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Changing sea-level along the north coast of Kuwait bay

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CHANGING SEA-LEVEL ALONG THE

NORTH COAST OF KUWAIT BAY

by

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TO MY PARENTS

ABSTRACT

Field investigations have been carried out to study the changes

of sea level-along the north coast of Kuwait Bay. Four zones have

been studied in detail viz: Kathma, Ghidhai, Mudairah and Al-Bahra.

The area is characterized by the existence of several terraces which lie between

the Jal-Az-Zor escarpment and the coastline which may represent stages

of changes in sea-level.

Three techniques have been adopted to study the terraces:

1. Levelling, 2. Radiocarbon dating of shells, and 3. Sediment

analysis by particle size analysis and scanning electron microscope.

The results show that there are six terraces in the area. The highest

levelled point for the First terrace was obtained from Ghidhai at 92.62 m.

above Kuwait Datum, while the least elevation for a fragment of the

lowest terrace was 5.99 metres above Kuwait Datum, at Al-Bahra

The terraces, besides having a general tendency to decrease in height

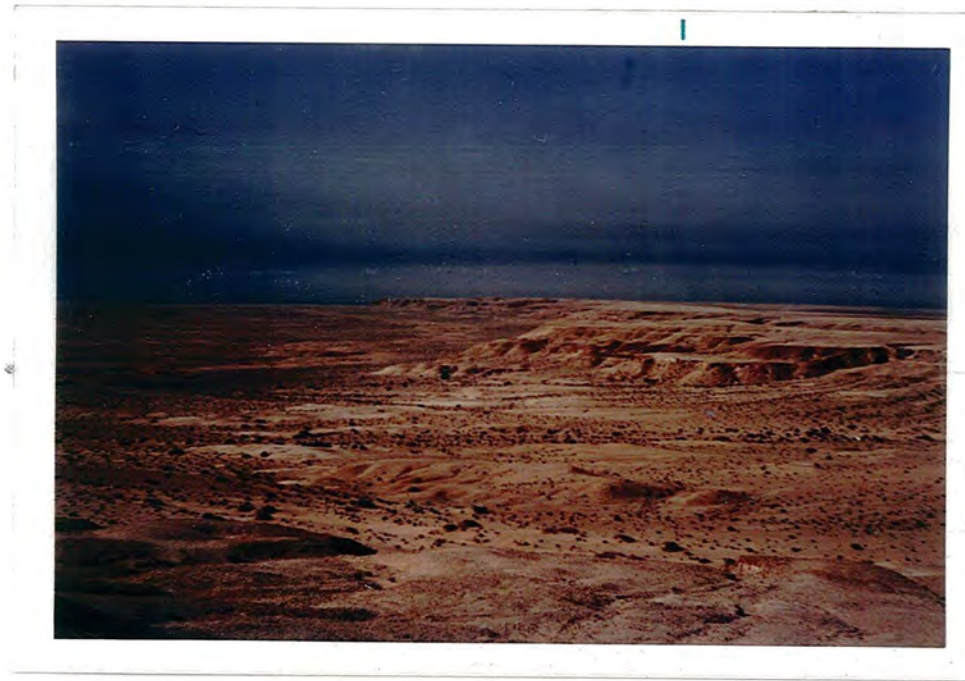from west to east, also indicate local instability and warping.

Although the upper terraces can be identified as conspicuous

physiographic features, it has been difficult to correlate them

according to their height. Radiocarbon dating of a small number of

shell samples from the Third, Fourth and Fifth terraces gave a range

of ages between >42,950 years BP. and 23,300±600 years BP.; no simple

correlation between height and age is observable and the possibility

of shell contamination cannot be excluded. The evidence as a whole

suggests that these upper terraces are not younger than Pleistocene

in age.

Radiocarbon dating for the extreme lowest terraces gave an age

range of between 4,570±70 years BP. and 3,560±60 years BP. which suggests

a time of formation in the Holocene.

The sediment investigations confirm the existence of three

depositional environments; fluvial, aeolian and marine. The sediment analysis results together with their geomorphological character indicate that it is possible that the upper two or three terraces originated as a result of fluviatile as well as marine action and were affected by tectonic movements. The lowest terraces are likely to be of marine origin deformed by tectonic movements.

FRONTISPIECE

General view of the coastal terraces, looking west

towards Ghidhai and Kathma

ACKNOWLEDGEMENTS

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CHAPTER 1

Introduction

The theme of this research is the study of the changes of sea-level along the north coast of Kuwait Bay by an investigation of the land surface in the area between Kathma and Al-Bahra (Fig. 1). The area is characterised by the presence of three main topographic elements (Fig. 2). First, the Jal-Az-Zor escarpment, an outstanding feature. The escarpment is composed of rocks of Miocene and Pliocene age capped with more recent deposits. It extends from west to east for a distance of about 65 kilometres, with a maximum height of about 145 metres. The escarpment follows a north-easterly direction, until near Al-Bahra where it changes its course and swings northwards in a gentle arc through east to the southeast. The escarpment is also dissected by several wadis which are most evident in the area between Kathma and Mudairah. Secondly there is the slope-area at the foot of the escarpment which varies in width from Kathma to Al-Bahra with several breaks of slopes scattered throughout the area. Here, are conspicuous terrace forms, covered by marine and terrestrial deposits, at different levels. Lastly, there is the area between high and low water mark sometimes wide, marshy and ill-defined, sometimes with clear beach characteristics.

The area under investigation has been chosen for the study of sea level changes because of the existence of the terraces and fragments of terraces which have already been mentioned above, and because this part of Kuwait coast has not been physically disturbed by the creep of settlement and building of seaside cottages to which a large part of the southern coast is exposed. The research area is not permanently settled apart from a few wandering groups of people. However, it is worthwhile mentioning that Kathma used to

Fig.(1) LOCATION MAP
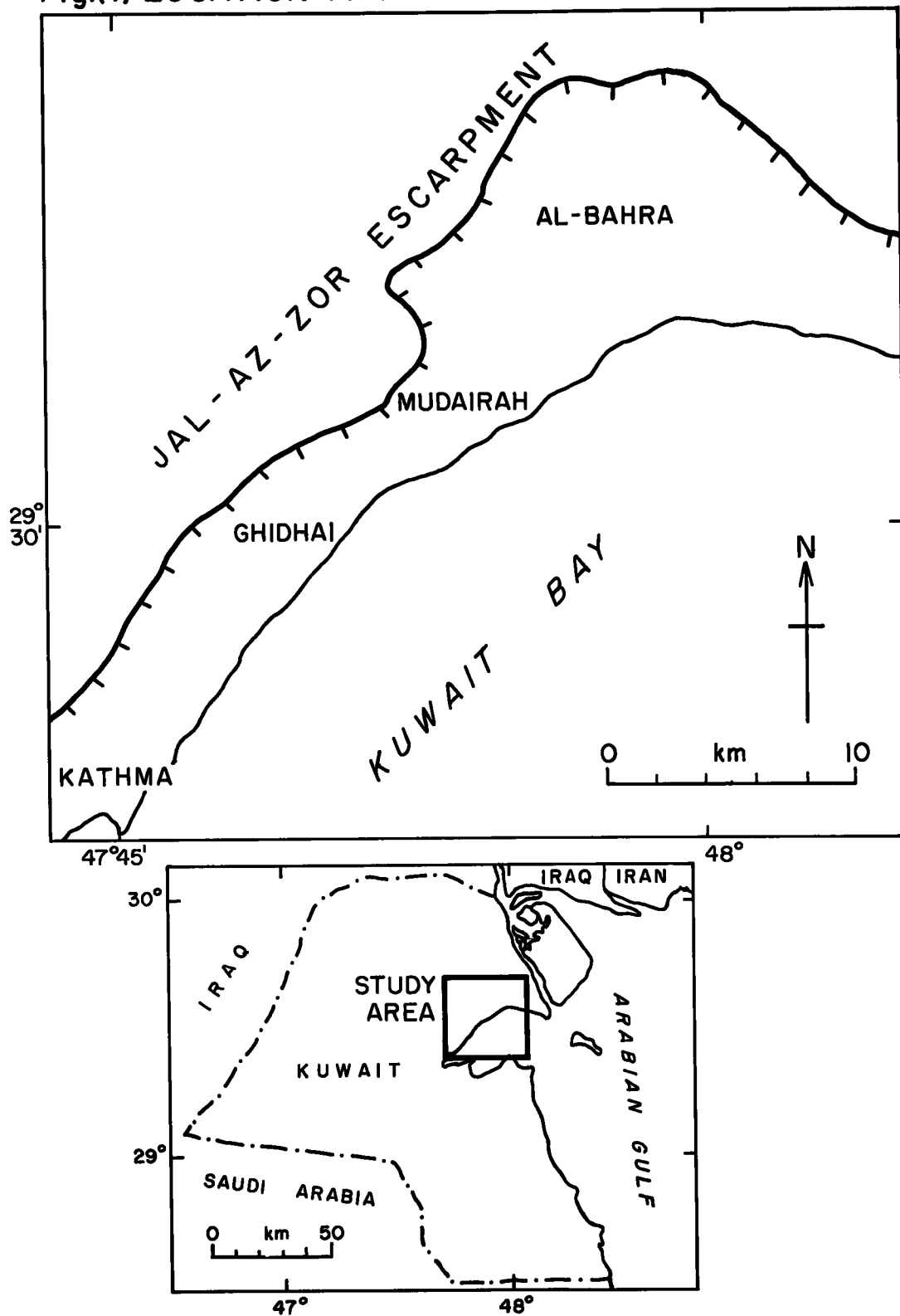
be a town of some importance in the early Islamic period and previously extended from its present location as far west as the village of Al-Jahra. A preliminary archaeological investigation by a Danish expedition has referred to the existence of some implements found in Kathma and Mudairah belonging to civilisations of the Stone Ages. (Al-Kuwait Al-Youm 1958).

Some obstacles which were met in the research, included the physical conditions of the area during the fieldwork - mainly the dust storms and the high temperatures, and the fact that there has never been previous research focussed on sea-level changes in Kuwait.

The basic but limited geological reports have contributed to some extent to our understanding of the geological history of the area, but as will be seen in Chapter Two, the extent and certainty of our knowledge of the historical geomorphology of the Gulf is very limited. Accordingly all the material presented in this research is original and all possible efforts have been made to present this as an initial start to the study of sea-level changes on the Kuwait coast.

The first portion of this study presents a brief summary of the available relevant literature about the Gulf and adjacent areas, physical characteristics of the Gulf, the structural stability of the head of the Gulf (important because of its location close to the area of research), as well as the study of evidence of sea-level changes around the Gulf. This is followed by an introductory chapter on the geology and physical geography of Kuwait.

Chapters four and five discuss the methods which have been adopted for the investigation of this research and the raw data

Fig.(2) Topographic Map of the Research Area

- - - -	Track	△ Trigonometrical station
≳≥	Watercourse-well defined	
	Watercourse-shallow indistinct	0 km 10
▼▼▼	Low feature or bank	
ᴛᴍᴍᴛ	Cliffs, Escarpments or high features	N
·.·ᐟ.·ᐟ	Mud or sand flats	↑
⅏ ⅏	Swampy ground	
-··-··-	High water mark	

From K O.C. maps 1961
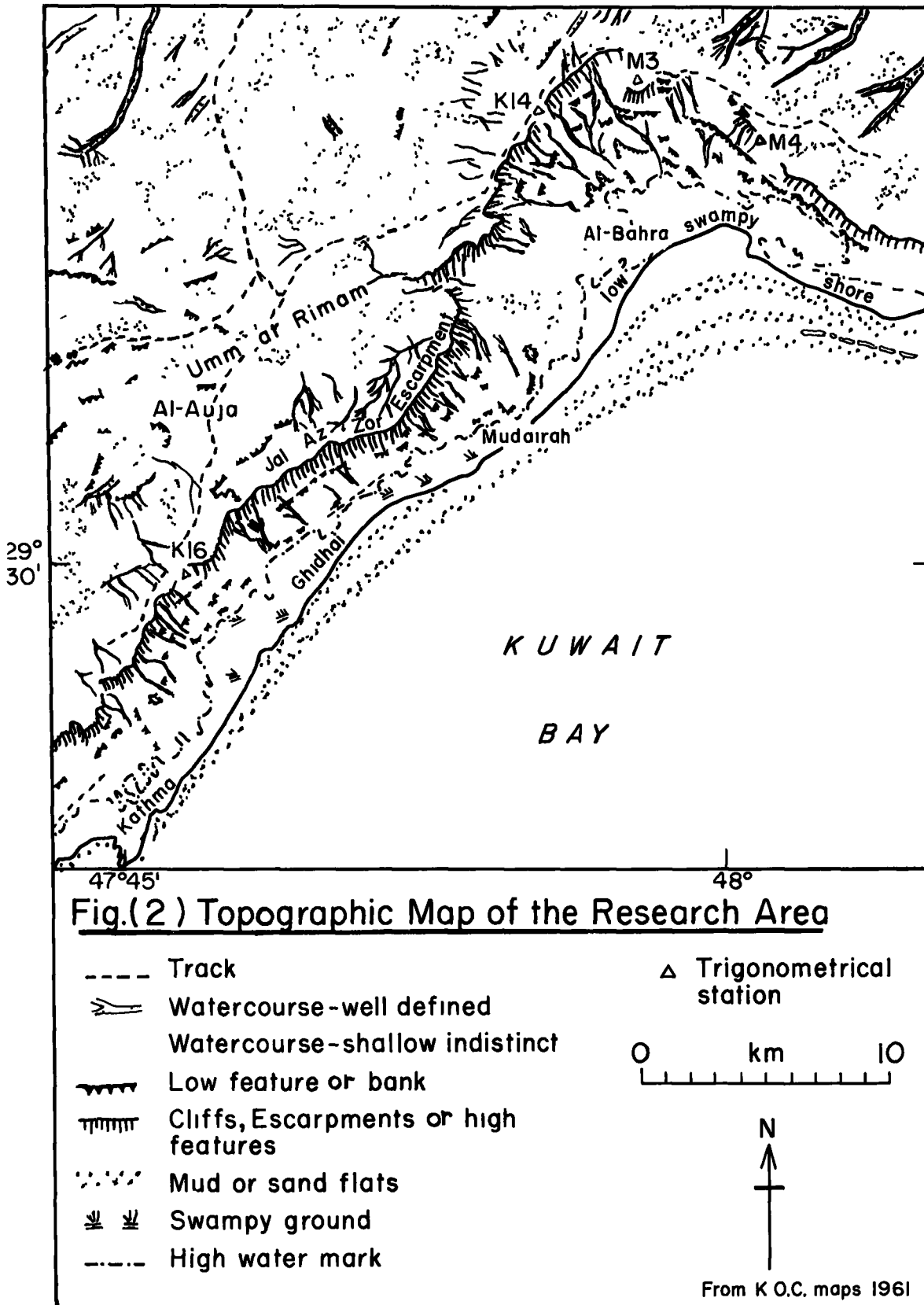
obtained from each method. In the fourth chapter, the methods dis-
cussed include levelling, radiocarbon dating and sediment analyses,
the importance of each method in relation to the present work being
fully discussed, while the fifth chapter presents the results
obtained independently from each method of investigation.

Chapter six presents the interpretation of the results obtained
by the various methods of investigation; it attempts a correlation
between the terraces or fragments of terraces between Kathma, Ghidhai,
Mudairah and Al-Bahra. A comparison and correlation between the
results of this research with world-wide changes of sea-level is also
presented.

The last chapter (7) is the conclusion which reviews the
procedures followed in this work and the results obtained. The implication
of the Kuwait Bay finding and the Geomorphic evolution of the Gulf is
tentatively discussed. Lastly, this chapter also considers whether there
is any correlation between the results obtained from Kuwait and those in
other parts of the Gulf.

CHAPTER **2**

SUMMARY OF RELEVANT LITERATURE ABOUT THE

ARABIAN GULF AND ADJACENT AREAS

Since the coast of Kuwait extends along the northwest shore of

the Arabian Gulf, it is necessary first to outline our present state

of knowledge as shown in related literature about the Gulf and

adjacent areas.

2.1 The physical characteristics of the Gulf

The Arabian Gulf is a shallow sea oriented in a NW, SE direction

with an open connection with the Indian ocean through the strait of

Hormuz and the Gulf of Oman. In general, the Gulf is located between

the northwest-southeast trend lines of the folded and thrust ranges

of the Zagros mountains of Iran and the Pre-Cambrian Arabian shield.

The latter, which is tilted slightly towards the northeast, is covered

by Palaeozoic, Mesozoic and Cainozoic sediments: Powers et al (1966);

(Evans 1966). The low western coast of the Gulf is broken at its

southern end by the Oman mountains which resulted from the folding

and crushing movements that started at the beginning of the Cretaceous

period and were completed in the Mio-Pleistocene, Pilgrim (1908).

The Zagros mountains emerged from a geosyncline squeezed between

the relatively resistant mass of Iran and the Arabian foreland

(Mitchell 1958), the ranges representing a belt of folded and faulted

Palaeozoic, Mesozoic and Cainozoic rocks. The tectonic movements

started in the upper Cretaceous period, reaching their peak in the

late Tertiary and in the Pliocene (Powers et al 1966). The area is

still active as can be witnessed in the river terraces on the

Makran coast, Lees and Falcon (1952); Falcon (1947). The geology of

the Arabian Gulf has been much discussed, see e.g. Pilgrim (1908);

Geogr. Sect. Naval. Intell. Div. Naval Staff. Admiralty (1918);

Lees and Richardson (1940); Henson (1951); Lees (1953); Hester (1965);

Evans (1966); Mina et al (1967) and Kassler (1973).

The Arabian Gulf has an area of about 24,000 sq. kms. and is

characterized by relative shallowness. The average depth is 31 metres,

and the maximum depth is about 110 metres near the Strait of Hormuz

(Fig. 3) as compared with depths of 900 m found in the Gulf of Oman.

In the Gulf basin, the greatest depths occur along the Iranian

coast; here the coast differs topographically considerably from the

west as it is mountainous and the mountain ranges run parallel to the

coast, in some cases close to the coastline and forming cliffs through

which several rivers discharge into the Gulf.

The Arabian coasts are generally low with desert characteristics

and an absence of freshwater discharging into the sea. The head of

the Gulf is an area of deltaic sedimentation formed by the Euphrates,

Tigris and the Karun rivers. The southwest coast is generally flat

except where the Oman mountains, in the extreme south, reach the sea

around Ras Musandam. The southwestern parts of the Gulf, especially

around Abu Dhabi and the Qatar peninsula have been studied in further

detail by Houbolt (1957); Evans et al (1964); Butler (1966); Evans et al

(1969); Kendall and Skipwith (1969); Evans (1970); Shinn (1973).

The Gulf is also characterized by its high temperature and high

rate of evaporation, with a maximum evaporation in December and a minimum

in May (Privett 1959). These conditions, together with the absence of

large supplied of freshwater except from the Tigris and Euphrates river

system (and these also vary seasonably), from the Karun and some inter-
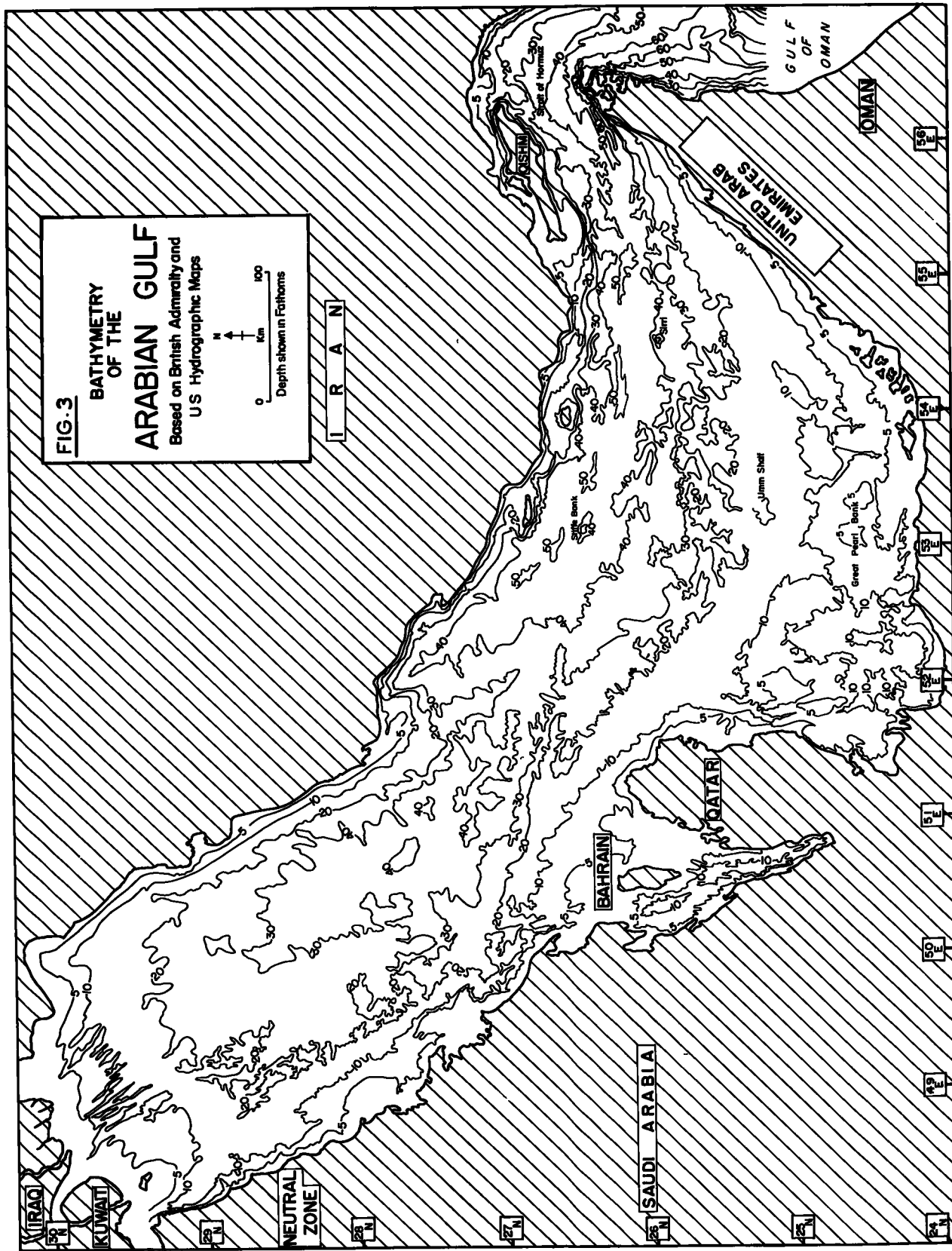
FIG. 3

BATHYMETRY
OF THE
ARABIAN GULF
Based on British Admiralty and
US Hydrographic Maps

Depth shown in Fathoms

mittent small streams flowing from the Zagros mountains produce a high
rate of salinity, Schott (1908); Emery (1956); Sugden (1963) and
Evans (1970). The replacement of the loss occurs by the broad anti-
clockwise surface current which brings in new ocean water which affects
the distribution of temperature and salinity in the Gulf. Water made
dense by evaporation sinks to the bottom and leaves the Gulf following
the deeps near the Musandam Peninsula (Emery 1956 ; Purser and
Seibold 1973). The tidal range in the Gulf is from 2 to 3.5 metres.
Winds in the Gulf are southeasterly as well as northwesterly, but the
latter is predominant; this is known locally as the 'Shamal' (the
Arabic version of the north, implying the source of wind). The shamal
is a very dry wind which blows more continuously in summer than in
winter and carries a large dust load which, as well as sometimes
making visibility difficult, carries terrigenous sediments to most
parts of the Gulf especially the Arabian coasts and causes waves and
surface currents.

2.2 Structural stability of the head of the Gulf

The northwestern part of the Gulf is an area of both structural
instability and extensive deposition caused by the Tigris-Euphrates and
Karun rivers. The geological history of the northern part of the
Arabian Gulf has been confused by two contradictory points of view
put forward by archaeologists and geologists. Because the structural
history of this part is closely bound up with that of the area under
review it is necessary to pay special attention to the viewpoints
concerned.

The general thesis of the archaeologists, supported by De Morgan
(1900), is that the shoreline at the head of the Gulf is advancing
towards the south because of the long-continued deposition of the

sediments brought down by the Tigris-Euphrates and Karun rivers.

Several estimates have been put forward as to the rate of accumulation

and progradation of the head of the Gulf; Beke (1835) stated that

originally both the Tigris and Euphrates discharged their water by

separate channels into the Gulf and during the last two thousand

years there has been an accession of land area considerably greater

than one thousand square miles. Rawlinson (1857) estimated that during

the historic period the advance of the area towards the Gulf was about

a mile in 30 years. According to Loftus (1857) the growth of the

Tigris and Euphrates Delta was a mile in about every 70 years. Geo-

logical support was given to these ideas in 1900 by De Morgan, who

attempted to demonstrate that most of the land at the head of the

Gulf has appeared as a result of the silt brought down by the Tigris-

Euphrates and Karun rivers. He produced maps on the basis of which the

Geographical Section of the Naval Intelligence Division produced a

summarized map (Fig.4.1). De Morgan summarized the classical evidence

of the changes of the shorelines since early Assyrian times. He

referred to Assyrian documents which discuss the naval expedition

of Sennacherib in 696 B.C. when he invaded Elam. De Morgan also

reviewed the journey of Nearchus in 326-325 B.C. Both sets of records

may be interpreted as showing that the four rivers of Tigris, Euphrates,

Karkeh and Karun earlier flowed separately into the Gulf, but by the

fourth century B.C. the sediments which were carried by Karun and Karkeh

had pushed their deltas from east to west across the Gulf and built a

chain of islands which separated from the sea a lake, which later became

filled by Tigris and Euphrates sediments (the lake is represented at

present by marsh). As a result of the advance of the coastline,

the land behind gradually dried out in places to produce the present

Advance of the Euphrates-Tigris delta since early historic times (after maps of de Morgan).
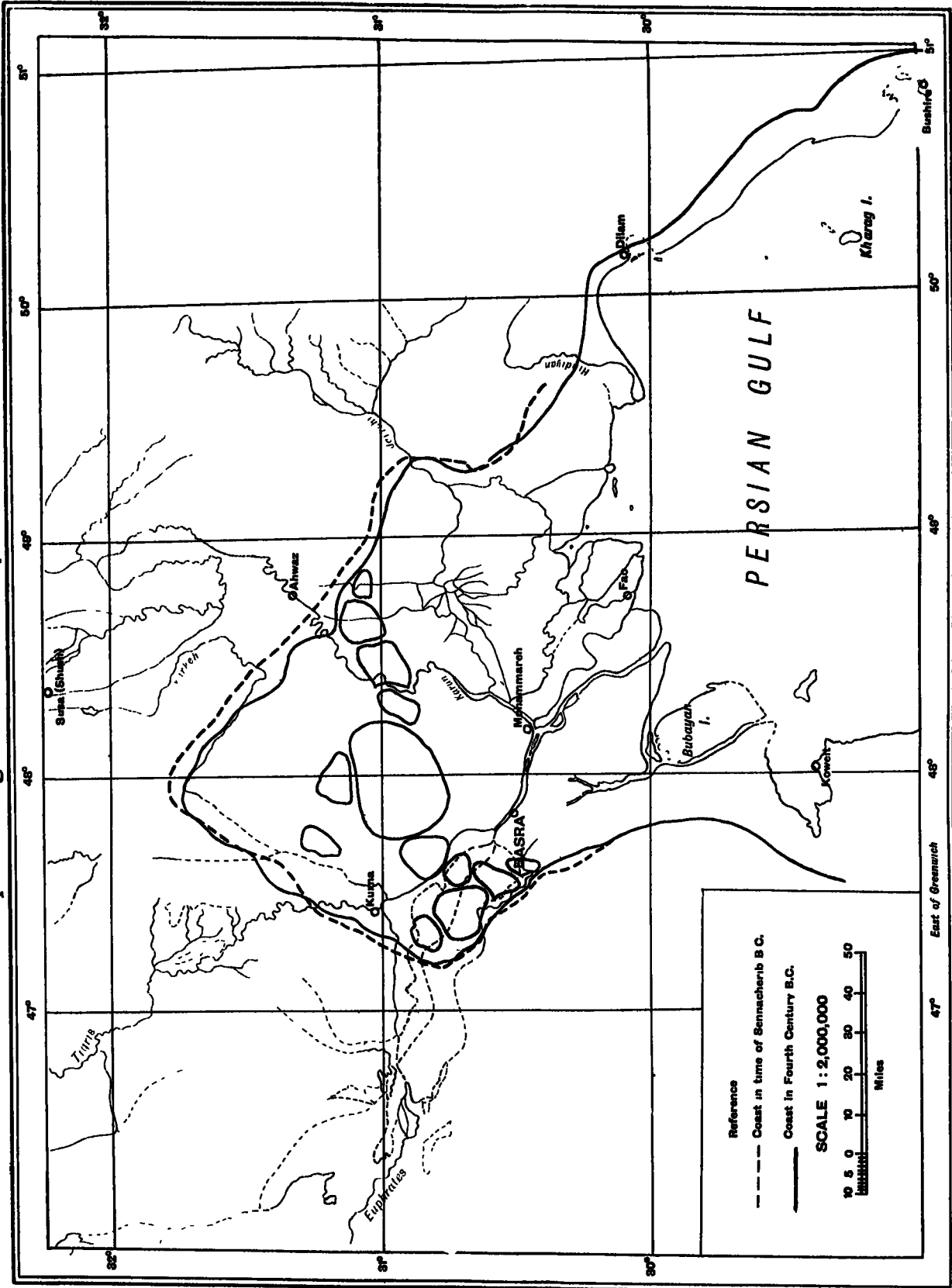
FIG(4.1)

Source: "Geology of Mesopotamia and its borderlands", compiled by the
geographical section of the naval intelligence division, naval
staff. Admiralty, HMSO, 1918.

Note· This is essentially the same as that produced by
Lees and Falcon,1952.

conditions. Woolley (1938) mentioned that advancing deposition had covered many cities of older civilizations; excavation at Ur showed that there is a bed of clay which separates implements and painted pottery of an old period from the more recent remains of Sumerian period. He attributed this deposit to the 'Deluge' which is correlated with the story of Noah in Sumerian history. Lloyd (1943), in recording the list of the Kings of Sumer and Akkad divided the chronology into two parts, before and after a great flood which occurred about 3,000 B.C. He also suggested that the shoreline before 4,000 B.C. was about 60 miles northwest of Baghdad, while in Sumerian times it was in the neighbourhood of Ur (Fig. 4.2).

Holmes (1944) and recently Sarnthein (1972) put forward a contradictory point of view stating that the northern shoreline of the Gulf had retreated northward, and that the basin of the Gulf was a dry land during the Pleistocene glacial epoch, but after the melting of the ice sheets, the water level rose and the sea advanced northward in the Gulf depression. In (1952) Lees and Falcon claimed that the picture is more complicated than the simple explanation presented by the archaeologists, and the head of the Gulf had never been northwest of its present limit since early Pliocene. They presented a geological point of view in which they showed that the area of the head of the Gulf is structurally unstable and that the dominant vertical movement is one of crustal subsidence. They also maintained that the continued existence of the marshes and lakes at the head of the Gulf resulted from tectonic movement since otherwise they would have been silted up; they stated "It is important that the events of the Recent history of the Mesopotamian plains should be understood, as the dominant motive is subsidence. It is not just that a static depression is being filled
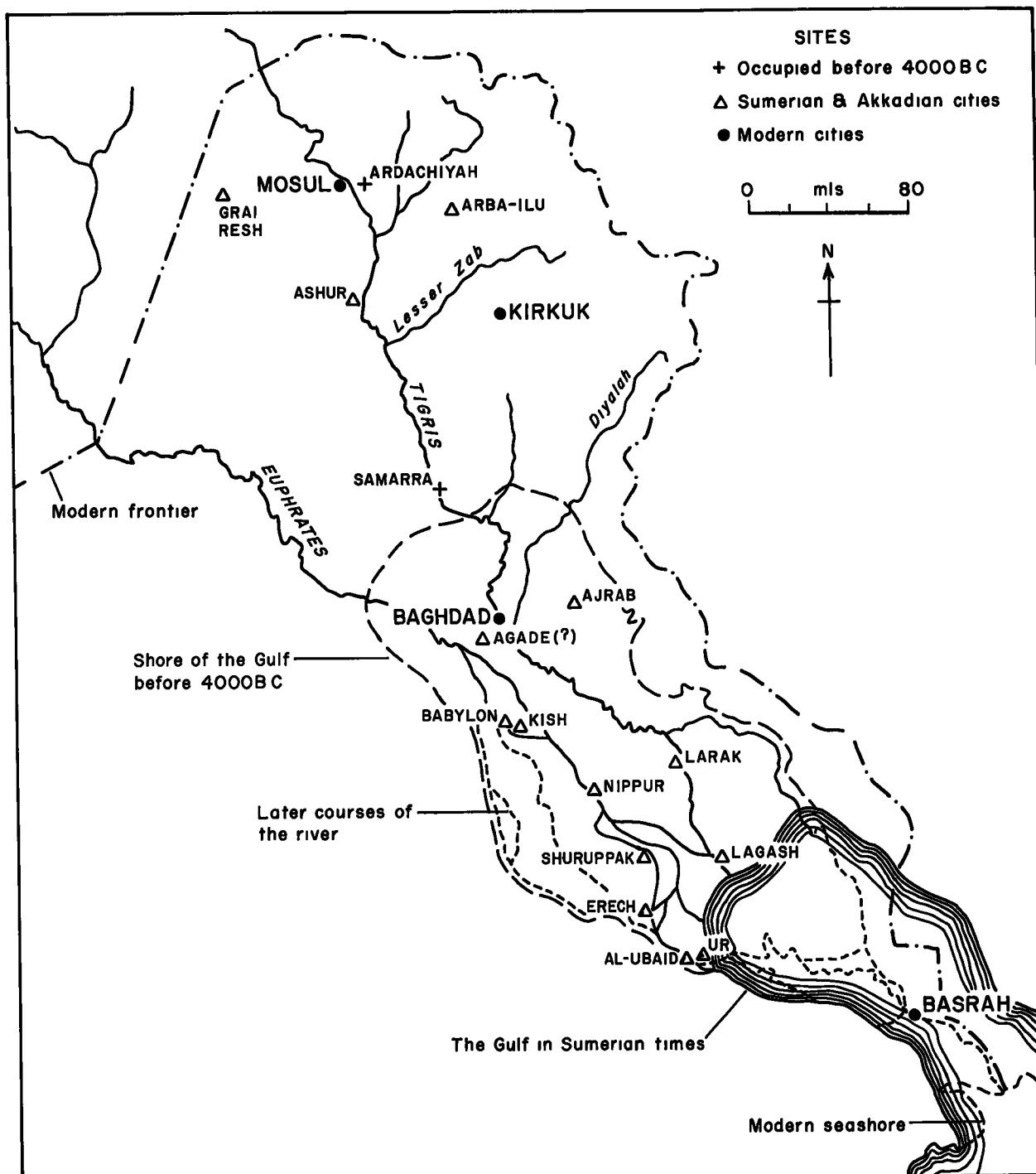
Fig(4.2)Changing shorelines at the head of the Arabian Gulf (From S Lloyd 1943)

by river sediments; it is the long continued subsidence which allows
the sedimentation to continue. In addition to the broad and dominant
downwarp there may also be local depressions caused by slight synclinal
movements between anticlines which are still being gently folded. The
geological evidence of the Recent history of the "Sunkland" of Iraq
would seem therefore to point to continuing depression, and this is
the simplest explanation of the extensive marshes". Lees & Falcon
(op.cit.) also maintained that the general rise of sea-level as a
result of glacial-eustatic movement had in all probability expanded
prior to the time of the earliest organised civilization in Iraq and
that the marine terraces in the areas surrounding the Gulf are related
to tectonic movements which are still active. The authors presented
a variety of evidence to demonstrate the tectonic movements during the
Recent times among which is the archaeological evidence from the old
site at Dar-i-Khazineh dated archaeologically between 3000-4000 B.C.
Lees & Falcon (1952) claimed that the site of Dar-i-Khazineh represents
a stand-still period of alluviation and occupation from 4,000 B.C. to
3,000 B.C. during which alluvium was built up. Between 3,000 B.C.
and probably the Sassanian period, it appears that the build up of
sediments was interrupted by an erosional event. The latter was
followed by deposition of coarse river gravels, sand and silt. These
fluvial deposits were overlain by 2 metres of silt which was laid down
into the Sassanian times. According to Lees & Falcon (op.cit) the
next great event occurred as a result of the rejuvenation of stream
erosion which caused the exposure of the Dar-i-Khazineh site. This
rejuvenation resulted from the renewed subsidence of the plain to the
southwest, or by a tilting of the hill country to the northeast or by
both reasons: Lees & Falcon (1952) also recorded that the Bubiyan

Island of Kuwait was affected by subsidence to the north and that this

is shown by the island's drainage trend towards the northwest and the

increasing area of land in the southern part of the island. These

geological points of view have been rejected by Ionides (1954) and Smith

(1954). More recently, Larsen (1975) has reexamined the Lees and Falcon

results (1952) in the light of more updated data about the area. He

argued that the alluviation of Dar-i-Khazineh, the stream erosion and the

drowned irrigation systems in the Khor Musa and Khor Zubair, do not indicate

such factors but have resulted from various environmental causes. These

variables include post-glacial sea-level movements and climatic changes as

well as hydrology. Larsen (1975) mentioned that as a result of post-

Pleistocene marine transgression of sea-level, stream erosion would be

replaced by alluviation. Accordingly, as the sea attained its present

level near 4000 - 3000 B.C., the streams would tend to alluviate and hence,

settlements in riverine of marsh environments before 4000 - 3000 B.C. would

at present be covered by alluvial sediments as in the case of Dar-i-Khazineh

site. The Holocene marine transgression sediments in the area are overlain

by 2 to 3 metres of alluvium which according to Larsen (op.cit) has resulted

from the advance of the Mesopotamian delta by 150 to 180 kilometres during

the last 5000 years. His conclusion indicates structural stability at the

head of the Gulf which disproves Lees and Falcon's (1952) results, but does

not disagree with the De Morgan (1900) view although a different interpretation

has been presented. Kassler (1973) has also considered the structural

stability of the Delta area of Tigris - Euphrates in discussing an unpublished

oil company report by V.S. Colter, and noted that the latter referred to the

subsidence of the Kuwait part of the delta by 37 metres during the last

5,000 years. Colter used as evidence for this the occurrence of dolomitic

muds in association with marine mud at -37 metres which he took to indicate

shallow water conditions. The C14 dating of *Oyster* shells from the marine

mud gave ages from 5080 to 5980 years old. However, Kassler (1973) rejected

Colter's evidence and maintained that not only is dolomitisation not
necessarily associated with shallow marine water conditions, but there is no
evidence of any occurrence of shallow-water sedimentary structures. On the
contrary, he believed that the Kuwait part of the delta is relatively stable.
Kassler has referred to a -16/-20 fm (-29/-37 m) marine platform which "has
been mapped" from offshore of Abu Dhabi to Kuwait, and held that this marine
platform is similar in depth to the more or less horizontal surface identified
by Colter at about -115 feet (35 m) on which deltaic sediments have been laid.
Kassler (op.cit) has suggested that the age of that surface is about 9,000 to
11,000 years BP.;, and that if this corresponds to the more extensive marine
platform which stretches to the south then, in general, stability characterised
the Holocene with some possibility of slight subsidence.

Working in the area between Tharthar-Habbaniya and Abu Dibis in
south Iraq, Mitchell (1957a) stated that there is evidence of some east-west
anticlinal structural movement in the area which has blocked the continuation
of an old drainage pattern. Mitchell (1958) concluded that the warping there
has attained values of 25 metres during Recent times and noted that there
are Recent marine fauna to be found near Najaf at heights of between 40.70
to 41.30 metres above present sea-level. The possibility of Recent movements
within the delta as well as the effect of changes in sea-level is strengthened
by such evidence, (Mitchell 1958).

2.3 Morphological studies of changing sea-level in the Gulf

Very little has been written about geomorphological research into
marine transgression in the Gulf, especially during the Pleistocene period.
Most of the research has been concerned with Holocene sedimentation in the
Gulf, and even then, there are large areas of the coast which have not yet
been investigated. However, there are scattered studies of marine terraces
and raised beaches along the Gulf coast and submarine platforms in the Gulf
itself. Lees (1928) writing about the physical geography of south-eastern

Arabia mentioned that he discovered "sub-Recent" marine shells on the west side of the Oman mountains at a height of 375 metres which have been uplifted by recent movements in the Oman mountain zone. He also found fragments of sub-Recent marine shells scattered on the surface of Wadi Hatta; the shells were in a similar state of preservation to those of the low sub-Recent raised beaches along the coast. The shells were at a height of 1045 feet (318.5 m) and contained *Venus* sp,*Turritella* sp, *Cerithium* sp, and *Dentalium* sp. Archaeological excavation in Hasa (Saudi Arabia) by Cornwall (1946) uncovered the remains of ruined and abandoned settlements such as Uqair; this was deserted for several reasons, according to Cornwall, among which was the recession of water level by 1.5 to 3 metres. South of Al-Khobar, he found remnants of elongated heaps of shells which contain *Pinctada margaritifera*. According to the evidence produced from these sites and from the pearling activity of the people living there, he came to the conclusion that those sites must represent old pearling camps, and the reason for the exposure of these heaps of shells is the recession of the sea-level of the Gulf. About 12 kilometres north of Umm ar Ruus, there are two parallel strips of habitation sites, one an old "mediaeval" field which has been partly buried by sand dunes, and a more recent settlement on the Gulf side. The distance between the two settlements is about 2.8 kilometres, the change of the settlement location (Cornwall, op.cit.) resulting from a gradual retreat of the shorelines which made the settlement's inhabitants move towards the new shoreline.

From the Makran Coast of Iran, Harrison (1941), Falcon (1947) as well as Vita Finzi (1975) referred to the river terraces and beaches which attain various levels as a result of uplift. Falcon (1947) mentioned that the uplifted raised beaches are at altitudes of 80-90, 30 and 15 metres above sea-level. However, Butzer (1958) suggested that the previous raised beaches were also affected by eustatic changes of sea-level; Butzer (op.cit) added a 60 metres level and suggested that the whole sequence then agrees

with the altimetric sequence from Sicilian to Monastirian. The same sequence occurs on Kharag Island, while the shorelines of 30 and 15 metres are found on Qishm Island and Bushire.

The result of dating two shells of the material from Makran Coast gave ages of 23,390 ± 400 BP and 25,610 ± 640 BP. The samples were collected from the beach at Jask and were at a height of about 8 metres above high water, but the result is believed to be contaminated by younger carbon (Vita Finzi 1975).

In 1872, Blanford indicated that the Persian coast of the strait of Hormuz was rising, while that of Arabia was sinking. The scientific expedition carried out in the Musandam peninsula by the Royal Geographical Society (Cornelius et al 1973; Falcon 1973; and Robinson and May 1974) as well as the expedition by the Royal Geographical Society/Imperial College of Science and Technology on the Makran Coast (Falcon 1975); and (Vita Finzi 1975) have confirmed the result obtained by Blanford 1872 and revealed new information about the Quaternary history of the areas. The Musandam expedition data which was collected from offshore hydrographic and geological work as well as from the alluvial stratigraphy, point out that the peninsula is tilting towards the northeast. The drowned valleys of the Musandam Peninsula indicate that the area is sinking towards the northeast, although the Oman mountains have been uplifted. According to Vita Finzi (1973), the vertical displacement appears to have exceeded 60 metres during the last 10,000 years. No raised beaches have been noticed in the Peninsula, but there are alluvial deposits which are well exposed and sufficiently a really constant to justify the formation of a generalised sequence called the Makhus formation. These deposits were formed about 35,000 years ago equating with the last marine regression. The Makhus deposits have been traced inside the Gulf as cemented wadi gravels which have been covered by the Flandrian transgression. It seems also that the Makhus alluvial deposits were deposited at the same time as that of the Tehran alluvail of Northern and Western Iran dated archaeologically between 36,000

and 7,000 years ago (Vita Finzi (1969).

