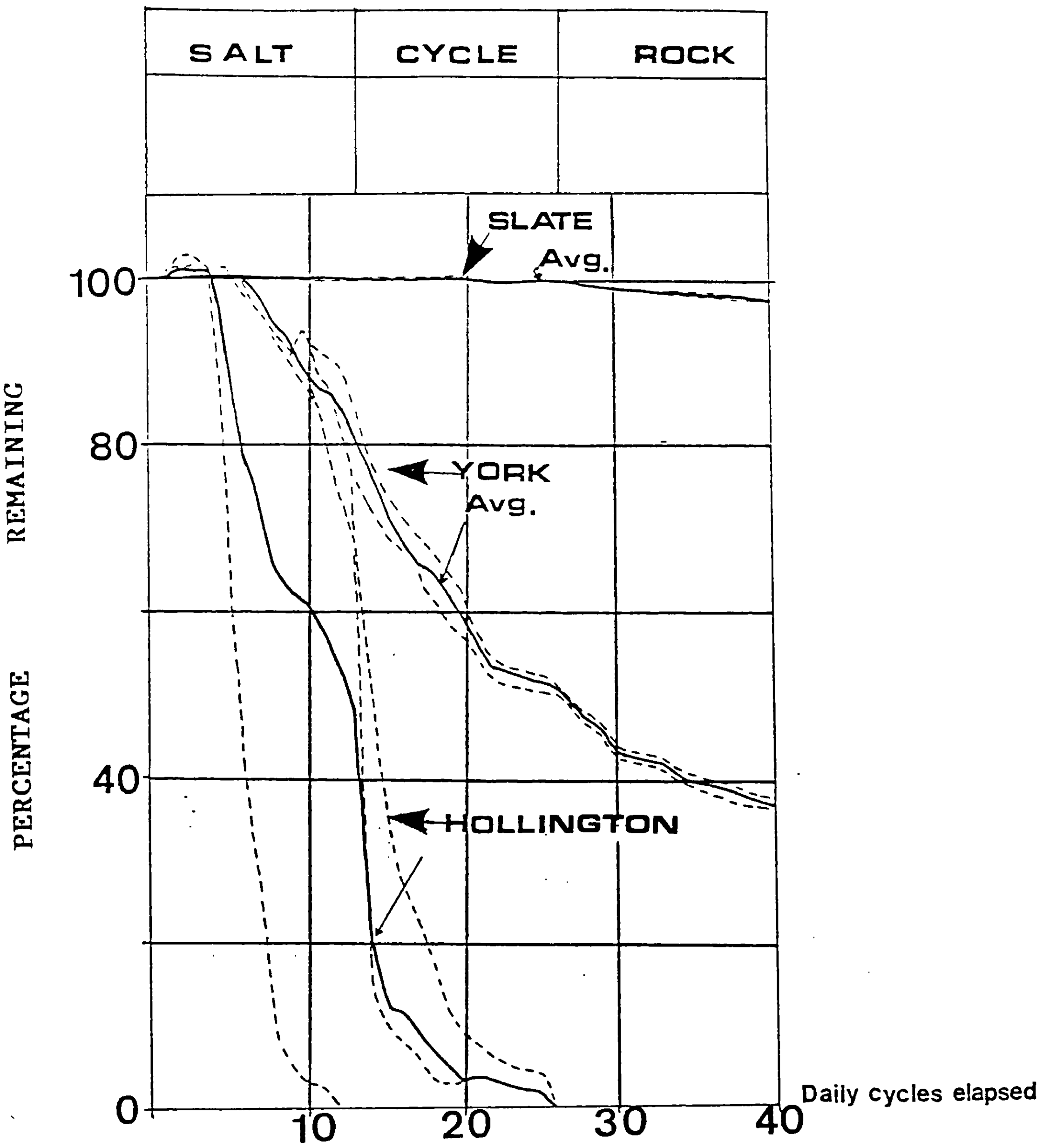


FIG.9.10 LABORATORY EXPERIMENT OF SIMULATE THE SALT WHEATHERING PROCESSES UNDER DESERT CONDITIONS (COOKE 1978).

showed that the rock samples experienced a different response to sodium sulphate compared with other salts (Fig. 9.11 ).

Mottershead (1982) studied the response of a range of fresh microtopographic rock forms on a shore platform in the zone immediately above H.W.M. at Prawle Point in S.Devon, England, where rapid rock weathering was suspected. A laboratory experiment indicated that the process responsible was most likely to be crystallisation of sodium chloride from sea water. Chapman (1980) described salt weathering of sandy limestone in Saudi Arabia's Arid Eastern province near the Arabian Gulf. Geological and chemical studies of an intensely weathered calcareous sandstone and slightly weathered sandy limestone bed showed that soluble salt (mainly NaCl) was concentrated in the outer weathered parts. Chapman concludes the weathering was the direct result of salt accumulation causing the disintegration of the rock. Derbyshire et al. (1981) used a solution of sodium sulphate and magnesium sulphate in their experiments. They used cemented Miocene limestone from the Suez area and subjected it to periods of wetting and drying. The result suggested that the Miocene marine limestone should not be used on construction work in saline environments such as those in the Suez area, because of the quick disintegration produced by sodium sulphate and magnesium sulphate. McGreevy and Smith (1982) demonstrated the power of salt weathering under hot desert conditions. They noticed that $CaCO_3$, $CaSO_4$ and NaCl were the salts frequently associated with salt weathering. Smith and McGreevy (1983) reached the conclusion, based on a short simulation experiment, that a considerable amount of rock breakdown can be achieved on samples of bedded sandstone using a relatively low maximum temperature (53°C) and a 10% salt solution of