The steps which sea-level followed to reach its present level since
the beginning of the Flandrian transgression have left their marks as submarine
platforms cut by still stands of rising sea-level; Houbolt (1957) recognised
four submarine terrace-like levels around the north and east of Qatar
peninsula. He called them: 1. The near-shore terrace, at a depth of-3.9
fathoms (5.5 - 16.5 m); 2. The first off-shore terrace at depth of 11-17
fathoms (20-31 m); 3. the second off-shore terrace at a depth of 17-28
fathoms (31-51 m) level, and 4. central Persian Gulf, which is the deepest
terrace at about 30-40 fathoms (55-73 m). All the terraces have slight dips
towards the axis of the Gulf deeps and are separated from each other by clear
zones of steep gradient towards the offset Gulf axis. According to Houbolt
(1957) these four terraces or levels, represent five stages of post-glacial
rise of sea-level. By comparing the values of the deepest terrace (40
fathoms or 73 metres) with estimates which have been made of the amount
of recession of sea-level during the Pleistocene, he came to the conclusion
that the area round Qatar peninsula and most parts of the Arabian Gulf were
above sea-level during periods of maximum glaciation and assumed that these
terraces resulted from eustatic changes of sea-level during the post-glacial
period. Radiocarbon dating of an age of 9,910+100 BP. has come from Fao in
Iraq and it is represented in a graph (Fig. 5) showing the eustatic rise
of sea-level during the last 14 thousand years BP., (Godwin et al 1958). The
sample is a freshwater detrital mud which represents an organic layer at a
depth of about 32 metres below sea-level, (Godwin and Willis 1959).

Possibilities of high stands of the sea in the Arabian Gulf in Pleistocene
times were noticed by Holm (1960). The highest sea-level implied a marine
transgression at the base of present east facing cliffs and wave cut benches
at an elevation of 150 metres. Sabkhahs as the same height were found inland,
which indicates that they may have been early embayments of the Gulf at that
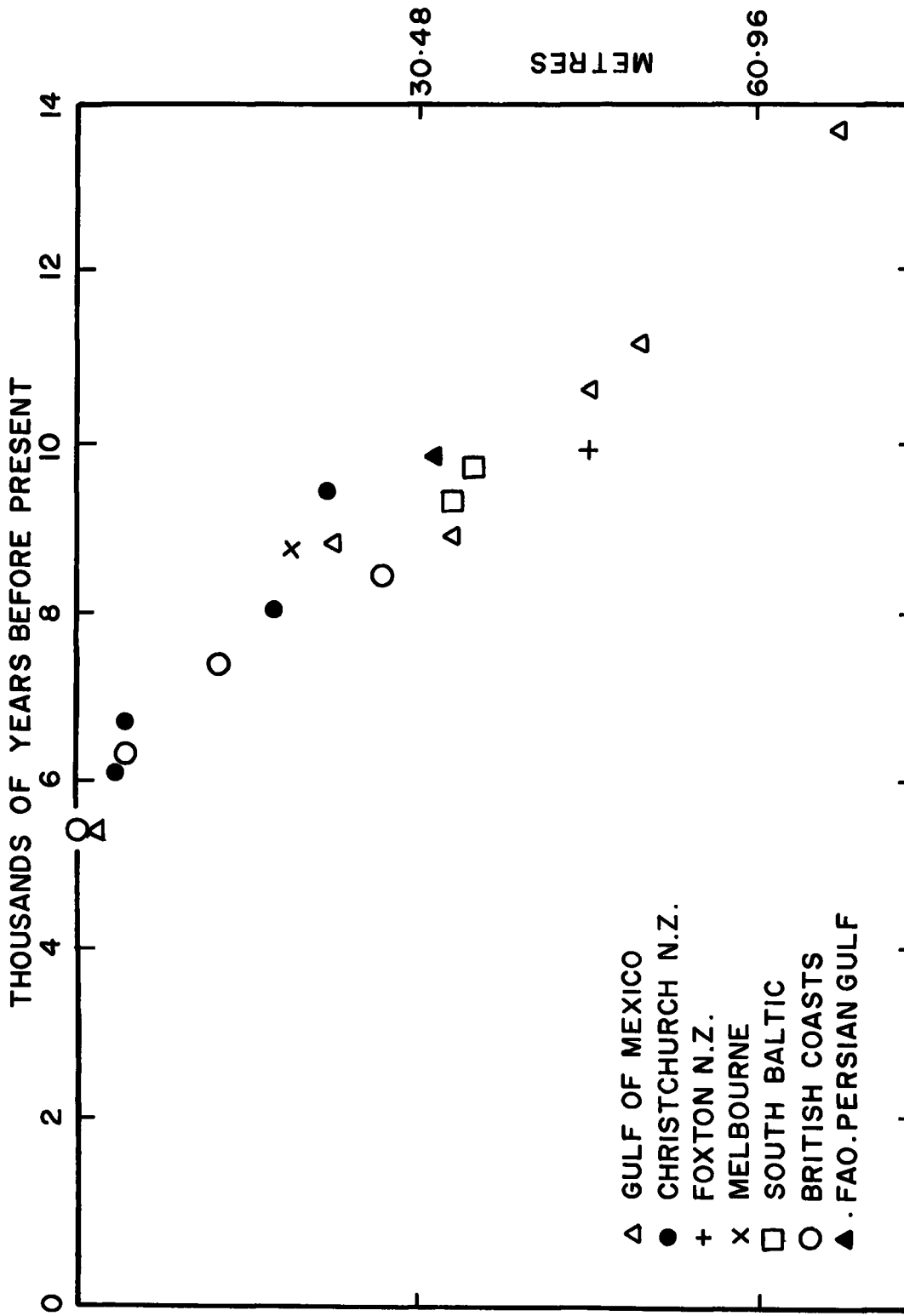
Fig-(5) Eustatic rise of ocean levels (from Godwin, Suggate & Willis 1958)

height. Glennie (1970) has also suggested that the inland Sabkha of Umm
as Samim in Oman, which stands at an elevation of less than 70 metres, may
represent a relict arm of the sea. Holm (1960) mentioned that there is
evidence of a low level shell bed at a height of 1.5 to 2 metres above sea
level along the coast between Ras al-Misha'ab and Salwah, and along the
Trucial Coast. Powers et al (1966) referred to marine transgression of
Pleistocene age and maintained that there are marine terraces which extend
along the coast of Saudi Arabia from north of Al Jubayl to southern Dawhat Salwah.
They are of sand and coquina and are found at heights of 1-2 metres above mean
high tide. Along Dawhat Salwah there are well preserved marine fossils existing
in soft pebbly sandstone and coquina of maximum thickness of about 3 metres.
Other Quaternary marine fossils are found about 3m below mean high tide of
Sabkhat Sawda Nahil. The possibility of a higher Pleistocene sea-level was
suggested by Kapel (1967) who referred to C14 dating of shells which gave
an age of $>$ 39,800 years old. The sample was collected from current
bedded formation of calcareous sandstone which occurs as raised beaches at a
height of about 25 to +30 metres. Voute (1957) mentioned the occurrence
of recent marine fauns on raised beaches of the Abu Dibbis depression in Iraq.
A high sea-level of about + 25 metres would be required to connect Abu Dibbis
with the sea (Larsen 1975). Radiocarbon dating of Sabkhah sediments in Abu
Dhabi revealed that the Sabkhah was formed during the past 7,000 years when
a marine transgression inundated the coastal area of Abu Dhabi where it reworked
the coastal sandstone and reached the level of about 1 metre above present sea
level sometime before 4,000 Years BP (Evans et al 1969). Taylor and Illing
(1969) mentioned that there are old strandlines in Qatar, these strandlines being
represented by cemented sands which stand at heights between 1.5 and 2.5 m.
above sea-level. The ages of the dated samples are 3,930±130, 4,200 ± 200
and 4,340 ± 180 years BP. In 1972, Sarnthein presented a study of the late
Pleistocene - Early Holocene transgression in the Gulf; he maintained that

during the last glacial period, the Shatt al-Arab reached the Shelf margin in the Gulf of Oman which today stands at -110 metres. Holding that throughout the Holocene the Gulf was not affected severely by tectonic movements, he supported his claim by referring to the several level surfaces at different depths which he believed to represent still-stand transgressions. The depth of these surfaces are -64/-61 m, - 53/-40m and about -30 metres. Kassler (1973) quoting an unpublished oil company report written by W.A.C. Russell, mentioned that Quaternary raised beaches are found on many islands of the Gulf. They are at a height of +60 metres on Das Island, at + 45 metres on Zirko and at + 18 metres on Ardhana and Qarnain Islands. He also referred to six submarine platforms of post-glacial age which occurred as a result of stillstands of rising sea-level. These platforms are mainly found in the Arabian parts of the Gulf : 1. -62 fm (-120m); 2. -55 fm (-100m); 3. -36 /-44 fm (-66-80m); 4. -16/-20 fm (-29/-37m); 5. -10 fm (-18m); 6. - 5 fm (-9m). Kassler (1973) indicated that at present, both the northeast of the Gulf of Oman and the Arabian Gulf are tectonically stable. He built his suggestion on the occurrence and constancy of two submarine platoforms at depths of -62 fm (-120 m) and -55 fm (-100 m). The first platform occurs in both the Gulf of Oman and the Strait of Hormuz, while the other one occurs in the Gulf of Oman and the Arabian Gulf.

The picture which appears from these studies is one of continued disagreement concerning the relative importance of the main dominant processes affecting the physiography but it is possible to conclude that during different periods of the Pleistocene and Holocene the two main forces, eustatic sea-level changes and structural instability, including isostatic changes were variously balanced in different areas of the Gulf. One is therefore faced with a regionally varied and complex geomorphological history which can only be further elucidated by further detailed studies.

CHAPTER 3

GEOLOGY AND PHYSICAL GEOGRAPHY OF KUWAIT

Kuwait is situated at the northwestern part of the Arabian Gulf and lies between latitudes $28^{\circ}30'$ and $30^{\circ}5'$ north and between longitudes $46^{\circ}30'$ and $48^{\circ}30'$. Kuwait is bordered on the north and west by Iraq, by Saudi Arabia in the south west and south and by the Arabian Gulf in the east, and there are several islands belonging to Kuwait, the largest of which is Bubiyan Island, in the north.

Summer in Kuwait is very hot with an absolute maximum of $49^{\circ}C$ and cold in winter with an absolute minimum temperature of $-3^{\circ}C$. the mean temperature in July is $37^{\circ}C$ and $13^{\circ}C$ in January. The prevailing wind is NNW by west followed by SSE by east. Dust storms laden with very fine sand often occur there, frequently in spring and summer. Rainfall is generally variable, falling between November and April. Meteorological reports covering the period 1955-67 (Directorate General of Civil Aviation), show that the annual rainfall never exceeded 195.8 mm.

3.1 Geology

Kuwait is situated at the border of the Tigris-Euphrates sedimentary basin and at the edge of the Arabian foreland, precisely the most unstable part of the Arabian Shelf; Mitchell (1957b); Powers et.al (1966). The Arabian Shelf represents the northeastern part of the Shield which has been slightly tilted northeast towards the Tethys trough, allowing marine transgressions across the tilted area which buried the crystalline rocks beneath with relatively horizontal sediments. This region has gentle deformations but according to Milton (1967) the general dip in Kuwait towards the northeast is about 9 feet per mile. Higginbottom (1954), indicated that there is a slight northerly dip along the Jal-Az-Zor escarpment which accords with the evidence of subsidence at Zubair and the north end of Bubiyan Island. He also

mentioned that there is an indication of an uplift of the whole

northern shore of the Bay as there are recent marine shells on

the surface of terrace-like features at the foot of the escarpment,

although aerial photographs which have been taken at intervals over

a number of years showed that the tendency of the uplift is at

present reversed and the sea is slowly advancing (Higginbottom 1954).

A local structure of note is the Bahra Anticline, which Cox and Rhoades

(1935) describe as a symmetrical, plunging anticline exposed only in

its northern parts, (Fig. 6)

The tectonic history of Kuwait shows that from the Cambrian to

Middle Cretaceous times it was exposed to a steady downwarping which

gave way to the accumulation of sediments. That was followed by

uplift movement, then renewed general subsidence during the upper

Cretaceous and the Eocene with the main structures steadily rising

relative to their surroundings (Fox, 1959). The Zagros orogeny in

Persia had small-scale effects on Kuwait, limited to gentle folds

superimposed upon earlier uplifts occurring since upper Cretaceous

time.

Local interruptions of the general northeastern gradient of

the sediments are not obvious except along the coastline zone. The

features in that zone can be attributed not only to structural move-

ments of Tertiary-Quaternary origin, but also to the rejuvenation

of the older structural elements probably of the Mesozoic period.

Evidence from seismic, aeromagnetic and gravity surveys has served

to identify a fundamental lineation in basement rocks below Kuwait.

The structure termed the Kuwait Arch has a N-S orientation and extends

from the Wafra area in the south of Kuwait to at least as far north

as the Zubair area in southern Iraq. It has exerted the predominant

influence upon Mesozoic folding and upon contemporaneous and subsequent

sedimentation patterns in the area. Isopach maps of post-Cenomanian

Fig.(6) APPROXIMATE LOCATION OF BAHRA ANTICLINE

0   km   10

N

— — — Anticline

Khor Al-Sabbiyah

●Al-Bahra

●Mudairah

29°
30'

KUWAIT   BAY

●Ghidhai

●Kathma

After Cox and Rhoades
1935; and Moody 1947

47°45'   48°
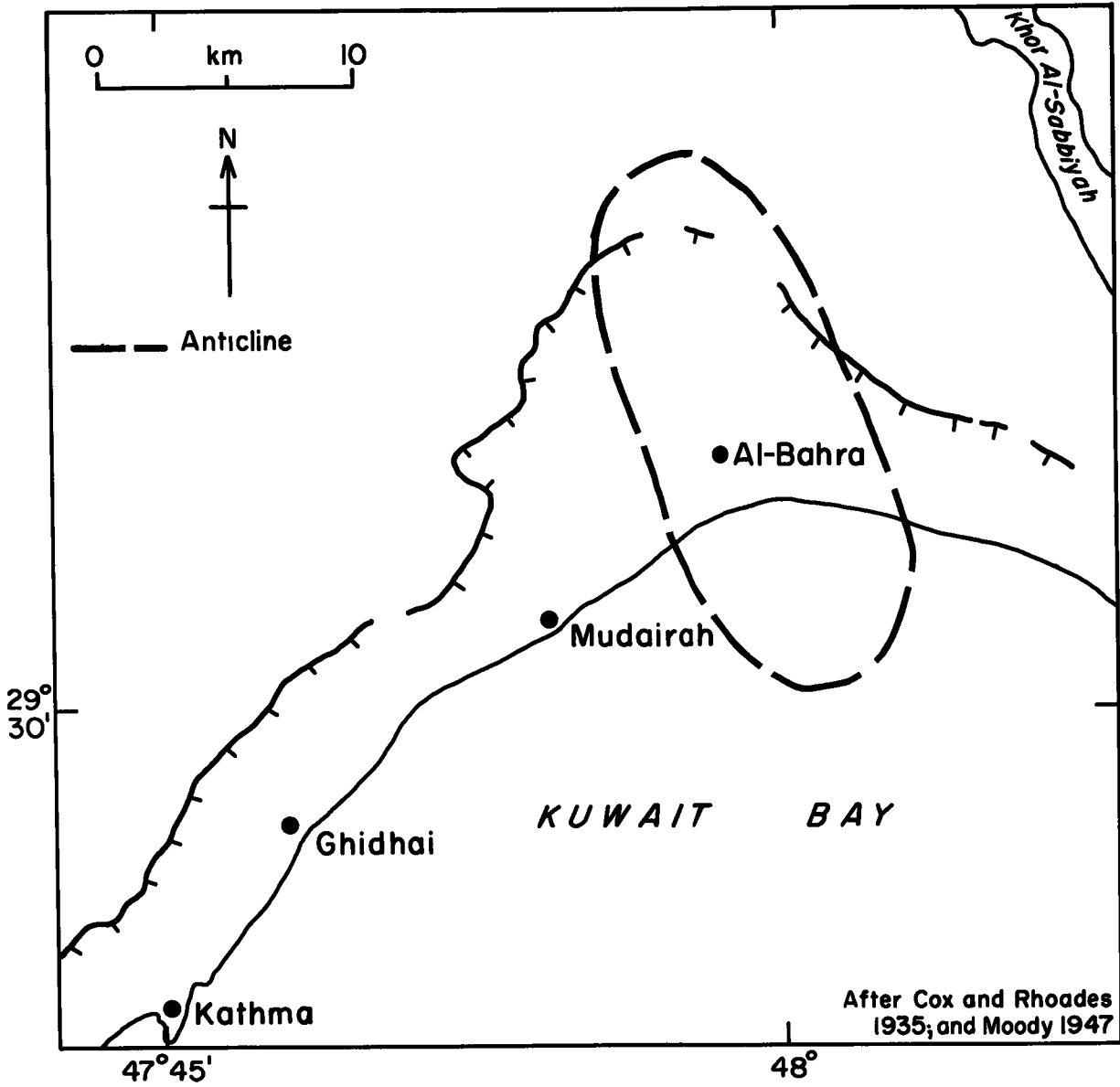
stratigraphic units show the evidence of continental growth beyond the Mesozoic and possibly throughout the Cainozoic (Davies C.C.S., personal communication). Several features are found related to the "Kuwait Arch" as in the gentle arching within Jal-Az-Zor escarpment and the remnant surface heights of the Burgan Hills and the elevated areas of Magwa field. Moody (1947) noted that it is possible that the Kuwait Arch continues into Saudi Arabia and that in the Kuwait area at least it is still undergoing uplift at the present time.

According to Milton (1967), the Ahmadi Ridge is related to the Zagros orogeny of post-Eocene times and appears to have resulted from horizontal compression, while the growth of structures such as Umm Gadir, Manageesh and Raudhatain is the result of vertical movement which has been growing since at least the Middle Cretaceous and are possibly as old as the late Jurassic. It is also possible that the axis of the Ahmadi fold continues under the Bay of Kuwait and is responsible for the change of the Jal-Az-Zor escarpment's direction behind Al-Bahra and for the elevated area at Al-Rakham (Higginbottom 1954). Fox (1959) mentioned that the Burgan and Magwa features are uplift features of salt intrusion. This phenomenon of salt purges is common in the surrounding areas, the nearest being Jabal Sanam, south of Iraq. The origin of the Jal-Az-Zor escarpment has not been definitely decided. However, Owen and Nasr (1958), and Fuchs et al (1968), related it to faulting origin with some kind of relationship with the Wadi Al-Musannat in the southwest of the country, disagreeing with Milton (1967) who described the Jal-Az+Zor escarpment as being possibly an erosional feature because no indication for a tectonic origin has been discovered in oil wells in the Al-Bahra area.

The phenomenon of the raised beaches which appears in Mina Sa'ud

and Ras al-Jlay'ah in the south but dies away towards Salimiyah, and
similarly occurs between the Sabbiyah promontary and the head of the
Khor Al-Sabbiyah has been interpreted by C.C.S. Davies (personal
communication) to have resulted from the progressive tilting of the
surface towards the north, with the southern sector acting indepen-
dently from the northern, and separated by an ENE-WSE line of dis-
continuity in Kuwait Bay (Fig. 7). The line of separation between
the two blocks is believed to be a right-lateral transcurrent fault
in the Pre-Cambrian, striking NE-SW and generated at the time of the
Zagros folding as a result of the arcuate drift of Arabia away from
the African continent. However, he mentioned that there is no con-
firmation of its existence in the geophysical survey results and the
only indirect evidence for its position can be offered from considera-
ation of possible surface effects. Accordingly, Davies thinks that
the Jal-Az-Zor escarpment originated as a flexure in cover rocks
overlying the basement fault which has subsequently been cut by the
joint action of fluviatile and the marine erosions with the latter
post-dating the former and becoming the main influence agent.
River channels extended in an almost straight line along this flexure
over a distance of several hundred kilometers and flowed northeastward
from the Arabian Highlands into the direction of southern Kuwait. The
previous characteristics indicate control by a fundamental structure
lineation with surface expression and a flexure which has provided the
appropriate control. The distribution of the gravel trains west of
Kuwait suggests that they represent several stages in stream migration
from an original Musannat-Kuwait Bay flow to the more recently developed
channel of the Wadi Al-Batin   (C.C.S. Davies),

Fig.(7) RELATIONSHIP OF SURFACE DRAINAGE TO TERTIARY TECTONICS

After C C S Davies (personal communication)
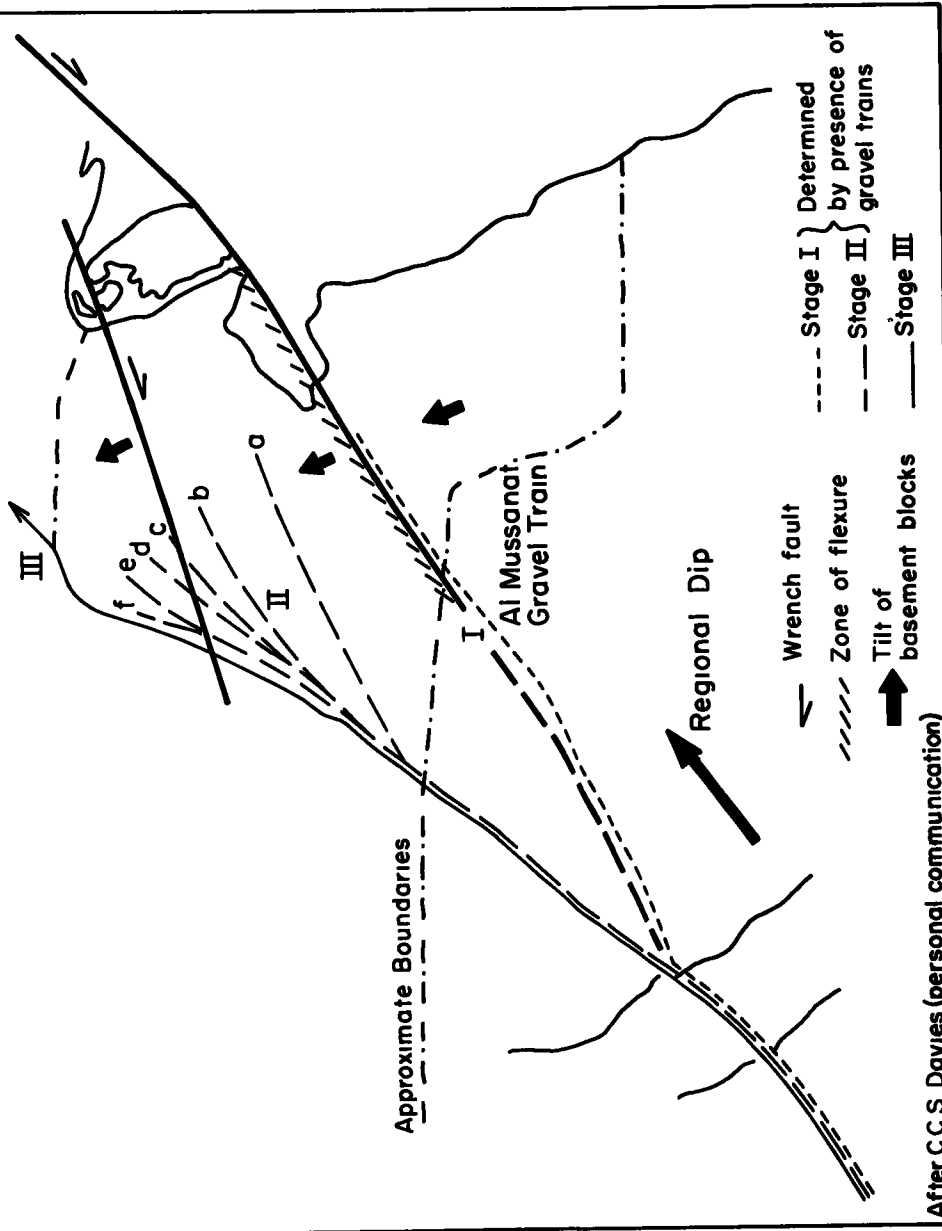
Stratigraphy of surface deposits (Figs. 8 and 9)

The surface of Kuwait is formed of sedimentary rocks and sediments of Middle Eocene to present age (Fuchs et al 1968). The very slight dip and the lithological similarity of most of the sedimentary strata together with the lack of fossil evidence, make correlation of formations difficult. It is only along some parts of the Jal-Az-Zor escarpment that three formations can be distinguished because of the presence of the fossiliferous Lower Fars Formation.

Fuchs et al (1968) have provided the most recent classification of the surface rocks in Kuwait, a classification which is largely followed in this study.

Dammam Formation (Middle Eocene)

This is the oldest sedimentary rock exposed in Kuwait. Parsons (1963), quoted by Fuchs et al (1968), recorded that the highest point of the top of this formation was encountered at a depth of about 80 metres southwest of Kuwait. The formation has a gradual dip towards the north and northeast except for the slight interruption by local structures. It appears at a depth of about 400 metres at Raudhatian. The approximate thickness of the Dammam formation is 200 metres. Parsons (1963) divided the formation into three parts according to lithological criteria, from top to bottom.

1. Lower Dammam (Group 3)

    Shelly, chalky to granular porous limestone with hard siliceous cherty limestone on top

2. Middle Dammam (Group 2)

    Composed of chalky, locally shelly limestone with thin siliceous cherty limestone at the top and siliceous limestone with sand beds at base.

Fig.(8)GEOLOGY OF KUWAIT

Source-Geologic Map of Arabian Peninsula(U.S. Geological Survey 1963)
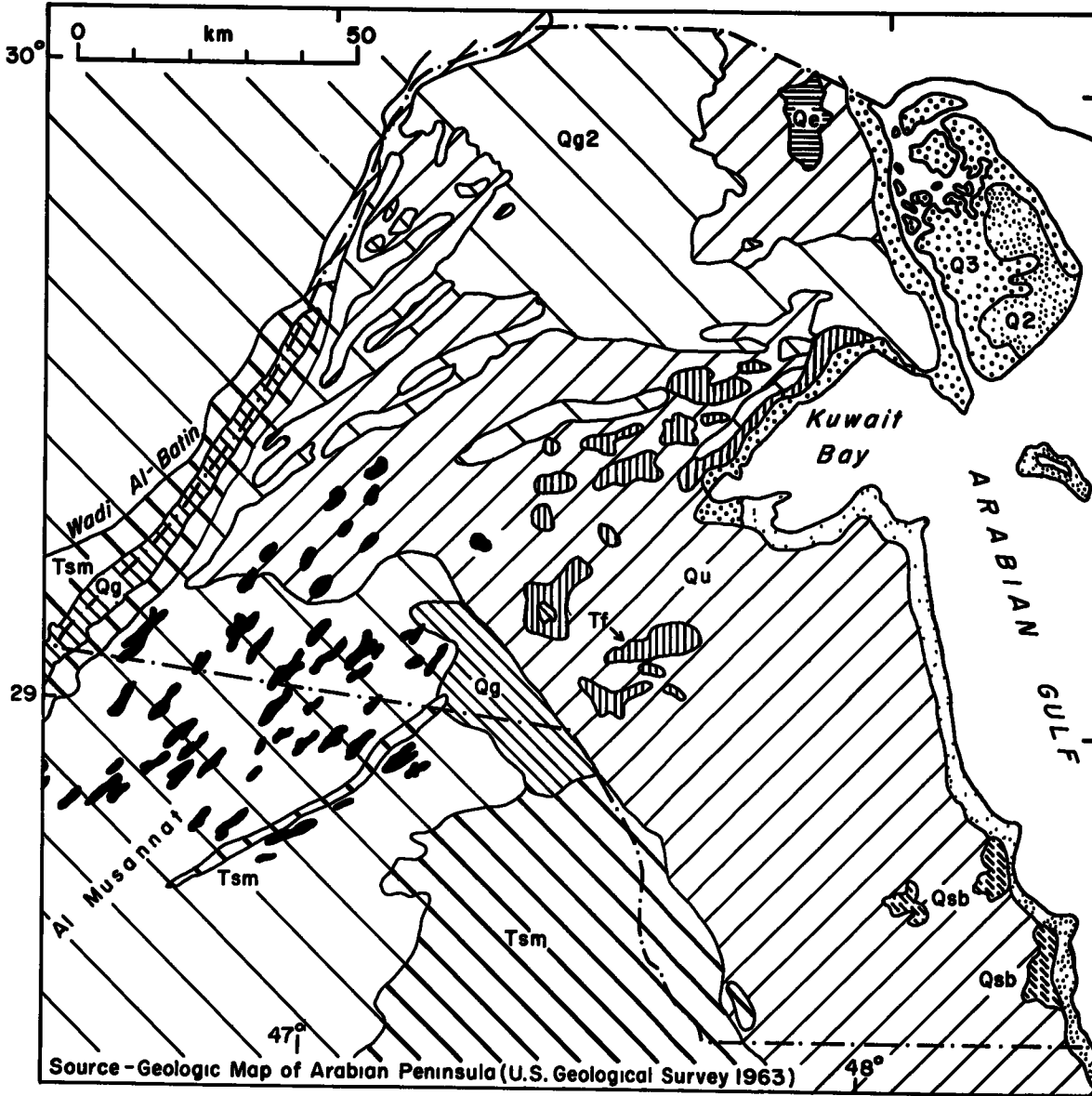
QUATERNARY

Qe Eolian sand

Qsb Sabkhah deposits

Qs / Qg Qu Gravel, sand and silt

Qg2 Gravel

Q2 / Q3 Terrace and mud flat deposits

TERTIARY (Miocene and Pliocene)

Tsm Sandstone, marl and limestone

Tf Lower fars formation

3. Upper Dammam (Group 1)

Dense dolomitic limestone, with a lower fossiliferous dolomitic

limestone, thin and green shale beds at base.

According to Fuchs et al (1968), this subdivision of the formation

makes it possible to recognise the intensity of erosion which took

place from late Eocene to probably early Oligocene times.

Ghar and Lower Fars Formation (Oligocene? to Lower Miocene)

Ghar Formation II

This formation is easy to identify especially in the Jal-Az-Zor

escarpment because of the overlying fossiliferous Lower Fars Formation.

The Ghar formation is composed of coarse-grained, pebbly, current

sandstones with intercalation of sandy limestone and marls.

According to Owen and Nasr (1958), there is a close similarity

between this clastic formation and the overlying clastic Dibdibba

Formation. In case of the absence of the middle fossiliferous bed

of Lower Fars Formation, reference to all three formations is included

in the so-called "Kuwait-Group".

Lower Fars Formation I
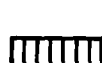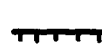
A fossiliferous unit overlying Ghar Formation. According to Cox

and Rhoades 1935, this formation outcrops in the Jal-Az-Zor escarpment

area as a 38 metres thick unit. The formation consists of alternating

red and yellow sandstone, red and green clays and various intermediate

clay sandstones and silt clays. Small *Lamellibranchs* is probably the

most abundantly represented fossil in the formation and found either

alone or associated with other fossils such as *Ostrea Vestita, Ostrea*

Latimarginata, Turritella sp., *Lucina* sp., and *Balanus* sp.

Zahra Formation (Miocene - Pliocene)

This formation consists of sandy limestone often showing the

Fig.(9) GEOLOGY OF THE RESEARCH AND ADJACENT AREAS
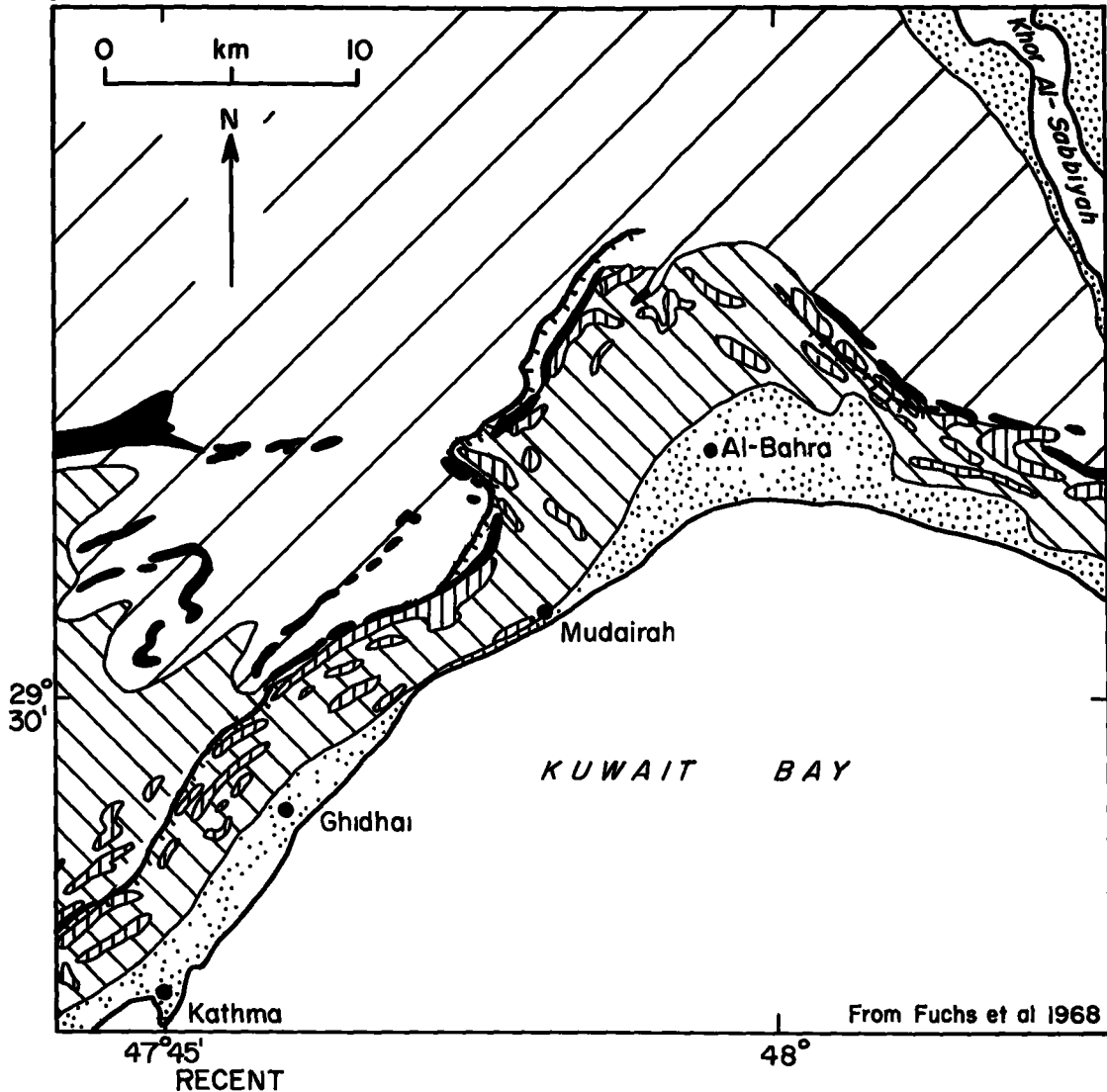
RECENT

Beach sand, marshes

NEOGENE-PLEISTOCENE

Gravel capped ridges, relics of a former extensive fluvial gravel blanket Components of igneous, metamorphic and sedimentary origin

'Dibdibba formation', gravel and sand, medium to coarse, occasionally cemented, calcareous and gypsiferous

NEOGENE EXPOSED

Medium grained to conglomeratic sands and sandstones, calcareous or quartzose, occasionally cross-bedded, partly fossiliferous, marly limestone; variegated shales

NEOGENE CONCEALED

'Kuwait group', medium to coarse, calcareous-gypsiferous sand and sandstone with subordinate pebbles

Jal-Az-Zor escarpment

remains of freshwater fossils. Examples of this formation can be seen

especially in the southern area of Kuwait such as Wara Hill and Burgan

Hills. Lithological comparison of their fossil content with those of

Zahra Formation in southwestern Iraq revealed a close relationship

between them.

Dibdibba Formation (Pleistocene)

According to Fuchs et al (1968), the formation consists of a

fluviatile sequence of ungraded, often cross-bedded sands and gravels

with subordinate intercalations of layers such as Lenticular bodies of

sandy clays. The sediments are locally cemented by lime such as gypsum.

Fuchs et al (1968) suggested two different sedimentary cycles: the

first and older cycle which consists of all deposits older than Dibdibba

Formation is characterised by a uniformly heavy-mineral association

(predominantly Zircon). The second and younger cycle, to which belong

the sands and gravels of the Dibdibba Formation, shows different and

varied assemblage of heavy minerals such as garnet, pyroxene, amphiboles

and epidote. The Dibdibba Formation has been deposited over the area by

powerful rivers during the Pleistocene, and the source of most of the

gravel material may have been the large volcanic flows of Syria and

northern Arabia of Pliocene and Pleistocene age, according to Fuchs et al,

(op.cit). Also during many of the glacial periods of Europe, this part

of the world was experiencing pluvial periods during which streams from

the western mountains, fed by considerable precipitation, carried their

loads and deposited them over this part of the Arabian Peninsula.

Other Pleistocene deposits of fine-grained thin-bedded, partly

cross-bedded, oolitic limestones of a thickness of up to 10 metres,

form the low but steep coastline south of Kuwait Bay, the spur of Ras

Ashairij and the small island of Umm Al-Nemel. This sediment frequently

changes laterally and vertically into fine-to coarse-grained unbedded

to indistinctly or well-to cross-bedded local firmly cemented quartz

sandstone with a varying content of oolitic grains and of sporadically

reworked reddish-brown clay balls (Fuchs et al, op.cit.). They

commonly contain relics of molluscs which correspond to recent shells.

Recent Deposits

These are composed of deltaic and tidal mudflats, and are found

around the north shore of Kuwait Bay, along the northeast coast of

Kuwait and Bubiyan Island. According to Milton (1967), these deposits

are composed of plastic clay and silt having a high saline content. The

material is considered to be of deltaic origin from the Tigris-Euphrates

river system.

"Coral rocks", which are composed of stratified, porous, often

poorly consolidated calcareous sandstones with a varying content of

fossils are found in the tidal zone of the southern edge of the Bay

of Kuwait and around the isles. Reworked reef material, comprised of

organic debris and high-quartz sand, firmly cemented, surround the

small isles of Kubbar and Umm Al-Maradim, (Fuchs et al .1968)).

Playas, represented by a thin sheet of silty clays, cover the bottom

of small shallow basins in the interior of Kuwait. Windblown deposits

are found covering wide areas of the state. Salty marshlands (sabkha)

extend along the southern coast, and the northern shore of Kuwait bay.

3.2 Topography (Fig. 10)

Apart from the Wadi Al-Batin, Jal-Az-Zor escarpment and the Ahmadi

Ridge, Kuwait generally has a gentle surface and the altitude rises from

sea-level in the east to about 300 metres in the southwestern part of

the country. The greater part of Kuwait and especially the north and

Fig (10) TOPOGRAPHY OF KUWAIT
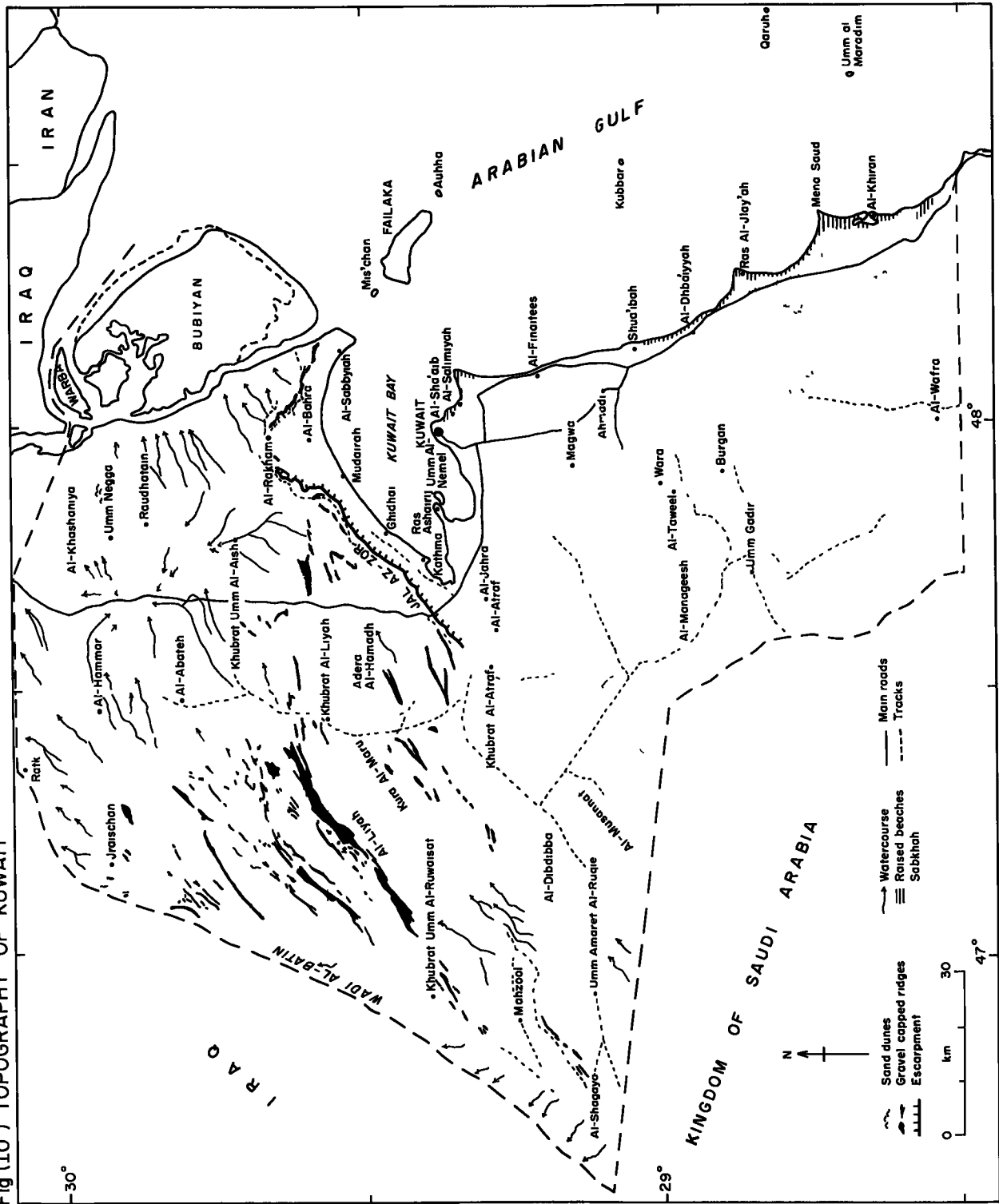
Based on several sources

west part of the country is covered by sand and gravels. According to

Fuchs et al (1968) northern and southwestern Kuwait represents parts of

a wide pediment formed during Pleistocene times by rivers or sheet floods.

Holm (1960) stated that the Rimah-Batin Wadi System was one of active

surface water action during the pluvial periods of the Pleistocene. It

carried its debris, which was composed of igneous, metamorphic and

sedimentary rocks eroded from the crystalline uplands and sedimentary

steppes of north Najd, and spread it towards the northeast of the

Arabian peninsula as a coastal plain called ad-Dibdibba. The wadi

Al-Batin forms a conspicuous negative feature extending along the west

border of Kuwait. It has a SSW to NNE direction of about 150 km in

length. According to Cox and Rhoades (1935), the wadi Al-Batin feature

is the result of stream erosion, the course of which was no doubt con-

trolled by a tectonic line of unknown character. Owen and Nasr (1958)

mentioned that it may be due to subsidence recurring along a northeast-

southwest, deep-seated line of faulting. Al-Batin and Al-Musannat wadis

are both thought by Fuchs et al (1968) to represent old tectonic lines.

The width of wadi Al-Batin varies from (6.4) kilometres at Hafar to about

(3.2)kilometres at Riqat (ar Ruqi) but it is very broad and shallow at

Ratk near its end. However, Higginbottom (1954) suggested that Wadi

Al-Batin is constructed near its downstream end at Jraischan and widens

towards its upstream. Also the numerous depressions around there tend

to converge and meet at Mahzool. The conclusion he came to is that the

former drainage of wadi Al-Batin was of southwestern direction towards

the Arabian interior, but as a result of the geosynclinal subsidence

around the Zubair area, the drainage pattern had become reversed. West

of Kuwait the plain is dissected by northeastern parallel elongated

depressions, separated by gravel capped ridges and holding some vegeta-

tion for some parts of the year. The northern and northwestern parts

of the country are covered by drainage systems of different sizes and

patterns. Khalaf (1969) mentioned that their patterns range from long

Wadis as in the Raudhatain Al-Abateh and Al-Hammar-Liyah areas to those

small in size as in Al-Sabbiyah area. There are dendritic drainage

patterns in the gravelly areas such as in Raudhatain - Al-Abateh and

Al-Shagaya areas. Parallel and subparallel drainage patterns are

found in the Hammar-Liyah area, and pinnate drainage in Sabbiyah

towards Khor Al-Sabbiyah. There are no true sand-dunes in Kuwait

except in the area between Al-Kashaniyah and Umm Negga in the north.

The height of these crescent dunes is about 25 metres.

One of the most conspicuous features in Kuwait is the Jal-Az-Zor

escarpment which extends north of Kuwait Bay for a distance of about

65 km, with a maximum height of about 145 metres. From Al-Atraf, the

escarpment follows a northeastern direction, until near Al-Bahra where

it changes its course and swings to the southeast. According to Fuchs

et al (1968), there are several terraces developed at the foot of the

escarpment reflecting the sea-level changes during the Pleistocene

period. Behind the escarpment the surface slopes gently towards the

north. West of Jal-Az-Zor there are several gentle ridges such as

Kura Al-Maru and Al-Liyah. They tend to take a north-eastern direction

and usually are dissected by depressions. Numerous depressions which

are usually called "Khubrah" or "Themaila" are distributed over Kuwait,

e.g. Umm Gadir, Umm Al-Aish, Umm Amaret Al-Ruqie, Al-Atraf, Umm Al-Ruwaisat.

The southern part of the country is generally featureless except

for some depressions or hills and the conspicuous feature is the Ahmadi

ridge which has an elevation of about 137 metres. It lies about 8 km

inland, with both the east and west slopes being very gentle. The ridge

separates the coastal plain from the plain of Burgan and it is related

to the Zagros orogeny of Post-Eocene times. Apart from the Ahmadi ridge

there are the conical hills of Wara with a local relief of about

30 metres and the Burgan with a height of about 46 metres.

3.3 General remarks on the coastal geomorphology

The coast of Kuwait is generally of low-land type with conspicuous features of low character which are partly covered during tidal flow e.g. the north coast of Kuwait Bay especially around Al-Bahra. It is also characterised by the presence of numerous coves extending along the southern coast of Kuwait Bay. Parallel to the coast there are several islands extending from Warba in the extreme north to Bubiyan, Mis'chan, Failaka, Auha, Umm Al-Nemel, Kubbar, Qaruh and Umm Al-Maradim. The first two islands are greatly affected by the sediments brought down by the Tigris-Euphrates river system. The north part of Bubiyan island has a northern dip towards the north and accords with the general sub-sidence at Zubair area (Lees and Falcon 1952), while the southern part of the island is characterised by a system of strand-lines which may represent a storm beach. Extensive deltaic mudflats of sandy and silty clay deposits spread across the northeast coast. Perry and Al-Refai (1957) mention that the 6 metres of uplifted cliffs at Ras Al-Jlay'ah on the southeast coast of Kuwait are formed of oolitic sandstone; they also claim that this deposit, as well as containing fossils of Recent age, is similar to the deposits which extend along the Saudi Arabian coast in the south, suggesting eustatic lowering of the shore-line. Fuchs et al (1968) referred to the Pleistocene deposit which consists of fine grained thin-bedded partly cross-bedded oolitic limestone of a thickness of up to 10 metres; it spreads south of Kuwait Bay, the spur of Ras Ashairij and Umm Al-Nemel island. The deposit often changes laterally and vertically into fine-to coarse-grained unbedded to indistinctly or well-to cross-bedded firmly cemented quartz sand-

stones with varying amounts of oolitic grains. According to Milton (1967), these sediments are of recent deposition. Examples of these formations have been noted by the author on the southern coast near Al-Dhba'iyyah and around Al-Jlay'ah at a height of about 5 m above Kuwait land chart datum. The deposit often contains relics of recent shells. Higginbottom (1954) mentioned that there are recent marine deposits which include shelly sands and other deposits, often with calcareous cementing agent. The deposits extend along the southern coast of Kuwait Bay and continue south of Kuwait territory along the coast of the Arabian Gulf. More recently, Khalaf (1969) mentioned that the calcareous sandstone has a thickness which varies from a few centimetres at Al-Sabbiyah to about 4 metres at Ras-Ashairij, and merely consists of oolitic limestone with some shell fragments at Al-Khiran. According to Khalaf (op.cit) these rocks contain fragments of shells which are similar to those in recent beach sediments and hence he considered them to be Recent marine "terrace" deposits. An extension of this marine terrace has been noticed during the fieldwork in Al-Sha'aib area, although it has no lateral continuation with that mentioned by Khalaf (1969) in Al-Salimiyah because most of the sands of this part of the coast have been used by the inhabitants for building purposes. The north shore of the Bay is low and covered by marshland.

Little else is factually available concerning the geomorphology and terrain characteristics of Kuwait. It is in the context of the data which are available and which has been presented in Chapters 2 and 3 that we shall consider the specific research work carried out in Kuwait.

CHAPTER 4

Methods

Three methods were used to carry out the present work;

1) The survey of morphological features including precise levelling.

2) The radio-carbon dating of shells.

3) The analysis of sediments by particle size analysis and scanning

electron microscope.

It was decided to apply these methods in order to help in correlating

the field data. The reasons for the choices of methods are examined below.

Besides these methods, topographic maps (scales 250,000 and 100,000) and

aerial photographs were consulted.

4.1 Levelling

Surveying is an important technique in the study of raised beaches

and the present survey was carried out for the following purposes:-

1. To trace and determine the number of the terraces around the north coast

of Kuwait Bay, between Kathma in the west and Al-Bahra in the east.

2. Measure their height above Kuwait Land Chart Datum.

3. Elucidate the tectonic history of the area and to find out whether or

not these terraces are horizontally warped, and if they are warped, by how

much and in which direction.

4. To reveal any relationships, if they exist, between the present area of

research and the Mesopotamia area.

First, the choice had to be made of the position and alignment of

the transect lines. A reconnaissance was made of the Kuwait coastline in

order to identify significant stretches of coastal zone in which, as noted

on page (1) , there was little or no human disturbance of materials and slopes.

The research area was the only such zone existing and it also had the positive

advantage of possessing the largest height amplitude over relatively short

distances - up to about 145 metres amplitude over 3 to 5 kilometres. In this

area, four trigonometrical stations had been established before 1961 by the

Kuwait Oil Company with reference to the Admiralty Chart Datum and located on the top of the escarpment.

At the request of the author and the Botany Department of the University of Kuwait, the Kuwait Municipality established two temporary bench marks by reference to a K.O.C. trigonometric station or bench mark. The temporary bench mark at Mudairah was surveyed from Trigonometric station K16, and that at Kathma from bench mark 1491 (Table 1).

Table (1)   List of the Stations which have been used for levelling

Station	Location	Height	Source
*T.B.M.	Kathma	3.37	Municipality of Kuwait
K.16	Ghidhai	110.12	Kuwait Oil Company
T.M.B.	Mudairah	83.13	Municipality of Kuwait
K.14	Al-Bahra	94.21	Kuwait Oil Company
M.3	Al-Bahra	80.61	Kuwait Oil Company
M.4	Al-Bahra	60.38	Kuwait Oil Company

*Temporary bench mark.

The number of levelling transects which could be surveyed was in part determined by the maximum number of accurate bench marks and trig-onometrical stations which were established or could be provided since errors could be minimised by working from such points. During the first field season between April and August 1971, during which it was necessary to complete the levelling programme, the time available was limited con-siderably by the weather dust storms in particular. It was finally decided to choose seven transect lines, each of which could be based on a fixed bench mark or on a surveyed point which could be established from such a bench mark. Each transect was also chosen, following reconnaissance on the ground, so as to cross the longest and best defined terrace fragments. The location of the transects is shown in Fig.11.

The procedure adopted in each case was to open the traverse at a height point established as described above. A line of constant direction was first marked by ranging poles aligned by prismatic compass from the starting point. Before levelling commenced the accuracy of the level and

Fig (II) LOCATION OF THE PROFILES
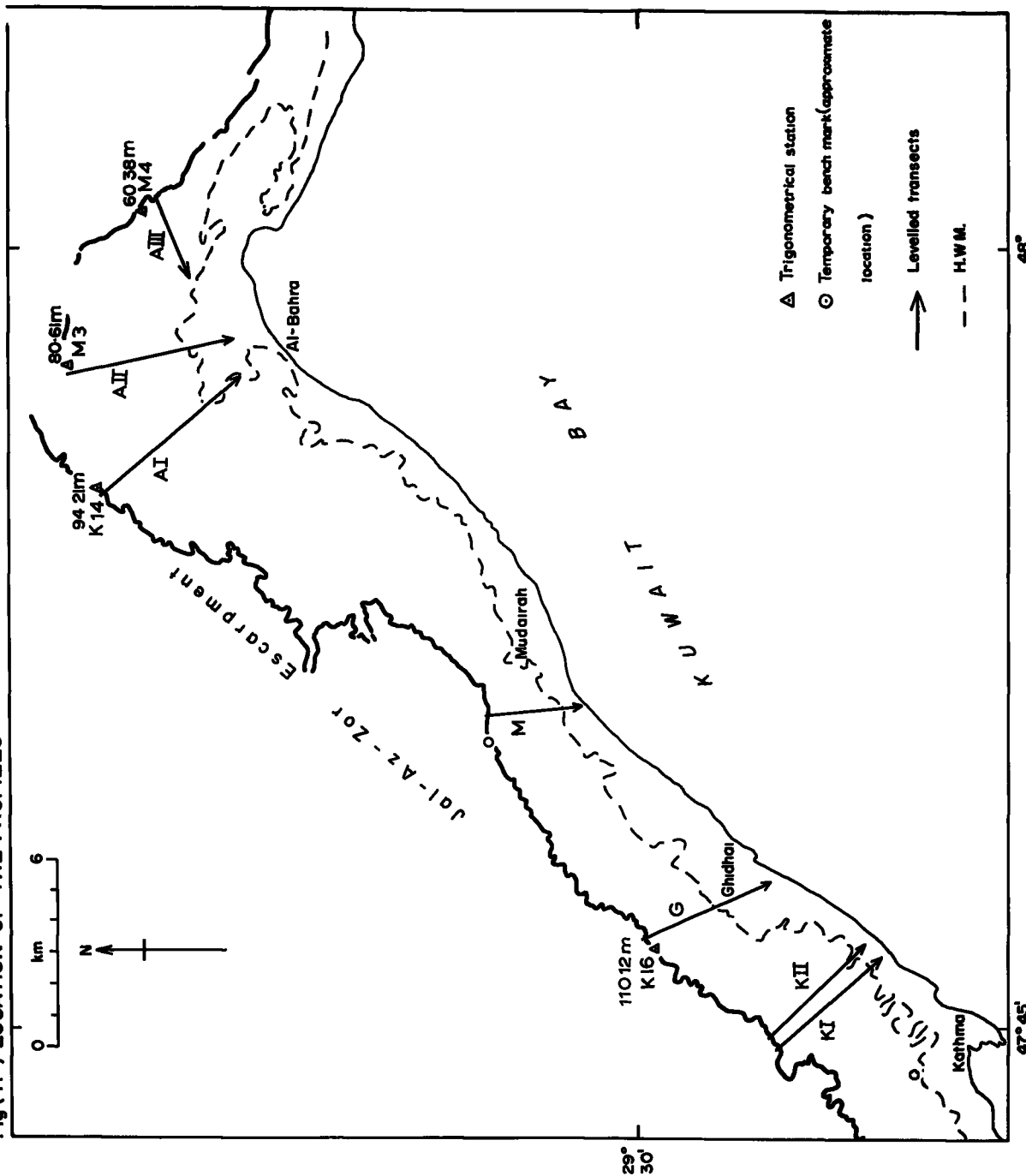
setting was established on each occasion by backsighting and foresighting over distances averaging 500 metres. The sequence of each traverse is described individually below.

The survey was carried out using a Kern Automatic level GKI-A, the readings were taken to the nearest millimetre, by estimation, all the distances were measured optically which increased the speed of taking the measurements. In all the cases, a metric staff was used and fore-sights and backsights taken on each station; the sighting were taken in full daylight. The actual distance between stations was determined very largely by the detailed ground topography. Surfaces in most cases were extremly uneven and changes in gradient often extreme over short distances, particularly on the higher terraces, therefore some levelled distances had to be as short as 2 metres.

Given the very small number of trigonometrical stations and bench marks to which reference could be made, together with the fact that all but one of these were located on the Jal-Az-Zor, it was impossible to close each traverse. The checking adjustment traverses made before levelling commenced indicated that, over an open traverse of up to 5 kilometres, height measurement was accurate within $\pm$ 1 metre. Thus, while the detailed measurements of heights are presented in Table 3 (p.126), the values obtained from the survey indicate differences between terrace heights all of which are significantly greater than the possible levelling error. There is no statistical invalidation of later analysis or of the preservation of terrace correlations in Fig.44 (p.235) or Table 12, arising from this element of survey error. This question is further examined in Chapter 6 - Basic assumptions and sources of errors.

PROCEDURE

A series of seven lines of levelling were run along the Jal-Az-Zor escarpment towards the present coast north of Kuwait Bay (Fig. 11). starting from the west in Kathma towards the east in Ghidhai, Mudairah and Al-Bahra areas. The Profiles are coded as follows according to their location; Kathma profiles are KI and KII, Ghidhai profile is G, Mudairah profile is M and Al-Bahra profiles are AI, AII and AIII.

Kathma I

Owing to the lack of trigonometric stations and bench marks on the upper surface of the escarpment in Kathma, it was necessary to carry out the survey starting from a temporary bench mark in the lower part of the Kathma coast. This temporary bench mark was fixed by Kuwait Municipality by running a line of levelling from bench mark No. 1491 west of Kathma to its present location, which was chosen by Kuwait University. However, it was found that the temporary bench mark was, first of all, not very accessible in distance from the present area of research. Secondly, the point was covered by the sea for most of the time. Accordingly, it was decided to choose the third levelled point inland towards the land at a height of 3.37 m and at a distance of 100 metres from the first point which was often covered by water. Regarding the first obstacle, a line of levels which covered a distance of 3852.2 metres was run from point 3.37 metres towards the east to as far as a point of suitable position at a height of 6.53 metres. A value of 0.47 metre was added in order to establish heights which will match with the Kuwait Land Chart Datum.* This will also make it easier to find out whether there is any correlation between the features of the present area and other features on the southern coast which elevation data depended on the Kuwait Land Chart Datum. From the last point which has a height of 7.0 m. (6.53 +

*Kuwait land Chart Datum is 0.47 metre above Kuwait Oil Company measurement, the latter is the same as admiralty Chart Datum.

0.47) above Kuwait Datum a line of levels was run towards the escarpment.
During the levelling it was possible to pick up several breaks of
slopes which tended to become more distinguishable as one progressed
towards the escarpment. The surveying ended on the upper surface of the
escarpment behind which the surface slopes gently towards the north. The
line covered a distance of 4523.2 metres.

Kathma II

The starting point for this line was established by levelling from the
last point in line with Kathma I to a point of elevation at 93.37 metres.
From this point a series of levels were run down the escarpment towards the
coastline. When completing the survey several breaks of slopes were also
noted. The line covered a distance of 4333.4 metres.

Ghidhai

Trigonometric station No. K. 16 at an elevation of 110.12 metres was
used to run a series of levels. According to the Kuwait Oil Company, the
height of the trigonometric station refers to the top of the concrete
pillar. As the levelling was carried out while the metric staff was on
the ground, 0.61 metre, representing the height of the concrete
pillar, were deducted from 110.12 metres. A value of 0.47 metre was
added and according to the previous procedure, the height of the starting
point was 109.98 metres. From trigonometric station No. K. 16 the survey
was run towards a suitable position at a height of 108.921 metres. Then
the levelling was carried out from the top of the escarpment towards the
present shoreline. During the working of this line it was noticed that
some of the terraces were strewn with shells, and also that there was a
greater number of terraces along this line than in the Kathma lines. The
distance of the surveyed line was 4500 metres.

Mudairah

A temporary bench mark was established in Mudairah by Kuwait Municipality for the purpose of the present research. The elevation of the point was decided by running a series of levels from trigonometric station No. K. 16.

The height was given as 83.13 metres. A difference of 0.47 metre was added which gave a fixed height of 83.60 metres. As was previously done with the other lines, the levelling was carried out from the temporary bench mark to a suitable position at a height of 82.25 metres. The survey then continued down the escarpment for a distance of 3057 metres during which several terraces were noticed. Until Mudairah, the Jal-Az-Zor escarpment runs more or less parallel to the coast.

Al-Bahra I

In Al-Bahra, the surveying was carried out in three areas. The escarpment here tends to follow a northeast direction. The first line is located west of Al-Bahra and a trigonometric station was used. The concrete pillar of the trigonometric station No. K.14 has a height of 94.21 metres. The metric staff was on the ground and hence 0.61 metre was deducted, then 0.47 metre was added, giving a fixed height of 94.07 metres. From this point, which is located on the upper surface of the escarpment, the levelling was carried on down the escarpment for a distance of 5724.6 metres.

Al-Bahra II

Surveying for this line was carried out from trigonometric station No. M3 at a height of 80.61 metres. The first reading was taken while the metric staff was on the concrete pillar, so it was only necessary to add 0.47 metre. The elevation of the trigonometric station was 81.08 metres. A series of levels was first run to the west of the pillar to a point 76.65 metres in height. The levelled line covered a distance of 5301.7 metres.

Al-Bahra III

The last line of levelling is in the east portion of Al-Bahra area, where the survey started from a trigonometric station No. M4 which, according to the Kuwait Oil Company (Table I), has an elevation of 60.38 metres. The station is situated on the upper surface of the escarpment. The metric staff was placed on the concrete pillar and hence a value of 0.47 metre was added which gave an ultimate height of 60.85 metres. From that point, a series of levels was carried out first towards the east to a temporary point established at an elevation of 55.27 metres. The surveyed line towards the coast covered a distance of 2744 metres. The results of the levelling are given in the following chapter.

4.2 Radio-carbon Dating Technique

In order to obtain some absolute chronology for the terraces it became necessary to select material from the terrace surfaces which would be associated with their formation and also was suitable for one of the dating techniques.

One type of such techniques commonly used is radiometric and sepcifically, radio-carbon dating. Radiometric analysis would have to be carried out in specialised laboratories and of these, a greater number are able to carry out contract work for radio-carbon dating than any other method. Moreover, the radio-carbon dating method is now a well-established process which has been used in the great majority of studies in changing sea-level. The degree of precision of dating by using this method has been reasonably well-established and most of these technical problems are identified by specialist workers in this field.

This is a method used effectively in determining geological and pre-historic chronology. The specific prognosis of the occurrence of radio-active carbon (C14) in the atmosphere was made by Libby in 1946. In 1947, Anderson et al pointed out the potentiality of using C14 for the age determination of organic matter. Subsequently Libby, Anderson and Arnold (1949) made first world-wide measurements of C14 residual from specimens of wood, peat, charcoal and other organic matter. The method was later given a somewhat surer foundation in archaeology by comparing the age obtained by the C14 method with archaeological objects whose ages were already known within narrow limits from other evidence; early Egyptian materials were particularly useful. The results were generally found to be satisfactory (Arnold and Libby 1949), but since then, further research has been carried out and has led to extra refinements in the technique.

The radio-carbon dating technique itself was described by Libby in 1955. The fundamental assumption of the theory can be summarised thus: first, C14

is formed in the upper atmosphere under the influence of cosmic rays. This C14 mixes freely with atmospheric carbon dioxide and achieves a theoretically uniform global distribution; for this reason, taken with carbon dioxide into all living organisms, radio-active carbon is present in the structure of all creatures, plants or animals. As soon as the organism dies, there will be no further uptake or exchange of radio-carbon. On the contrary, the radio-active carbon present in the dead organism will disintegrate at a rate corresponding to a half life of 5,730 years and therefore the proportion of radio-carbon found in a fossil can be used to give the age of the sample.

The span of dating enabled by present techniques reaches back to a maximum of 70,000 years and the objects acceptable for this technique include all organic material such as wood, charcoal, shells, hair, and leaves. However, although this method has been accepted universally and has helped in answering many questions, the results of the dating ought to be accepted with care as there are errors which may affect the absolute value of the technique. Butzer (1964) and Shotton (1967) have considered the possible sources of errors relating to this technique. These include the temporal and spatial variations of carbon 14 in the atmosphere, the contamination of old carbonaceous matter, contamination by modern organic matter, the contamination of the samples during or after collection, as well as statistical errors concerned with the technique.

Since part of the problem of elucidating the recent geomorphological history of the Kuwaiti littoral is one of chronology of sedimentation, an attempt was made to use the radio-carbon dating technique to date suitable material in the area studied.

In the field, reconnaissance observation showed the presence on the terraces in some localities of fossil or fossil-casts of molluscs. This was the only material which existed and was suitable to radio-carbon analysis.

It was not possible in Kuwait to carry out any sampling below sea-level.
The presence of molluscs fossil material was noted during reconnaissance
and during levelling. The shells were found either loose on the surface
or cemented on to the terrace surfaces by carbonate deposits. The
origin of the uncemented shells is generally doubtful since they could
have been transported by many agencies long after a first hypothatical
deposition. However, where they were found in large clusters - always
more than 50 and usually more than 100 contiguously -, whether cemented
or uncemented it was assumed that the probability was high of them
either being in their original position or having been mass transported
at a later date by some geomorphological process. This latter
possibility would have to be taken into account after dating and during
correlation.

The shells which could be validly sampled therefore, had to
be taken from those few clusters which lay within a narrow zone
centered on each levelled traverse. Whenever a sample was taken
from a point more than 3 metres from the traverse line, the height
was established as accurately as possible by a clinometer. Such non-
levelled heights were recorded and are shown in Table (5). Each
sample contained up to 10 shells selected for their contiguity regardless
of species. In all over 25 samples were collected from those sites
which, on the basis of clustering and lack of disturbance, appeared most
suitable. A constraint on sampling resulted from the need to transport
all the samples to Durham and from the limitation of identification and
analysis facilities.

Shell samples for radio-carbon dating were collected in polythene
bags and no further treatment was given to them before submitting for analysis.
The minimum weight of each shell sample sent to the laboratories was 20 gram.

The amount of material actually analysed by each laboratory had to be at their discretion. The shell assemblages have been obtained from different parts of the research area (see Chapter 5, part 1). They occur either in shell beds covering parts of the terraces, as in Kathma and Ghidhai areas, or scattered on the surfaces of the terraces. The locations of the dated samples are plotted in Figures 15, 19, 21, 25 and 27.

Eighteen samples have been submitted for dating of which seventeen came from the research area between Kathma and Al-Bahra. The last sample came from Al-Dhbaiyyah area which is located on the southern coast of Kuwait, the sample came from a terrace at a height of about 5 metres above Kuwait Datum.

The limit on the number of individual shell samples which could be dated was imposed by several factors. First, some of the group samples were contaminated during air-freight by damage to the containers. Secondly, there was a question of cost; the cost of the dating which was carried out was about £600. Thirdly, most of the radio-carbon dating laboratories are heavily loaded with samples for analysis and ultimately five different laboratories had to be used to get the samples analysed. It was recognised that the results would not be as accurately comparable as otherwise they would be but there was no alternative. Other points concerning sources of errors are examined in Chapter 6. In Table (5) the laboratory reference as well as sample reference is given in each case so that the error element can be assessed. Some of the samples have been submitted to the Radiological Dating Laboratory, Trondheim, Norway. Professor F.W. Shotton has dated two samples at Birmingham and others have been dated at Sydney University Radiological Laboratory. In addition, Dr. M.A. Geyh of Hannover dated one sample and two samples have been submitted to Teledyne Isotopes of New Jersey.

4.3. Sediment Analyses

The purpose of the analysis of the sediment is to deduce their depositional environments, which will assist in understanding the processes involved in the development of the coastal terraces as well as other physiographic features in the research area.

Two methods of investigation have been applied: 1. Particle size analysis, as a main method and 2. The investigation of the sediment by scanning electron microscopy as a subsidiary technique.

4.3.1 Particle Size Analysis

Introduction

Particle size analysis or mechanical analysis is an important sedimentological technique which has been greatly used for the interpretation of sedimentary particles. It may give information about the agent or environment responsible for the origin of the sediment. This includes the distinction between marine, lacustrine, fluviatile, aeolian and other deposits as well as possible knowledge about the physical properties of the transporting agent e.g. capacity, current velocity and wave action. Investigators have become able to assume that the nature and structure of a deposit is a reflection of the sorting agent (running water, wind-wave action etc.) which deposited sedimentary particles of different sizes, densities and shapes.

As early as 1898 and 1914 Udden used this technique as a correlative and discriminative method and noticed that there is a relationship between the type of sediment involved and the results obtained from the analysis of particle size. Since then, many workers have contributed to advances in the application of this technique, some concerning themselves especially with the interpretation of results of particle size analysis e.g. Krumbein (1934); Otto (1938). Keller (1945) was the

first to discriminate between beach and dune sands.

Identification of ancient environments on the basis of grain size
has been discussed also by Moss (1962, 1963); Visher (1965); Shepard and
Young (1961); Solohub andKloran (1970). Others have attempted to
relate statistical parameters from grain-size distributions to different
environments of deposition, Otto (1939); Inman (1952); Folk and Ward
(1957); Mason and Folk (1958); Friedman (1961, 1962, 1967); McCmmon
(1962) and Chappell (1967).

Folk and Ward (1957) studied the grain size parameters of a bar
on the Brazos River, Texas. By plotting skewness against kurtosis,
they were able to interpret the genesis of the sediments. The very
high or low values of kurtosis suggest that part of the sediment was
sorted in a high energy region, and that it was then transported with-
out change of character to another environment, possibly of low energy,
where it was mixed with another type of material. This mixed type of
sediment will be strongly bimodal.

Mason and Folk (1958) showed that the grain size analysis was
successful in distinguishing three environments of beach, dune and
aeolian flat on Mustang Island, Texas. Skewness and kurtosis are the
best parameters to identify the environments because these properties
reflect the changes in the "tails" of the distribution. Beach sands
had nearly normal curves, dune sands had nearly normal kurtosis but
were positively skewed, while those samples of aeolian flats were
positively skewed and had high kurtosis.

Friedman (1961) identified the environment of deposition and
the processes involved. He analysed 267 sand samples derived from
dunes, rivers, ocean beaches and lake beaches. These samples were
collected from a widely distributed geographical location including
Canada, the United States, Mexico, the Bahamas, Bermuda, North Africa

and Hawaii. The parameters used for analyses were the mean, skewness and kurtosis. An almost complete separation of the fields of dunes and beach sand is made when the mean grain size is plotted against skewness. When plotting skewness against kurtosis for river and beach sands most of the river samples showed positive skewness as did the dune sands. However, some of the beach samples also exhibited positive skewness; these came from southern Padre Island, Texas, opposite the Rio Grande delta from which they have inherited the positive skewness. The wind and river transportation resulting from indirect flow is believed to explain the positive skewness of dune and river sands. Samples of beach origin have generally negative skewness, because sands on a marine beach are exposed to two unequal forces; the incoming waves and outgoing wash which are acting in opposite direction and bring the removal of the fine particles. Friedman (1961) plotted the skewness against standard deviation for beach and river sands, this method showed that sorting is helpful in distinguishing beach from river sands. Beach sands of positive skewness have a low value for standard deviation (better sorted) while the negatively skewed river sands can be distinguished from beach on the basis of their high numerical values of their standard deviation. Three fields of environments have been noticed by Friedman (1961) when standard deviation is plotted against mean size, river, dune and overlapping fields.

Khalaf (1969) investigated the grain size distribution of the beach sediments of Kuwait. The results showed that samples located in the Kuwait Bay area and near the Shatt-al-Arab area are of the clay sand type, while those collected from the south are generally of the sandy type.

Many workers tend to encourage the use of the statistical

parameters as a good discriminative measurement between environments, while others have dealt with interpretation of the shape of the grain size distribution curves and relate them to specific environment of deposition.

The researches have indicated that there are three modes of transport; suspension, saltation, and surface creep or rolling. These modes give the final shape of the grain size distribution of any sediment and hence information about the genesis of the sediment investigated. Reineck and Singh (1973) summarised the characteristics of the three modes.

1. Suspension transport The maximum grain size of sediment which may be held in suspension varies in different environments and also depends upon the hydrodynamic conditions at the time of sedimentation and their transporting medium. In general the grain size is usually less than 0.1 mm.

2. Saltation transport Reineck and Singh (1973) quoting data of the U.S. Waterways Experiment Station (1939) showed that grains up to 1.0 mm in diameter were sampled 60 cm above the bottom. The maximum size transported by saltation depends upon different factors, e.g. the current velocity and water depth.

3. Rolling transport The coarsest grains in the sediment are transported by rolling, but in some fluvial sediments it is not possible to differentiate completely between rolling and saltation subpopulations. Fuller (1961) made a detailed mechanical analysis of shallow marine sediment from the coasts of the Cape of Good Hope. He suggested that in many cases the value near 2 phi represents the break between saltation and rolling subpopulations.

Deoglas (1946) attempted to recognise the genesis of deposits from visual inspection of the shape of curves plotted on arithmetic size scale. The main points of Deoglas's work on texture can be

summarised in two parts: 1) The grain size distribution of a sediment is a mixture of several component distributions or populations.

2) These distributions have resulted from different transport conditions. In 1949, Inman published a significant paper in which he related the sedimentation dynamics to textures. He pointed out that there are three fundamental modes of transport, surface creep, saltation and suspension. Sindowski (1957) classified size distribution curves and provided a careful study of the relation of sediment textures from known depositional environments to the shape of grain size curves. Spencer (1963) mentioned that all clastic sediments are a mixture of three or less log-normally distributed populations (gravel, sand and clay). He recognised sorted and truncated deposits by the shapes of the graphs. The three processes (rolling, saltation and suspension) are important in characterizing the textural parameters of river and beach sands, but while in the deposition of river sands, saltation and suspension are usually active, and commonly rolling as well, beach sands show a straight line indicating deposition by saltation only (Friedman 1967). The size of the grains affected by each of the three modes varies, rolling or sliding affecting the grain size between 0.25 mm and larger than 0.50 mm (+2.0 ϕ to < 1.0 ϕ), saltation from a finer point of about 0.14 mm (about 2.80 ϕ) to 0.062 mm (4.0 ϕ), while suspension affects grains of less than 0.14 mm (about 2.80 ϕ) and especially those in the < 62 micron range (4.0 ϕ).

Visher (1969) studied log-probability grain size distribution curves of modern as well as ancient environments and recognised the subpopulation within each individual grain size distribution which is related to a mode of transport (suspension, saltation, rolling) e.g. beach samples have two saltation populations which are related to swash and backwash in the foreshore zone. The truncation point differs

from 1.0 to 2.0 phi. Dune sands adjacent to the beach have one
saltation population which represents about 98% of the distribution.
The sorting of this population is the best and is indicated by a better
graph slope than with the beach samples. The truncation of the coarse
traction (rolling) is also between 1.0 and 2.0 phi. Marine sands, from
the lower tidal flat to a water depth of about 17 feet, have three
characteristics. 1) a poorly sorted, coarse, sliding or a rolling
population. 2) a very well sorted saltation population of a size
range of between about 2.0 and 3.5 phi. 3) a variable percentage of
suspension population which depends upon the location of the depositional
site from the source of fine clastics. The marine sands samples from
the zone of breaking waves are characterised by having relatively high
percentages of material of rolling population and range from a few to
80 percent of the grain size distribution. The saltation population is
truncated at its fine end and this percentage of the suspension population
is small. Finally, the modern fluvial samples are characterised by a
well developed suspension population of about 20% of the distribution.
A truncation between suspension and saltation is between 2.75 and 3.5 phi
with a saltation population range in size from 1.75 to 2.5 phi. For the
present research, mechanical analysis has been carried out to investigate
the grain size distribution of the sediments, from which their sedimentary
origin can be deduced.

Method

Numerous sediments have a range of size from coarse to fine particles;
for such sediments, a composite method of analysis is required so that the
coarse material may be sieved and the fine material then analysed by a
sedimentation method. Details of these techniques have been described by
several investigators e.g. Krumbein and Pettijohn (1938); Milner (1962);
Irani and Callis (1963); British Standards Institution (1967); and

Griffiths (1967). More recently, Iriondo (1972) has introduced a rapid

method for size analysis of coarse sediments by using a photographic

method which aims to avoid the problem of carrying heavy samples. For

the present work, the British Standards Institution (B.S. 1377) method

has been adopted.

Methods of coarse analysis involve dry and wet sieving through a

nest of sieves beginning with the largest aperture sieve. The sieves are

placed on an automatic shaker and the sample retained on each sieve is

weighed and recorded after a finite time. For silt and clay analysis, two

methods are available, the pipette and Hydrometer. Both involve a gradual

settling in water of a sample suspension maintained at a constant temperature.

For the present work the pipette method has been applied.

The grain size analysis was carried out on 65 samples collected from

different parts of the research area and along the levelled profiles.

(Chapter 5, part 1). Several authors have dealt with the sampling procedure

e.g. Thompson (1937); Apfel (1938); Emery and Stevenson (1950); Krumbein

(1953 and 1954); Krumbein and Slack (1956); Griffiths (1967).

On this basis, the samples were collected selectively rather than

randomly and all the samples (except for 3) were collected along the transect

lines during the levelling procedure. The only three samples which were

collected offset from the transect lines came from Kathma and Ghidhai, two

of the samples came from the Fourth terrace west of the first levelled

transect in Kathma (where a shell sample was also collected for C14 dating).

The third soil sample came from the Fourth terrace in Ghidhai; it was

collected from west of the levelled line and near a shell sample submitted for

C14 dating.

All the samples were collected from the deposits covering the base

of the terrace in order to find out the origin of the deposits laid down on

the terrace base itself, material covering the slopes was avoided because the

slopes are often covered by recent windblown sands. The range of the
collected samples along the transect lines covers the area from the top
of the escarpment to the present beach. The purpose as well as to
distinguish the origin of the sediment on those particular sites is also
to find out the differences as well as the similarities in the historical
depositional environments under which materials on the top of the escarpment,
the terraces and the present beach, were laid down.

From each locality four samples were collected from a standardised
depth of about 50 centimetres. This was sufficiently deep to avoid the
collection of superficial and possibly recently transported material while
greater depths could not have been sampled in all localities without some-
times required major excavation into hard concreted masses. The four
samples were combined together so as to produce a composite sample. They
were collected in polythene bags fitted inside cloth bags in order to prevent
the loss of the fine material in the samples and breakage during their
shipment.

The question of the weight of the sample collected was decided according
to several considerations, one of which was that the sample should be repre-
sentative for the purpose of analysis, but small enough to be manageable
for transportation (as the analyses were carried out at Durham University).
Accordingly, a sample weight of about 2 kilograms was collected from each
locality.

In the laboratory, the wet samples were broken by hand and put to dry
in the drying cupboard, maintaining a temperature of 105-110°C, while the
dry consolidated deposits were crushed gently in a mortar using a rubber
tipped pestle. Each sample was passed through a $\frac{3}{4}$" British Standard sieve,
and a representative sample of 500 grams for coarse particle size analysis
was obtained by a riffle. The representative sample largely depends upon

the size ranges being sampled, e.g. whether a wide or small range of particles. There is no general agreement about the size of the analysed samples, as different sizes have been suggested by various authors, e.g. Krumbein (1953); Cochran, Mosteller and Tukey (1954); McIntyre (1959); Gees (1969). However, a large sample will give better results than a smaller one, but one also has to remember not to overload the sieves as this will help in increasing the error of analysis. A total range from coarse sand to fine sand was mechanically analysed by automatic shaker using wet and dry sieving methods (Appendix). There is no fixed time for which the sample should be shaken; Wentworth (1927) examined the question of sieving quantitatively and found that separation of particles, especially among smaller size, can never be complete. He concluded that shaking in an automatic shaker for five or ten minutes is usually sufficient. It has also been found by (King 1967); (Griffiths 1967) that shaking for 15 to 25 minutes is sufficient, this being based on a compromise aimed at avoiding the wear of sieve mesh and particles which tends to take place after 20 minutes. Accordingly, it was decided that sieving the sample for 15 minutes was sufficient to produce a reliable separation of the particles.

The total amount of time involved in the analysis by coarse analysis and pipette was considerable as each sample took about 3 days from start to finish.

A further 500 grams were passed through sieve No. 8 B.S. for pipette and for scanning electron microscope.

The particle size categories are dependent on the type of equipment available. The present writer has used a nest of sieves which has been recommended by the British Standards Institution (B.S. 1377, 1967). Their grade scale is as follows:

	Diameter in millimetres		
Cobbles	200.0	-	60.0
Coarse gravel	60.0	-	20.0
Medium gravel	20.0	-	6.0
Fine gravel	6.0	-	2.0
Coarse sand	2.0	-	0.6
Medium sand	0.6	-	0.2
Fine sand	0.2	-	0.06
Coarse silt	0.06	-	0.02
Medium silt	0.02	-	0.006
Fine silt	0.006	-	0.002
Clay	Smaller than 0.002		

Other scales exist, such as the Wentworth scale (1922), and the phi scale which is devised by Krumbein (1934) and are more convenient for presenting the data than if the values are presented in millimetres.

The advantage of this method is that small fractions are not required for the smaller particles and that for many of the common sediment sizes the results in phi units are positive (Table 2). The ϕ units are found by conversion from the millimetre scale, where phi is $- \log_2$ of the diameter in mm. Conversion from millimetres to (phi) units means that one division on the Wentworth grade scale, a commonly used scale, is equivalent to one unit on the phi scale. For every unit on the phi scale, the value on the Wentworth scale in mm is either doubled or halved. Negative values of ϕ units are the values coarser than 1 mm, and as the ϕ units increase, the size of the particle decreases. Nomagrams for conversion from millimetres to ϕ Units have been presented by several authors (Krumbein 1936); (Folk 1959), also numerical conversion tables have been made by Page (1955), Griffiths and McIntyre (1958). For

Table (2)   Conversion of millimetre scale to phi units

Millimetre	phi units
12.5	-3.64
6.0	-2.58
2.0	-1.00
1.2	-0.26
0.600	0.74
0.420	1.25
0.300	1.74
0.210	2.25
0.150	2.74
0.100	3.25
0.075	3.74
0.063	4.0
0.02	5.64
0.006	7.39
0.002	9

the present work Page's (1955) conversion table has been followed.

The results of the particle size analysis (are shown in Chapter
5.3) have been plotted as cumulative percentage curves against phi
diameter on arithmetic probability paper. This type of paper has the
advantage that the normal distribution curve would plot on this paper
as a straight line. Deviations from a normal distribution are indicated
by deflections from the straight line. Also, the tail of the curve can be
of considerable importance in studying the characteristics of the
sediment and this can be obtained if the figures are plotted on arithmetic
probability paper.

4.3.2. Sediment investigation by scanning electron microscope

The application of the scanning electron microscope (SEM) for the investigation of sediments has been greatly used in recent years for solving problems of Quaternary geology, geomorphology and paleoclimatology. Investigators have shown that depositional sedimentary environments can be identified by examining the surface textures which are developed on sand grains. The agent of deposition can be identified by studying the surface features particularly on the quartz grains because each agent imposes characteristic surface features. The first results of examining the surface textures of sand grains using the transmission electron microscope were obtained in 1962, when valuable information about the surface textures of quartz grains was provided by Krinsley and Takahashi (1962a, 1962b, 1962c); Biederman (1962), Porter (1962); and Kuenen and Perdok (1962). These authors concluded that the mechanism of transport and the conditions of the environments of deposition characterise the nature of the quartz grain surface textures.

The features can be observed at magnification by using either a transmission electron microscope (TEM) or a scanning electron microscope (SEM). In this study the SEM was used. Schneider (1970) and Krinsley and Doornkamp (1973) noticed the advantages of using the scanning electron microscope rather than the transmission electron microscope for the following reasons. With the use of the SEM, the grain surfaces can be observed directly without duplication which meant the avoidance of artifacts and distortions. More details can be observed by using the SEM than with TEM because when using the TEM, several small features are obliterated or distorted with the replica method. With the SEM, more than 40 sand grains can be mounted together in one single specimen stub without the need to change the specimen while the specimen stub

can also be tilted, rotated or raised and lowered so that more than

half of the surface of the grains can be directly examined. Also, one

of the advantages of the SEM is that it gives a simulated three-

dimensional view of the objects which help in the interpretation of

the features.

Numerous papers have dealt with this subject and some examples

will be reviewed. Krinsley and Funnel (1965) examined the surface

textures of quartz sand grains of the lower and middle Pleistocene

deposits of Norfolk, England and their results agreed with the previous

investigations based on the fauna and general sedimentary character of

these deposits. They also recognised several surface textures assoc-

iated with glacial, littoral, aeolian environments and with chemical

etching. Soutendam (1967) quoting Cailleux(1942) mentioned that the

amount of well-rounded frosted grains in a sediment increases propor-

tionally with the intensity of wind-action the sand has undergone.

For instance, in desert sands about 98% of the grains are well-rounded

and frosted; sands from coastal dunes next to a sandy beach contain

an average of 81% of these grains, but the amount decreases to 0%

when the dunes are thin and deposited on a rocky coast. The surface

textures of more than 4000 quartz grains were examined by Krinsley

and Donahue (1968) and they have concluded that the characteristics

of surface textures created in different environments are sufficiently

distinct and standard for these characteristics to be used as standard

reference indicators for environmental identification. Hodgson and

Scott (1970) applied the combined methods of size analysis as well

as the electron microscope to find out whether beach sediments

are present within the Lower Carboniferous Fell sandstone of South-

east Scotland and North England. The results of both confirmed the

presence of the beach sediments. Surface textures of the quartz sand can be affected both by mechanical and chemical weathering depending on the environments involved. Doornkamp and Krinsley (1971) have demonstrated these features from a tropical environment (Uganda).

Accordingly, and on the basis of the surface structure of quartz, electron microscopy has made it possible to discriminate between several different sedimentary environments.

Method

18 samples from the total of 65 field samples have been investigated by scanning electron microscope; the samples were taken from the same bags as the mechanically analysed samples. The purpose of using this technique as with particle size analysis is to investigate the origin of the deposits in the area. The particle size analysis and the application of the scanning electron microscope to the same sample must give similar or different results. If they both give positive results, they will increase the certainty of our knowledge of the origin of the sediments.

Samples were prepared for the scanning electron microscope first in the laboratory by boiling in concentrated HCL to remove $CaCO_3$ and any iron staining. The samples then were washed by distilled water, dried and sieved to obtain the find sand fraction. The sample was placed in Bromoform, a heavy liquid, to separate off the light grains from the heavy grains. The separated quartz grains were washed with acetone to remove the heavy liquid. Approximately 100 grains for each sample were available for preparation for scanning electro-microscope analysis. The samples were then prepared at the Physics Department, Salford University, where a random sample of the prepared grains was sprinkled on to the face of a small metal stub. The grains were then covered

with gold palladium under vacuum. The specimen was then placed in a

Cambridge Mark II scanning Electron Microscope and was ready for

viewing.

CHAPTER 5

PRESENTATION OF DATA

In Chapters 1 to 3, the geological and geomorphological background of Kuwait and the area chosen for field study has been examined. The methods adopted for investigation have been outlined in Chapter 4. Here, the research data obtained in the field area are reviewed. The chapter is divided into three sections.

The first is concerned with examining the field data concerning the levelling results and description of the terraces, including the general topography of the area where the levellings were carried out. The lithology of the bedrock of the terraces is described wherever it is possible to distinguish their vertical succession. Also, the morphology of the terraces is examined, together with their heights, their superficial deposits, the location of the soil samples collected for analysis and the location of the shells which were collected for radiocarbon dating.

The second section is devoted to the marine fossils found in the area and to the results of radiocarbon dating of the shells collected during field investigation.

The last section is concerned with the results of sediment analyses, these results contributing to confirmation or the rejection of hypotheses of marine action in the research area.