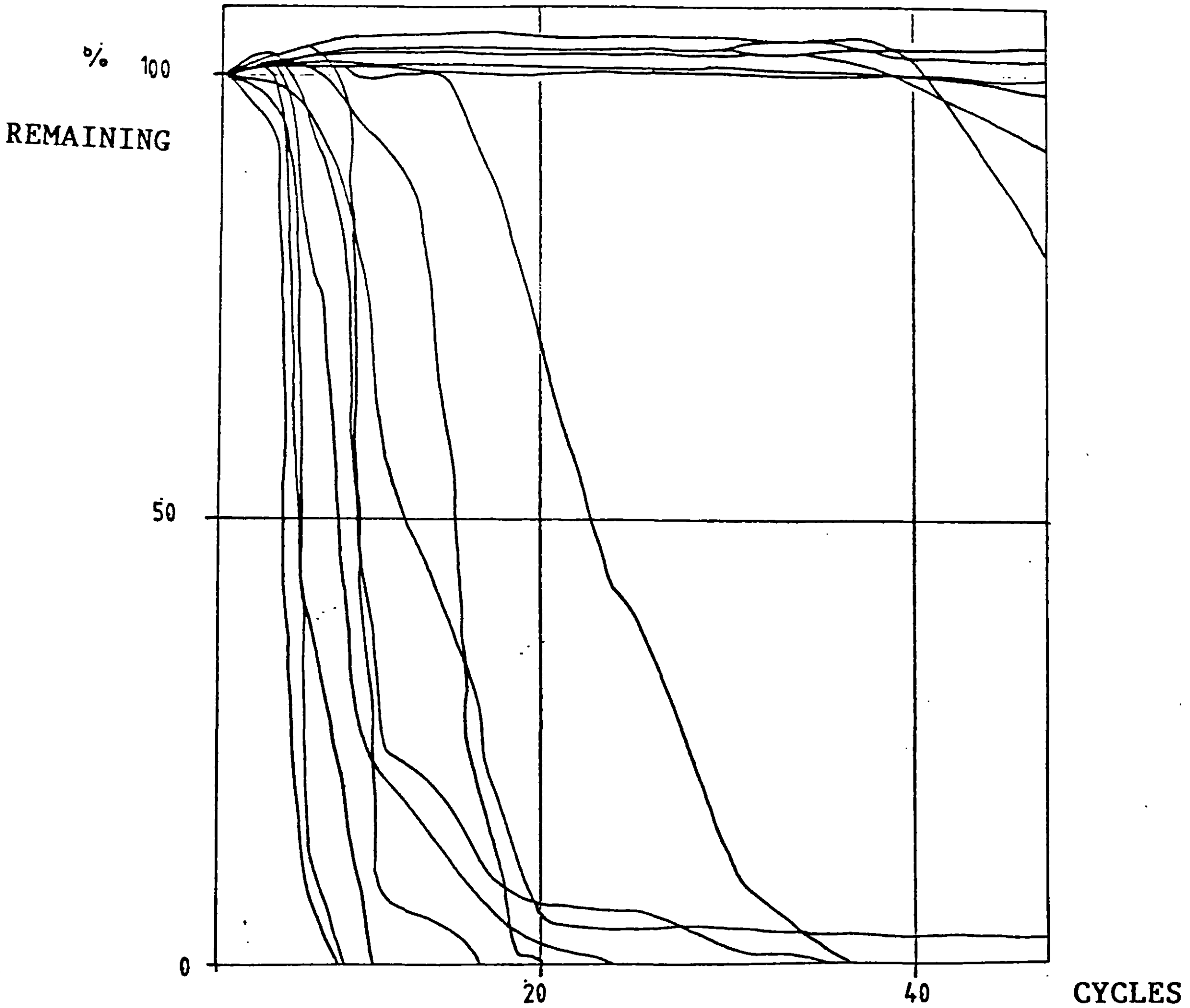


FIG.9.11 SALT WEATHERING USING SODIUM SULPHATE IN BAHRAIN (DOORNKAMP, 1980).

$MgSO_4$, NaCl and $Na_2SO_4$. McGreevy and Smith (1984) provided some indication of the potential significance of clay minerals in determining the pattern and rate of rock breakdown by salt weathering, but they were not sure if the clay minerals played an active weathering role (i.e. by swelling) and complementary salt weather effects, or if their importance is indirect through their control of microporosity, which itself favours salt damage. Their experimental results are added evidence to the contention that weathering processes rarely operate in isolation and the many weathering phenomena are polygentic in origin, and this seems to be the case in Qatar.

## 9.8 Salt weathering on the Qatar Peninsula Coast

### 9.8.1 Laboratory experiment

In this experiment blocks of rock approximately 3cm in size were used. Eleven samples (types and location are listed on table 1 and Fig. 9.12 were first weighed and then immersed in distilled water. Three saturated salt solutions were prepared, one of sodium sulphate, one of calcium sulphate, and one of calcium chloride. Fragments of the different rock types were then weighed and dried in an oven at 60°C for 6-7 hours. This temperature of 60°C is approximately equivalent to daytime rock surface temperature on the Qatar coasts. Then the temperature was held at 30°C for the remainder of each 24-hour cycle, which is a temperature approximately equivalent to the rock surface night-time temperature on the Qatar coasts. The daily cycles were repeated for 30 days for the samples immersed in sodium sulphate. Calcium sulphate and distilled water, and 13 days for samples treated by calcium chloride, or until the sample had disintegrated completely. The