5.1 Field data, levelling results and description

The transects located in fig.(11) were levelled using the technique described in Chapter 4.1, and the results are plotted in figures (12) and (13) . Each profile is later presented in three forms or divisions; the first represents the complete altitudinal transect from the upper surface of the escarpment to the present shoreline. Thus, in figures (12) and (13) all the complete profiles may be compared. Secondly, the most

Fig.(I2)
COMPLETE PROFILES of KATHMA, GHIDHAI and MUDAIRAH

KATHMA I

KATHMA II

GHIDHAI

MUDAIRAH
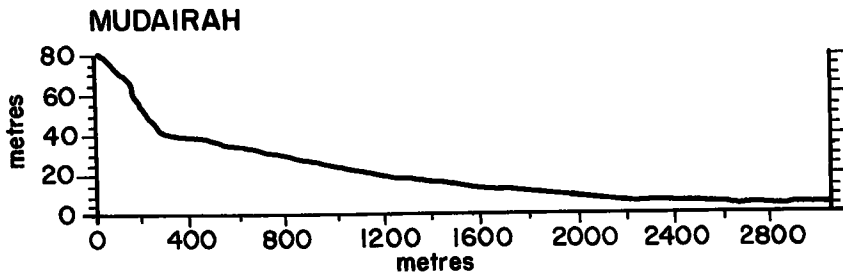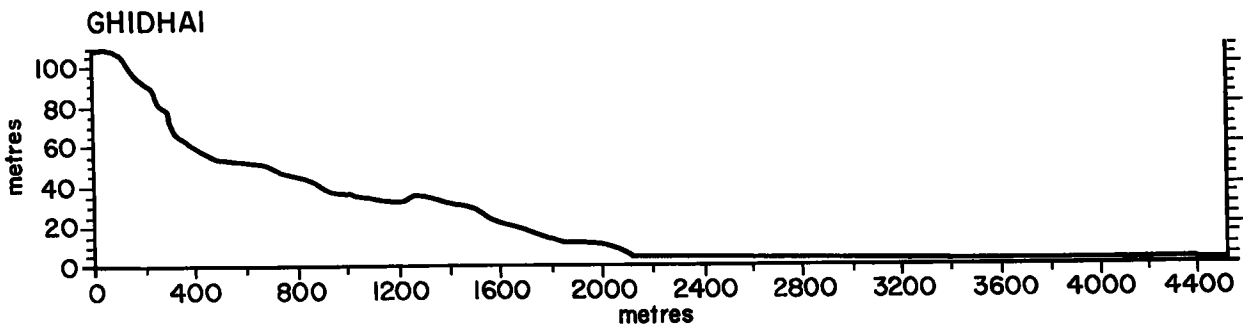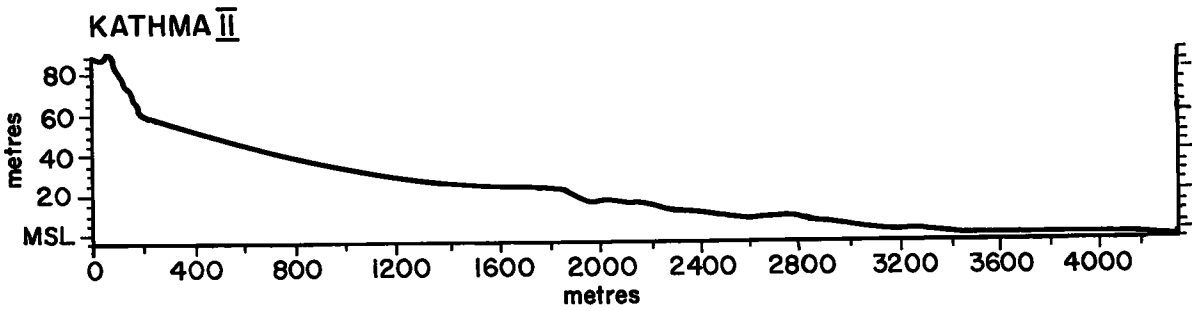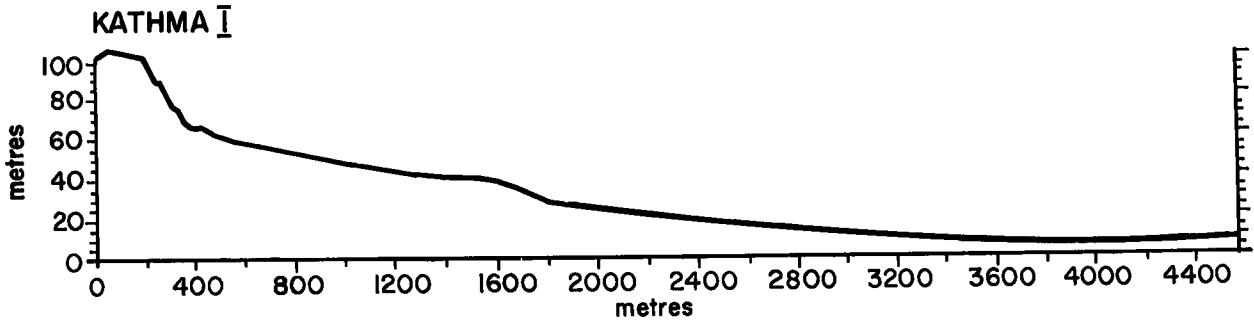
Fig.(13)
COMPLETE PROFILES OF AL-BAHRA
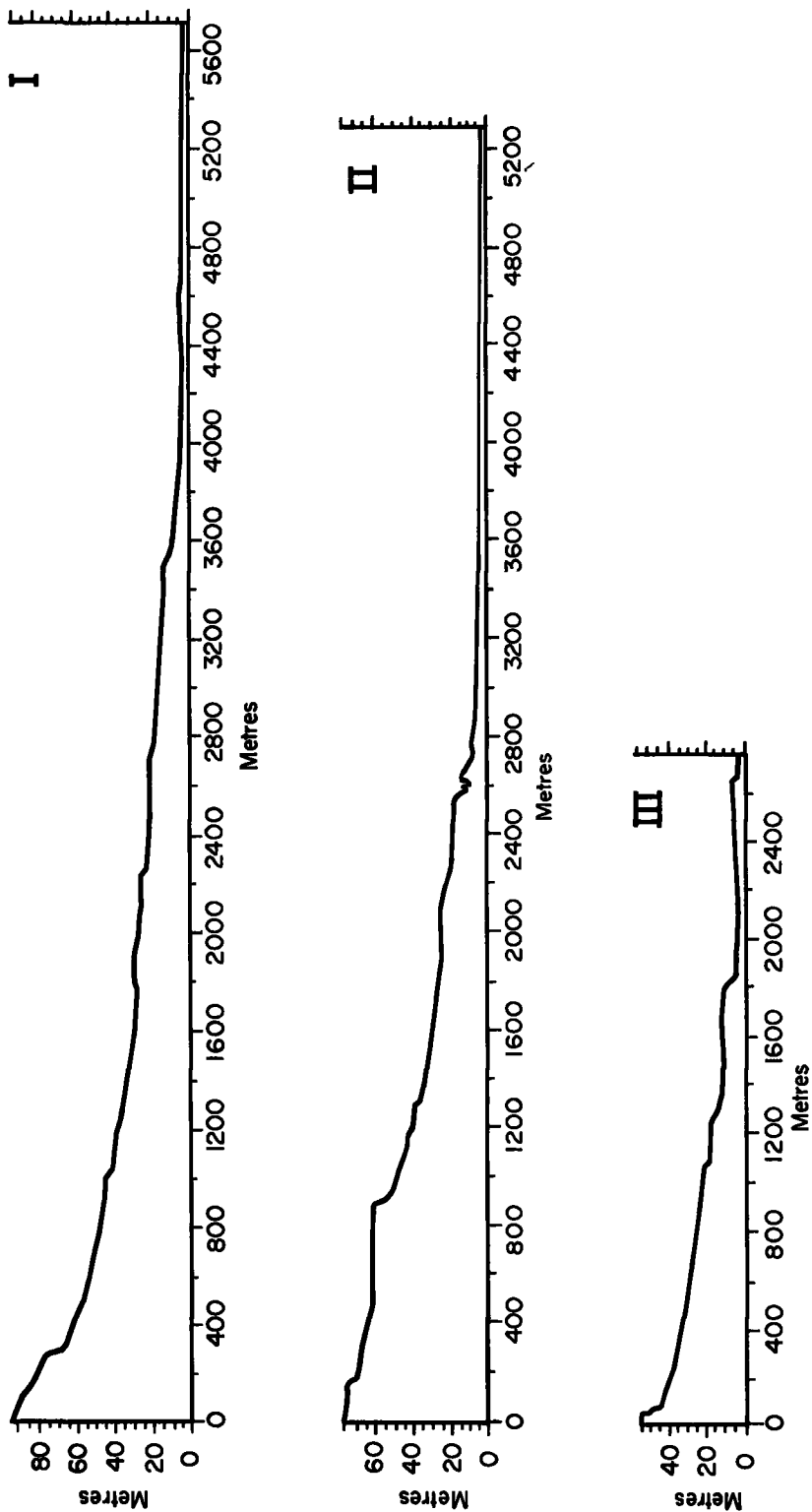
significant part of the profiles has been divided into two main

sections; the upper section profile and the lower section profile.

The extreme seaward part of the profiles (except for one transect

in the Al-Bahra area) have not been enlarged as they are all

characterised by a gentle slope and partly covered by water at high

tide. The scale of the complete profiles is uniform for all the

transects, but has been modified when the profiles are enlarged into

two sections. Both the upper and the lower profiles have the same

vertical scale, but differ in the horizontal scale. The reason is

that the terraces, especially those of the lower sections, do not

appear clearly in the complete profiles, and in order to show the

terraces in a manner similar to their existence in nature, either their

horizontal or vertical scales had to be changed. At the same time,

in order to present the profiles in a reasonably compact form, it

proved better to change the horizontal rather than the vertical scale.

Each profile has been further sub-divided for reference to individual

slope elements so that the higher elements have the lowest numerical

value, for example, Kathma I is further divided into KI.1 to KI.7

progressively from West to East. The lithological descriptions are

given for identifiable beds in the lithological succession. The

measurements given in metres are of depth below the surface of the

escarpment.

KATHMA

Two lines of levelling were surveyed in Kathma, the first area to

be investigated. In general, it does not differ in its geomorphological

features from the neighbouring areas to the east and west. Here, the

coastal plain is covered by both marine and terrestrial deposits and can

be divided into two parts, a lower and upper part according to the cover

of the superficial material. The lower part is composed of a low-angle spread of beach sands and marshes and is partly covered by the sea at high tide. The upper part of the coastal plain is characterised by its "staircase" topography. Several terraces extend along the escarpment and between the lower section of the coastal plain and the escarpment. This upper part of the coastal plain is dry throughout the year except in the rainy season. It is largely covered by terrestrial deposits and scattered with rocks and debris brought down from the escarpment. Large blocks of detrital rocks have accumulated, especially along the margin of the escarpment. The plant communities in Kathma are typically *halophytic*, becoming less so as one progresses inland away from the coast.

KATHMA I

Lithology and Stratigraphy of the Bedrocks

The method of levelling in Kathma has been previously described. In this section the bedrock is described along the surveyed profiles. Along Kathma I (KI) it was possible to identify four separate terraces at heights ranging from a mean height of 50.76 metre above K.D. for the lowest terrace to 90.60 metre above K.D. for the highest. The stratigraphy of these terraces was examined in the field and it was possible in many areas to identify the vertical succession of terraces along the escarpment where erosion has exposed sections in the terraces. This was especially so on the steep section of the escarpment where wadis are well developed (plate 1) The stratigraphic sequences are illustrated in fig.(14)as follows:

0-0.5m. The upper surface of the escarpment at the profile Kathma I (KI) is covered by lag gravels and windblown sands.

(KI.1) 0.5-6.5 metres below the surface, there is a horizon of fine

FIG (14)

PROFILE SECTIONS OF KATHMA $\underline{I}$ SHOWING THE LITHOLOGY OF THE
BEDROCKS

COMPLETE PROFILE

LOWER SECTION

Conglomeratic Sandstone
Calcareous Sandstone
Calcareous Sandstone with clay ball
Sandy limestone, partly fossiliferous
Beachsand and marshes
Probable limit of the bedrocks — — — —
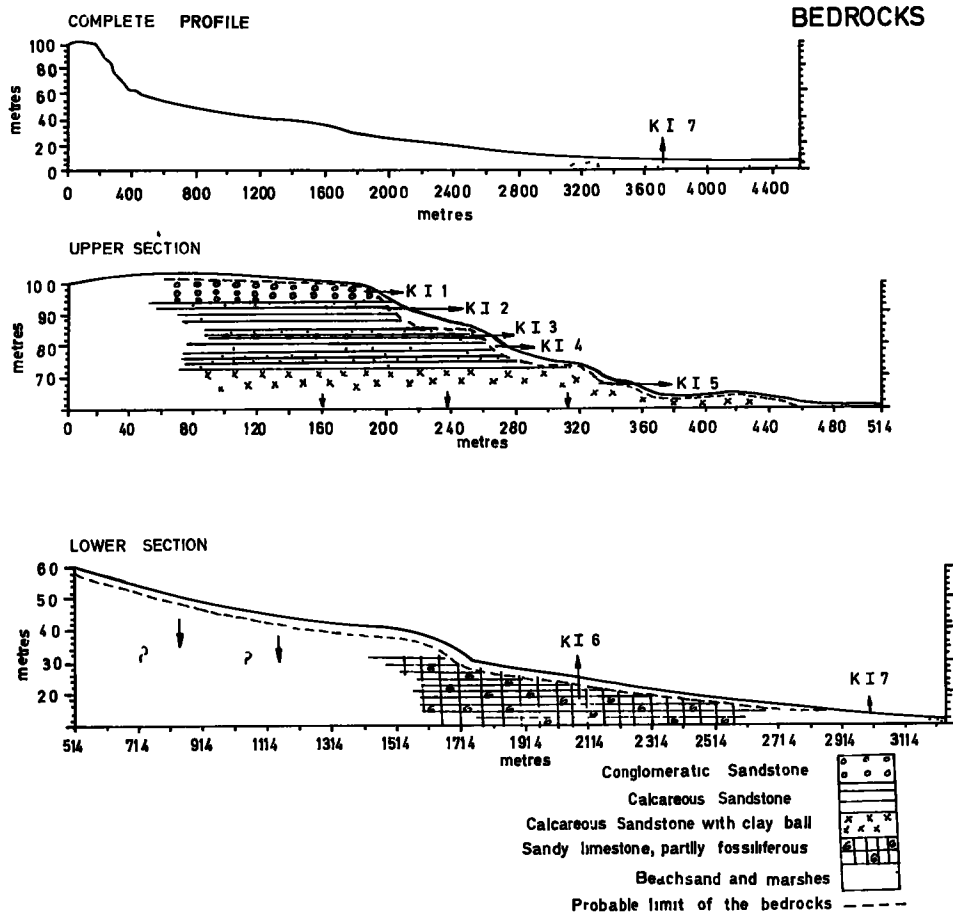
conglomeratic sandstone the material is cemented by carbonate, it has

a thickness of about 6 metres.

(KI.2) 6.5-15.5 metres, on the levelled line, there is a calcareous

sandstone, thickness is about 9 metres.

(KI.3) 15.5-16.5 metres. Conglomeratic lamina of a thickness of

about 1 metre.

(KI.4) 16.5-27.5 metres. Calcareous sandstone of medium hardness,

thickness is about 11 metres.

(KI.5) 27.5-?m Calcareous sandstone with clayballs rich in gypsum.

Depth unknown. (Stratigraphy at this depth uncertain).

(KI.6) Medium grained to conglomeratic sands and sandstone,

calcareous or quartzose. Occasionally cross-bedded, partly fossiliferous,

mainly limestone; variagated shales. This deposit could not be observed,

in the field in the area, and the former description is based on the

geologic map of Kuwait. (Fuchs et al 1968).

(KI.7) Beach sand and marshes of Recent age.

Morphology of the terraces

Four clear terraces have been identified along this profile

(Fig. 15). The terraces are characterised by their lack of marine

deposits, apart from a few shells strewn on the lower terrace.

(These are probably not in situ). The superficial deposits are of

terrestrial origin, and the upper surface of the escarpment is

covered by lag gravels and sands of which a soil sample has been

collected (Fig. 15)

The escarpment gravels have been interpreted by Cox & Rhoades 1935,

Milton 1967, Fuchs et al 1968 to be of Pleistocene age; this layer has

a thickness of about 50 cm and is strongly calcareous.

FIG (1 5)

PROFILE SECTIONS OF KATHMA Ī SHOWING THE LOCATION OF THE SAMPLES
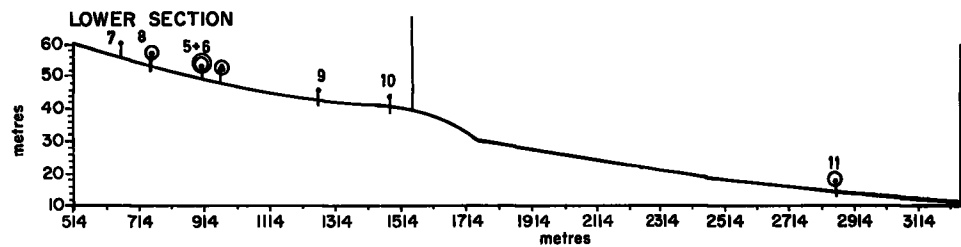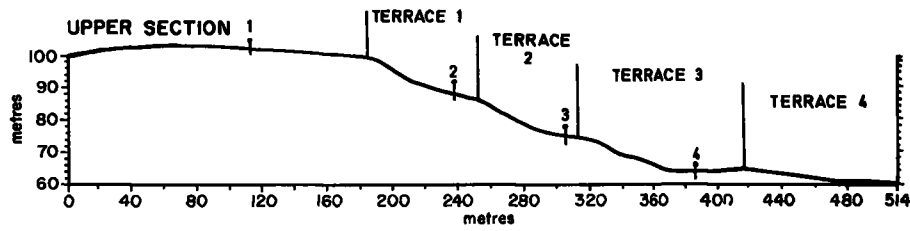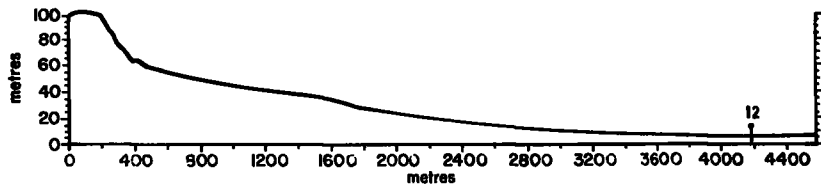
COMPLETE PROFILE

UPPER SECTION 1

LOWER SECTION

| SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS

SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS AND SCANNING ELECTRON MICROSCOPE

SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS AND SCANNING ELECTRON MICROSCOPE OFFSET FROM THE TRANSECT LINE

C 14 DATING OF SHELLS OFFSET FROM THE TRANSECT LINE

The surface of the escarpment slopes gently towards the north approximately accordant with the general dip. On its seaward face it displays a fine staircase topography. The slope of the First terrace is covered mainly by locally derived weathered material and windblown sands. The First terrace has a width of 70.80 metres and a mean height of 90.60 metres above K.D. The height of the terraces has been established by averaging the height of the relatively clearly identifiable edge of the terrace and the height of the terrace surface at its junction with the back-slope; for example the height of First terrace is the mean height of (94.75 + 86.43 m).

The reason for taking the mean height arises from the difficulties resulting from the accumulation of deposits which cover the junction between the landward point of the terrace and its slope.

In the field it was noticed that this terrace continues laterally for some distance on either side of the chosen transect line. No positive traces either of marine erosional or depositional features have been traced on this terrace and both the terrace flat and the slope above are covered with the same material. A soil sample has been collected for laboratory analysis (Fig. 15).

The Second terrace, in descending order, also has a similar character, the terrace base of this conglomerate lamina joining the upper calcareous sandstone. Neither bed is exposed except in the wadi sides which trench the terraces, as its surface is veneered by fine sands and weathered conglomeratic rocks. The width of the terrace is 56.4 metres and its mean height is 77.92 metres above K.D. The material covering the terrace is the same as that covering the back slope and a sample has been collected from there. This terrace too, can be followed laterally for some distance.

The Third terrace is at a mean height of 67.38 metres above K.D.
The surface is eroded in parts and gives rise to what looks like, in
sections, another terrace but this feature was only found on the line
of levelling and is assumed to be due to aeolian erosion. A soil
sample was also collected from this terrace. Sands and fine gravels
also cover this terrace which has a width of 120 metres, after which
it gently slopes towards the Fourth terrace. The slope is dissected
by several streams beds.

The last terrace in this sequence (Terrace 4), is at a mean
height of 50.76 metres aove K.D. It takes the form of an elongated
hill of about 1091 metres in width and is composed of cemented sands
covered with gravels from which several samples have been collected.

Approximately one kilometre west of this transect line, there is
a small terrace (Plate 2a), which appears to be a fragment of the
present terrace (4). The surface of this fragment terrace is covered
by a fossiliferous bed composed of shelly limestone (Plate 2b). The
shells of molluscs have been removed by solution leaving internal and
external moulds. The Molluscs fossils have been identified by Dr. J.
Taylor and C. Nuttal to be *bivalves, Paphia, Davaricella* and indeterminate
gastropods sp. Beneath this fossiliferous bed, there is a consolidated
calcareous soil containing traces of shell remains; the thickness of
this bed is about 1.50 metres.

In order to determine the origin of the sediment involved, soil
samples have been collected for further investigations by particle
size and scanning electron microscope. Concerning the fossiliferous
bed on the surface, fragments of indeterminate shells were collected
in a polythene bag for radiocarbon dating (Fig. 15)

Plate (1). An example of the wadis dissecting the
Jal-Az-Zor escarpment.

Plate (2a). A fragment of the Fourth terrace in Kathma
looking west towards the village of Al-Jahra.

Plate (2b). The fossiliferous limestone which covers the
fragment of the Fourth terrace in Katham.

Plate (3). A cluster of *Ostrea* shells in Kathma

Behind this terrace, there is a fragment of a higher terrace of a similar height to terrace No. 3 in profile KI. Also, there are small clusters of *Ostrea* shells of different sizes (Plate 3). The origin of these shells is not certain; they may represent marine deposits left by higher sea-levels, or they may have been carried down to this level by another agent of transportation; they may belong also to the fossiliferous Fars formation which is exposed in some part of the research area. This problem will be discussed later.

The last terrace slopes gently towards the coast with no traces of more terraces. *Xerophytic* vegetation covers the coastal plain from which soil samples have been collected for particle size and scanning electron microscope analysis. The vegetation increases in density near the coastline.

KATHMA II

The location of this profile is about one kilometer east of profile KI (Fig. 11). The terraces along this line are more or less a continuation of those in profile KI. Apart from the coastal plain which can be considered as a recent terrace in process of formation, there are four terraces cut by the transect.

Lithology and Stratigraphy of the Bedrocks

Apart from the thin superficial deposits which do not exceed one metre on the topmost of the escarpment, the following stratigraphic sequence shows the thickness of each bed from the top of the escarpment to the present coastline   (Fig. 16). The results are derived from field investigation and supplemented from the geological map of Kuwait only when it was very difficult to follow the lowest solid bed. (KII.1) 1-5 metres, conglomeratic sandstone, the clastic grains about 2-4 mm in diameter, usually hard and light in colour. According to Fuchs et al (1968) this formation of gravels and sands is of Dibdibba Formation of Pleistocene

age. The thickness identified in the field is about 3-4 metres.

(KII.2) 5-15 metres . Calcareous sandstone, contains calcareous patches

and has a thickness of about 10 metre.

(KII.3) 15-15.75 metres.: A thin conglomeratic lamina about 0.75 m

in thickness.

(KIII.4) 15.75-23.75 metres. Calcareous sandstone of medium hardness

of a thickness of about 8 metres.

(KII.5) 23.75-31.25 metres. Calcareous sandstone with clay balls rich

in gypsum. The thickness identified is about 7.5 metres. It is not

possible to follow the depth of this formation nor to establish whether

it extends in depth to join (KII.6) or whether there are other

formations between them.

(KII.6) Medium grained to conglomeratic sands and sandstones,

calcareous or quartzose, occasionally cross-bedded, partly fossiliferous;

mainly limestone, variagated shales (Fuchs et al 1968). This formation

is exposed in the lower section of the profile below the more recent

marine deposits.

(KII.7) Beach sand and marshes of Recent age.

Morphology of the terraces

Similarities have been noticed in the field between the terraces

along this line of levelling and those identified in KI. The terraces

in KI extend laterally into KII and give some indication that they might

have had the same history.

In general, the terrace surfaces are covered by superficial deposits

which have been laid down either by wind, as is usually the case, or by

marine agents; the latter have been noticed on the lower terraces. The

escarpment is covered by lag gravels which are usually of fine and

medium sizes of thickness varying from a few centimetres to about one

FIG (16)

PROFILE SECTIONS OF KATHMA Ⅱ SHOWING THE LITHOLOGY OF THE BEDROCKS
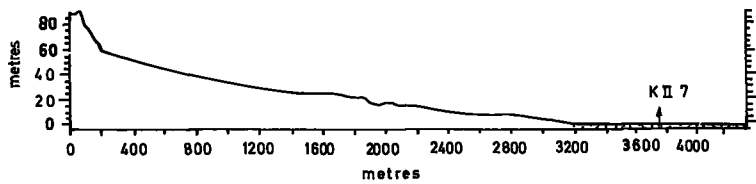
COMPLETE PROFILE
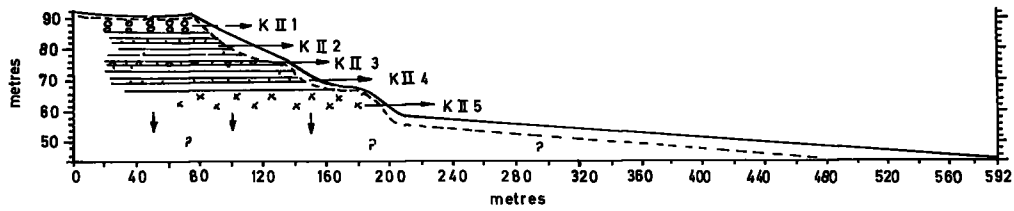
UPPER SECTION

LOWER SECTION
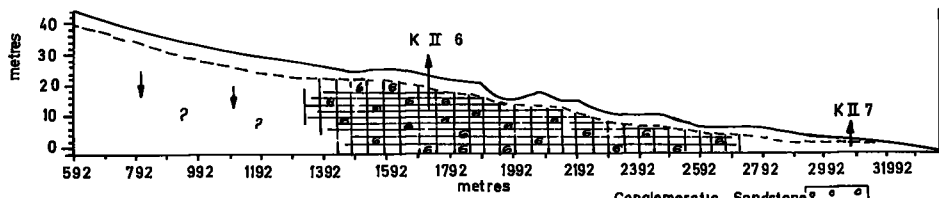
Conglomeratic Sandstone

Calcareous Sandstone

Calcareous Sandstone with clay ball

Sandy limestone, partly fossiliferous

Beachsand and marshes

Probable limit of the bedrocks

metre; from this material a soil sample for particle size analysis
and scanning electronmicroscopy has been collected. (Fig. 17). The
surface of the escarpment slopes steeply into the First terrace,
which appears to be less in width than the First terrace in KI. The
width of this terrace is 60.8 metres, both the terrace and its slope
being covered with the same deposits as KI except that the base of
the terrace has thinner deposits than its back-slope. The existence
of a thick deposit of detritus covering the slope causes the terrace
base to be very narrow in width, and made it very difficult to find
the real width of the terrace base (Fig. 16) although an arbitrary
line was traced below the deposits covering the slope in order to
establish the approximate height of the landward edge of the terrace.
The deposits covering the slope and the terrace are composed of
weathered material from the surface sediments and from the bedrock
together with fine partly cemented sands and gravels. A sample
has been collected for analysis. The mean height of this terrace is
81.53 metres above Kuwait Datum; there were no traces of notches or
caves at the back of this terrace.

The Second terrace has a mean altitude of 69.65 metres above K.D.
and a width of 49 metres. In the field, it was also possible to
follow this feature laterally to terrace No. 2 in KI, and it was
possible to establish the lithology of this terrace and its slope as
they are partly eroded. There were pieces of rocks from the bedrock
broken and settling at the sides of the slope. A soil sample has been
collected from the material covering the slope which seems to be
similar to that covering the First terrace, but the terrace itself is
covered by recent desert deposits and fragments of small size rocks,
from which another sample was collected.

FIG (17)

PROFILE SECTIONS OF KATHMA II SHOWING THE LOCATION OF THE SAMPLES
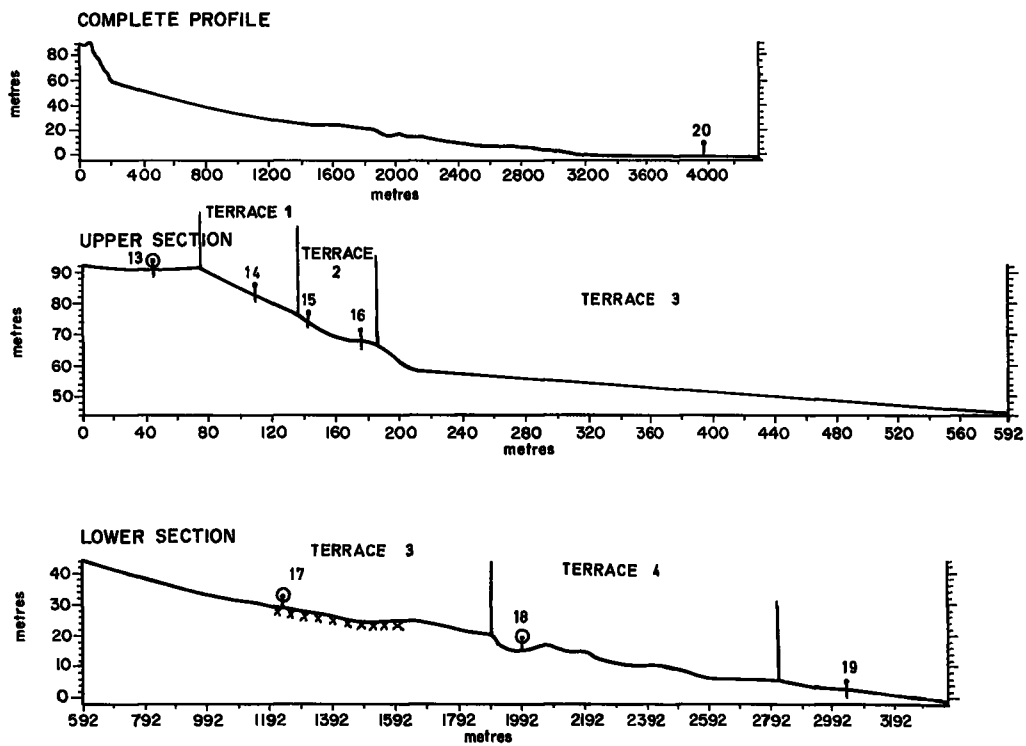
COMPLETE PROFILE

UPPER SECTION

LOWER SECTION

↑ SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS

φ SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS
↑ AND SCANNING ELECTRON MICROSCOPE

xxx FOSSILIFEROUS SURFACE MATERIAL .

From this terrace, the profile slopes to the Third terrace at

a mean height of 40.55 metres above K.D. As fig.(17)shows, this

terrace is very wide in comparison with the last two terraces as it

occupies a distance of 1708.6 metres. Material covering this terrace

is both of terrestrial and marine origin, the upper part of the

terrace, which is illustrated in the upper section of the profile,

is covered by terrestrial deposits. The lower part of the terrace

which is illustrated in the lower section profile, is composed of

partly decalcified shelly limestone, bioclastic, and the shell

of molluscs have been removed by solution leaving internal and

external moulds. The limestone matrix contains sand grains. Shells

include small indeterminate *bivalves*, an internal mould of a *buccinid*

gastropod sp. and part of a high-spired *cerithiid gastropod*.

According to Dr. Taylor and C. Nuttal, the molluscan fossils of

this deposit contains *Turritella?*, *Crassatella*, venerid *bivalves*.

This material is cross-bedded and spreads over a considerable area

(Plate 4). About 1 to 2 metres beneath this deposit, there is a white

fossiliferous bed. According to the geological map of Kuwait, this

formation represents the exposed Neogene which is described in KII.6

Patches of this deposit are exposed on the surface in several places.

A soil sample was collected from the marine deposits for further

investigation and its location is illustrated in fig. (17) . The

surface of this terrace slopes gently towards the Fourth and last

terrace. A distinct concave feature appears at the beginning of the

terrace which is possibly related to the role of erosion in the area,

and a soil sample has also been collected for both particle size analysis

and scanning electron microscopy. The terrace has a mean height of

10.7 metres above K.D. and a width of 985.8 metres. No traces of marine

Plate (4). The Cross-bedded fossiliferous superficial
deposits which overlie the Lower Fars Formation

Plate (5). General view of the terraces in Ghidhai,
looking from the top of the escarpment towards the
south.

action have been traced on this terrace apart from a few shells which could have been transported by the wind. After this terrace the land has a gentle slope and the superficial deposits change from dry sandy terrestrial soils into soft wet soil near the present shoreline with an increase of vegetation near the sea.

GHIDHAI

The third profile is in the Ghidhai area, about 6 kilometres north east of Kathma. Investigation of the area between Kathma and Ghidhai shows that the landscape does not change considerably. The terraces appear consistently along the escarpment and the fossiliferous bed which was found on the terraces at the foot of the escarpment in Kathma appears occasionally in the area. However, Ghidhai itself is an area of more interesting geomorphological features than Kathma; (Plate 5) Here, there are six separate terraces, the height of these terraces ranging between a mean height of about 13 metres for the lowest terrace and 92.62 metres above K.D. for the highest. Plant communities in this area are similar to that of Kathma area.

Lithology and stratigraphy of the bedrocks

As in the previous two terraces, the upper crest of the escarpment is covered by lag gravels and sands of recent and of Pleistocene age with a thickness of about one metre. Beneath this deposit the following beds are found in descending order: (Fig. 18)

(G.1) 1-4 metres. Conglomeratic sandstone similar to that of KI.1 and KII.1 in Kathma area. It has medium hardness and a thickness of about 3 metres.

(G.2) 4-17 metres. At a height of about 4 metres from the surface, there is a fossiliferous white marl, more or less friable, and containing indeterminate shell fragments; the thickness of this bed is about 13 metres.

FIG. (18)

PROFILE SECTIONS OF GHIDHAI SHOWING THE LITHOLOGY OF THE BEDROCKS

COMPLETE PROFILE

UPPER SECTION

LOWER SECTION

Conglomeratic Sandstone
Fossiliferous marl
Fossiliferous Limestone
Calcareous Sandstone
Argillaceous Sandstone
Sandy limestone, partly fossiliferous
Beachsands and Marshes
Probable limit of the bedrocks
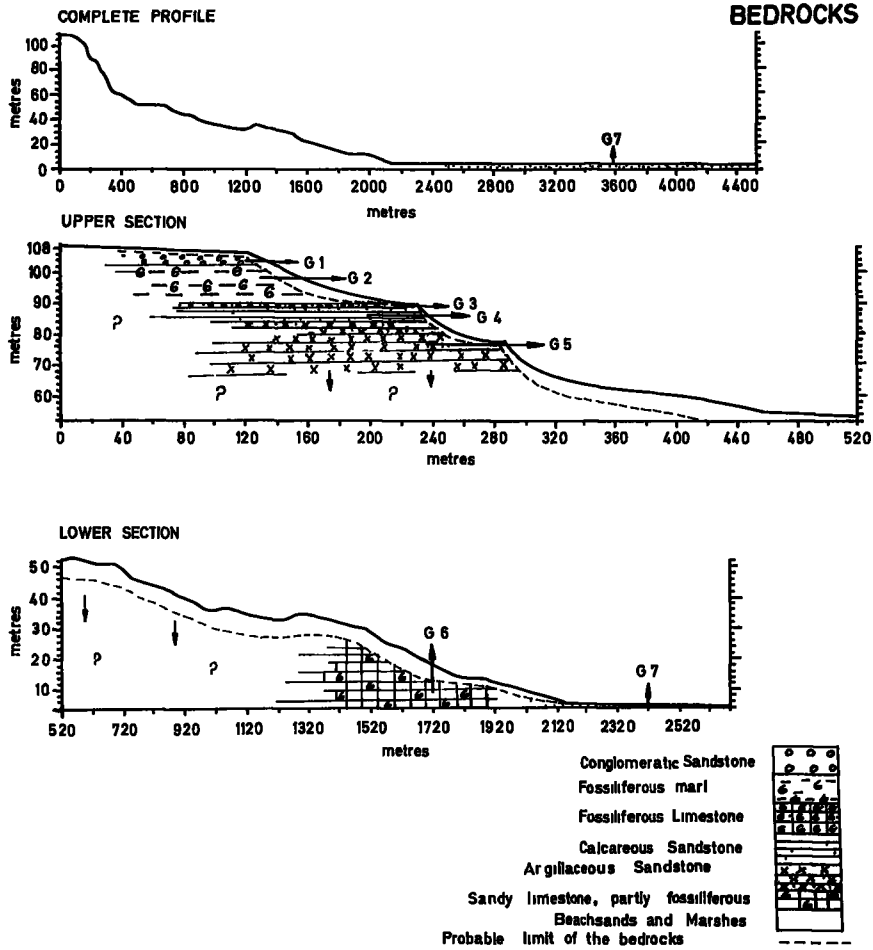
(G.3) 17-18 metres. A highly fossiliferous limestone, extremely rich in fossil shells. This bed is about one metre thick.

(G.4) 18-24 metres. Calcareous sandstone, medium hard with a thickness of about 5 to 6 metres.

(G.5) 24 - ?mCalcareous sandstone with clay balls, rich in gypsum. Its thickness is not known, neither whether there are any other beds between G.5 and the following G.6.

(G.6) Medium grained to conglomeratic sands and sandstone, calcareous or quartzose, occasionally cross-bedded, partly fossiliferous, marly limestone with variegated shales. This formation is sometimes exposed on the surface in between the lower terraces but it is largely covered by more recent deposits. This formation appears to belong to the exposed Neogene.

(G.7) Beach sand and marshes of Recent age.

Morphology of the terraces

A field examination of aerial photographs and topographic maps of the area showed that there are well developed terraces extending along the escarpment. Numerous shorelines can be followed for great distances by visual means (Plate 5). The terraces were found to carry patches of deposits which have been laid down by the wind or by the sea itself. The deposits which have been laid down by the wind hide the bedrock and the marine deposits. In some areas they are firmly cemented to the surface of the bedrock.

In contrast to the terraces in Kathma, the First terrace in Ghidhai is wide, - some 110 metres. The terrace has no clear extension east of the transect line and finishes there suddenly, giving way to the face of the escarpment which appears as a sharp cliff. To the west, the terrace tends to be more evident, although it changes in width. The

mean height of this terrace is 92.62 metres above K.D. and it is covered

by fine gravel and sand except along the gully sides where the bedrock

is exposed on the surface. Both the landward edge and the slope of the

terrace, as well as the top of the escarpment, are covered with deposits

similar to those covering the base of the terrace. The tracing of the

landward end of the terrace was almost impossible because of the thickness

of the deposits covering the slope. This phenomenon in fact applies

to almost all the terraces and has been noticed in the previous area and

the following areas and similar problems arise.

At the edge of the terrace about 20 centimetres below the surface,

there exists a fossiliferous bed carrying superficial deposits from which

a sample has been collected, (Fig. 19) This horizon is about one metre

in thickness and is highly fossiliferous and containing the remains of

gastropods, bivalves, half shell of *Thais* species, very closely related

to *Thais carinifera* (Lamarck). This horizon can be easily observed

as it is exposed along the slope and faces the sea. (Fig. 19)

The slope of the Second terrace is steeper than that of the First.

Fragments of the fossiliferous bed mixed with the terrestrial deposits

hide the slope and a large part of the back of the second terrace. The

mean elevation of the terrace is 79.27 metres above K.D. and has a

width of only 58.4 metres as well as a very limited horizontal extension;

it may represent a fragment of a larger terrace. The bedrock of the

Second terrace is largely exposed on the surface with a very thin super-

ficial deposit mainly composed of windblown sands, and consolidated sands

and fine gravel, from which a soil sample has been collected.

The Third terrace is at mean height of 65.0 metres above K.D., its

slope is covered by partly consolidated sands and fragments of white

limestone, from which a sample has been collected for analysis. A large

FIG(19)

PROFILE SECTIONS OF GHIDHAI SHOWING THE LOCATION OF THE SAMPLES
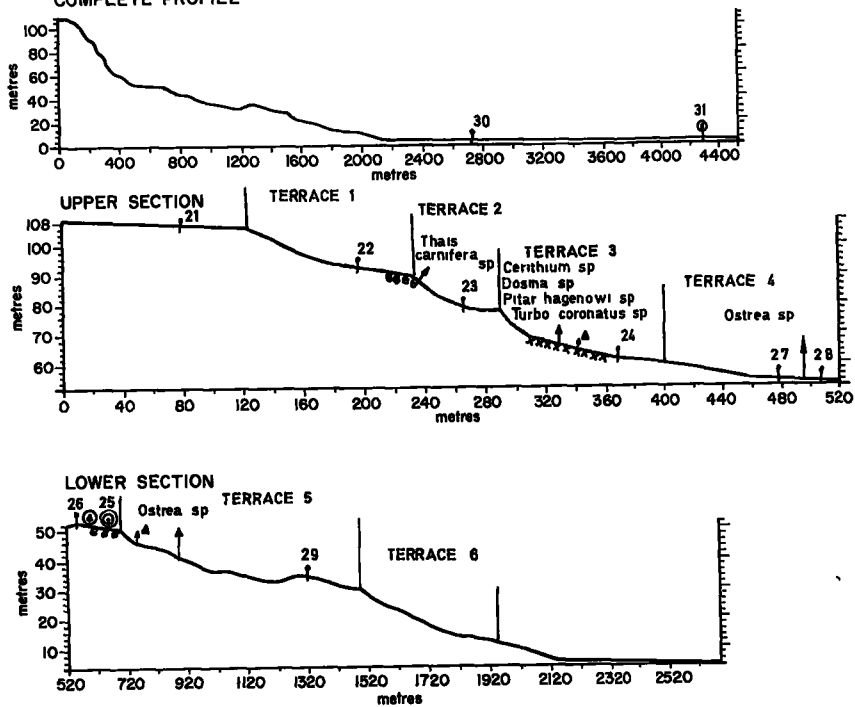
COMPLETE PROFILE

UPPER SECTION

LOWER SECTION

| SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS

φ SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS
AND SCANNING ELECTRON MICROSCOPE

◎ SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS
AND SCANNING ELECTRON MICROSCOPE FROM POINTS
OFFSET FROM THE TRANSECT LINE

xxx FOSSILIFEROUS SURFACE MATERIAL

᪲᪲᪲ FOSSILIFEROUS BED

↑▲ C 14 DATING OF SHELLS

◉ C 14 DATING OF SHELLS OFFSET FROM THE TRANSECT
LINE

↑ IDENTIFIED MOLLUSCA SPECIES

part of the terrace is covered by fossiliferous deposits (Fig. 19)

consisting of bioclastic limestone and sand grains with casts of

gastropods and *cirithiids* which have been weathered out of limestone

by solution and mechanical weathering. The terrace is also strewn

with shells of different sizes of *Ostrea* sp ., similar to those found at

Kathma area. Other shell species which were found there and

identified by M.H. Biggs include *Dosinia* sp, *Turbo* sp., *Pitar hagenowi* and

Cerithium sp. (Fig. 19). A sample has been radiocarbon dated for age

determination of this terrace which extends in width to 107.2 metres.

This terrace is dissected by small and long wadis descending from the

upper crest of the escarpment.

The Fourth terrace has been traced almost continuously along the

escarpment from Kathma to Ghidhai and almost as far as the Al-Bahra

area to the east. It stands at a mean elevation of 52.94 metres above

K.D. but this height changes along the escarpment from west to east,

and has a width of 250.2 metres. The most conspicuous feature of this

terrace is the fossiliferous deposit which is exposed on the surface

in some areas but in others is covered by aeolian deposits. At the

seaward part of the terrace a profile section shows that the upper

surface is composed of shelly limestone of marine origin, contains fragments of

shells and indeterminate *bivalves, veneracea*. This discontinuous deposit

has a maximum thickness of one metre; a sample of fragments of shells

was collected (Fig. 19) and submitted for radiocarbon dating in order

to find out whether there is an age relationship between this terrace

and that of Kathma which carries similar fossiliferous bed.