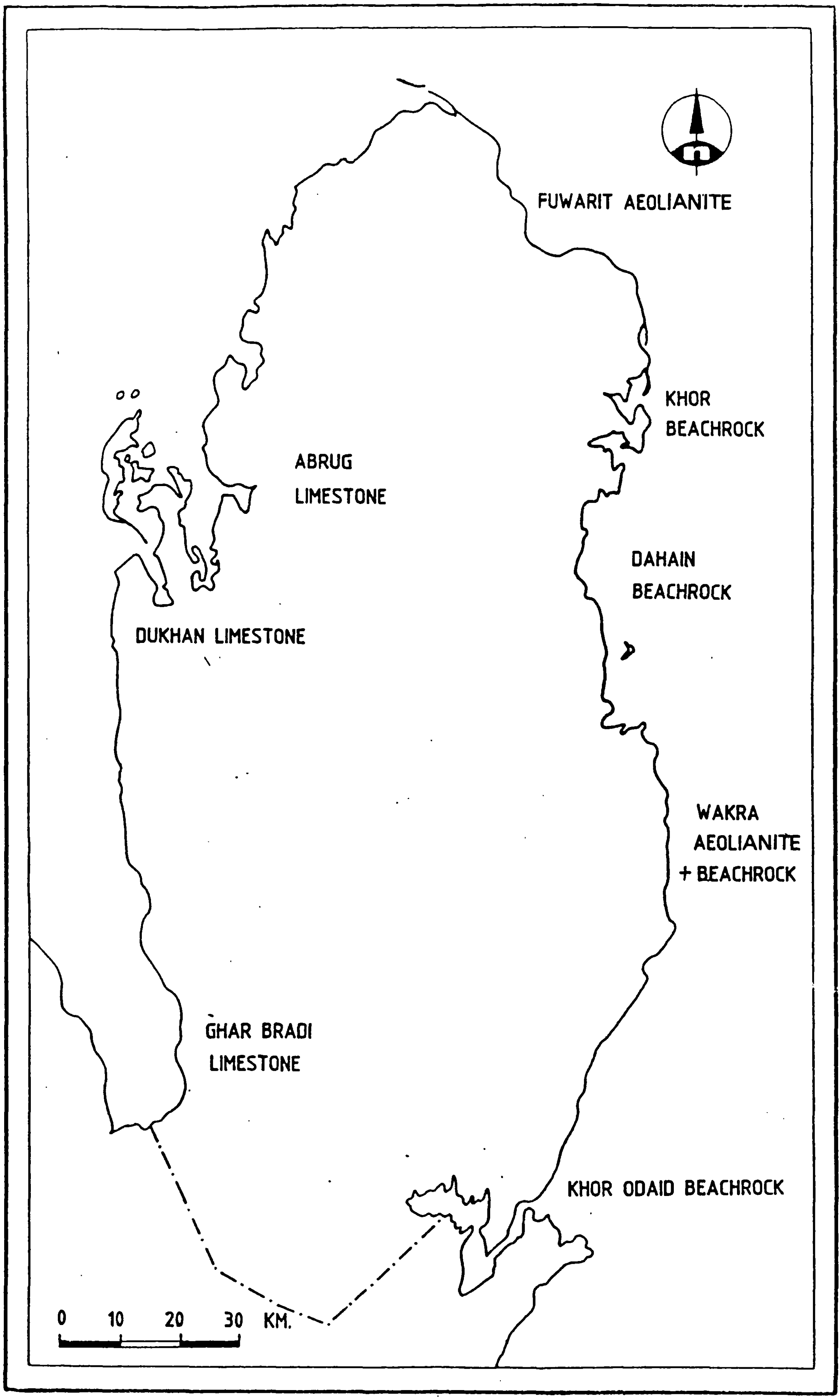


FIG.9.12 LOCATION OF ROCK SAMPLES FOR ROCK WEATHERING EXPERIMENTS.

Table 9.4 Rock types used in salt weathering experiments

| Rank | Location | Type |
|---|---|---|
| 1. Wakra | East coast | Aeolianite |
| 2. Khor Bay | NE coast | Beachrock |
| 3. Dukhan (1) | West coast | Limestone |
| 4. Dahain | East coast | Beachrock |
| 5. Fuwairt | N.E. coast | Aeolianite |
| 6. G. Bradi | S.W. coast | Yellow limestone |
| 7. Abrug, West | West Coast | Limestone |
| 8. Abrug, East | West coast | Limestone |
| 9. Dukhan (2) | West Coast | Limestone |
| 10. Wakra | East coast | Beachrock |
| 11. Khor Odaid | S.E. coast | Beachrock |

Table 9.5 The resistence of aeolianite to salt weathering

| Rank | Treatment | Weight after 30 cycles (%) |
|---|---|---|
| 1 | Salt crystallisation (D.W.) | 12.00 |
| 2 | " " $CaSO_4$ | 87.00 |
| 3 | " " $CaCl_2$ | 0.00 gone after 2nd cycle |
| 4 | " " $CaCl_2$ | 0.00 " " |
| 5 | " " $CaSO_4$ | 93.00 |
| 6 | " " D.W. | 91.00 |
| 7 | " " $CaCl_2$ | 90.00 |
| 8 | " " $Na_2SO_4$ | 0.00 gone after 30th cycle |

Table 9.6 The resistance of beachrock to salt weathering

| Rank | Treatment | Weight after 30 cycles(%)* |
|---|---|---|
| 1 | Salt crystallisation (D.W.) | 88.00 |
| 2 | " " $CaSO_4$ | 86.00 |
| 3 | " " $CaCl_2$ | 0.00 gone after 7th cycle |
| 4 | " " $Na_2SO_4$ | 0.00 " " 9th cycle |
| 5 | " " $CaCO_4$ | o5.00 |
| 6 | " " D.W. | 90.00 |
| 7 | " " $CaCl_2$ | 84.00 |
| 8 | " " $Na_2SO_4$ | 0.00 |
| 9 | " " D.W. | 88.00 |
| 10 | " " $CaSO_4$ | 87.00 |
| 11 | " " $Na_2SO_4$ | 0.00 gone after 20th cycle |
| 12 | " " D.W. | 88.00 |
| 13 | " " $CaSO_4$ | 87.00 |
| 14 | " " $Na_2SO_4$ | 0.00 gone after 17th cycle |

* 30 cycles for salt weathering using sodium sulphate, distilled water and calcium sulphate, and 13 cycle for calcium chloride.