Terrace number 5, which has a mean height of 33.6 metres above K.D.

possesses no evidence of marine action and the bedrock is composed of medium

coarse grained calcareous sandstone, covered by windblown sands

consolidated with fine gravels from which a soil sample has been collected for particle size analysis. As fig. (19) shows, it extends for some distance and slopes gently into a fragment of a sixth terrace of a mean height of about 13 metres above K.D. It has no clear lateral extension along each side of the levelling line, but fragments of this terrace have been traced around the area.

On the surface of this terrace and on the landward parts of the terrace, a sample of *Ostrea* sp. was collected for radiocarbon dating. Shells of different sizes were found in clusters in a similar manner to those found in the Kathma area.

The coastal plain slopes gently towards the present shoreline and it is covered by deposits of terrestrial and marine origin. The plain is scattered with plant communities similar to those found at Kathma. Sabkhah covers a very narrow strip at the end of the levelled line which is partly covered by vegetation.

MUDAIRAH

This area is situated in the middle of the coastal zone north of the bay of Kuwait before the escarpment changes its direction in the Al-Bahra area.

The landscape here is characterised by being more gentle than Ghidhai, but there are few scattered hills which are of sands or sandstone.

At the edge of this area salty sabkah appears. The sabkah is bare of vegetation and can be observed as a white plain extending east of Mudairah. In general, there is a similarity between the plant community of this area and those of Ghidhai and Kathma. Investigation of the area between Kathma, Ghidhai and Mudairah showed that the terraces appear more or less consistently along the escarpment,

especially the upper three terraces. Patches of the white fossiliferous bed, which was found at the foot of the escarpment in the previous two areas appear between Ghidhai and Mudairah. The same was also noted in connection with the thin fossiliferous bed (G.3) in line G of Ghidhai. This was found also between Ghidhai and Mudairah, although it is more clearly visible in some places than others and the thickness varies from about one metre to a maximum of about 2 metres.

Stratigraphy and lithology of the bedrocks

Collecting rock samples to draw the stratigraphic sequence of this line (M) was more difficult than in the previous areas, as the bedrocks here are not often exposed along the gully sides. The stratigraphy of this profile (Fig. 20) has been drawn from field observations and from information provided by the cross-sections drawn by Fuchs et al. (1968).

Five terraces have been traced along the levelling line, their heights ranging between a mean height of 11.60 metres for the lowest terrace to a mean height of 71.12 metres above K.D. for the highest. The terraces here appear generally to lie at a lower height than in the previous areas.

As in the last three profiles, the topmost of the escarpment is covered by lag gravels mixed with windblown sands. The thickness of this deposit varies from place to place, so near the seaward side of the escarpment it has a thickness of about one metre.

(M.1) 1-9 metres. Conglomeratic sandstone of a medium hardness is one metre below the surface of the topmost level of the escarpment and was traced to a depth of 8 metres.

(M.2) 9-19 metres. This horizon is harder than (M.1). It is composed of calcareous sandstone and covers the First terrace. It has a thickness of about 10 metres.

(M.3) 19-26 metres. From a depth of 19 metres beneath the upper surface

down to 26 metres and for a thickness of about 7 metres, the rock is
composed of soft limestone with many well rounded sand grains.

(M.4) 26-27 metres. Highly fossiliferous limestone, extremely rich
in fossils (shells)(Plate 8a & 8b). This is a thin horizon of about
1 metre.

(M.5) 27-30·Calcareous sandstone of medium hardness, with a
thickness of about 3 metres.

(M.6) 30-31.0 metres. Another fossiliferous bed of a maximum
thickness of one metre. It was difficult to decide whether this
horizon is superficial or whether it is part of the stratigraphy
of the terraces, due to the difficulty of finding an exposed surface.
The thickness of this horizon is about 1 metre.

(M.7) 31.0-? metres, medium grained to conglomerate sands and sandstone,
calcareous or quartzose, occasionally cross-bedded, partly fossiliferous,
mainly limestone; variegated shales. This formation belongs to the
exposed Neogene (Fuchs et al 1968).

(M.8) Beach sands and marshes of Recent age.

Morphology of the terraces

The landscape below the escarpment is rather gentle, with remnants
of terraces scattered in the area (Plate 6). On this part of the
escarpment three clear terraces (Plate 7) and two low ones have been
identified. Marine action in this area is expressed in the fossiliferous
deposits and fossil shells scattered on the terraces. The mean height
of the terraces ranges between 11.61 metres for the lowest and 71.12 metres
above K.D. for the highest, while their width varies from a few metres
to over one kilometre.

The upper surface of the escarpment is artificially pitted by holes,
as a result of the collection of gravels for building purposes.

FIG (20)

PROFILE SECTIONS OF MUDAIRAH SHOWING THE LITHOLOGY OF THE
BEDROCKS

COMPLETE   PROFILE

UPPER   SECTION

LOWER   SECTION

Conglomeratic Sandstone
Calcareous Sandstone
Sandy Limestone
Fossiliferous Limestone
Sandy limestone, partIy fossiliferous
Beachsand and marshes
Probable limit of the bedrock   — — —
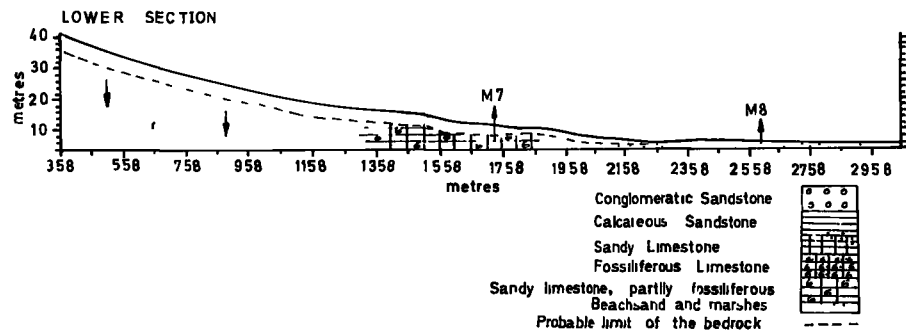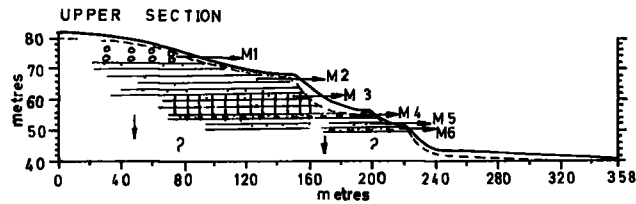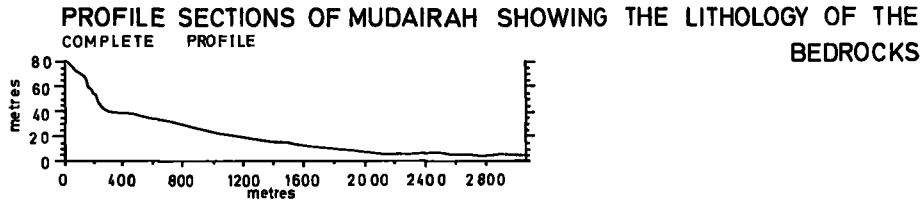
Plate (6). General view of the terraces in Mudairah
looking east towards Al-Bahra area. Note the low
topography of the terraces.

Plate (7). Profile of the upper three terraces in
Mudairah, view looking west.

The thickness of this deposit reaches to about 2 metres in some areas, but this decreases when one descends, and a sample was collected for analysis (Fig. 21). From the upper surface of the escarpment, the land slopes gently into the First terrace which has a width of 76.8 metres, this is a well developed terrace and its lateral continuation can be followed visually for a considerable distance. Both the terrace base and its slope are entirely covered by terrestrial deposits from which a sample was obtained. It is only towards its seaward end (Plate 7) that the bedrock is exposed, at which point the mean measured height of the terrace is 71.12 metres above K.D.

Descending to the Second terrace it was found difficult to trace the junction between the base and its slope, because as the photograph illustrates(Plate 7), more recent deposits especially fine windblown sand as well as fragments of the bed of the First terrace cover the landward part of the terrace, where the soil sample was collected. The bedrock is exposed in some parts, especially near its slope, but towards the seaward end of the terrace the limestone bed tends to be thinner and give way to the fossiliferous bed to appear on the surface and along both sides of the terrace, (Figs. 20 & 21 and Plates8a and 8b). This horizon is similar to that which was found in Ghidhai and it may belong to the same origin. It is composed of shelly limestone which contains casts of *bivalves* and small *gastropods* . This terrace has a mean elevation of 59.57 metres above K.D. and a width of 49.2 metres. From this, we descend to the Third terrace which is small in size and has very limited lateral extension on both sides of the levelling line. Its width does not exceed 20.2 metres. A fossiliferous bed resembling that which was found on the Second terrace is found on the base of this terrace (Fig. 21) although its thickness here does not exceed ½ metre. The mean height of the terrace is 52.30 metres above K.D.

FIG (21)

PROFILE SECTIONS OF MUDAIRAH SHOWING THE LOCATION OF THE SAMPLES
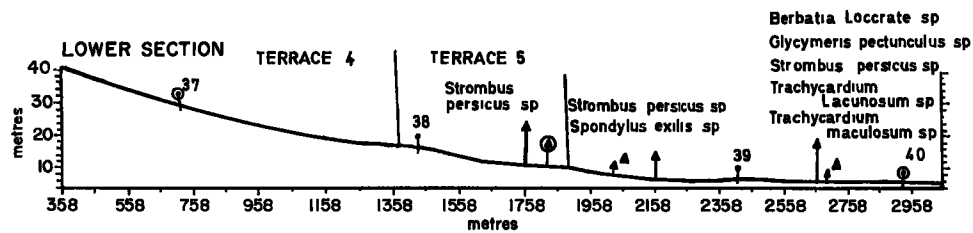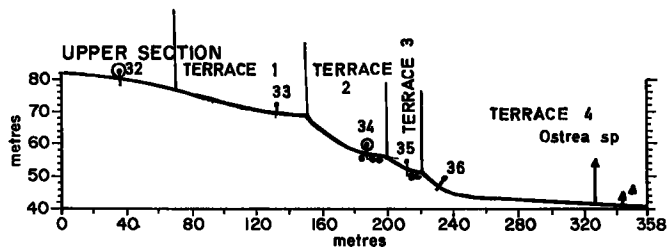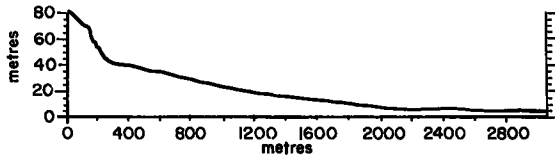
COMPLETE PROFILE

UPPER SECTION

TERRACE 1

TERRACE 2

TERRACE 3

TERRACE 4
Ostrea sp

32 33 34 35 36

LOWER SECTION

TERRACE 4

TERRACE 5

37 38 39 40

Strombus persicus sp

Strombus persicus sp
Spondylus exilis sp

Berbatia Loccrate sp
Glycymeris pectunculus sp
Strombus persicus sp
Trachycardium
Lacunosum sp
Trachycardium
maculosum sp

| SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS

⌽ SOIL SAMPLES USED FOR PARTICLE SIZE ANALYSIS
AND SCANNING ELECTRON MICROSCOPE

⊛⊛⊛ FOSSILIFEROUS BED

↑▲ C 14 DATING OF SHELLS

⊕ C 14 DATING OF SHELLS OFFSET FROM
THE TRANSECT LINE

↑ IDENTIFIED MOLLUSCA SPECIES

Plate (8a): An exposure of the fossiliferous bed at
the edge of the Second terrace in Mudairah.
(Hammer is resting against the bed).

Plate (8b): A close-up photograph of the fossiliferous
bed.

and a soil sample has been collected from there. The slopes of this

terrace and the one below are covered by windblown sand.

Lower still extend two terraces, the Fourth has a width of 1149.2 metres

and the Fifth of 521.4 metres. Their mean heights range from 31.23 metres

for the former and 11.61 m. above K.D. for the latter. Aerial photographs

and field investigation show that there are fragments of the Fourth

terrace extending all the way from Kathma to Mudairah. Here the terrace

is covered by terrestrial and marine deposits. The latter being found

on the upper part of the terrace. The marine deposit is composed of sand

with millet seed grains and quartz pebbles. Fragments of partly

decalcified bioclastic shelly limestone contain casts of large buccinid

gastropods. Fossil shells of *Ostrea sp.* have also been found scattered

around and a sample has been submitted for radio-carbon dating. It was

found at a height of about 40-42 metres above K.D. The slope of the

terrace is covered by terrestrial deposits as well as some parts of

the middle from which a soil sample has been investigated by particle

size and scanning electron microscope, and the seaward part is formed of

red sandstone with a thickness varying from a few centimetres to about

50 centimetres. The last terrace along this profile (M) is represented

here by a fragment of an older more extensive surface; the mean height

is 11.61 metres above K.D. The superficial deposits covering its base

are similar to those covering the previous terrace, but have no deposits

of marine origin. This terrace has no obvious lateral extension, but

from observations in the area, fragments of similar height and

composition are scattered around Mudairah. Shells (*Strombus persicus*)

are strewn on the terrace here and a sample has been collected for dating,

soil samples for analysis have been collected from this terrace and the

lower coastal plain (Fig. 21.).

South-east of this terrace, the land slopes gently to the coastline where deposits are composed of saline soil covering parent material of shelly sand. The drainage in this area is poor and the texture ranges from sand to clay. Vegetation is richer in this area, especially near the coastline. Marine shells are scattered in this zone (Fig. 21) and have been identified by Mr. H. Biggs as: *Strombus persicus sp.,* (Swains)

Valves of *Trachycardium Lacunosum* (Reeve),

Valve possibly *T. maculosum* (Wood),

Valves *Glycymeris pectunculus* (Linné)

Valve *Barbatia lacerata* (Linné), (parmulophora) Corrugata (Dillwyn),

besides fragments of *Spondylus, ?exillis* (Sowerby).

Two samples of shells at a height of about 7.23 and 5.11 metres above K.D., have been also submitted for age determination by radiocarbon dating method.

AL-BAHRA I

Immediately north of Mudairah, the escarpment gradually retreats further inland, allowing the coastal plain to expand to where it reaches its maximum width in central Al-Bahra, (Fig. 2). From the latter locality the scarp swings in a broad arc through east to a south-east direction until it meets the present shoreline as a cliff-face. The escarpment also has a more gentle gradient within this part of the area than in Kathma, Ghidhia and Mudariah and its crest declines gradually towards the east. Deep wadis do not appear to have a role in this area. Here again, the terraces have a lower elevation than in the previous areas and some of the terraces are only represented by short discontinuous fragments. This phenomenon is common in Al-Bahra as was discovered during the fieldwork and from aerial photographs. Another general characteristic of Al-Bahra is the width of the terraces. In general, they have the greatest width, but they are less well preserved,

As far as the plant community is concerned, a large part of the Al-Bahra is covered by its coastal sand association of vegetation, chiefly *Panicum turgidum* and *Rhanterium epappossum*, which covers almost all the area.

Profile number (AI) in Al-Bahra is situated west of the Al-Bahra area (Fig. 11). Along that profile six terraces and fragments have been located. One of the difficulties met in this region was to trace rock outcrops along the profiles, because, as has been mentioned before the low topography of the area and the poor state of preservation of the terraces together with the lack of valleys cutting across the terraces made it almost impossible to draw clear stratigraphic lines. However, the following stratigraphic description along the profile (Fig. 22) is tentatively presented, drawn almost entirely from field investigation.

Three main horizons have been identified on the upper section profile (Fig. 22) where there were eroded sections along the terraces. 0-1 metre. The upper surface is covered by the lag gravel of the same deposit and origin as that which covers the topmost surface of the escarpment in Kathma, Ghidhai and Mudairah. The thickness of this deposit varies from a few centimetres to one metre.

(AI.1) 1-12 metres. White conglomeratic sandstone containing many sand grains and pebbles. The approximate thickness is about 11 metres (Fig. 22).

(AI.2) 12-24 metres. Calcareous sandstone of medium hardness with a thickness of about 12 metres.

(AI.3) 24-? metres. White limestone containing sand grains; this horizon is not exposed in a continuous area but it is thought that it extends into the Second terrace. Its thickness cannot be decided because of the long gentle slope of the terrace. Neither was it possible to

recognise whether there are other formations between this horizon and formation No. AI.4).

(AI.4)-?metres..According to the geological map of Kuwait the area between the Jal-Az-Zor escarpment and the beach material is part of the exposed Neogene; however, this formation was not identified along this line except on the landward slope of the last terrace. It is composed of medium-grained conglomeratic sands and sandstone, calcareous or quartzore, occasionally cross-bedded, partly fossiliferous, mainly limestone, variegated shales.

(AI.5) Beach sands and marshes of Recent age.

Morphology of the terraces

More terraces have been identified in this part of Al-Bahra than those in previous areas, as it was possible to trace and level the remains of six terraces   (Fig. 23). ʾ Almost all the terraces slope gently towards the sea and most of their surfaces are covered by solid rocks. Two kinds of deposited material were found covering the terraces; deposits of marine and terrestrial origin. The latter are mainly concentrated on the upper sections of the profiles on the highest terraces along the escarpment, while that of marine origin is found mainly on the lower terraces. A few shells found very close to the coastline have been collected and are similar to those of the Mudairah area with a predominance of *Strombus persicus*.

The topmost surface of the escarpment which is covered by the lag gravels and sands slopes gently into the First terrace which has a mean height of 79.85 metres above K.D. Both the slope and the terrace, which extends in width into 165.4 metres, are covered with fine gravels and sands partly consolidated and mixed with weathered material of the bedrock. Soil samples which have been collected along this line are

FIG. (22)

PROFILE SECTIONS OF AL - BAHRA I SHOWING THE LITHOLOGY OF THE BEDROCKS

PROFILE SECTIONS OF AL-BAHRA I SHOWING THE LOCATION OF THE SAMPLES

FIG. (23)

COMPLETE PROFILE

Metres

Metres

UPPER SECTION

FIRST TERRACE

SECOND TERRACE

Metres

THIRD TERRACE

FOURTH TERRACE

FIFTH TERRACE

Metres

LOWER SECTION

SIXTH TERRACE

Metres

Metres

Soil samples used for particle size analyses

Possiferous surface material

Soil samples used for particle size analyses and scanning electron 'microscope'
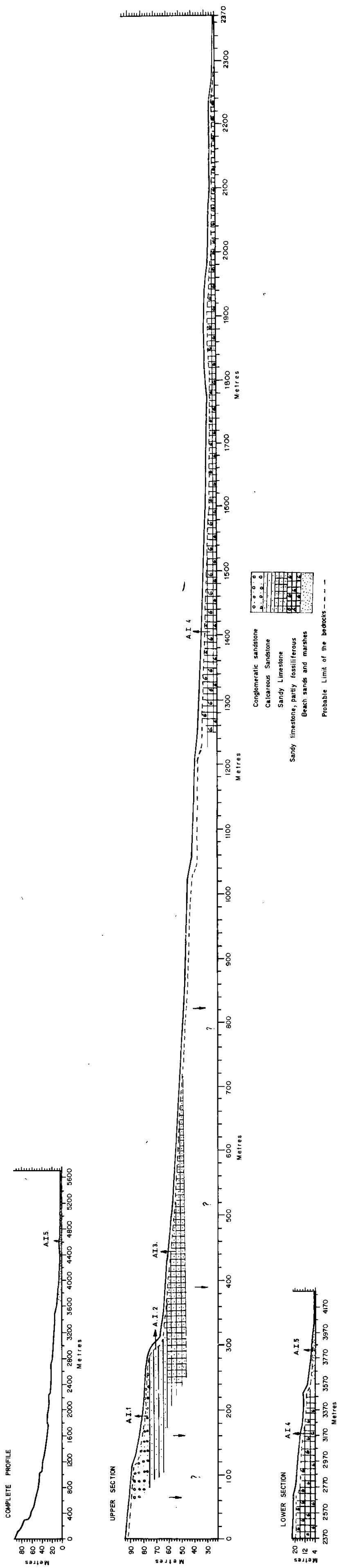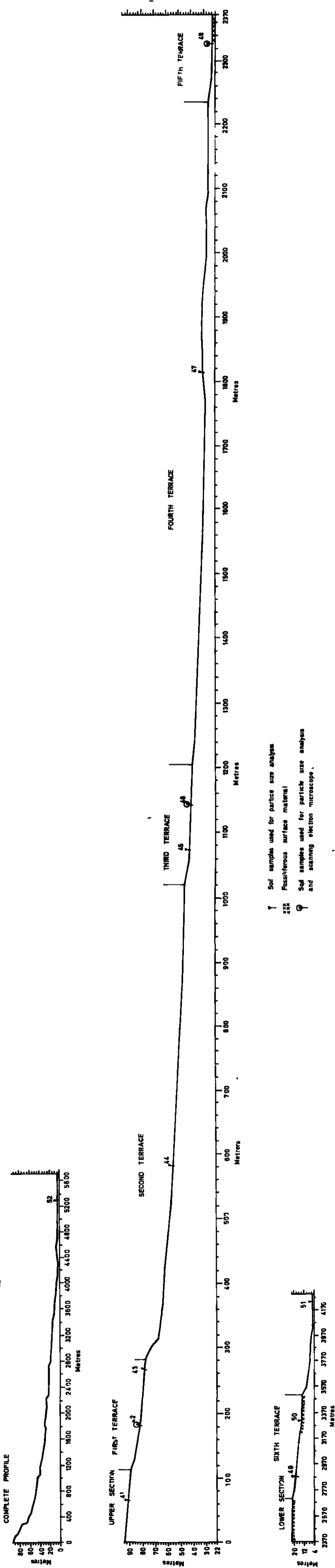
located in fig.(23). The bedrock of conglomeratic material is exposed along some parts of the terrace sides and no signsof marine action are imprinted in any way on that terrace.

From this terrace, the surface drops more or less vertically into the Second terrace. Neither the landward end of this terrace nor its slope possesses marine deposits, notches, or even holes which might suggest any biological action. The superficial deposits covering this part of the terrace are merely of terrestrial origin and the slope has been largely covered by windblown sands. It has been noticed also that the back of this terrace is dissected by several small shallow wadis filled with fine windblown sands. These wadis are the remains of an old drainage system which was once fed by water descending from the upper surface of the escarpment. The terrace has a mean elevation of 56.10 metres above Kuwait Datum and a width of 741.8 metres.

The Third terrace has a mean height of 40.39 metre K.D. There is no linear extension of this terrace and it is represented by fragments of terrace surfaces which can be followed towards the east and west. The terrace has a width of 183 metres and is only covered by fragments of red sandstone and thin terrestrial deposits. It grades into the next terrace with a very gently slope.

The Fourth terrace has a similar character in that it is composed of fragments of terrace surface. The slope of this terrace is covered mainly by weathered material from terrace No. 3 and windblown deposits, the terrestrial deposit which is mainly of sand and fine pebbles, has a thickness of about one metre. Reddened sandstone appears more clearly towards the seaward end of the terrace, it does not extend as one unit sheet of hard rock,

but is often broken into small pieces. The terrace stands at a
mean height of 31.79 metres above K.D. The dome feature which stands
near the edge of the terrace is merely an accumulation of medium and
fine gravels consolidated with sands covered with some vegetation.
The width of this terrace has been found to differ from place to place
in the area, and the distance measured here on the transect is 1030.2
metres.

The last two terraces in this area (Plate 9) were clearly
identified as following each other in downward sequence. Their lateral
extensions were also well-developed in the area. The surfaces of both are
covered by red sandstone, and veneered with sands and fine gravels.
The first of them (terrace No. 5) has a mean elevation of 22.32 metres
above K.D. and a width of 482.2 metres. The lower part (Fig. 23 and
Plate 9) of the terrace is covered by rose-colour granular, porous lime-
stone containing many fragments of fossils which have been identified
by Dr. Taylor of the British Museum as being the remains of Crab.
When the thickness of this deposit was measured, it was also found to vary
from place to place, but here it has a maximum thickness of about one metre.

The last terrace in the sequence is terrace number six. It has
a gentle slope covered by weathered material of the bedrock of terrace
No. 5 and terrestrial deposit. The terrace mean elevation is 16.10
metres above K.D. and most of its surface is covered by red sandstone
with very small amounts of sands. Vegetation is almost absent
on this terrace which extends to 779.8 metres in width. Only the
rocks at the outer edge (Fig. 23) contain fossil fragments, the red
fossiliferous rock having indeterminate *crustacean* fragments
(Dr. Taylor per. comm.).

This deposit overlies hard rocks composed of off-white compact
limestone, yellow and red stained in places which may belong to the

Plate (9).   Fossiliferous deposits at Al-Bahra

Plate (10).   The last terrace along AII transect showing
the embayment-like feature, the dotted line represents
the direction followed by the levelling line.

exposed Neogene in the area. These two formations form a cliff
in some parts at the edge of the terrace. It was not possible to
see the lower part of the cliff as it was covered by fine windblown
sand. In other parts of the terrace, this form of cliff disappears
and the terrace seems to converge very smoothly into the present
coastal zone. Immediately after the descent into the coastal plain
vegetation of *halophytic* type grows in density and holds the sand,
behind which small hills are sometimes formed, as the one which is
illustrated at the end of the present profile. The vegetation then
decreases in size and quantity until the area is composed merely of
sabkhah deposits.

AL-BAHRA II

The second line of levelling (A.II) is situated in the north-east
of the Al-Bahra area and just before the Jal-Az-Zor escarpment changes
its direction towards the south (Fig. 11). The escarpment here follows
an irregular shape and the terraces in this area are obscured and do
not have a clear areal extension. Most of the terraces, apart from the
lowest one, are represented by fragments, which can be followed around
the coast and usually end in a cliff. The marine deposits here are
confined to the lower terraces, especially on their seaward margins.
The upper terraces are entirely covered by terrestrial deposits which
occur on the surface of most of the terraces, hiding their bedrock
as well as their slopes. The thickness of these deposits ranges from
a few centimetres to more than a metre.

Lithology and Stratigraphy of the bedrocks

The difficulties in following the stratigraphy of the terraces in
some of the previous areas have also been met along this profile. The

main reason being the low amplitude of the terraces, the disappearance

of the deep wadis which were pronounced between Kathma and Mudairah

and cut exposures in the terrace sides, and the widespread terrestrial

deposits which, as has been mentioned before, cover large parts of the

base-rock. Information entirely depending on the rock samples

collected during investigating the area gives the following results:

(Fig. 24)

The surface of the escarpment is covered to a depth of 1.0 to 1.5 metres,

by superficial deposits of sand and gravels of fine and medium size.

(AII.1) 1.5-4.5 metres. Conglomeratic sandstone containing many sand

grains and sand pebbles of fluviatile or deltaic origin with a thick-

ness of about 3 metres.

(AII.2) 4.5-10.5 metres. Calcareous sandstone with small pebbles, of

a thickness of about 6 metres.

(AII.3) 10.5-28.5? metres. Soft bedded limestone containing many sand

grains. The thickness of this terrace is not certain, but the next bed

has been found 18 metres below this deposit on the second terrace. The

terrestrial deposit which covers parts of the terrace base and its slope

obscures the situation.

(AII.4) 28.5-29.5 metres, has been traced at the landward side of the

second terrace. It is composed of stratified pebbly sandstone with

calcareous cement and has a thickness of about 1 metre.

(AII.5) 29.5-32.5 metres, underlies the previous bed; there is also

contained another horizon composed of calcareous sandstone. It contains

large sand grains and small pebbles. As the base of the slope of the

next terrace is not largely covered by terrestrial deposits, it is easy

to trace this horizon into the next terrace. The thickness of this

horizon is about 3 metres.

(AII.6) 30.5-?m. Variegated orange to yellow fine grained sandstone with calcareous cement, partly fossiliferous; thickness is not known. It is more probable that the bed is a continuation of the exposed Neogene.

(AII.7) Beach sand and marshes of Recent age

Morphology of the terraces

The upper surface of the escarpment slopes into the First terrace, the slope being dissected by dry small wadis filled by sands. The First terrace along this line is remarkably wide, being 724.1 metres. It has a mean elevation of 63.72 metres above K.D. This terrace can be followed horizontally east and west of the levelled line. The superficial deposit is of windblown sands and gravels and small broken material of the conglomeratic deposit. The soil samples which have been collected are located in fig.(25). Towards the seaward part of the terrace, the deposit tends to be thinner and allows the bedrock to appear in some places.

The Second terrace in descending order, has a mean height of 47.82 metres above K.D. It is dissected by two distinct wadis which are dry with some scattered shrubs. The wadis meet at the lower part of the terrace. Although this terrace appears clearly to descend into another small and lower terrace, its lateral continuation is not very evident, but fragments of this terrace have been noticed scattered in the area. The width here is 282 metres but this width varies in the area and even with the help of the aerial photographs, it is difficult to follow the right remnants. The slope of this terrace is also covered by terrestrial deposits which become thinner towards the sea and the bedrock of red sandstone is exposed on the surface in several areas.

Although the superficial deposits indicate in the field that they are of non-marine origin, soil sample was collected for further laboratory examination (Fig. 25). From this terrace, the land slopes gently into a Third narrow terrace which has a mean height of 39.45 metres above K.D. and extends a short distance in width to 118.6 metres. The slope of this terrace is partly hidden by wind-blown sands, while the terrace base is veneered with fragments of red rock and very thin terrestrial deposits.

The lower, or the seaward part of the terrace is covered by a fossiliferous deposits (Fig. 25) which contains *gastropod* fragments. This deposit has been found scattered in the area in small patches.

Terrace Four is also characterised by being composed of several fragments. Sands and fine gravels are accumulated on the surface and beneath them there is a fine grained, stratified red sandstone of medium hardness. The mean height of this terrace is 29.86 metres above K.D. and extends in width to 864.4 metres. There is no trace of the Third terrace fossiliferous bed on this terrace, nor of any other marine action, except that in some places, about a metre below the surface, a hard base appears to be of the fossiliferous Neogene.

The terrace fragments slope into the last and Fifth terrace which has a mean elevation of 14.43 metres above Kuwait Datum. In the field it was clear that this terrace does not stretch parallel to the present coastline, but has an undulating face. Around the levelled area, the terrace to the west extends more or less parallel to the coastline, then it retreats towards the interior in a zig-zag shape, forming an embayment-like feature, (Plate 10). This has an effect on the recorded transect profile (Fig. 25), because the levelling line, following a straight direction from the upper part of the escarpment

to the present coastline, crossed twice over the same Fifth terrace.
The last concavity in the lower section profile represents the base
level of the lowland in between the terrace. The dotted line
represents the original slope of the terrace, while the two small
concave shapes beneath the supposed original base of the terraces
are also related to the levelling procedure. Material eroded from
the terrace surface and redeposited in a depression forms a small
rise. (Plate 10). The terrace width average along the transect line
zone is 616.6 metres and its slope is covered by weathered material
from the upper terrace as well as by fine windblown sands. The upper
part of the terrace is veneered by broken red sandstone of a thickness
which does not exceed 50 centimetres. Beneath it,is the variegated
orange to yellow medium to fine grained sandstone, calcareous and
partly fossiliferous. (AII.6)

Towards the seaward end of the terraces the bedrock is covered
by consolidated beachrock, yellow to red in colour. It is mainly
composed of indeterminate shell fragments and sand grains cemented
together by calcite. This marine deposit has a thickness varying
from a few centimetres to a maximum of 1.5 metres. It rests on a
cliff of sandy limestone (Plate 11)which has traces of fossils which
may, according to Dr. Taylor and Mr. C. Nuttal, be *Hydrobia*. The
cliff stands almost vertical and at its base there is a cave, the
exact height of which is not known because of the thick sands and rock
fragments from the superficial marine deposit which covers large
parts of the floor (Plate 11). Large blocks of the overhanging parts
of the marine deposit have collapsed, and been covered by aeolian sands, hiding
the bedrock in this area; as part of the topography they form the
convex shape just below the main part of the terrace noted on
figure 25.

Plate (11). Beach rock overlying the Bedrock and forming
a cliff. Note the small cave which is blocked by
falling rocks and sands.

Plate (12). The superficial deposits covering the top
of the escarpment, gravels of different sizes can be
noted.

Several broken and complete fossil shells have been scattered or cemented onto the surface of the beachrock and in the lowland in between the area, at different heights. Some of these shells have been dated by radiocarbon dating method and they have been identified as *strombus persicus* and *Thais cornifera*(lamarck,)(Fig. 25)

Downslope of this terrace the land slopes evenly into the coastal plain with scattered vegetation. The superficial deposits here are composed of sands of marine and terrestrial deposits with a higher percentage of clay content.

AL-BAHRA III

This is the last levelled line in Al-Bahra area, located about five kilometers south-east of line AII, (Fig. 11) The height of the terraces in this area conform with the general tendency of a decrease from west to east. The escarpment here changes its direction towards south-east and east, progressing towards the sea leaving a very narrow coastal plain. As a result the last terrace ends in a cliff in a similar way to that of AII but with a lower height.

Between the AII and AIII profiles, fragments of terraces are numerous (Fig. 2). Some of these terraces have been traced all the way between the two transects and often carry similar deposits. Here also marine deposits which were found to be confined to the lower terraces in all the previous areas from KI in Kathma to AII in Al-Bahra, have been recorded in this area. The upper terraces are covered with terrestrial deposits and have no particular geomorphological features related to sea-level changes, except that of the wide monotonous physiographic terrace surfaces which are dissected in the upper part by the old, now dry, drainage systems.

Lithology and Stratigraphy of the bedrocks

Samples for elucidating the lithology of the bedrock were collected from the few outcrop rocks along the levelled line. As for the slope of the First terrace, the superficial deposits covering it were not of great thickness, so it was possible to remove them and cut a vertical section along the slope, following which samples from each horizon were collected. Concerning the other parts of the profile, holes were made through the unconsolidated superficial deposits between the discontinuous hard superficial deposits until boring was met by a hard base. From that part the samples for the bedrock were collected. The samples have been examined in the field and in the laboratory and compared with the geological map of Kuwait. The result is summarized as follows:- (Fig.26)

Apart from the upper superficial deposit which has a thickness of about one metre, the stratigraphy of AIII is

(AIII.1) 1-6 metres. Conglomeratic sandstone of the same composition as AII.1, with a thickness of about 5 m.

(AIII.2) 6-12 metres. Calcareous sandstone with small pebbles, with a thickness of about 6 metres.

(AIII.3) 12-? metres. Coarse grained sandy limestone with bands of small pebbles. It was not possible to trace the thickness of this bed, nor ascertain whether there are other horizons beneath it. Samples of this bed have been traced to approximately the middle of the First terrace.

(AIII.4) Red mottled medium grained calcareous sandstone. This bed is similar to the exposed Neogene which extends from the escarpment to the lower part of the coastal plain. According to Fuchs et al (1968) the exposed Neogene is composed of medium grained to conglomerate sands, sandstone, calcareous or quartzose. It is occasionally cross-bedded,

partly fossiliferous, mainly limestone; variegated shales.

(AIII.5) Beach sands and marshes of Recent age.

Morphology and superficial deposits of the terraces

Four separate terraces have been levelled in this area (Fig. 27)

their mean height ranges from 33.11 metres above K.D. for the highest

to 5.99 metres for the lowest. Three of them, including terraces 1,

2 and 4, have been traced horizontally for a considerable distance,

some of them being extensions of those identified in the previous

areas. If one describes their morphological features with their

superficial deposits from which soil samples were collected for analysis

(Fig. 27), it will appears that they in fact do not vary significantly

The superficial material covering the topmost surface of the escarpment

is composed of windblown deposits cemented together with fine and medium

size   gravels by calcite. The surface is also covered in some place

with large size gravels (Plate 12) Cox & Rhoades (1935), Higginbottom (1954),

Milton (1967) and Fuchs et al (1968), have all related this gravel to a

fluviatile origin of Pleistocene age. This deposit covers the top of

the escarpment as well as the slope of the First terrace.

This terrace, which stands at a mean elevation of 33.11 metres above

K.D., is dissected on its landward part and slopes by shallow dry

wadis, these wadis now filled by fine windblown sands. To about the

middle of the terrace, the superficial deposits are mainly of windblown

sands mixed with fragments of the conglomeratic rocks from the upper

part of the escarpment. Soil samples have been collected from the

upper part of the escarpment as well as from the terrace base,

their location and the location of the other samples in the area

being shown in fig.(27). The width of this terrace is 1018

metres. Its lateral extension has been followed almost continuously

FIG. (26)

PROFILE SECTIONS OF AL-BAHRA Ⅲ SHOWING THE LITHOLOGY OF THE BEDROCKS

COMPLETE PROFILE

UPPER SECTION

LOWER SECTION

Conglomeratic sandstone
Calcareous Sandstone
Sandy Limestone
Sandy limestone, partly fossiliferous
Beach sands and marshes
Probable limit of the bedrocks
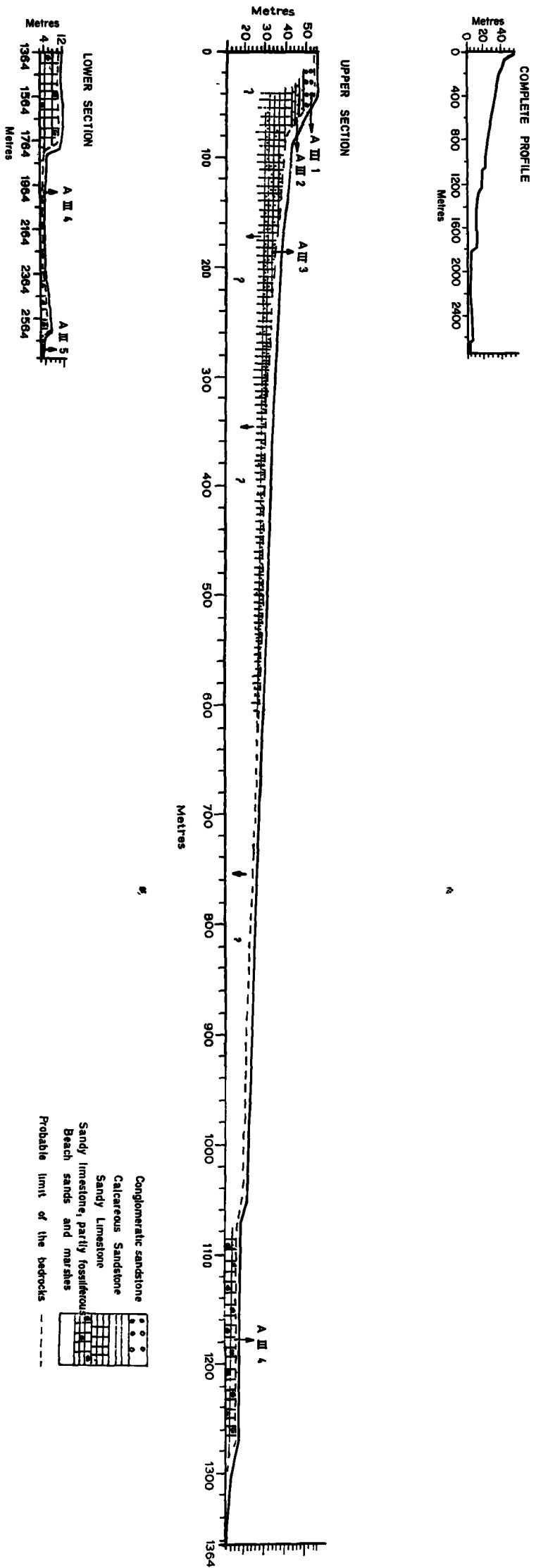
FIG(27)

PROFILE SECTIONS OF AL-BAHRA Ⅲ SHOWING THE LOCATION OF THE SAMPLES
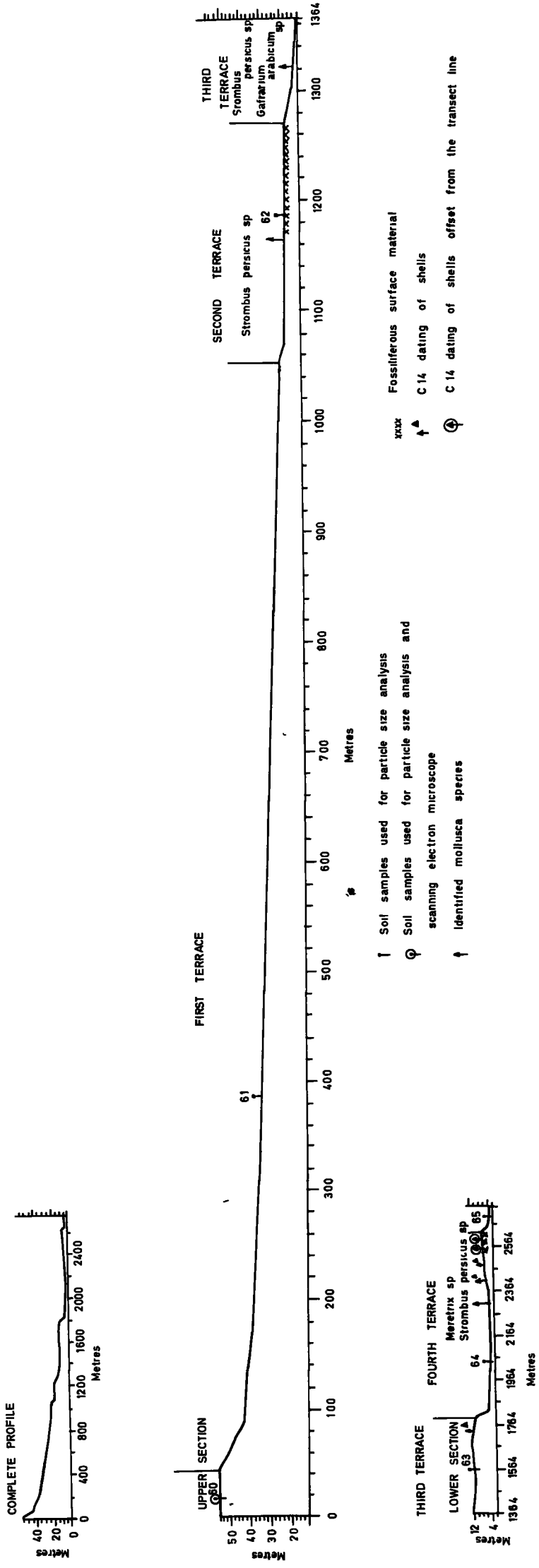
FIG. (24)

PROFILE SECTIONS OF AL-BAHRA II SHOWING THE LITHOLOGY OF THE BEDROCKS
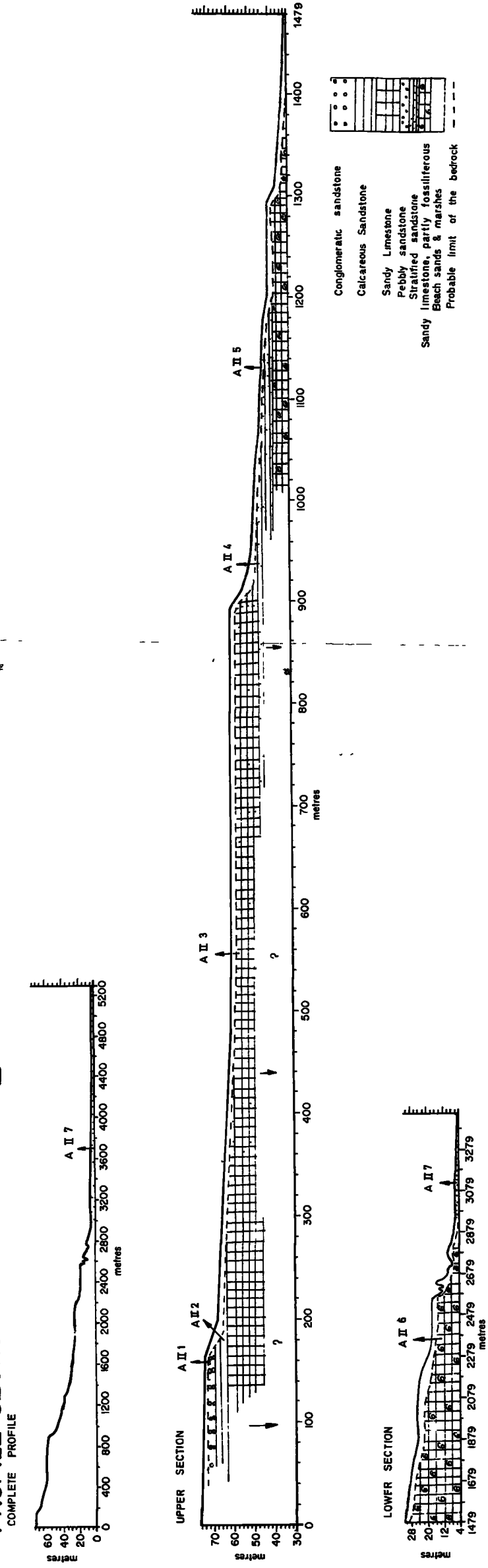
FIG. (25)

PROFILE SECTIONS OF AL-BAHRA II SHOWING THE LOCATION OF THE SAMPLES

COMPLETE PROFILE

UPPER SECTION

LOWER SECTION

FIRST TERRACE

SECOND TERRACE

THIRD TERRACE

FOURTH TERRACE

FIFTH TERRACE

Strombus persicus sp
Thais carnifera sp

| Soil samples used for particles size analysis
| Identified mollusca species
xxx Fossiliferous surface material
| C14 dating of shells
Ⓟ Soil samples used for particle size analysis
and scanning electron microscope
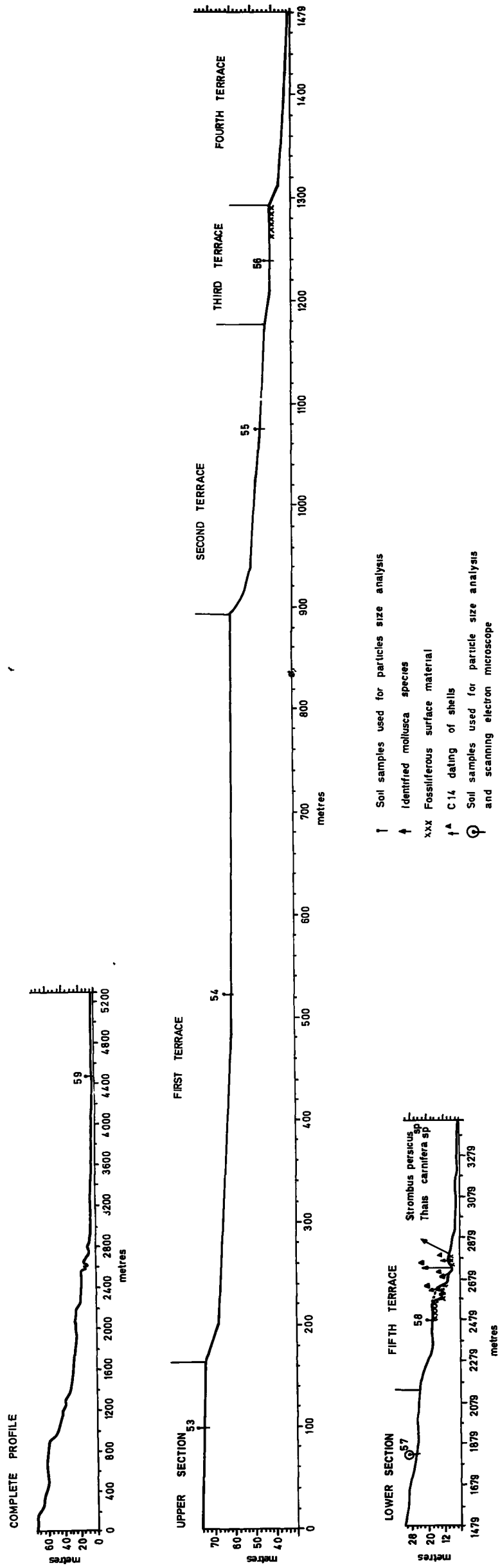
from both directions. Its width changes from place to place and becomes narrow towards the east. It was not possible to observe any signs of marine erosion along its base, nor was it possible to locate the probable junction between the terrace base and its slope, which is important for determining the height of the terrace: the reason, as before, being the terrestrial deposits which hide the junction zone.

The First terrace slopes gently into a small Second terrace with a limited width of 195.7 metres. It has a mean height of 18.58 metres above K.D., and is covered by both terrestrial and marine deposits. The former covers a very limited portion of the upper part of the landward side of the terrace, while the latter spreads on to a large part of the terrace (Fig.27). The marine deposits are composed of hard pink sandy limestone, cemented with traces of shell fragments. The slope of the terrace is hidden by weathered material and fragments of the bedrock of the First terrace. This terrace has a short lateral continuation and there were no traces of other fragments of the terrace alongside the transect.

East of the levelled line and between terraces one and two, there is another clear terrace extending parallel to the sea and facing the narrow coastal plain with a vertical cliff. The morphological feature of this terrace is very much similar to the last terrace found in the second profile in the Al-Bahra area (AII). The cliff carries rocks of consolidated beach material composed of sands, fine pebbles as well as the remains of *bivalves* and indeterminate shells; the deposit is cemented together with calcite. This deposit covers a large part of the terrace, especially the seaward part. The slope of the cliff is

largely hidden by broken pieces of the superficial deposits but the exposed height of the cliff is about 3.76 metres. This terrace extends linearly for about three kilometres, but as the Second, its height declines towards the east.

Going back to the main levelled line, the third terrace has a mean elevation of 11.72 metres above K.D. It is veneered by superficial rocks of sandstone which do not form a continuous sheet. Between the broken rocks, are spread sands of terrestrial origin which hide the original bedrock. The terrace slope is completely covered by terrestrial deposits. The width of the terrace is 551.2 metres and it was possible to trace its extension in the surrounding area.

Shells in complete shape and in fragments are scattered extensively on this terrace. They include *Strombus persicus* which represents the majority species as well as *Grafrarium arabicum* (lamarck); one sample at a height of about 12.5 metres above has been submitted for dating.

The last terrace (No.4) extends in width to a distance of 826.6 metres. It decreases in height from west to east, so it has a mean height of 5.99 metres above K.D. at the levelling line, while it declines to a vanishing point towards the east. The seaward part of the terrace ends in a cliff, the latter with a height of about 2 metres; it is composed of sandy limestone with iron stains and fragments and traces of shells, this bed is similar to the exposed Neogene.

The superficial deposit covering the terrace and its cliff is composed of red sandy limestone with shell fragment, it has a thickness of less than a metre which also becomes thinner and discontinuous towards the land. Other superficial deposits include the windblown sands which change in colour and texture from the surface, to the bedrock, e.g. the upper 30 or 50 centimetres are of pale brown sandy

soil, after that it becomes softer and the colour changes into yellow to brown soil. This last deposit overlies the original bedrock, and in order to examine the composition and sources of these deposits, samples have been collected for laboratory examination. The material covering the slope of this terrace is of windblown sands.

Investigation along this terrace showed that towards the west, this terrace meets the last terrace of profile AII in Al-Bahra. The superficial deposit is similar in many ways, but the terrace becomes higher towards the west. Also the marine shells of similar species have been strewn on the terrace between the two areas. The shells are not confined to the seaward end of the terraces, because they have been also found near the slopes. They contain *Meretrix sp* as well as *Strombus persicus*, and four samples of shells from which two along the levelled line and two offset the line have been submitted for C14 dating (Fig. 27);

The coastal plain in front of this terrace is very narrow and largely covered by the sea at high water mark, but it does not reach the base of the present cliff. Between the cliff and the present coastline the coastal plain does not have a gentle slope, it is rather steep and covered by fine sands at the foot of the escarpment, while downslope it contains a higher percentage of clay.

Finally the results of the levelling which show the numbers and mean heights of the terraces are illustrated in table (3). In Table 3 the terraces are numbered along each transect solely on the basis of the sequence in which they were visually identifiable in the field from the escarpment downward. At this stage, deliberately, no correlation between transects has been made.

Table (3)

Showing the mean heights of the terraces above Kuwait Datum (in metres) *

Terrace Number	Kathma I	Kathma II	Ghidhai	Mudairah	Al-Bahra I	Al-Bahra II	Al-Bahra III
1	90.60	81.53	92.62	71.12	79.85	63.72	33.11
2	77.92	69.65	79.27	59.57	56.10	47.82	18.58
3	67.38	40.55	65	52.30	40.39	39.45	11.72
4	50.76	10.70	52.94	31.23	31.79	29.86	5.99
5			33.60	11.61	22.32	14.43	
6			13		16.10		

* Although heights are given to two places of decimals of a metre, their accuracy is subject to an error of ± 1·1 metre (See pages 231-32)

5.2. Marine fossils and dating results

A total of 20 species of mollusca have been identified in the survey's fossil collection, of which 16 come from the research area between Kathma and Al-Bahra. The rest are from Al-Dhba'iyyah. The shells have been identified by H.E.J. Biggs as being of marine origin (Table 4 and Plates 13-18). A suspicion that freshwater mollusca were present among the samples arose for two reasons. The first is that the present area of research is close to the Tigris and Euphrates river system discharge area. Khalaf (1969) found that the Tigris and Euphrates river system is the main transporting agent of the detrital grain deposits found especially along the northern coasts of Kuwait. The other possibility of freshwater effect might have occurred during the Pleistocene period, especially since the superficial sheet of gravels which covers the north and north-east of Kuwait territory has been deposited by river action. Nevertheless, in the expert judgement of H.E.J. Biggs, all the samples identified are of marine origin.

In general, the state of preservation of the shells differs in correspondence with the heights above Kuwait Datum at which they were found; shells which come from near the present coastline are better preserved than those collected further inland. The only example from a height of 90 metres above K.D. was collected from Ghidhai area and is represented in one shell *Thais Carnifera* Lamarck (Plate 14 and Fig. 19). No other examples have been collected at similar heights in any other area. At heights between 69 and 60 metres above K.D., the dominant species were *Turbo Coronatus* and *Cerithium* sp. The first have been found to be completely dissolved and represented only by their casts (Plate 16), while the *Cerithium* sp. are partly preserved. Hence it was possible to submit the latter for C14 dating.

Table (4) List of Species

Name of Species	Locality
pelecypoda	
Barbatia Loccrata (Linné)	Mudairah
Circe (parmulophora) Corrugata (Dillwyn)	Mudairah
Dosina sp.	Ghidhai
Gafrarium Arabicum (Lamarck)	Al-Bahra
Glycymeris pectunculus (Linné)	Mudairah
Meretrix sp.	Al-Bahra
Ostrea sp.	Kathma, Ghidhai, Mudairah and Al-Bahra
Large and small bivalves indet	Kathma to Al-Bahra
Pitar hagenowi (Dunker)	Ghidhai
Plicatula sp. almost certainly p. *imbricata* (Menke)	Kathma
Spondylus exilis (Sowerby)	Mudairah
Trachycardium Lacunosum (Reeve)	Mudairah
Trachycardium maculosum (Wood)	Mudairah
Gastropods	
Cerithium	Kathma, Ghidhai and Mudairah
Strombus persicus	Kathma
" "	Ghidhai
" "	Mudairah
" "	Al-Bahra
Thais Carnifera	Ghidhai & Al-Bahra
Turbo Coronatus	Ghidhai & Al-Bahra.
Small gastropods indet	Kathma to Al-Bahra
	Al-Dhba'iyyah Area
pelecypoda	
Gafrarium arabicum (Lamarck)	
Glycymeris (Linné)	
Pinctada radiata (Leach)	
Spondylus exilis (Sowerby)	
Trachicandium maculosum (Wood)	
Gastropoda	
Ancillaria cinammomea (Lamarck)	
Murex Kilsterianus	
Strombus persicus (Swains)	
Turbo Coronatus (Gmelin)	
Vermetus sulcatus	
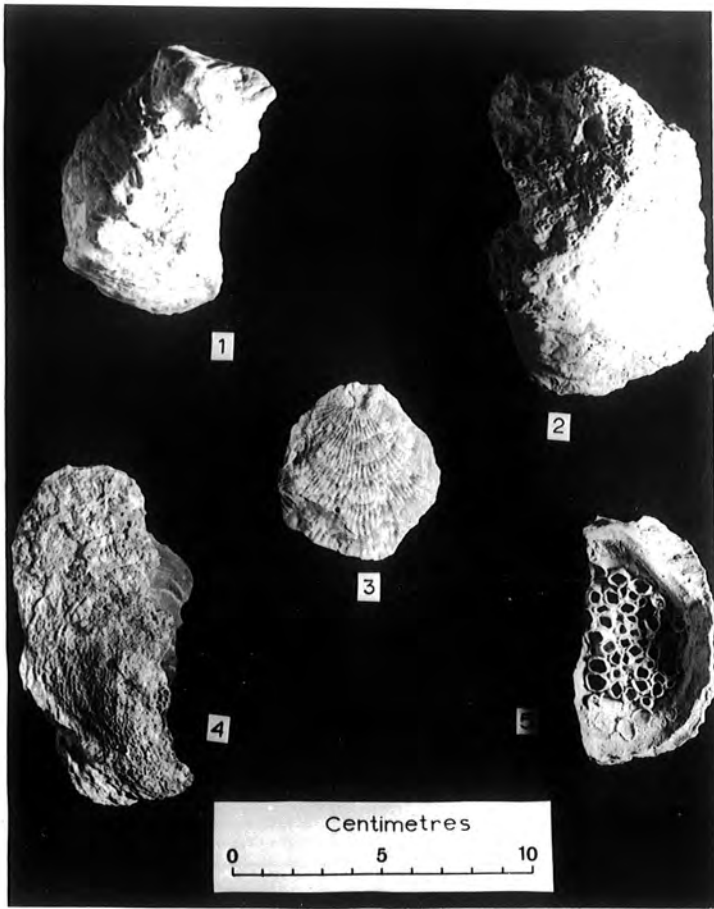
Plate (13) *Ostrea* sp.

Plate (14) *Thais Carnifera* (Lamarck)
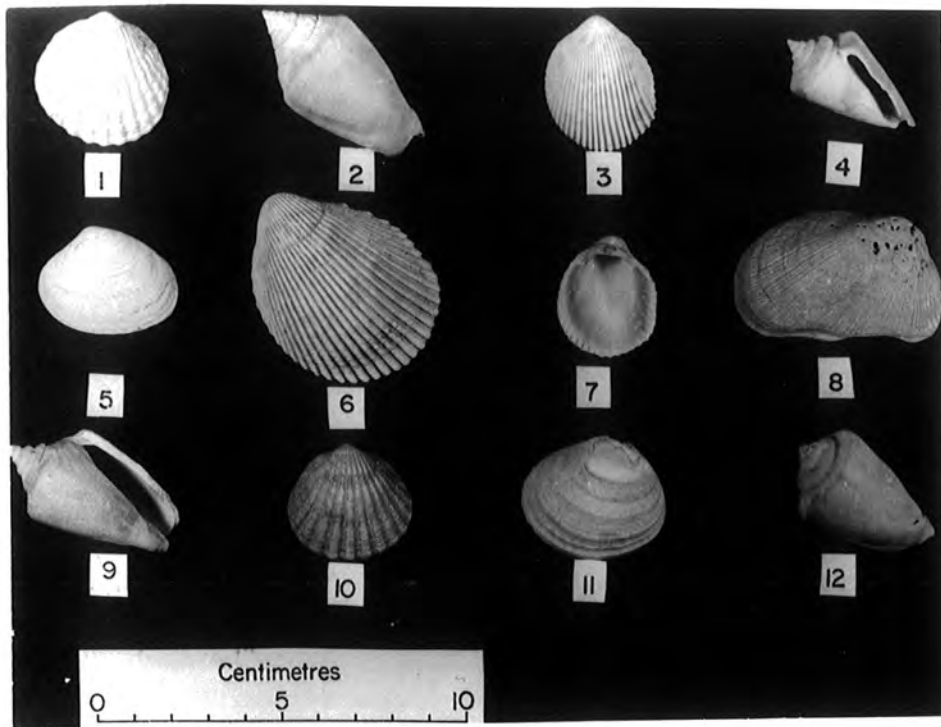
Plate (15) 1, 10. *Glycymeris pectunculus* (Linné), 2, 4, 9, 12. *Strombus persicus* 3, 6. *Trachycardium lacunosum* (Reeve), 5. *Gafrarium arabicum* (Lamarck) 7. *Possibly T. maculosum* (Wood), 8. *Barbatia Laccrata* (Linné), 11. *Circe (parmulophora) corrugata* (Dillwyn).
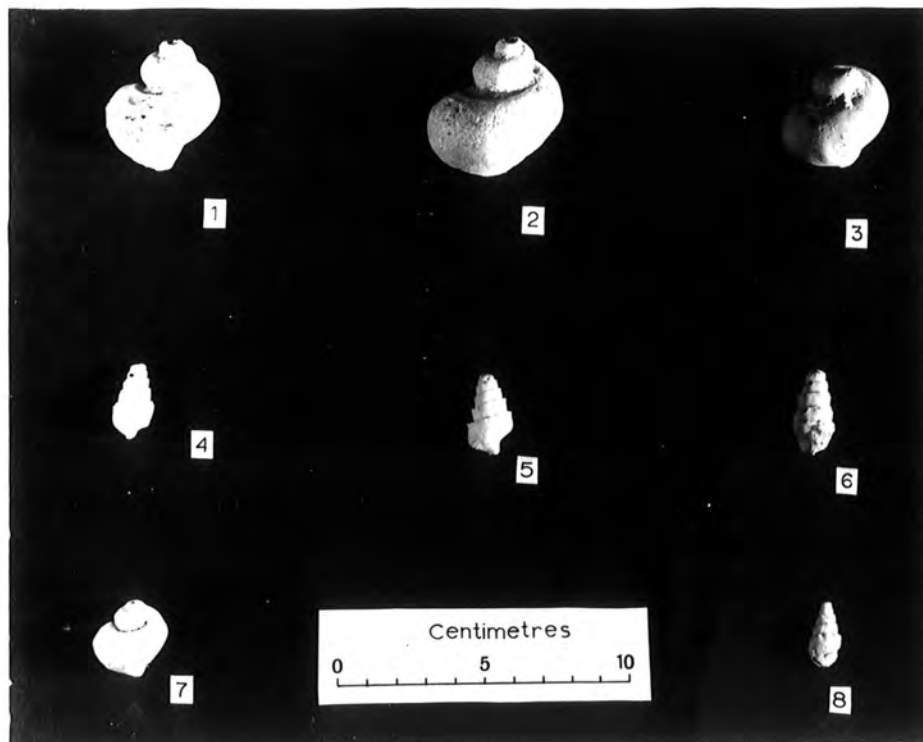
Plate (16) 1, 2, 3, 7. *Turbo coronatus* 4, 5, 6, 8. *Cerithium.*
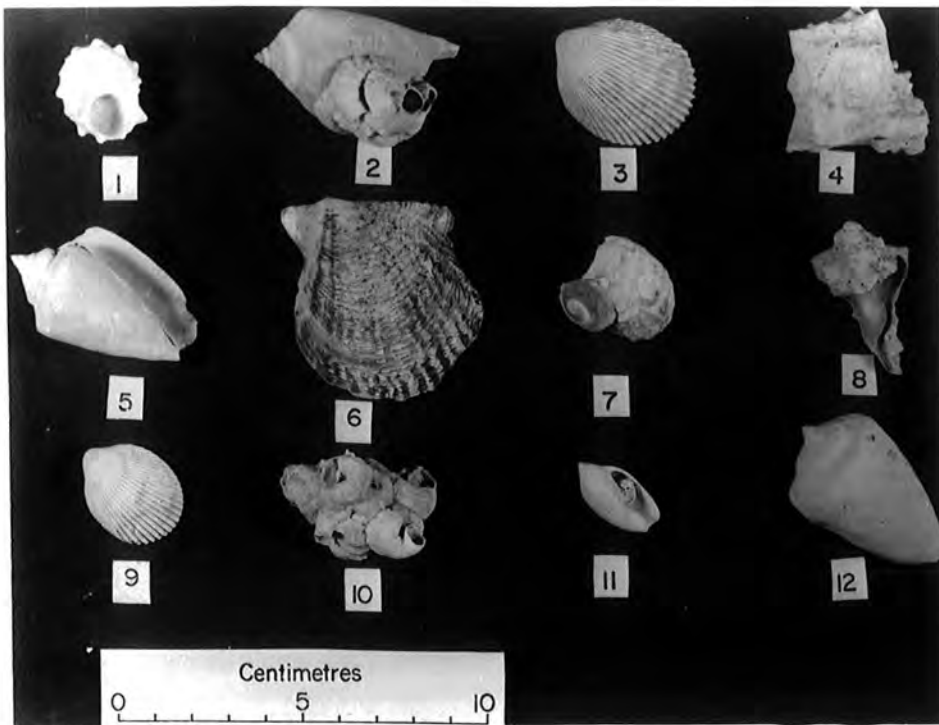
Plate (17) 1. 7. *Turbo coronatus* (Gmelin), 2. *Strombus persicus* and
Vermetus sulcatus? 3. *Trachycardium lacunosum* (Reeve),
4, 8. *Murex Küsterianus* 5, 12. *Strombus persicus,*
6. *Pinctada radiata* (Leach), 9. *Trachicardium maculosum* (Wood),
10. *Vermetus sulcatus,* 11. *Ancillaria cinammomea* (Lamarck).
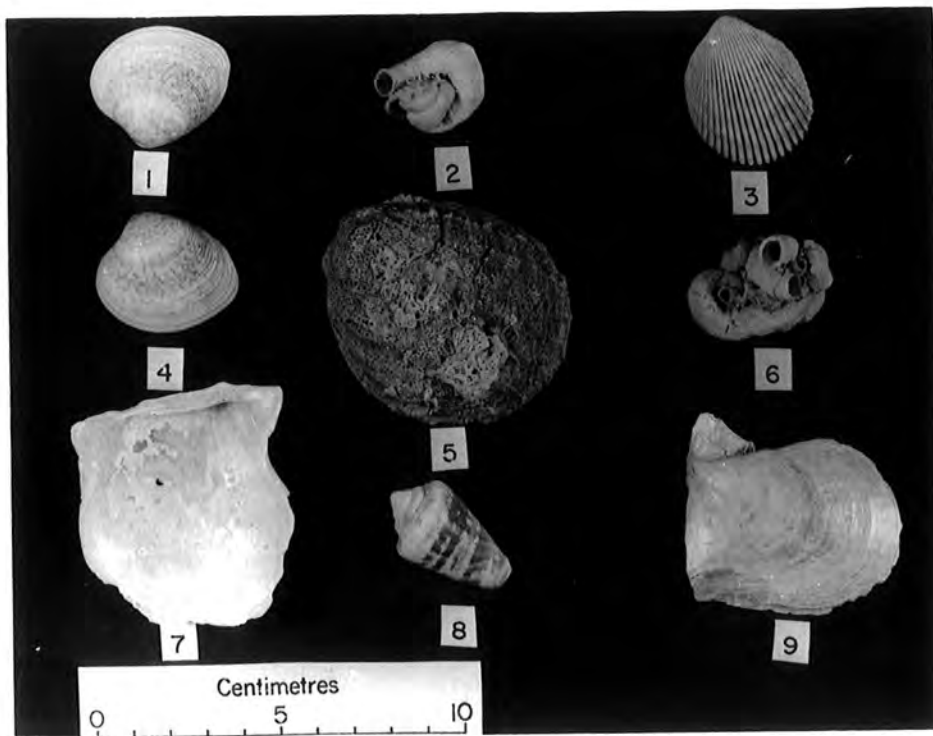
Plate (18)1, 4. *Gafrarium arabicum* (Lamarck), 2, 6.*Vermetus* sp.,
3. *Trachycardium maculosum* (Wood), 5. *Spondylus exilis* (Sowerby),
7. *Pinctada*sp. most probably *radiata* (Leach), 8. *Strombus persicus.*

The shell samples collected from Kathma shell bed are composed of fragments of, and whole, small shells, mainly *bivalves* and *Ostrea* sp. The shell assemblages from Al-Dhba'iyyah area are better preserved (Plate 17 and 18).

Literature on the mollusca of the Arabian/Persian Gulf has recorded the known distribution of the same and similar species to those which were found in Kuwait. They have been discovered on the islands and the coastal areas of the Gulf as well as along the coasts of the Indian Ocean, e.g. Melvill 1897; Newton 1905; Lees 1928; Cornwall 1946; Haas 1954; Biggs 1958; Biggs and Grantier 1960. There is, however, no adequate reference work concerning the mollusca of Kuwait. Steininger (1968) indicated that mollusca collected from the coastal area of Kuwait corresponded very well in type to known assemblages of living mollusca of the Red Sea and the Indian Ocean. However, Cox and Rhoades (1935) have referred to the fossil assemblages found in the Middle Zor formation (corresponding to Lower Fars Formation) which outcrops in the Jal-Az-Sor escarpment. They also referred to other Recent and post Kuwait series fossil found north of Kuwait Bay. The first is represented by *Dendritina cf. rangii, Ostrea Vestita, Ostrea Latimarjinata, Turritella* sp. *,Lucina* sp., and *Balanus* sp. Some of these species have been found at the foot of the Jal-Az-Zor escarpment during the fieldwork in the area. As to the Recent fossils found, Cox and Rhoades (op.cit.) mentioned that they are still flourishing on the present day beaches and include *Conus* sp., *Solen* sp., and *Turbo* sp.

From the coastal area of Al-Jlay'ah, Perry and Al-Refai (1957) recorded fossil assemblages which also match with present species on the shore. They contain *Conus* sp. *,Calliostoma* sp., *Cardium* sp., *mactra* sp., *pinctada* sp., *Arca* sp., *Astarte*.

Sieber (1968) identified the following fossils of Fars Group

(Miocene to Pliocene) in the area between Kathma and Al-Bahra,
Chlamys div. sp., *Ostrea Latimarginata, Clausinell* sp., *Spondylus* sp.,,
div. Veneridae, Natica sp., large and small *bivalves indet, Turritella* sp.,
Turbo sp., as well as small *gastropods.*

The most recent reference about the mollusca of Kuwait has been
published in 1968 when Steininger gave a list of the fossil assemblages
in Kuwait territory and its islands.

A list of the dated samples with their respective laboratory codes
is given in table (5).

Table 5

The results of Radiocarbon dating of shells

Laboratory Ref.	Sample Ref.	Location	Height above Kuwait Datun	Years B.P.
T-1054	E38 ZB	Al-Bahra	15.18 m	4510 ± 80
HV.4770	E39-40ZB	"	8.42 m	3875 ± 60
T-1055	E40 ZB	"	7.69 m	Outer fraction 4050 ± 90 Inner fraction 4110 ± 70
T-1056	E42 ZB	"	9.77 m	Outer fraction 4910 ± 70 Inner fraction 4570 ± 70
T-1057	F16-17ZB	"	12.5 m	4170 ± 170
T-1058	F18 ZB	"	8.27 m	Outer fraction 4030 ± 70 Inner fraction 4180 ± 70
T-1059	F20 ZB	"	8.87 m	Outer fraction 3650 ± 90 Inner fraction 3560 ± 60
T-1060	F24 ZB	"	7.44 m	Outer fraction 4050 ± 90 Inner fraction 3560 ± 90
T-1061	F27-28ZB	"	4.60 m	Outer fraction 3350 ± 90 Inner fraction 3810 ± 90
Birm. 285	G15-16ZM	Mudairah	40-42 m	Outer fraction $32,000{+2300 \atop -1800}$ Middle fraction $>31,500$ Inner fraction $>34,500$
T-1062	G32-33ZB	"	7.23 m	Outer fraction 3270 ± 80 Inner fraction 3250 ± 80
T-1063	G33-34ZB	"	about 11m	Outer fraction 3170 ± 110 Inner fraction 3750 ± 90
T-1064	G35 ZB	"	5.11 m	Outer fraction 4130 ± 90 Inner fraction 4050 ± 70
SUA-86	C15/Z	Ghidhai	63.30 m	28350 ± 1150
Birm. 283	C5/I	"	46.51 m	Outer fraction $35,000\pm1000$ 35,050 B.C. Inner fraction $>41,000$ B.C. $>42,950$ B.P.
I-7610	C6/Z	"	about 52m	$31,900\pm1300$ B.P.
I-7609	A.I/Z	Kathma	about 48m	$23,300\pm600$
SUA.85	E7-8D	Al-Dhba'-iyyah	5 m	940 ± 80

5.3 Results of the sediment analyses

5.3.1 Interpretation of the results of the particle size analysis

Can the parameters of the grain size distribution of the samples

under investigation be used to identify the environemnts of their

deposition? During field investigation of the research area, it was possible

to recognise the origin of some of the sediments in the area. Some were

difficult to distinguish and the uncertainty applied to several locations.

Our purpose in studying the mechanical analysis of the sediments is

to recognise their depositional environments and accordingly the origin

of the terraces existing in the area. The characteristics of each

individual sample have been analysed; (Table 6 and Fig. 28) the different

information resulting from different samples made it difficult to follow

these in the area. Hence, it was decided that samples belonging to each

individual terrace from Kathma I, Kathma II, Ghidhai, Mudairah and Al-Bahra I

to Al-Bahra III were best grouped together; the characteristic of these

samples together will reveal the origin of the terrace concerned. The

hypothesis implied by this treatment, i.e. that each terrace whatever

its location has a similar sedimentation history, was assumed for purposes

of further testing on the basis of the conclusions reached in earlier

chapters.

Several methods have been applied to investigate the origin of the

samples; (a) The Student's t test, (b) Interpretation of the four size

parameters and (c) correlation and comparison between the grain size

distribution curves.

Statistical measures used for analysis

Statistical analyses of cumulative frequency curves have been

calculated because they furnish a means of summarizing large amounts of

information in a convenient manner, as visual comparison of more than a

few curves is difficult. Also, it is an important key to the investigation

Table (6) Results of particle size analysis

Particle size in millimetres	Equivalent phi values	Sample numbers and percentage finer							
		1	2	3	4	5	6	7	8
12.5	-3.64	100	100	100	100	100	100	100	100
6.0	-2.58	98.92	99.27	94.97	99.20	-	-	-	-
2.0	-1.00	94.82	93.20	77.84	97.29	-	-	-	-
1.2	-0.26	73.17	74.42	62.10	91.07	99.16	99.77	99.90	99.92
0.6	0.74	65.51	61.94	53.64	87.36	98.06	99.49	99.74	99.23
0.42	1.25	57.70	45.09	44.28	67.40	96.52	97.64	95.68	92.23
0.30	1.74	51.84	32.34	37.94	49.97	91.48	89.60	71.05	67.37
0.21	2.25	46.59	24.06	32.26	46.07	77.44	71.56	48.53	33.30
0.15	2.74	39.94	18.45	25.88	34.54	49.69	41.52	27.99	16.64
0.10	3.25	32.83	15.56	13.45	27.15	32.55	23.66	17.97	12.98
0.075	3.74	25.49	11.65	10.21	13.07	25.51	18.20	14.89	12.01
0.063	4.00	20.07	8.36	5.84	7.90	22.81	16.58	13.25	11.45
0.02	5.64	18.59	7.81	5.42	7.49	22.41	16.36	12.76	11.25
0.006	7.39	4.63	6.12	5.22	3.84	10.83	5.21	5.66	3.79
0.002	9.00	2.07	5.15	3.92	2.56	7.16	4.20	3.89	3.29
		1.74	1.17	2.15	1.84	5.00	3.76	3.21	1.51

9	10	11	12	13	14	15	16	17	18	19
100	100	100	100	100	100	100	100	100	100	100
-	-	98.94	-	98.62	99.11	99.02	94.7	-	-	-
-	-	96.68	-	89.46	73.22	96.62	82.16	98.86	-	-
94.06	99.54	93.25	99.99	73.59	38.53	84.69	63.82	91.46	99.80	-
91.74	98.11	91.82	99.35	63.24	31.85	72.83	56.44	87.20	98.89	99.70
88.32	83.79	83.47	79.62	48.50	25.45	57.93	46.78	79.49	92.85	85.78
84.70	60.88	67.34	61.19	40.60	21.93	49.62	41.58	73.46	81.02	66.92
78.90	31.98	47.99	49.09	28.63	19.21	43.59	34.80	66.16	47.58	54.75
72.79	13.47	32.54	39.76	22.76	17.15	36.08	27.56	54.83	24.82	42.75
67.42	7.62	23.68	31.43	19.57	14.95	25.85	20.14	44.17	16.45	31.35
64.40	5.92	16.54	22.00	15.03	12.05	13.50	14.06	35.93	13.11	19.82
62.80	5.09	12.04	14.09	10.67	9.56	9.37	10.80	30.61	11.56	12.32
62.56	4.95	11.38	12.86	9.93	9.14	8.84	10.08	29.59	11.28	11.12
48.51	3.68	4.61	7.58	2.30	8.00	6.50	5.95	5.55	7.81	3.73
30.65	3.53	3.86	4.82	1.28	6.40	5.98	5.75	2.80	4.34	2.78
1.87	3.03	2.91	3.27	0.52	3.86	4.51	4.81	0.72	2.81	0.51

20	21	22	23	24	25	26	27	28	29	30
100	100	100	100	100	100	100	100	100	100	100
-	-	-	-	-	-	-	-	-	98.86	-
-	95.50	97.52	96.76	-	-	-	-	99.78	95.60	-
99.84	70.50	92.84	93.42	98.98	99.83	99.90	96.50	97.72	85.25	99.88
98.94	54.74	89.25	90.24	95.59	99.02	99.56	89.68	94.33	78.55	99.69
89.34	35.38	63.55	85.18	59.28	87.70	98.34	79.42	85.67	70.46	97.67
78.38	23.58	44.32	74.90	29.38	56.29	95.78	70.82	77.55	67.40	91.20
66.01	17.26	31.47	62.63	20.20	23.81	90.34	61.34	64.94	63.04	69.65
56.97	12.66	24.75	42.23	12.20	9.61	76.20	49.77	39.36	57.32	40.82
46.83	9.82	19.24	26.41	9.57	6.51	48.78	37.54	15.14	49.32	19.54
34.05	7.92	15.66	22.51	7.95	5.35	27.82	29.04	8.67	41.59	10.01
22.19	6.88	13.61	12.27	7.41	5.01	21.88	24.64	7.66	36.14	5.79
20.03	6.61	13.36	12.17	7.33	4.97	21.30	24.10	6.80	34.56	5.40
4.77	4.84	3.08	4.95	5.71	5.34	7.29	16.53	3.81	14.31	2.80
3.10	4.28	2.31	3.36	5.14	4.50	3.39	3.53	1.78	2.47	1.44
2.20	3.37	1.54	2.84	2.06	3.71	0.17	2.17	1.42	1.92	0.90

31	32	33	34	35	36	37	38	39	40	41
100	100	100	100	100	100	100	100	100	100	100
-	91.84	-	-	-	-	-	-	-	-	96.60
-	88.68	96.32	-	-	-	-	-	99.35	-	90.40
99.34	78.82	85.58	90.72	99.76	-	96.42	83.31	93.83	99.45	73.84
98.65	69.94	79.08	89.29	99.42	98.86	93.40	78.31	80.58	99.22	63.77
96.65	56.44	61.74	82.88	97.78	92.94	80.77	73.13	50.68	95.40	48.17
92.27	47.84	44.64	74.24	94.35	82.14	66.88	69.06	37.68	86.02	37.77
86.49	40.32	34.32	60.77	88.80	65.42	54.84	62.10	29.05	68.40	30.37
79.69	32.12	28.56	33.89	74.00	42.14	41.85	52.45	21.01	54.12	23.81
74.17	24.36	25.72	9.84	45.38	28.28	29.92	42.28	16.44	40.04	18.97
69.65	19.42	23.78	4.50	28.92	23.80	15.93	35.24	11.60	26.34	18.77
65.49	17.10	22.62	3.78	24.06	22.04	7.15	31.26	7.61	16.45	13.27
64.39	16.56	22.42	3.74	23.64	21.70	6.17	30.64	6.98	14.99	12.73
28.39	3.32	9.98	2.19	12.93	21.00	3.61	9.12	6.70	3.82	4.35
9.94	2.95	4.47	1.68	8.50	12.86	3.35	4.18	6.27	1.53	2.00
2.76	2.58	2.51	1.22	5.00	3.67	3.09	4.06	2.88	0.51	1.50

42	43	44	45	46	47	48	49	50	51	52
100	100	100	100	100	100	100	100	100	100	100
-	-	-	-	-	-	-	-	-	-	-
92.84	97.93	87.04	-	-	96.32	-	94.96	-	99.13	-
67.84	91.17	56.20	96.20	-	87.38	94.52	87.69	97.40	86.08	-
53.48	83.63	42.40	90.64	99.93	81.40	84.63	81.81	93.98	67.68	99.88
38.08	61.42	30.36	72.04	98.76	74.13	75.15	71.27	83.58	51.37	98.00
29.48	40.21	23.72	54.16	96.25	68.98	70.07	64.47	74.18	44.73	92.00
23.28	22.71	18.96	40.94	85.96	62.14	60.45	57.79	65.08	38.53	83.32
18.40	9.86	14.88	31.12	66.93	49.72	45.83	47.63	53.24	30.33	69.34
15.32	5.90	11.64	23.18	43.28	35.34	20.82	38.49	41.10	22.46	54.14
13.22	3.43	9.56	17.34	22.26	26.16	10.84	33.37	32.33	16.77	42.98
11.62	2.38	8.06	12.02	15.40	20.74	7.87	30.09	26.87	12.28	34.70
11.22	2.24	7.82	11.56	14.88	19.72	7.46	29.59	25.42	11.72	33.38
9.74	1.46	1.70	3.23	8.42	3.62	3.06	13.61	11.58	2.16	10.38
1.19	0.36	0.27	2.21	3.53	2.07	2.50	1.73	9.09	1.62	6.92
0.54	0.18	0.09	1.53	3.08	1.38	2.33	1.47	6.75	1.08	3.46

53	54	55	56	57	58	59	60	61	62	63
100	100	100	100	100	100	100	100	100	100	100
–	–	–	–	–	–	–	95.79	98.24	–	–
95.64	90.26	99.03	95.59	–	–	90.38	89.43	92.37	–	–
82.59	66.36	92.62	84.37	99.24	91.71	74.54	81.59	77.08	–	92.05
74.66	55.94	86.55	76.88	97.92	88.75	68.55	66.84	72.24	92.94	87.79
62.09	42.82	70.95	63.15	94.19	84.66	61.96	44.97	67.24	71.16	81.28
52.60	34.57	56.37	52.05	91.22	81.60	56.16	34.94	63.96	65.71	77.41
45.24	25.76	39.45	42.40	86.29	78.99	49.29	29.62	59.43	64.52	70.84
37.15	18.77	27.11	30.49	76.34	75.38	39.31	24.38	54.48	60.30	59.37
30.36	14.60	19.52	21.01	57.69	71.62	30.79	20.61	44.63	27.94	43.11
24.40	11.37	15.02	12.57	36.32	68.42	23.06	17.09	29.83	9.16	35.65
19.98	11.04	12.45	5.03	25.49	66.23	19.59	15.05	22.05	5.87	33.77
18.98	7.16	11.72	3.53	24.48	65.89	18.89	14.65	21.01	5.62	33.53
4.66	6.20	10.81	3.08	10.60	39.94	16.73	9.43	12.09	3.35	15.16
1.54	3.10	1.52	2.58	7.99	3.40	8.29	4.53	6.95	2.78	10.04
1.47	1.03	1.02	1.92	5.00	2.55	2.34	3.68	5.00	2.32	2.61

64	65
100	100
-	-
97.34	-
75.14	99.88
92.43	99.70
78.38	98.98
63.61	96.40
51.26	84.58
40.09	67.91
32.63	48.35
23.08	32.37
16.39	15.01
15.26	12.93
7.08	9.75
4.15	2.05
0.51	0.77

of the sedimentary environments. The properties of the cumulative

curves can be obtained either mathematically by method of moments or

graphically by reading selected percentiles of the cumulative curves,

both methods are summarized by Krumbein and Pettijohn (1938).

For the present study, the latter has been applied because it is

quicker and almost as accurate as the former.

Four size parameters were measured, mean, standard deviation,

skewness and kurtosis. These statistics have been discussed in a series

of articles by Trask (1932); Krumbein (1936); Otto (1939); Inman (1952);

Folk and Ward (1957); Friedman (1961, 1967); McCammon (1962); Chappell

(1967).

1. Mean

This represents the average of a series of readings and several

formulae have been suggested for the calculation of the mean. Inman (1952)

suggested the formula $M_\phi = \frac{1}{2}(\phi 16 + \phi 84)$. Folk and Ward (1957) indicated

that Inman's formula for the mean provides a good result for fairly

normally distributed curves, but if the curves are very asymmetrical, or

bimodal in character then the results are not so satisfactory. They have

suggested the following formula: $Mz = \phi 16 + \phi 50 + \phi 84/3$. They indicated

that the $\phi 16$ represents the average of the coarsest third of the sample,

and $\phi 84$ the average size of the finest third, while the $\phi 50$ gives the

average value of the middle third which will provide a more complete

view of the distribution.