Table 9.7 The resistance of different limestones to weathering

| Rank | Treatment | Weight after 30 cycles(%) |
|---|---|---|
| 1 | Salt crystallisation (D.W.) | 88.00 |
| 2 | " " $CaSO_4$ | 82.00 |
| 3 | " " $CaCl_2$ | 77.00 |
| 4 | " " $Na_2SO_4$ | 0.00 gone after 13th cycle |
| 5 | " " D.W. | 91.00 |
| 6 | " " $CaSO_4$ | 84.00 |
| 7 | " " $CaCl_2$ | 0.00 gone after 7th cycle |
| 8 | " " $Na_2SO_4$ | 0.00 gone after 2nd cycle |
| 9 | " " $CaCl_2$ | 95.00 |
| 10 | " " D.W. | 91.00 |
| 11 | " " $CaSO_4$ | 91.00 |
| 12 | " " $Na_2SO_4$ | 0.00 gone after 6th cycle |
| 13 | " " $CaCl_2$ | 96.00 |
| 14 | " " $CaSO_4$ | 80.00 |
| 15 | " " D.W. | 8.00 |
| 16 | " " $Na_2SO_4$ | 0.00 gone after 13th cycle |
| 17 | " " $CaSO_3$ | 89.00 |
| 18 | " " D.W. | 88.00 |
| 19 | " " $CaCl_2$ | 80.00 |
| 20 | " " $Na_2SO_4$ | 0.00 gone after 15th cycle |

weight loss from the sample rock cubes was recorded after each cycle and the weight compared with original dried sample: weight was used to calculate the percentage weight loss.

### 9.8.2 The resistance of different rock types

Three types of rock samples were subjected to standard salt crystallisation treatment with $Na_2SO_4$, and $CaCl_2$. The resistance of rock types after 30 cycles is shown in Figures 9.13 and 9. 14. The most striking feature of the three tables is that the salt crystallisation ($Na_2SO_4$, $CaSO_4$. $CaCl_2$) for the limestone, aeolianite and beachrock is clearly more effective than using distilled water. Tables 5, 6, 7, exemplify this further by ranking the processes in descending order of effectiveness. The results of this experiment are shown in Figure 9.13 and 9.14 and Tables 5, 6, 7. It is evident that sodium sulphate, sodium chloride and calcium sulphate are outstanding in their effect on the beachrock, aeolianite and limestone. They are, therefore, considered the saline component of sea water which produce the most damaging effect, and by their force of crystallisation causing the rock to break down.

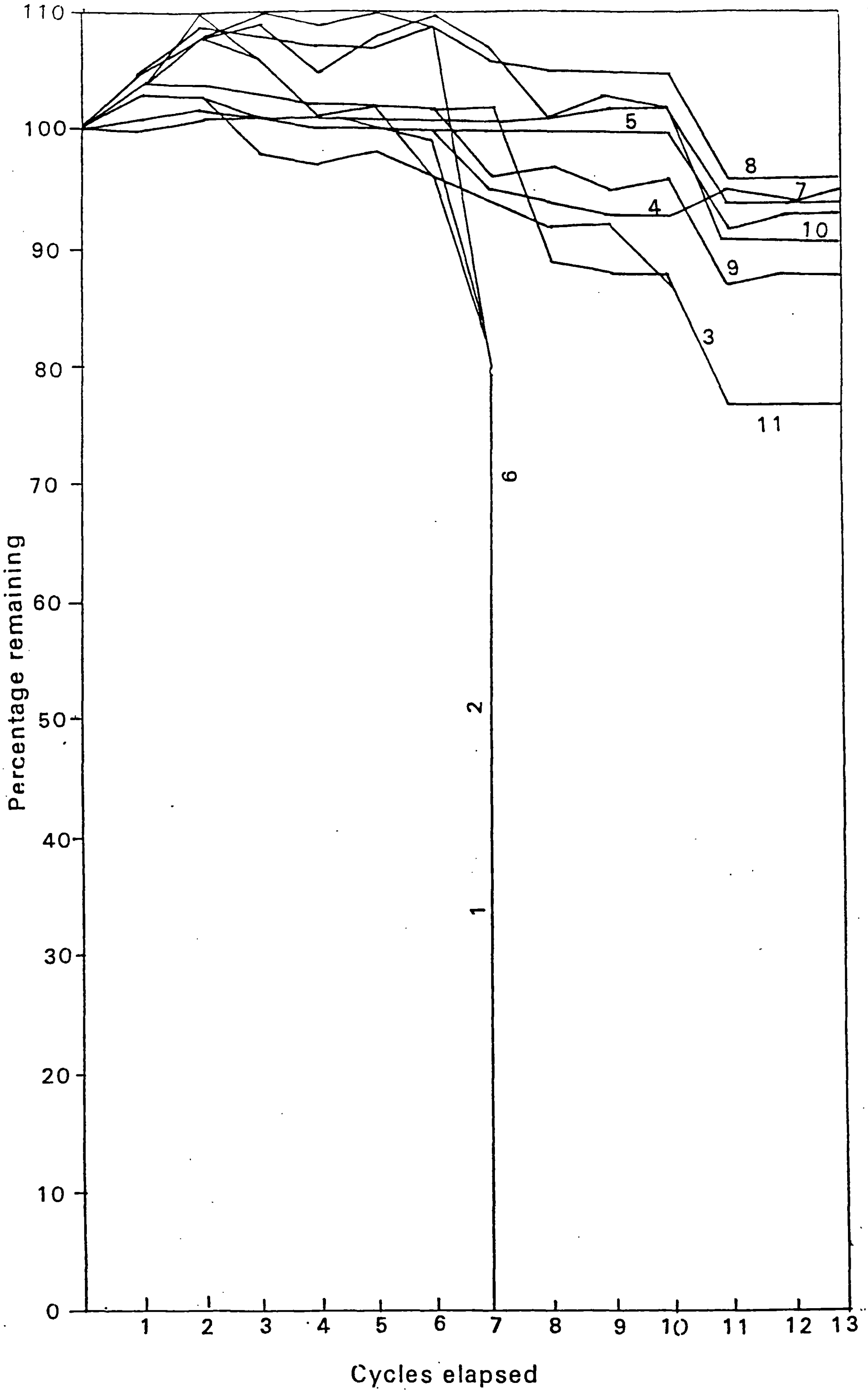
### 9.8.3 Salt weathering processes

According to Motterhead (1982) the processes of salt weathering operate in three ways: (1) the evaporation of saline solutions in rock pores leads to the growth of salt crystal; (2) salt already emplaced within the pores by crystallisation may undergo hydration as

SODIUM SULPHATE

SOLUTION

SOLUTION.


Percentage remaining
0
10
20
30
40
50
60
70
80
90
100
110
Cycles elapsed
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
5
6
7
8
9
10
11

a result of temperature and humidity changes; and (3) salt emplaced in pore spaces may expand due to heating.

From field observations it appears that sodium sulphate, calcium sulphate, are the most important salt influencing rock weathering on the coast of the Qatar Peninsula (Fig. 9.13 ).

Along the west coast many examples can be found representing the effectiveness of the salt weathering processes, such as caverns at the base of many cliffs in the Abrug Peninsula ( Plate 9.1 ). Compared with world ocean salinity values the salinity values around the coasts of Qatar reach between 40 to 50% (Fig. 1.16 ). These high values are highly effective cause of the rock breakdown as the result of pressure exerted by crystallisation salts.

There are several possible sources of the salts: (1) presented by the sea coasts in Qatar coast. Salts are provided by splashing of waves and from sea spray. The rocks most affected are those that frequently become wet and dry; (2) from the prevailing winds from the coastal sabkhas along the Qatar coasts (Chapters 1 and 4). These sabkha have dominant anions such as sulphate and chloride in addition to a quantity of sodium, calcium and magnesium which are the main cations (Chapter VI).

PLATE 9.13 EFFECTIVENESS OF SALT WEATHERING PROCESSES AS CAVERNS AT THE BASE OF CLIFFS IN ABRUG PENINSULA.

# CHAPTER X

# CONCLUSION

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# CONCLUSION

The coastline of the Qatar Peninsula is made up of a variety of landforms, such as extensive areas of Sabkha, or coastal saline mud flats, prograding aeolian dunes, extensive shore platforms, coral reefs and mangroves.

The prevailing wind in Qatar is from the north-west and north, the so-called "shamal" wind. The coast of Qatar is approximately 570 km long and developed on rock formations which are entirely of Tertiary and Quaternary age. For the most part the bedrock consists of limestones while the land surface is generally of low relief with a maximum height of 103 metres above sea level. In the west and south some additional relief features are produced by escarpments and meso-type hills. The classification of Qatar coasts has been prepared using a morphological approach to describe the broad division of the coastline of the peninsula which has been identified and deduced from the examination of maps (geological, topographical) as well as the field work investigations. The terms used by Johnson (1919), submergence, emergence and compound and those used by Shepard (1973), are avoided and greater emphasis is placed on the sequential development of the coastal features and the importance of coastal processes. Thus the coastline of the peninsula has been classified into a series of major units, such as the active sand dune and sand sheet.

The study revealed that the sand dunes consist of three different types; barchan dunes, sand sheets, and the fossil "relic" dunes or aeolianite features.

The study also revealed that sand dunes and sand sheets are migrating as a result of the prevailing "Shamal" wind from the north-west. Extensive sabkha or coastal saline mud flats were identified around the coast of Qatar, formed by build-up of silts, fine calcareous sands, most of the sabkhas being located between 1-2m above sea level. They are especially well developed north of Khor Odaid channel and south and west of the adjacent lagoons.

The coastal sabkhas cover an area of about 750 $km^2$ and in Umm Said penetrate inland for a distance of about 10 km, because of low relief.

Tidal currents frequently transgress their surfaces during high tides and when strong easterly winds raise sea level slightly. The sabkhas around Khor and Dakhera are composed of mud (10 to 20% dolomitic deposits) which may be to 50-65cm thick but 80cm to 1m thick in Umm Said sabkha. Elsewhere there is clear evidence of marine erosion accompanied by chemical activity and various land forms testify to the action of marine abrasion and intense solution of the limestone bedrock, such as cliffs and shore platforms. The coastal cliffs have been classified into two types, 'dead' cliffs which have resulted from a relative fall in sea level or slight tectonic uplift of the landmass, have been degraded as a result of prolonged weathering which has reduced the cliff angle to $30^{\circ}$ or less; examples are present in the Khor and Dakhera areas. The morphology of the 'active' cliffs appears to be controlled by characteristics of the rock type being eroded by the marine action and the local relief. Solutional activity by sea water is also important. For the most part the 'active' cliffs are confined to the north-west and the west coasts where wave action is stronger under the influence of the 'Shamal' prevailing wind (e.g. Abrug, Fuwairt, Ghar Brad and Dukhan). These coastal cliffs also include the fossil or relic dunes, the aeolianite sand dunes which also now form cliffs, some of which are active as are found on the east coast at Fuwairt. These cliffs range in height between 1-20 metres.

The study also identified the existence of the coral reefs that exist along the north-west and west coasts. The main reasons for their existence are: (1) the water depth that lies between 6-8 metres; (2) sea temperature exceeds 26°C in November and 33°C in August; (3) an adequate supply of oxygen; (4) salinity levels around the west and north-west coasts reach 42%, which is within the range for coral growth; (5) the absence of wind-borne sand and dune construction thus eliminating fine sediments which would present coral growth. Coastal segments dominated by mangrove growth are present on the east coast but not in the west. These mangroves are closely associated with saline mud flats and the accumulation of silt and fine sands (Chapman, 1976). The mangroves occur around the Khor and Dakhera embayments within an area protected from wave action. And they play an important part in the accumulation of the deposits in the bays and estuaries, and especially on the tidal flats where the mangrove vegetation achieves its greater density of growth (PLATE 6.2 ).

The factors determining the establishment and continued growth of mangroves around the embayments of Khor and Dakhera are:

(1) The abundance of silts and sand which are essential for the growth of the mangroves,

(2) low coastal relief and low off-shore gradient, and the protection afforded by the barrier beach bars and spits along the east coast of Khor and Dakhera, and

(3) low coastal wave energy.

The dominant type of mangrove vegetation is composed of Avacinnia marina, which dominate most of the area, achieving height of between 1-3 metres and widths reaching up to 5km.