In 1962 McCammon provided other formulas which included more per-

centiles; the efficiency of the commonly used formulae and his formulae

have been discussed and compared (McCammon 1962).
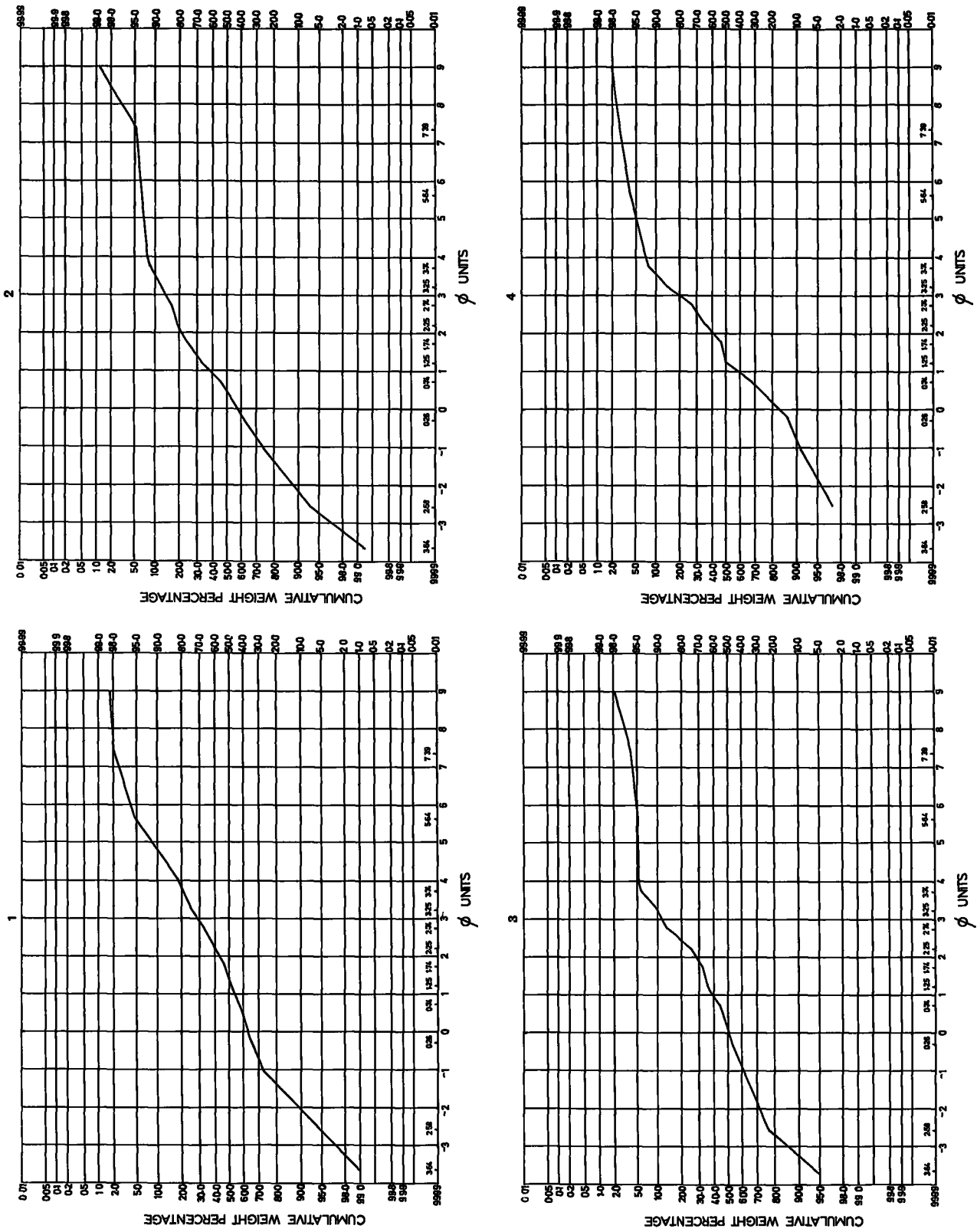
Fig. (28)