Because of the sediment supply and the importance of longshore movements by wave and current action, there has been a substantial accumulation of sediments in the intertidal zone. As a result many barrier beaches have developed representing a significant feature of the coastal morphology along certain segments of the coastline. These barrier islands and their related enclosed lagoons have been interpreted from field investigation and from the aerial photographs dated 1963-1977. Throughout these years some coastal changes have occurred, where spits have prograded because of the wind-driven waves by the 'Shamal' north-west wind.

Several profiles have been made in Khor and Dakhera and on the barrier island where beach rock has been identified. The cemented beach sands (and pebbles) occur at about 1 to +3.0 metres above sea level. The beach rock usually consists of several cemented layers of sands and pebbles usually dipping seaward at $5^{o}$ to $10^{o}$ with the cement composed of calcium carbonate.

Particle size analysis (mechanical analysis) of sediment has been used for the interpretation of the sediments to provide information about the agent of the transport. Suggested parameters used by Folk and Ward (1957) have been used, such as graphic mean size ($M_z$Ø), inclusive graphic standard deviation ( 1), skewness (Sk) and kurtosis (Kg).

Samples of sediments from a selection of beaches have been examined in some detail, from sites such as the beach deposits of Qatar peninsula, range in mean size from +0.46Ø (coarse sand) to 2.30Ø (fine with an average of 1.14Ø (medium sand); the mean size of the majority of the samples (56%) lies between 2Ø and 1.5Ø. The samples collected from the beaches range between 2.06 (moderately sorted to very poorly sorted (S = 2.08), and the samples collected from the beach berm crests average as poorly sorted (S = 1.89), and samples collected from the swash zones range between moderately sorted (S = 0.86) to very poorly sorted (S = +2.08). The values of skewness of the Qatar samples are mostly from very positively skewed (Sk = +1.12) to very positively skewed (Sk = 0.89) for samples collected from beach samples. Samples collected from swash zones are positively skewed, and very positively skewed (Sk = 0.58) for samples collected from berm crests. The samples collected from coastal areas of the Qatar Peninsula range in kurtosis from platykurtic (Ku = 0.90) to mesokurtic (Ku = 1.08).

The distribution of the beach, swash and beach berm crests due to the sorting mechanism by wave and current action driven by the 'Shamal' north and north-west, but there appears to be various factors that control the mean size of beaches sediments along the coastline of the Qatar peninsula. These are (1) source of sediment, and (2) wave energy.

The Scanning Electron Microscope (SEM) has been used to determine the grain, origin and shape. It revealed that the quartz grains collected in Qatar were mixed in shape from rounded to angular. The samples collected from the beaches are dominated by mechanical v-shaped pits and curved grooves, and some show sub-angular features with low relief irregular breakage patterns, and some high relief.

Quartz grains derived from the coastal dunes are characterized by well-round grains showing v-shaped pits caused by marine action as well as upturned plates, dish-shaped concavities and the grains are also characterized by modification of features by solution and precipitation.

Surface texture of quartz and grains from beach and sand dunes environments reveal the occurrence of two sets of processes, mechanical and chemical. The mechanical surface features are mainly generated by aeolian transportation of the sand from the north-west of the peninsula under the effect of the prevailing 'Shamal' wind. On the other hand, these sands are characterized by upturned plates which have been affected by chemical action. Subsequent beach reworking has given rise to the addition of the v-shaped pits.

Salt weathering experiments treated with sodium sulphate, calcium sulphate, calcium chloride and distilled water reveal that the most striking feature is that salt crystallisation ($Na_2SO_4$, $CaSO_4$, $CaCl_2$) for the aeolianite and beachrock is clearly more effective than distilled water. From field investigations it appears that the sodium sulphate and calcium chloride are most important on the coast of Qatar, especially on the west coast. There are caverns at the base of the cliffs on Abrug peninsula cliffs and at Dahain. Many cliffs and shore platforms show the intensity of salt/weathering, aided by the high salinity values around the coast reaching 45%. Salt weathering causes significant rock breakdown as the result of pressure exerted by the crystallisation of salt crystals.

Thus as in many other parts of the world, a variety of processes have been involved in the evolution of the coastline morphology of the Qatar peninsula. The most important processes are longshore currents, waves, and tides. Coastal features are the effect of different processes working on the available geological materials in the zone when the land meets the sea. Beaches, spits and marsh land have been shaped largely by depositional processes, while the cliffs and rocky shores have been created by erosional processes. These depositional and erosional features are mainly related to the pattern of waves, generated by winds blowing over the sea surface, and currents particularly those associated with the rise and fall of the tide (Bird, 1984).

Longshore currents are generated by waves breaking at an angle to the shoreline. Such currents, which are mainly confined to the surf zone, interact with the wave surf and produce sand transport parallel to the shoreline (Derbyshire 1978). These currents move southward, but when approaching the north coast of the Qatar Peninsula it branches in two, with one current moving parallel to the east coast, other branches moving parallel to the west coast. These currents are responsible for sediment alongside cast embayments. These deposited materials contribute to the formation of spits, barrier beach along the east and west coast. Wind-driven currents and waves are the most important mechanisms of sediment transport along the relatively shallow coast of Qatar Peninsula. Because waves and currents are related to the north-west 'shamal' wind they are directed toward the east and west coasts. Most of the Qatar coasts of Qatar Peninsula are exposed to these processes. The last process is the tide, which is mainly caused by the rotation of the moon around the earth, and represents the balance of gravitational force in the sun, moon and earth system, as they affect a mobile surface level in the ocean and seas (Bird 1984). The tidal cycle moves parallel to the longitudinal axis of the Gulf, and due to the flatness of the Qatar coasts the tidal waters overwhelm large areas near the coast leading to the formation of the coastal sabkha. These tides influence sediment size near the coasts of the Qatar Peninsula. All these processes, longshore currents, wind-driven currents and waves and tides, operate against a mixture of environmental conditions. What is important is identification of these processes which are only operating in the environmental conditions found in this part of the Middle East.

This thesis has identified a series of coastal morphological features in Qatar which owe their origin to processes which have operated during the late Tertiary and much of the Quaternary. Analysis of the processes and landforms has identified as being of primary importance and they are:

1. Sand dunes and sand sheets
2. Sabkhas (coastal sabkha (saline mud flats))
3. Cliffs (active cliffs, and aeolianite)
4. Beaches (spits, barrier beaches)
5. Mangroves

Finally, this thesis will be the starting point for a broader coastal classification of the Arabian Coastline (eastern coasts of the Arabian Gulf).

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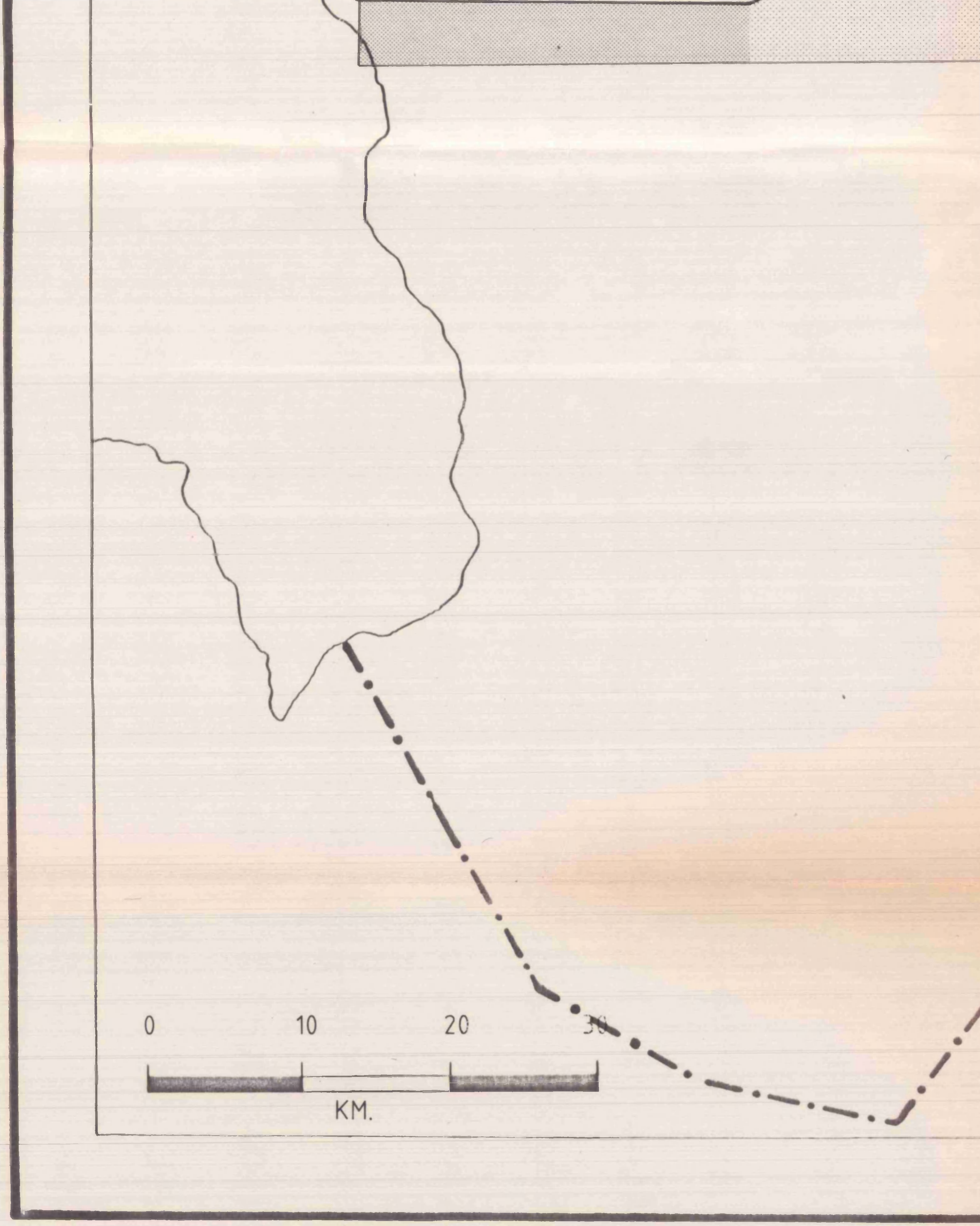

FIG.**8.9** WEST COAS

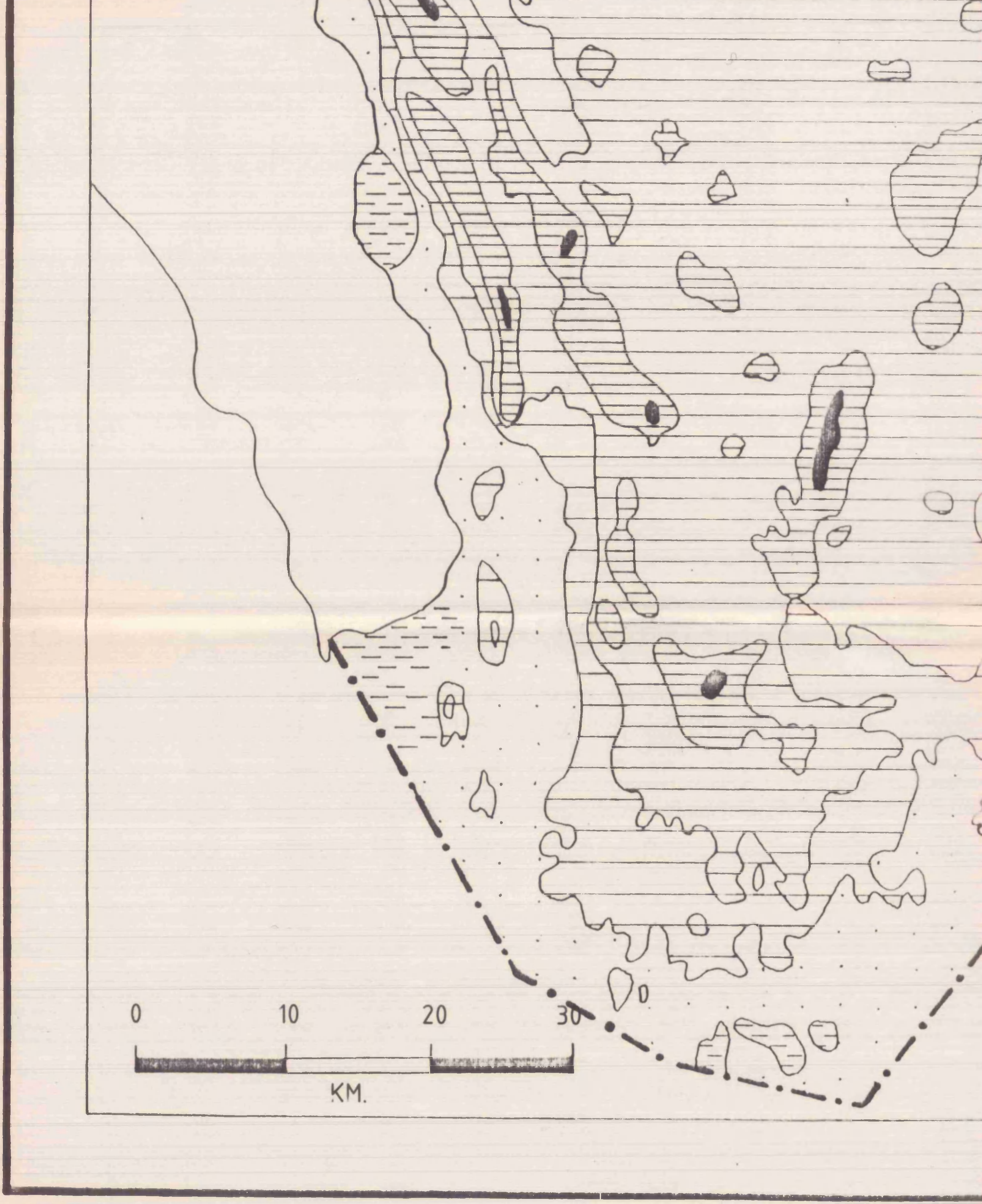

FIG.**1.3** RELIEF

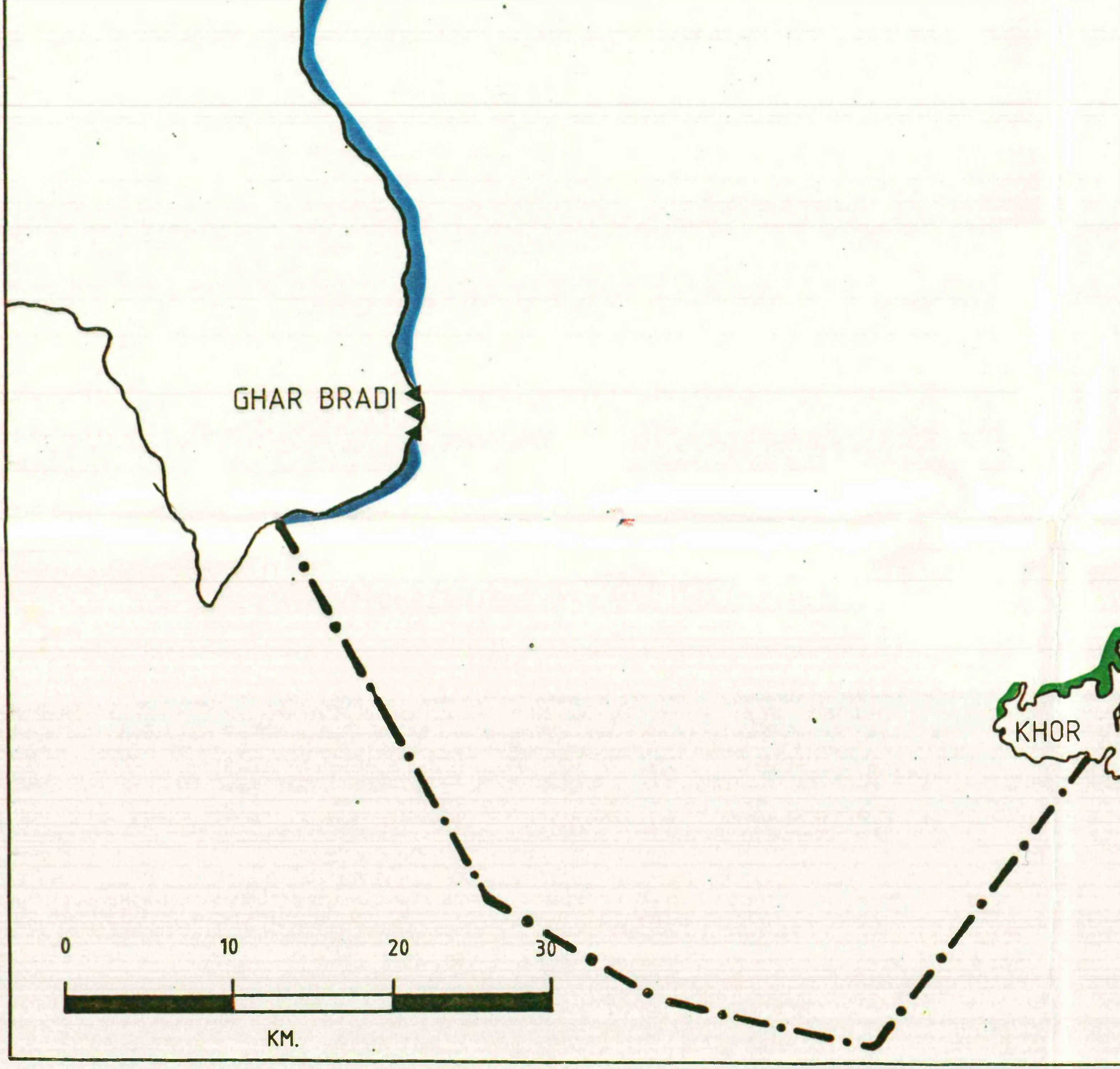

FIG.2.3 COASTAL CLASSIFICATION