Cumulative curves of the samples
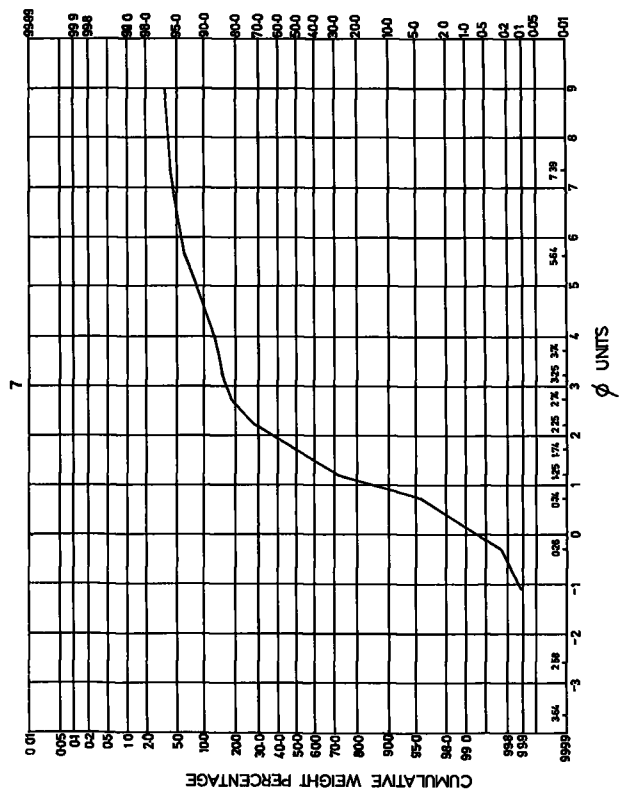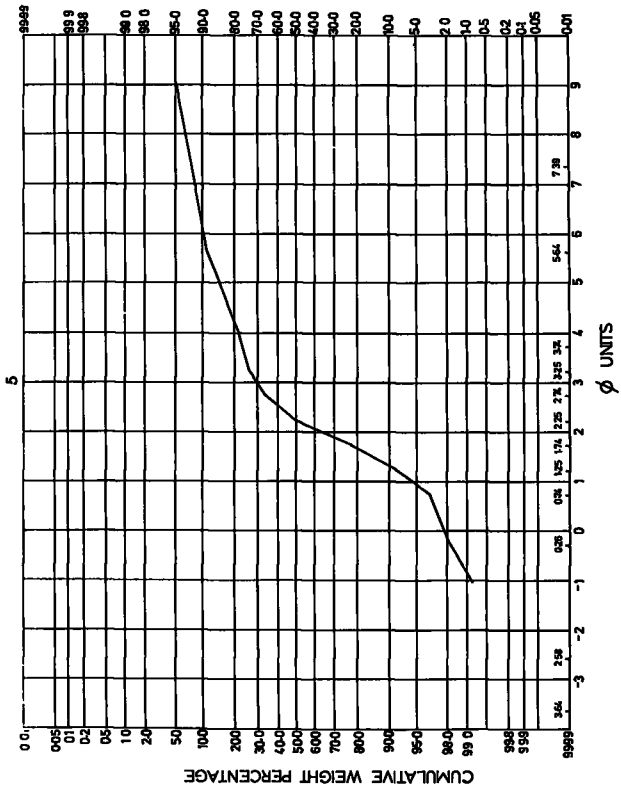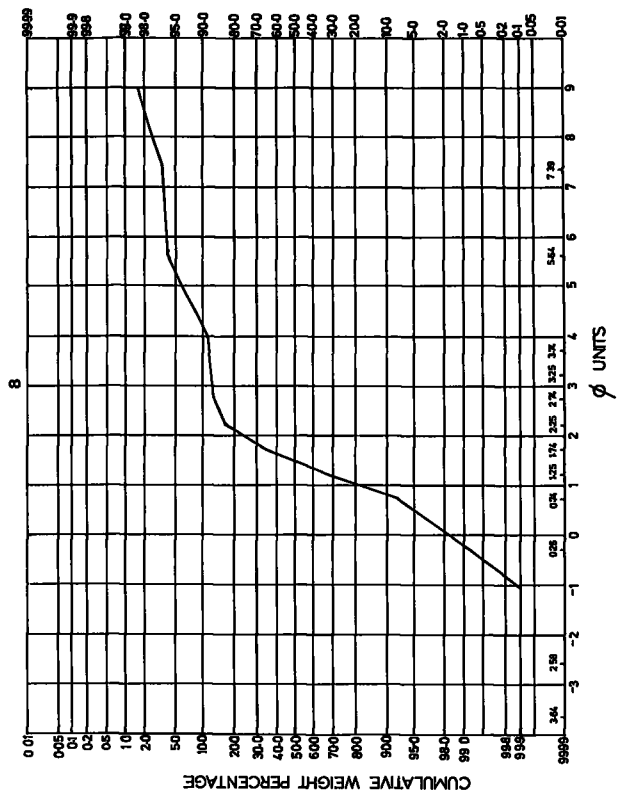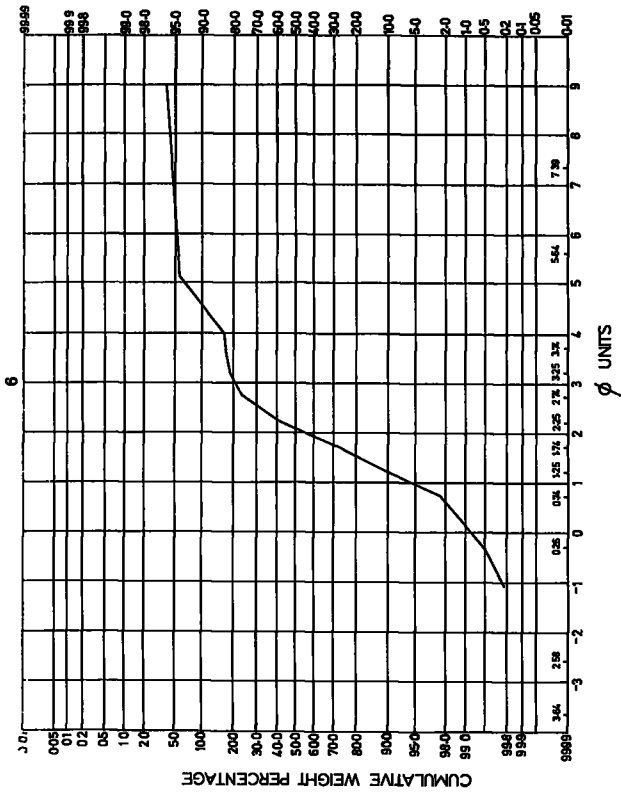
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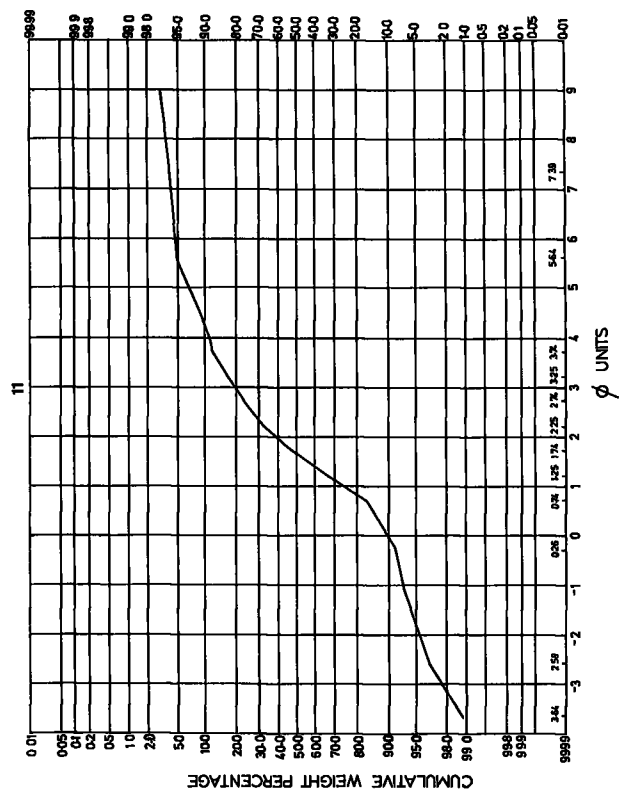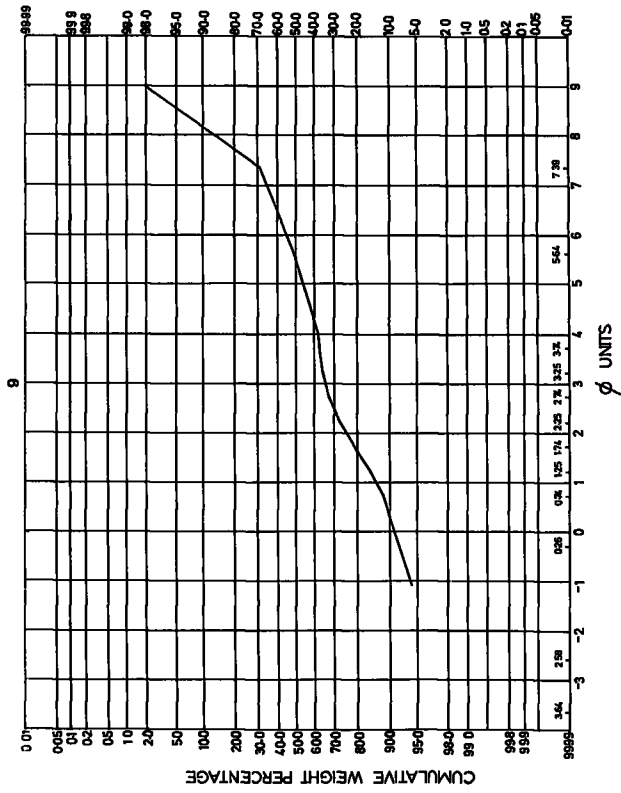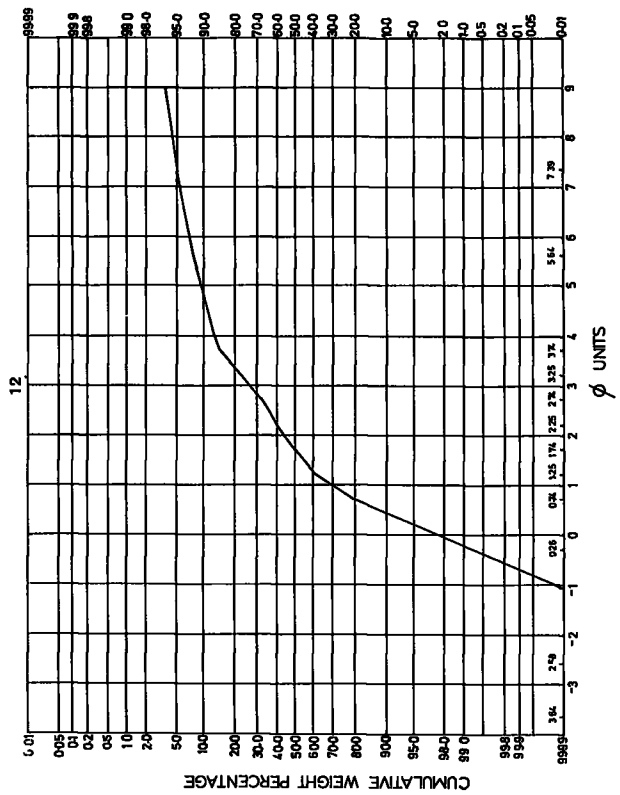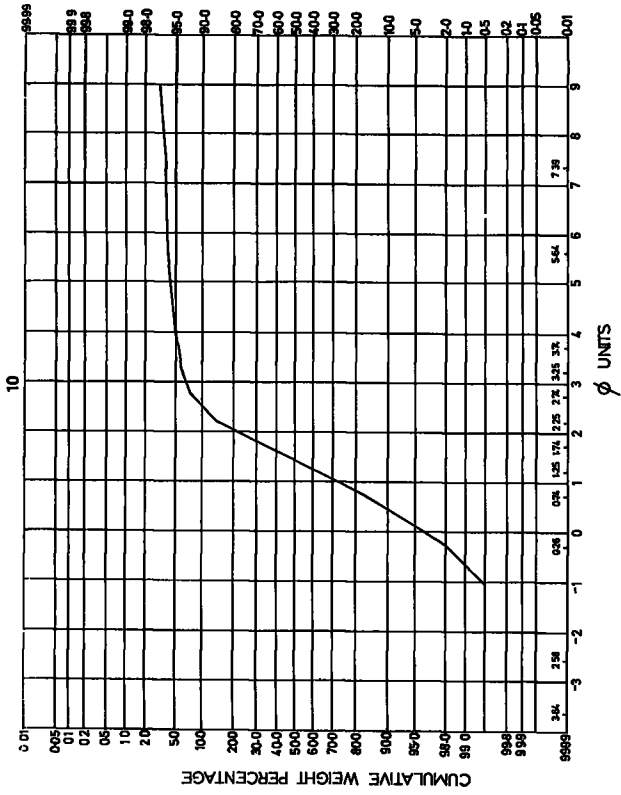
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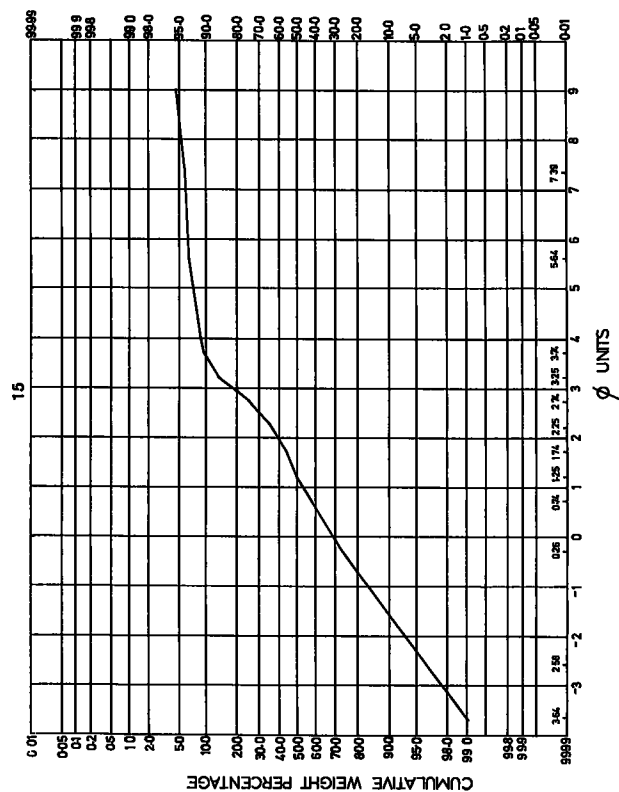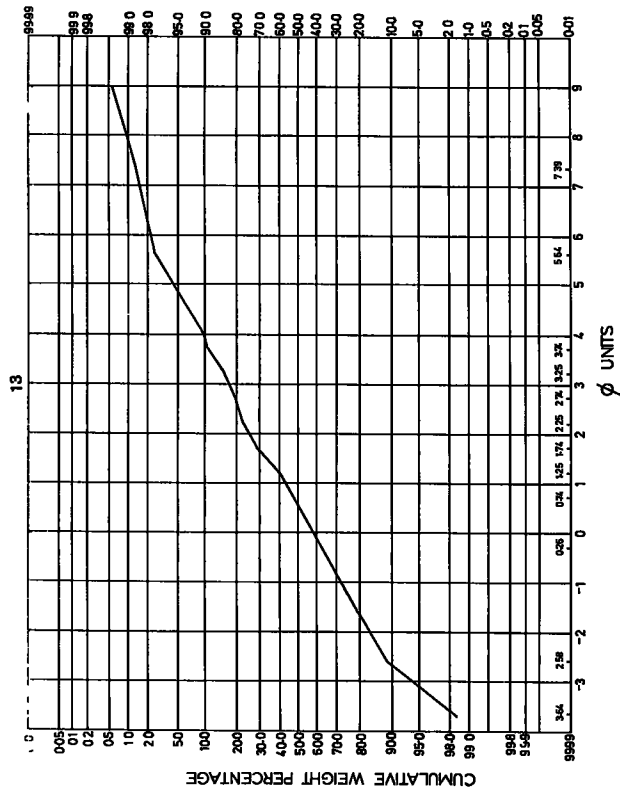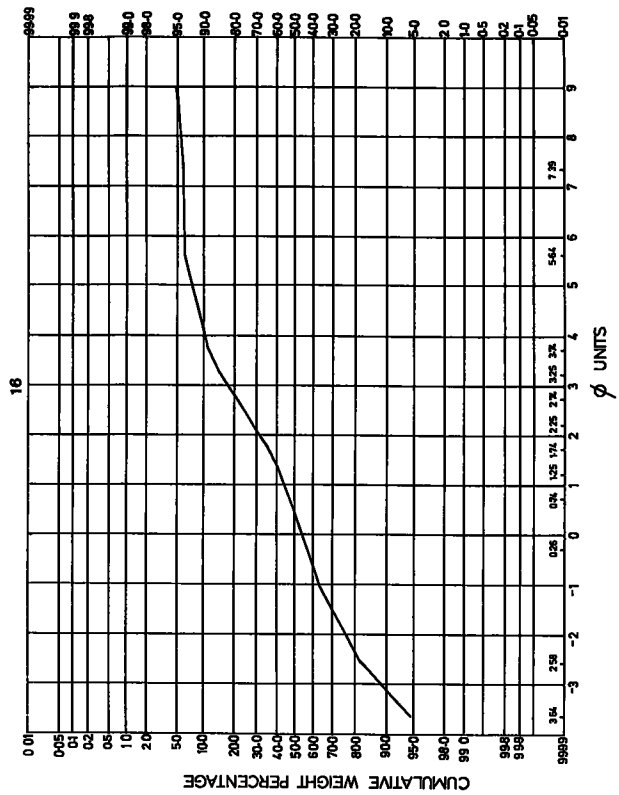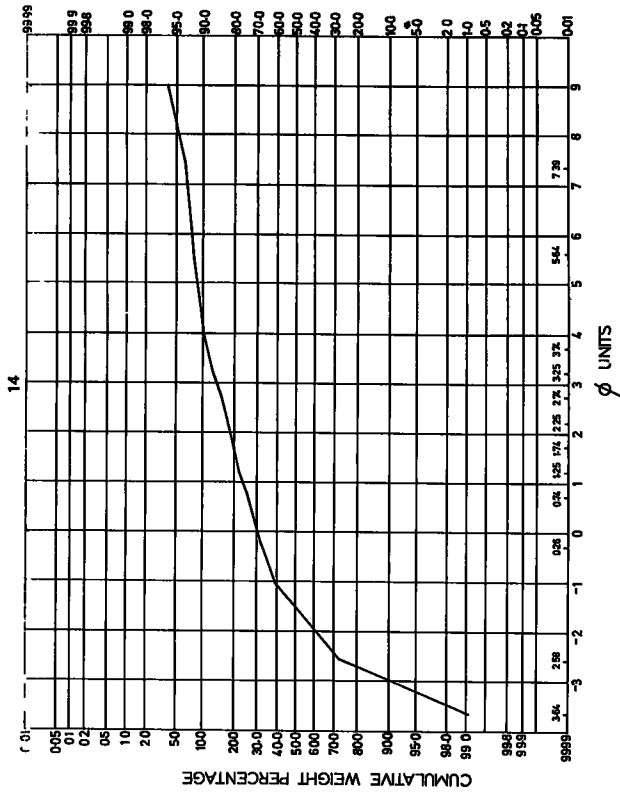
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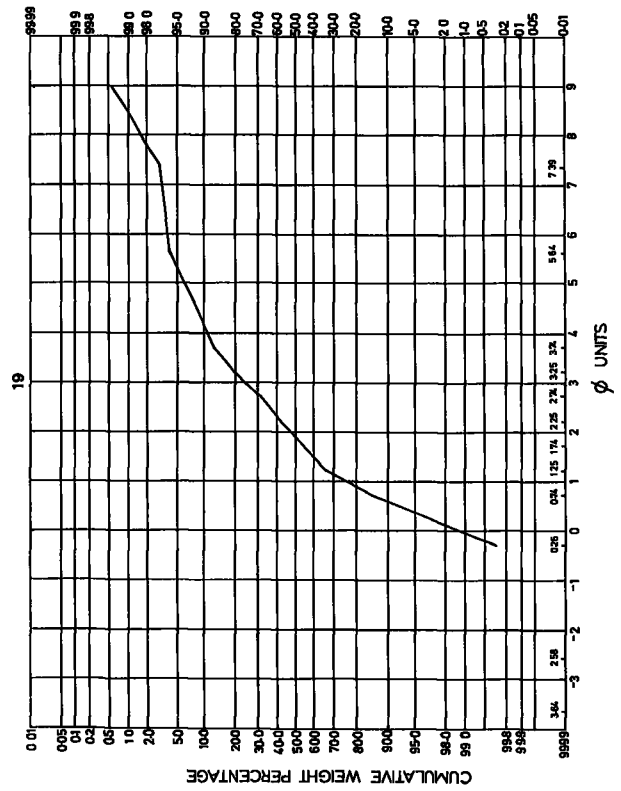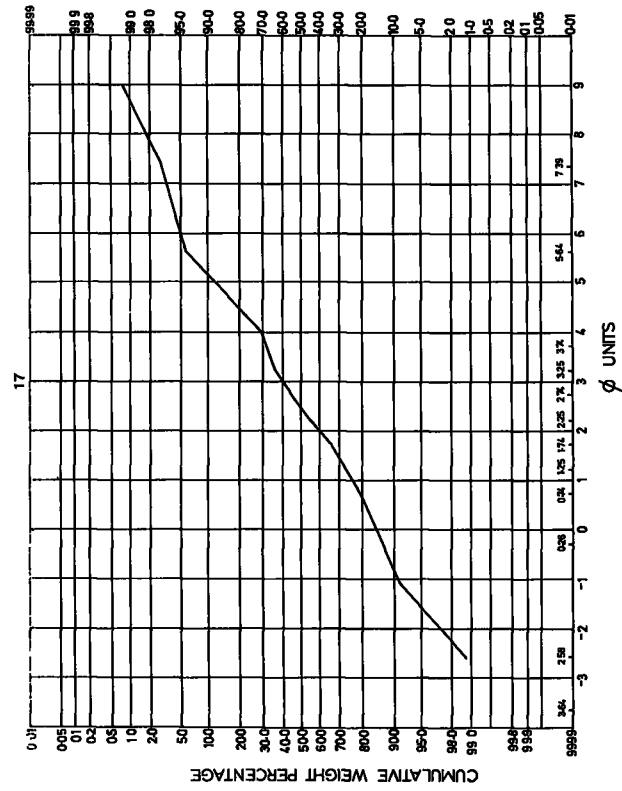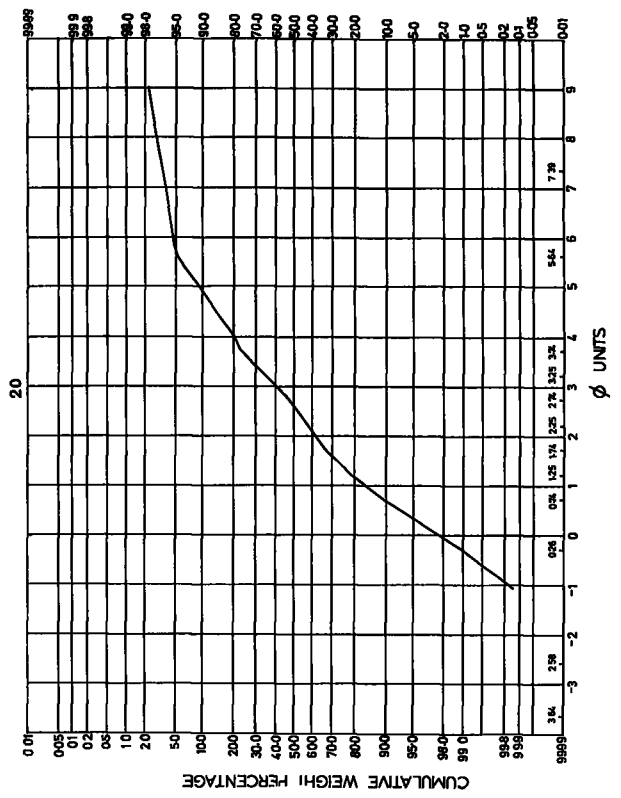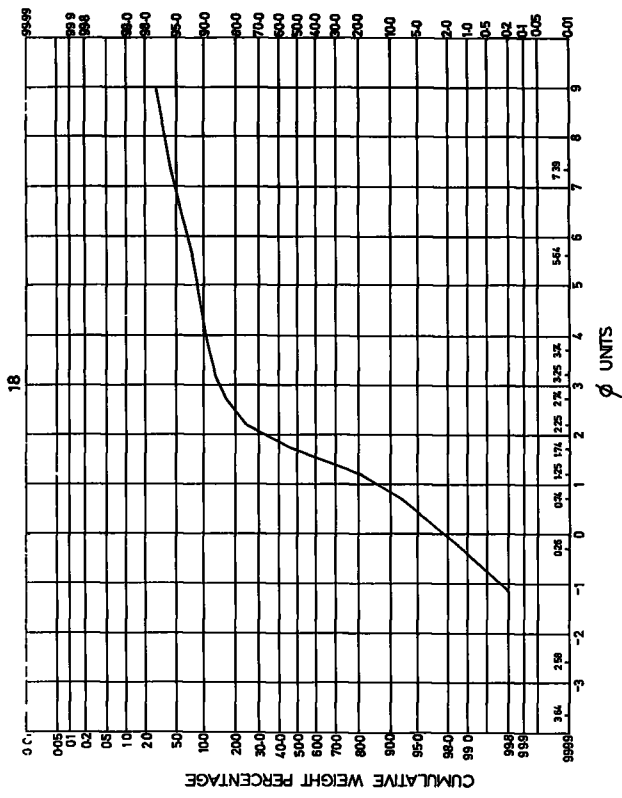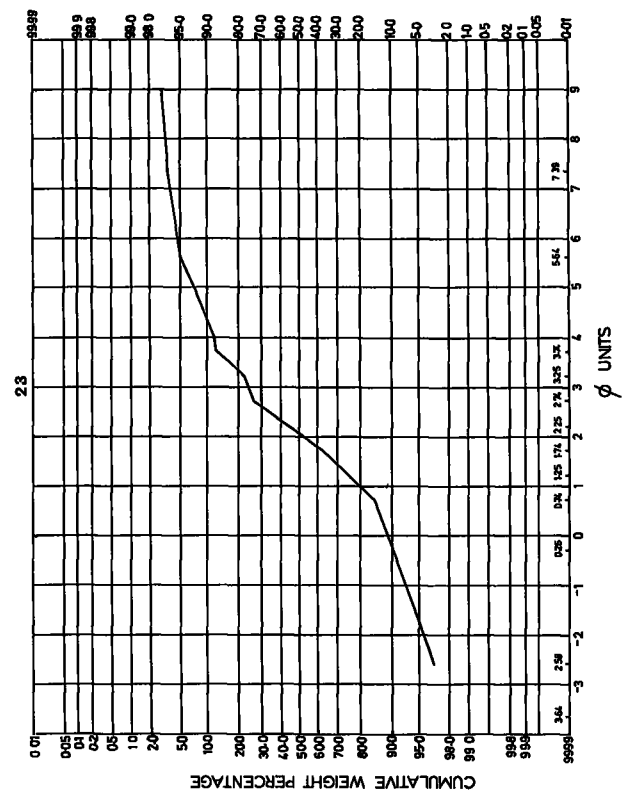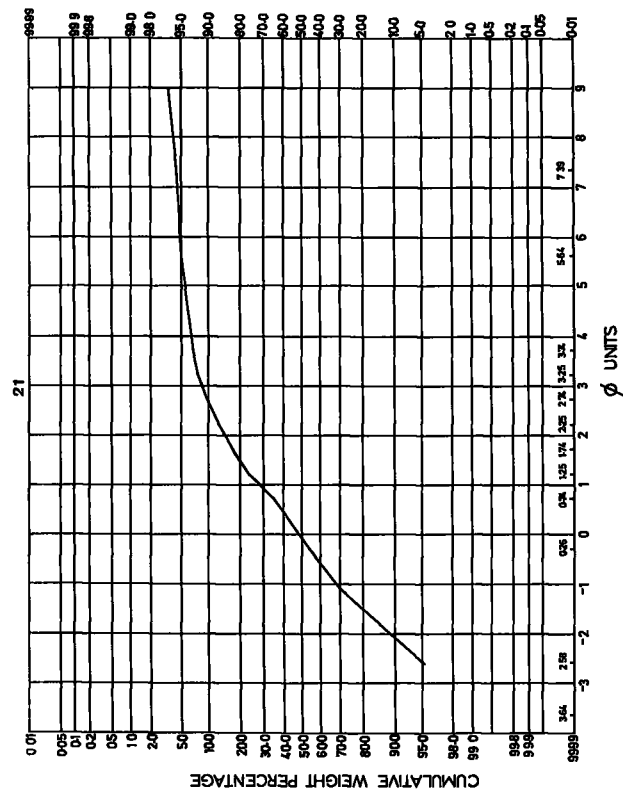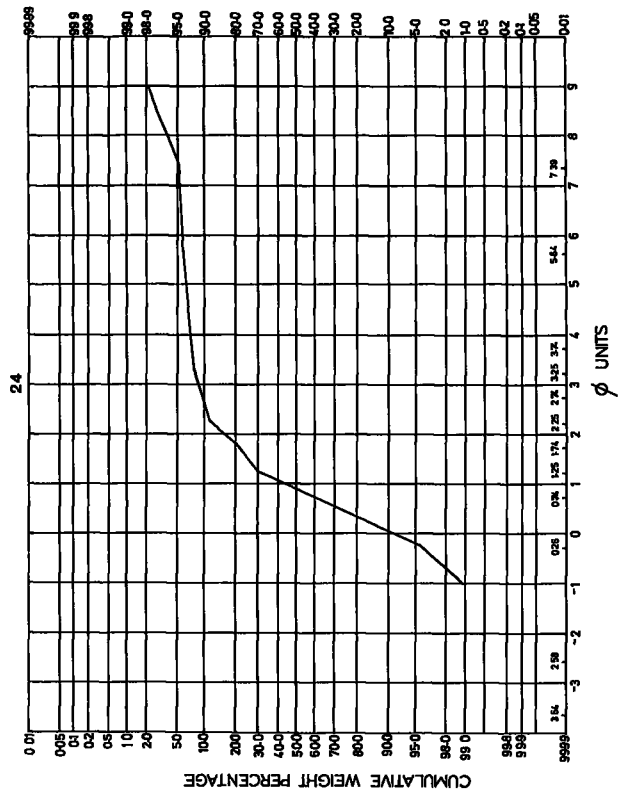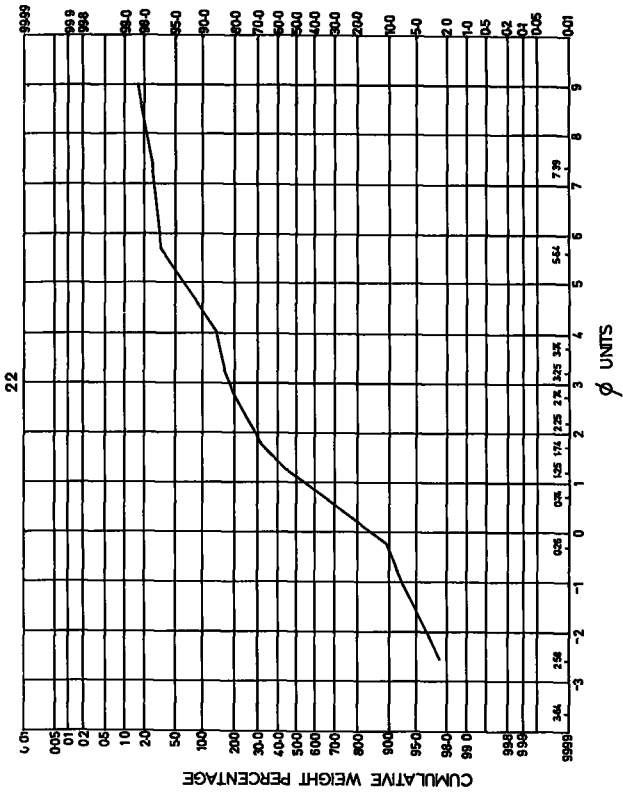
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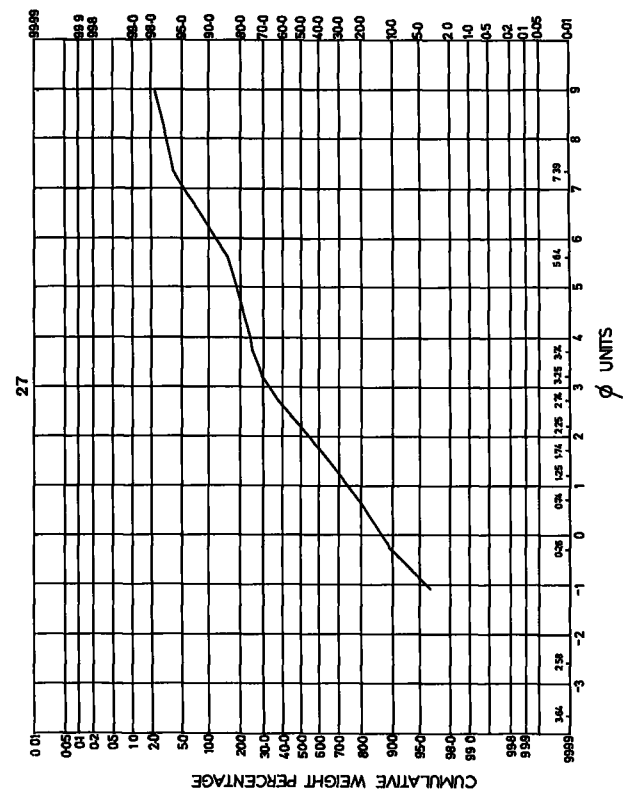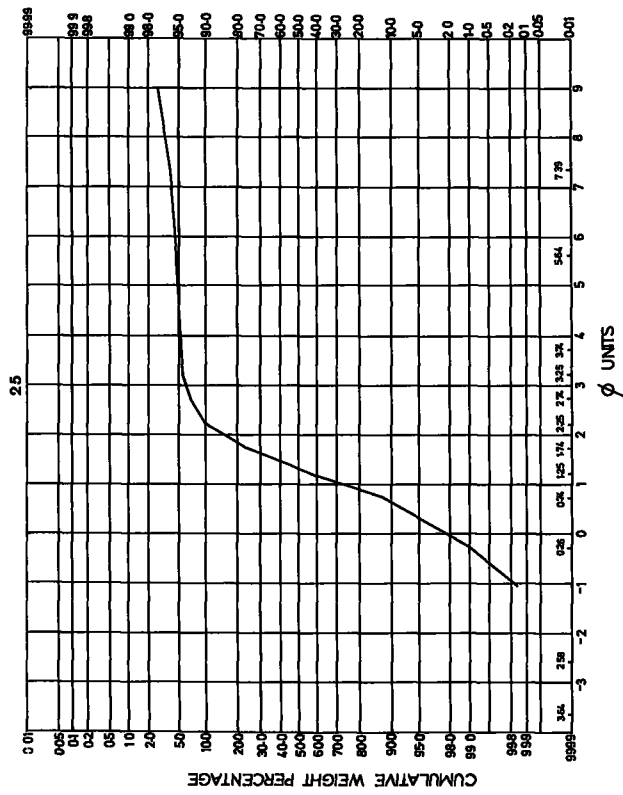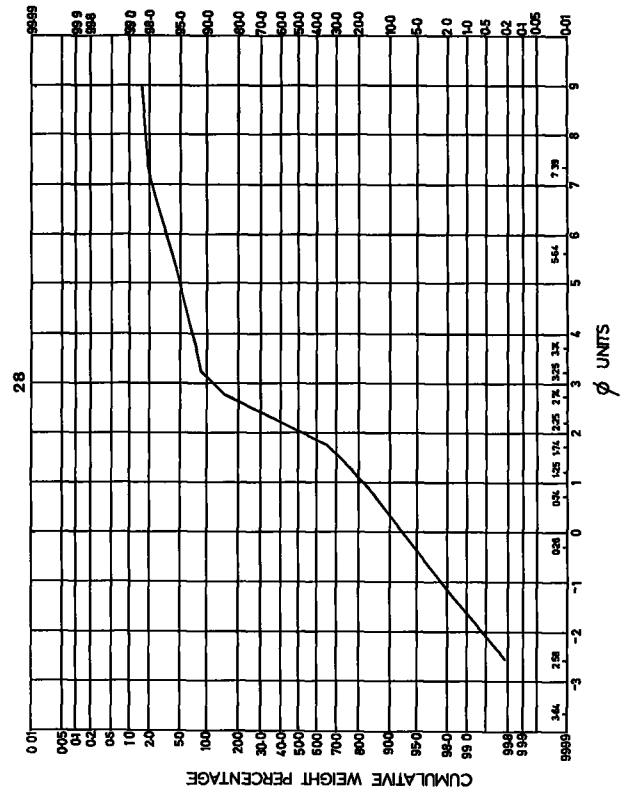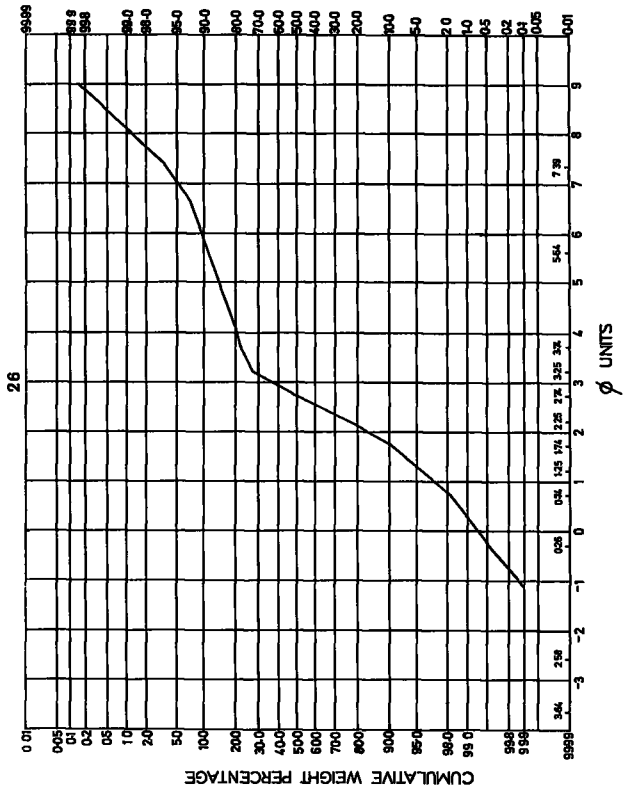
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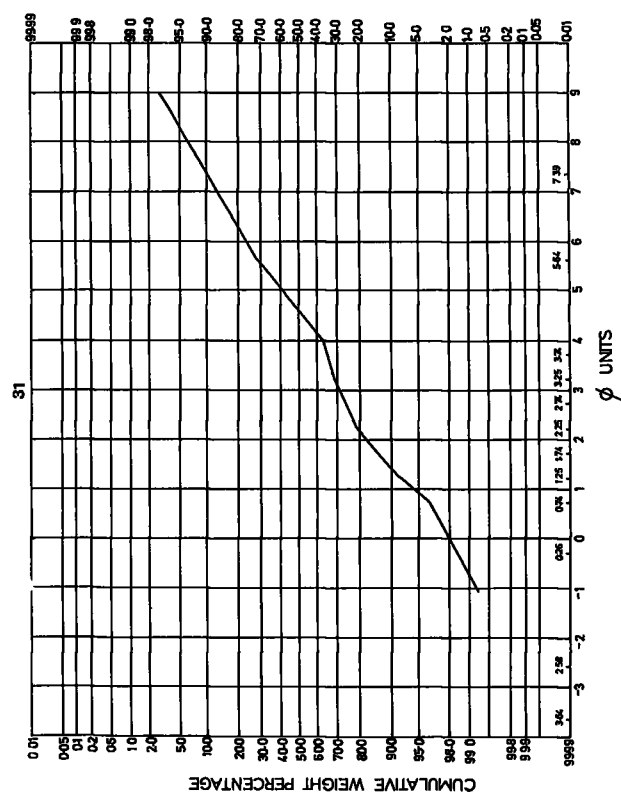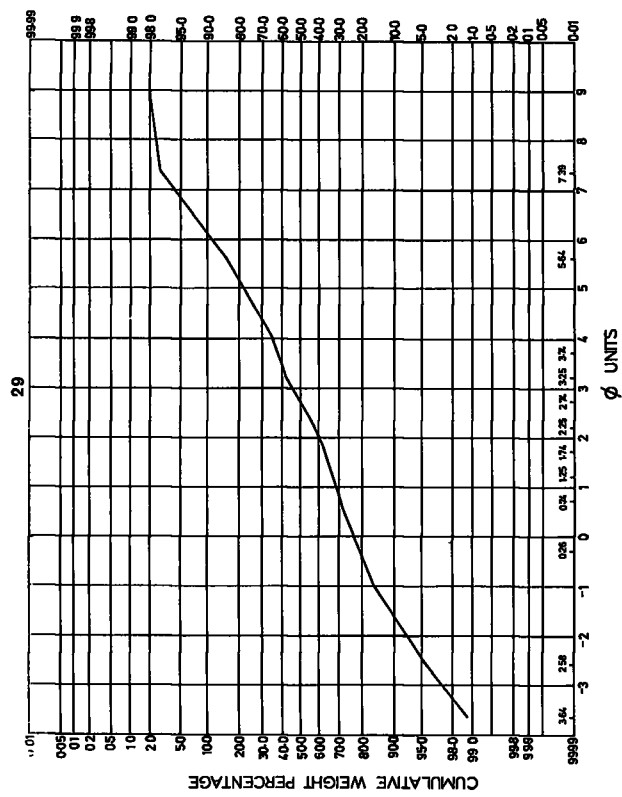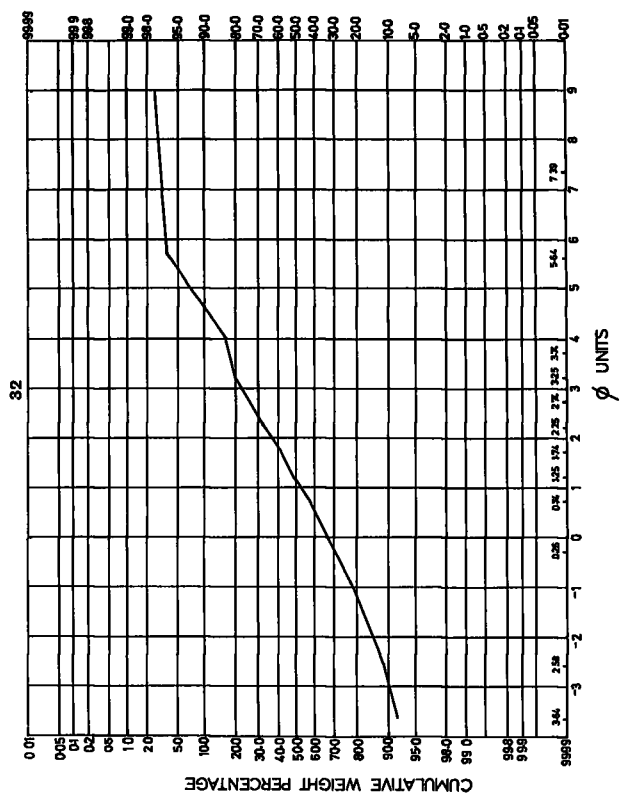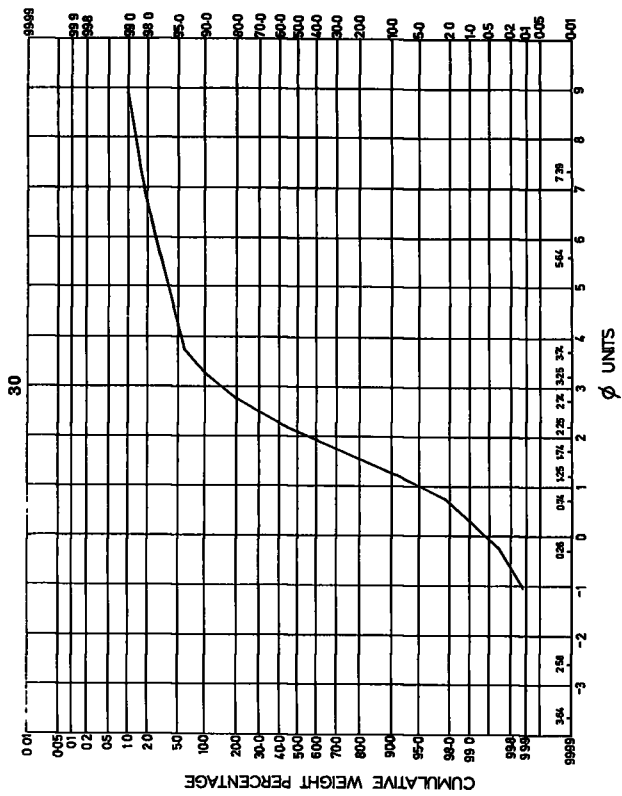
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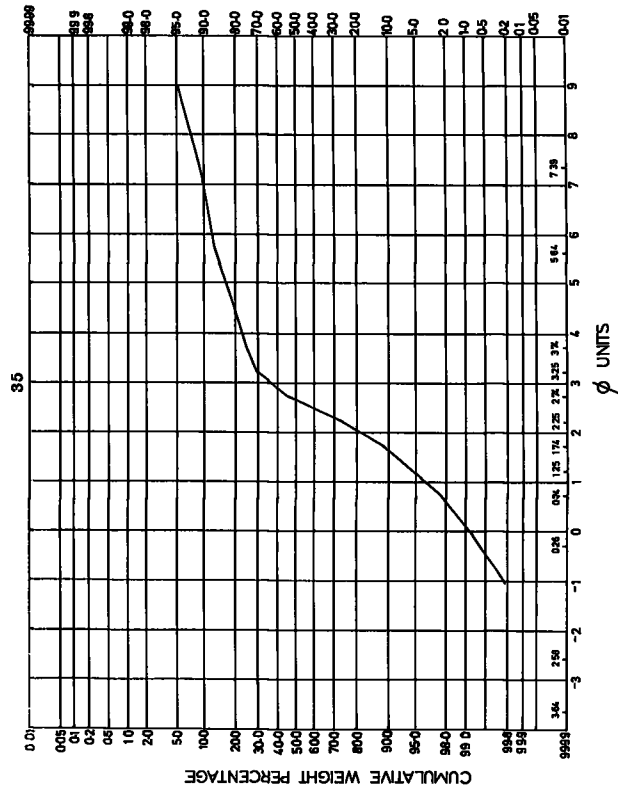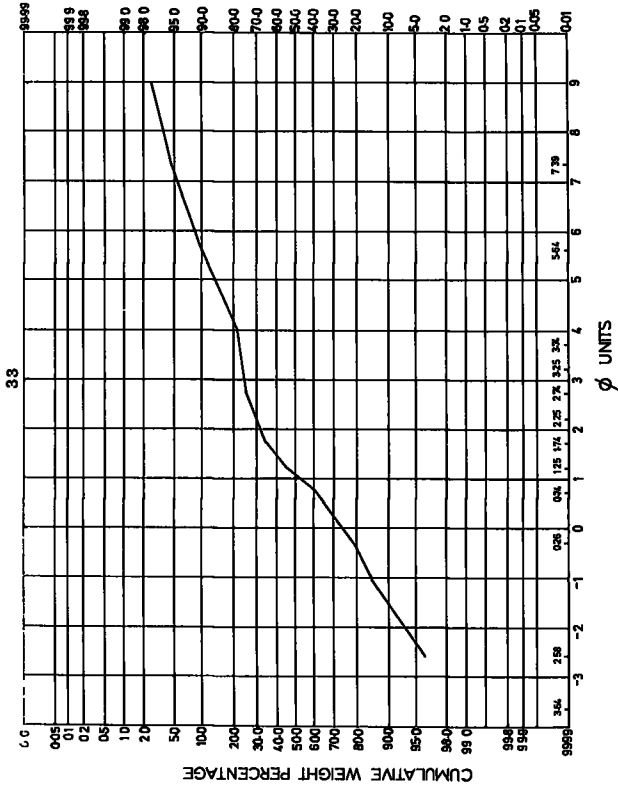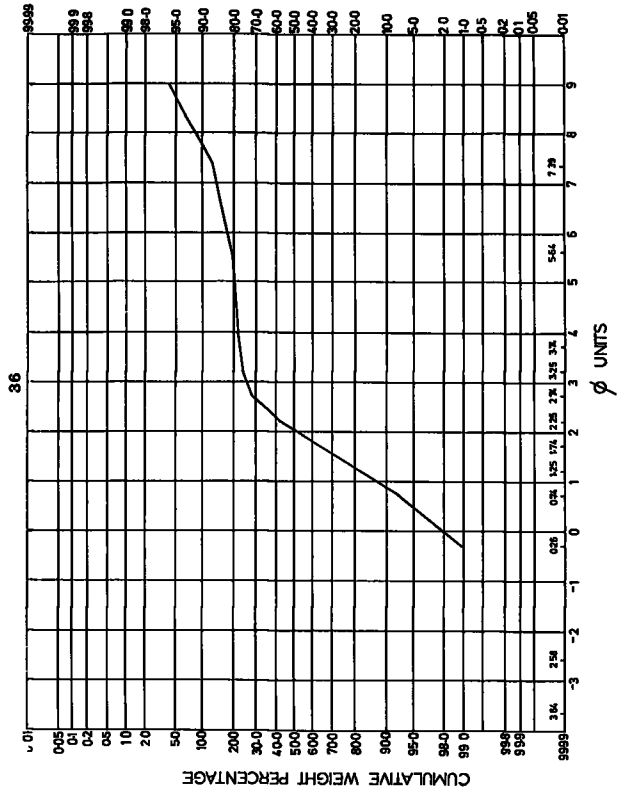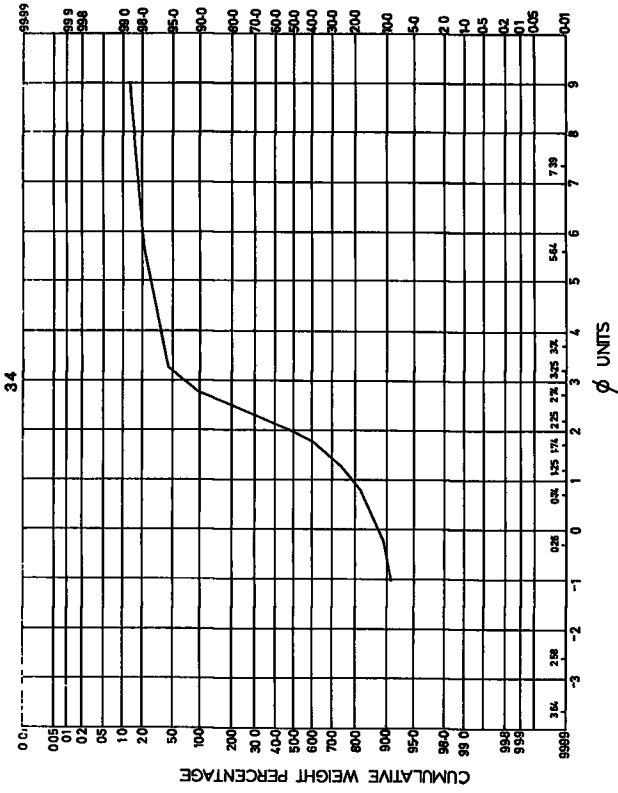
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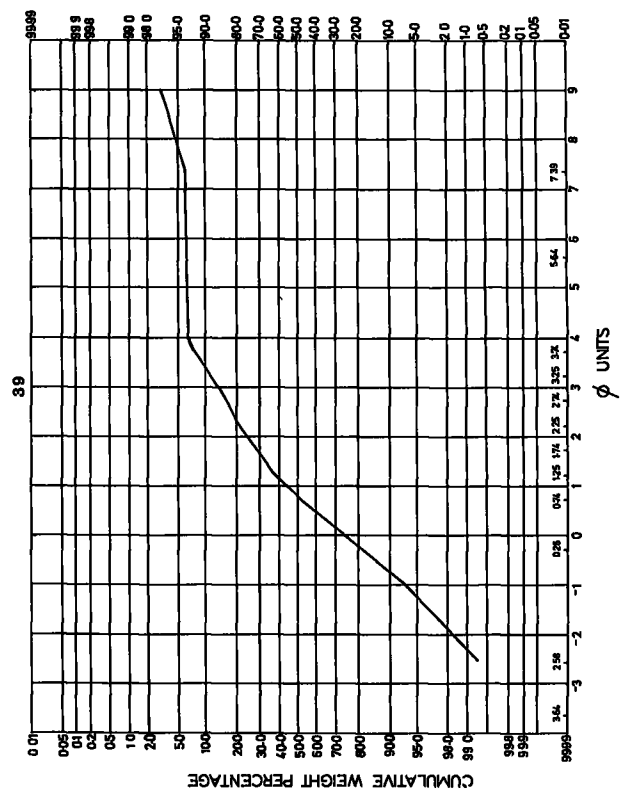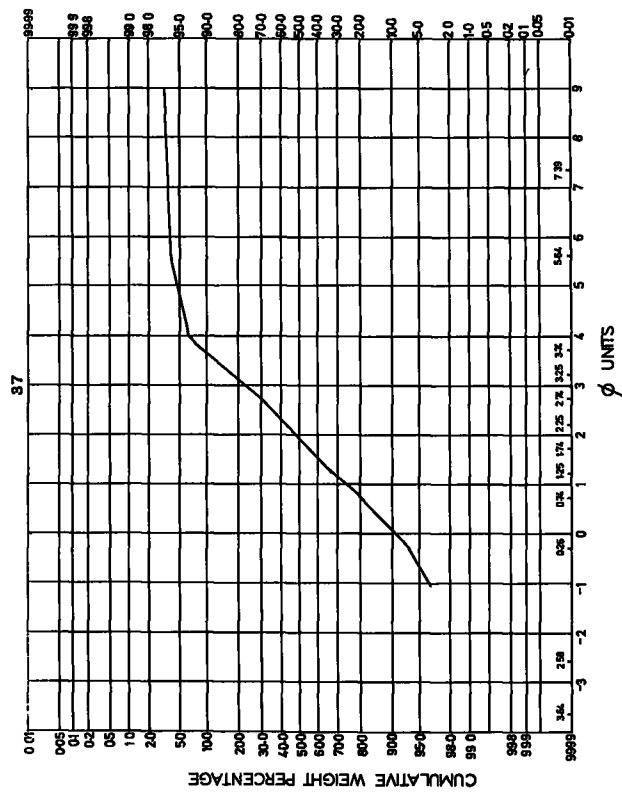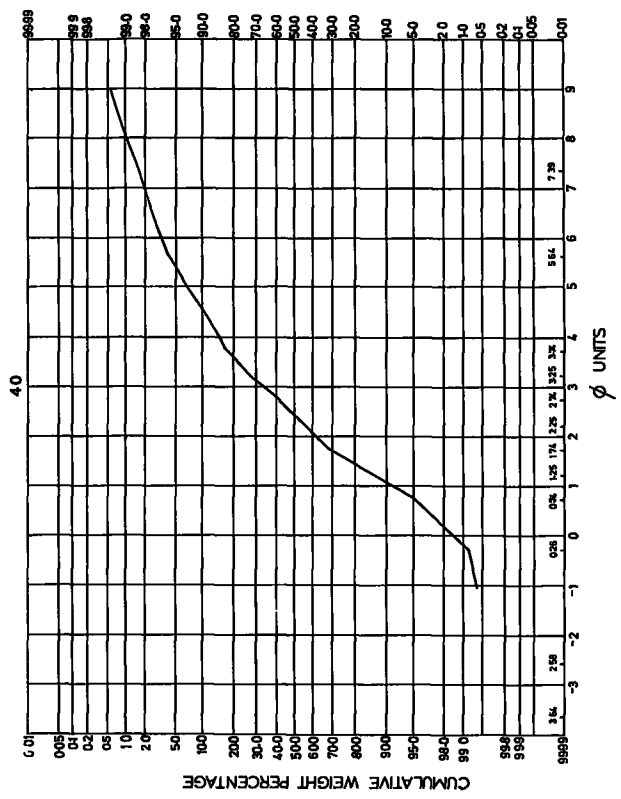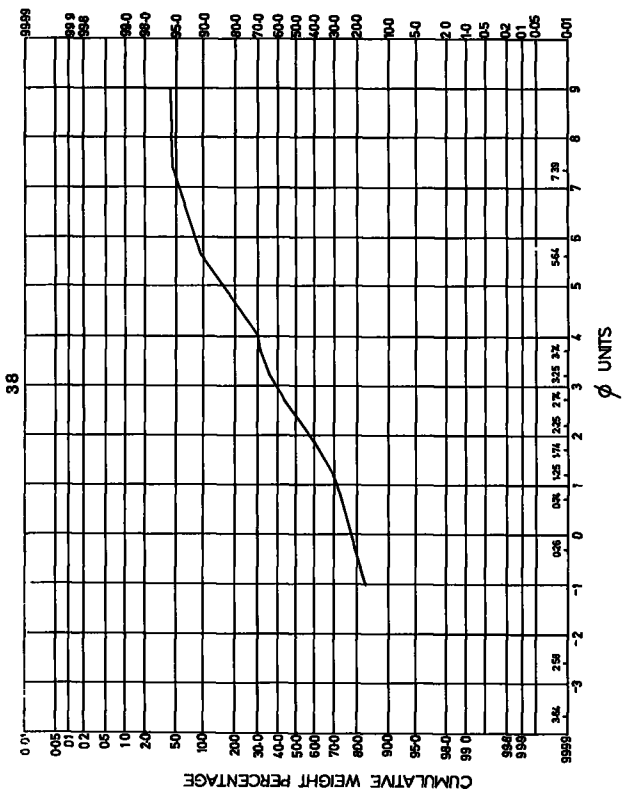
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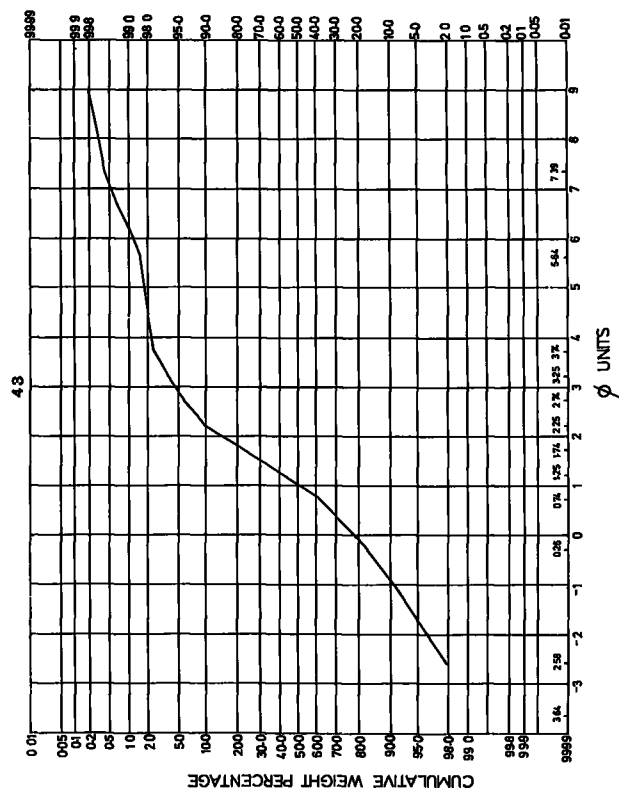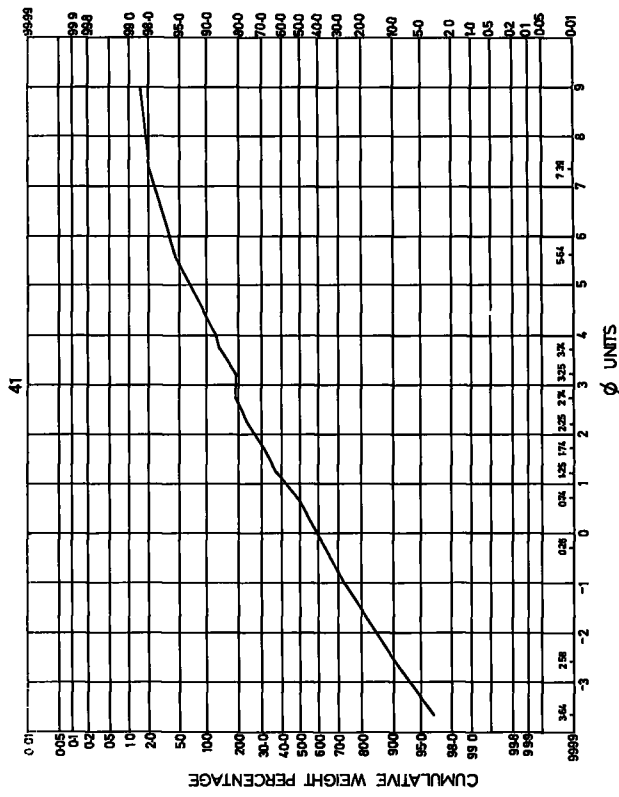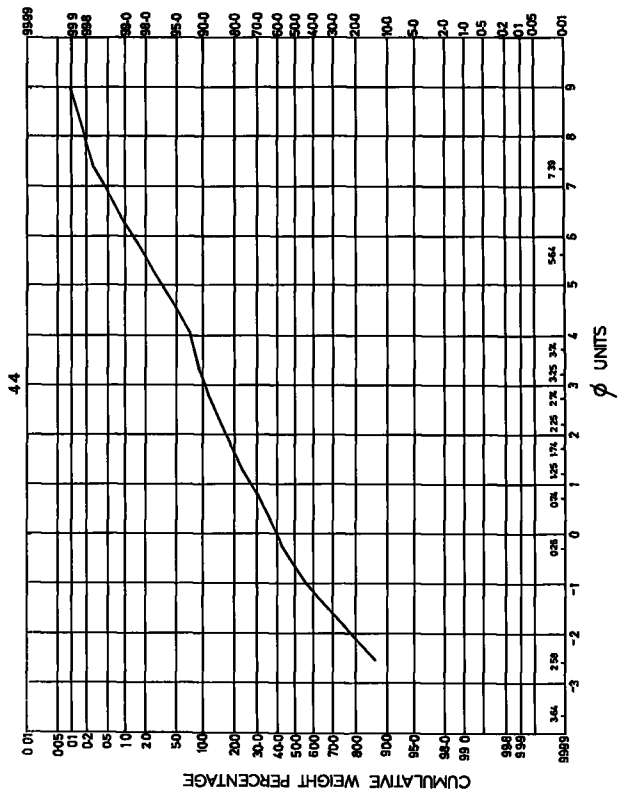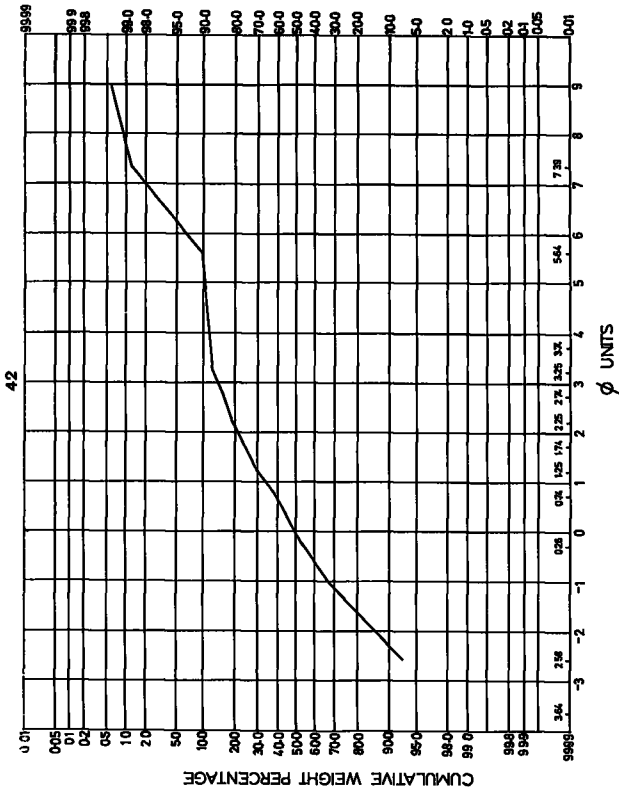
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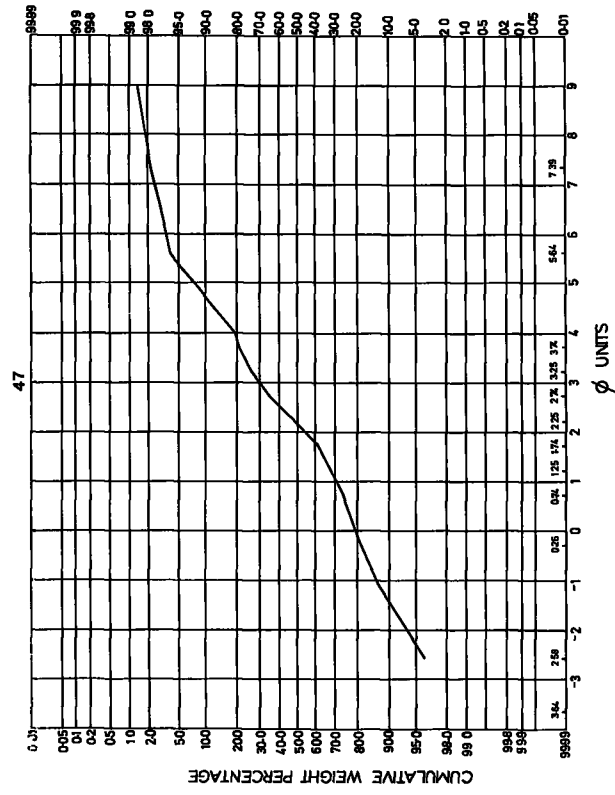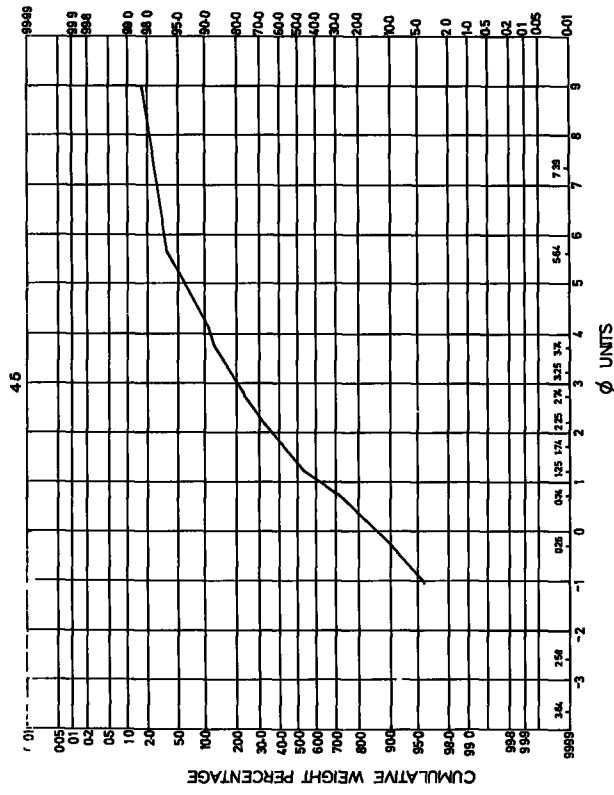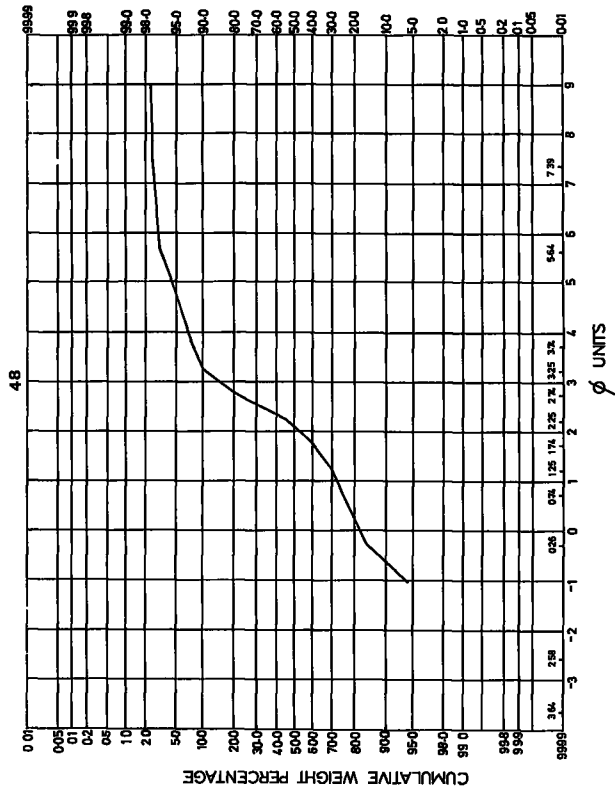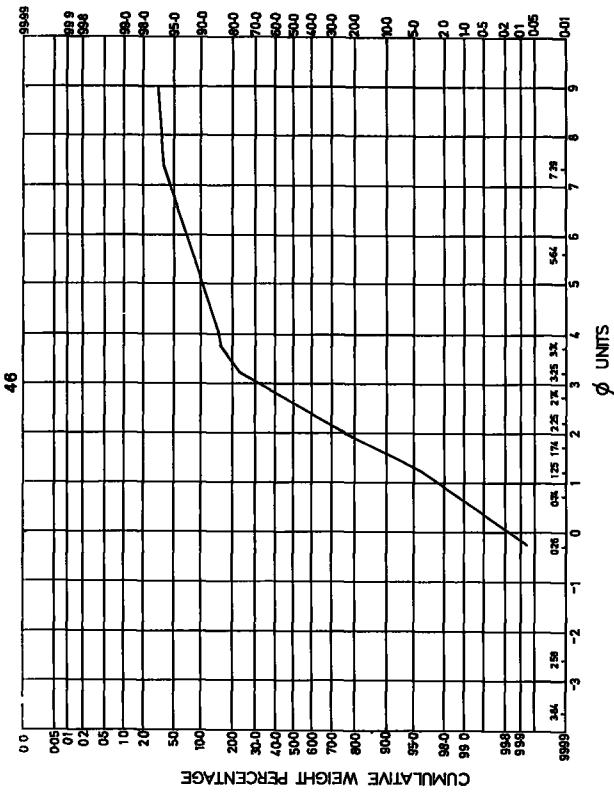
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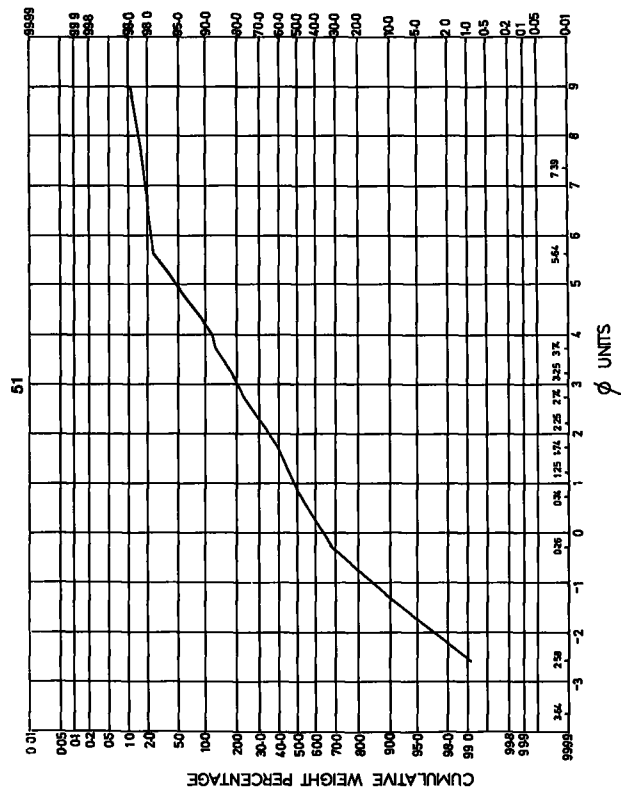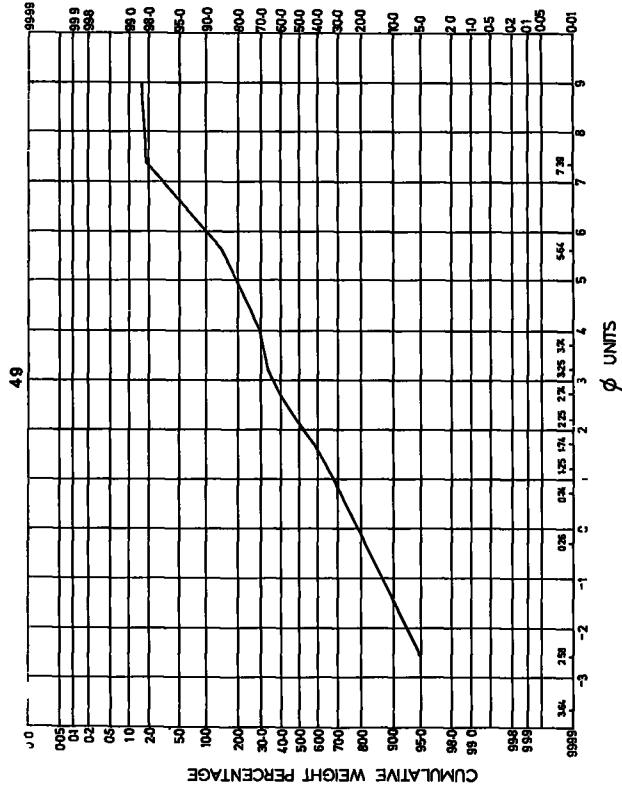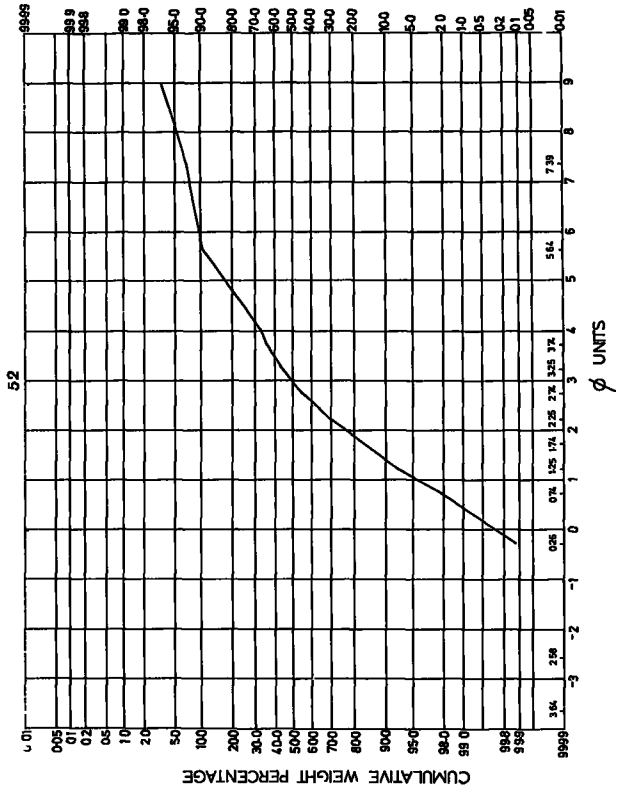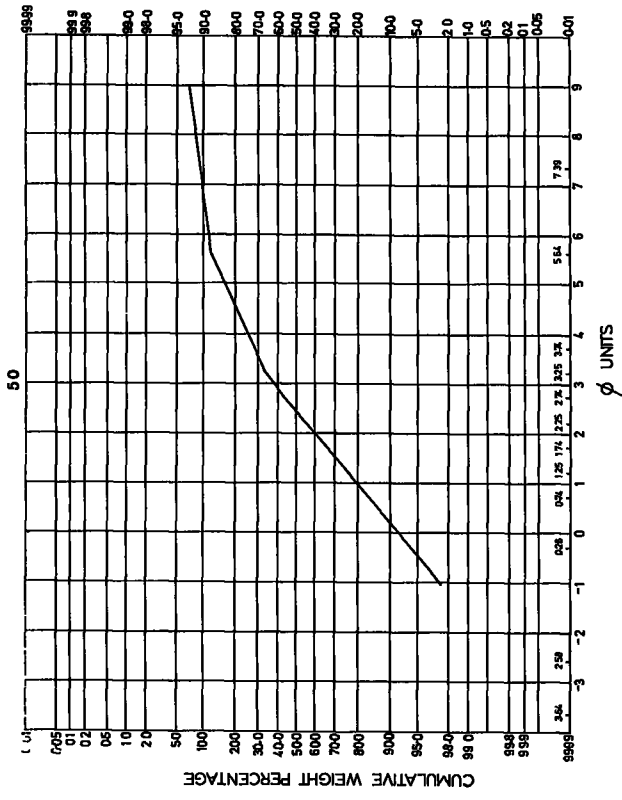
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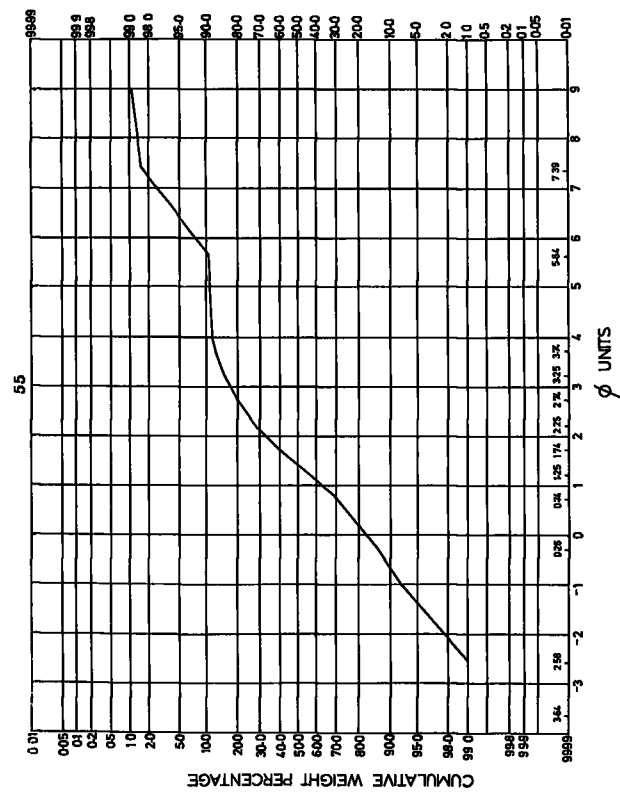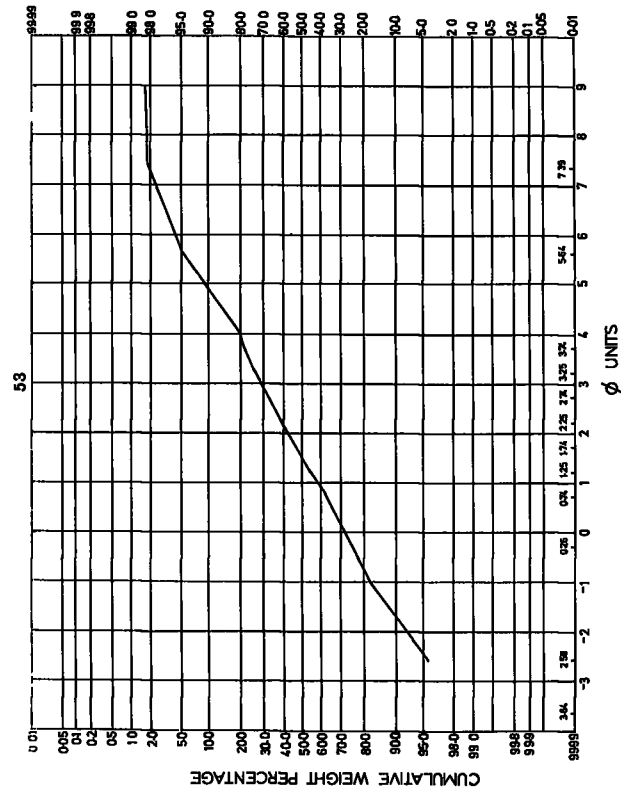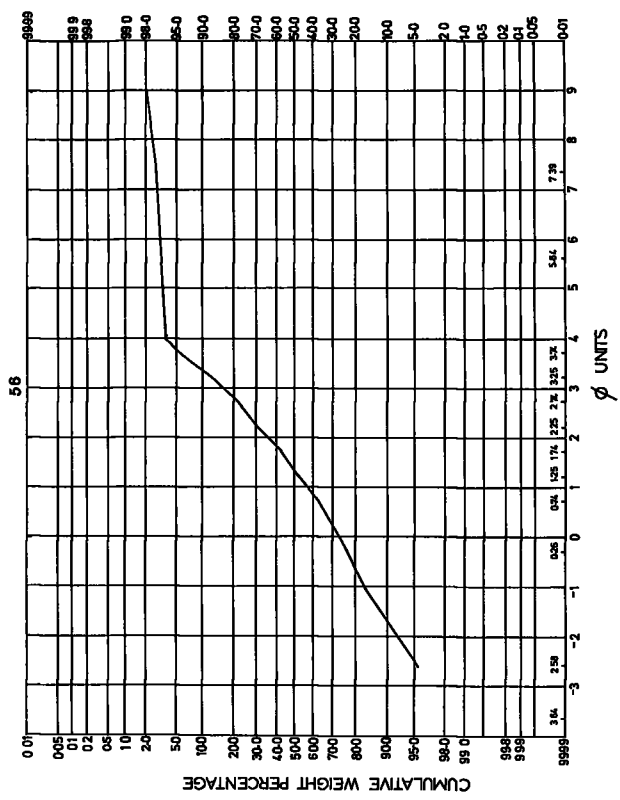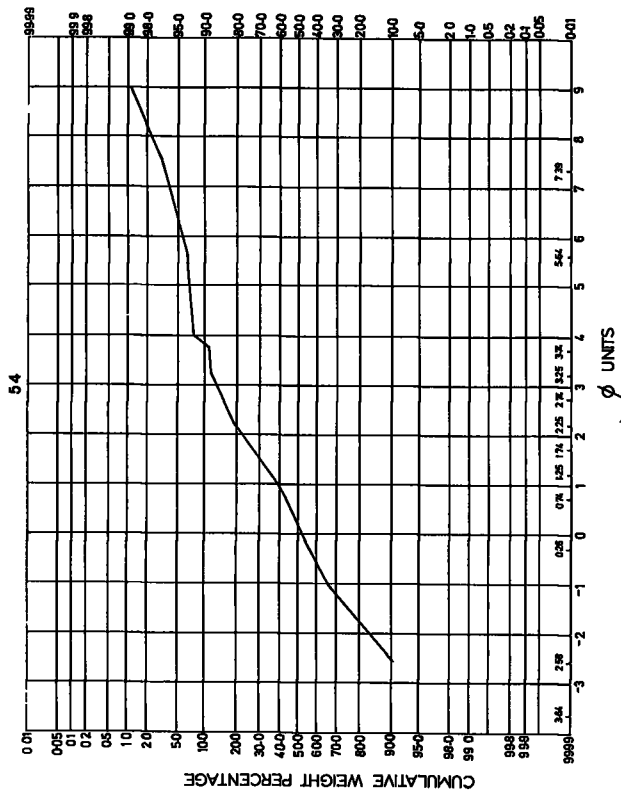
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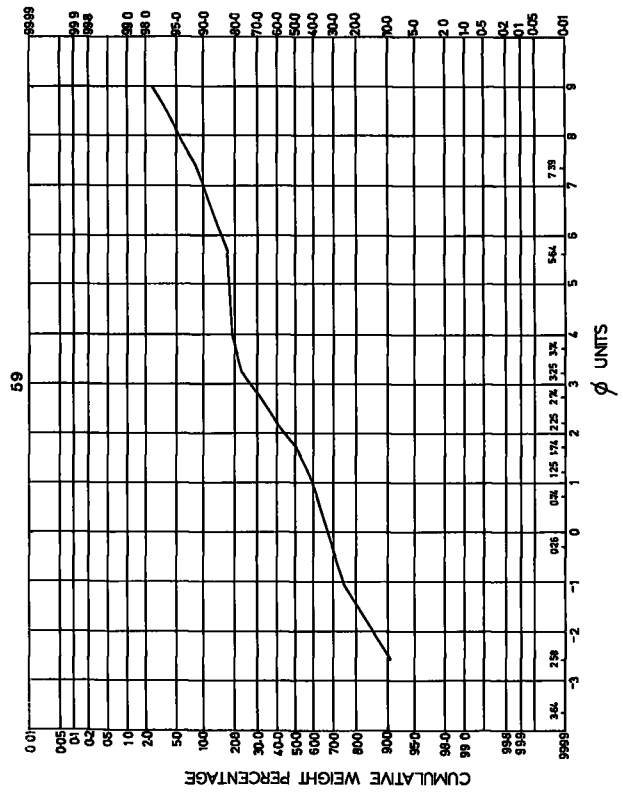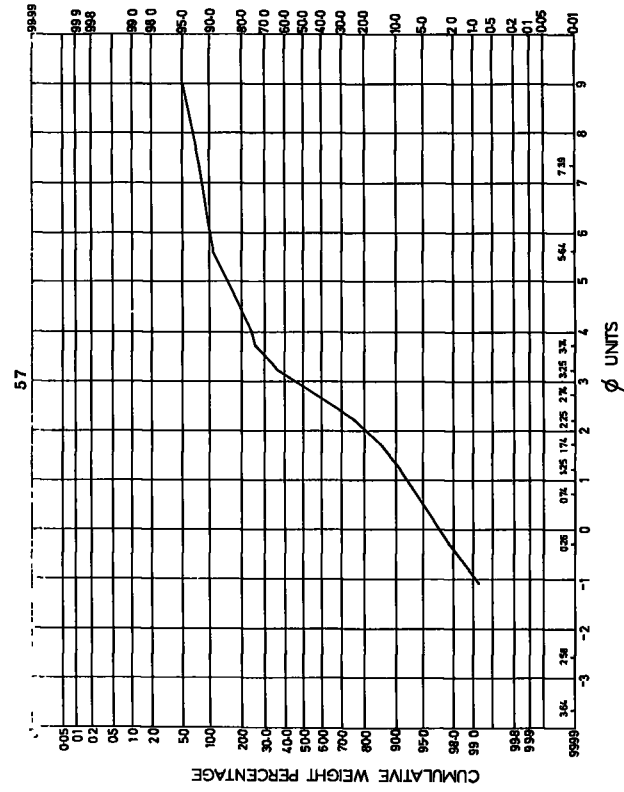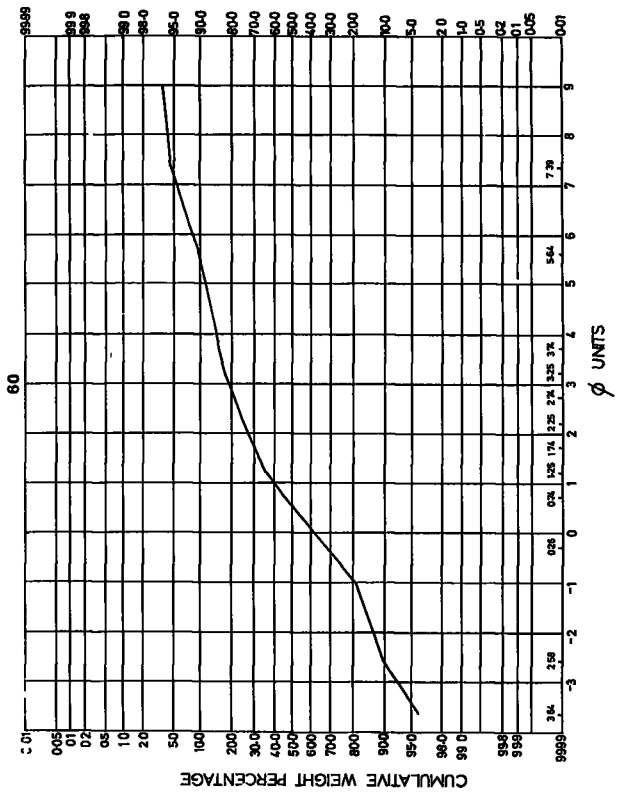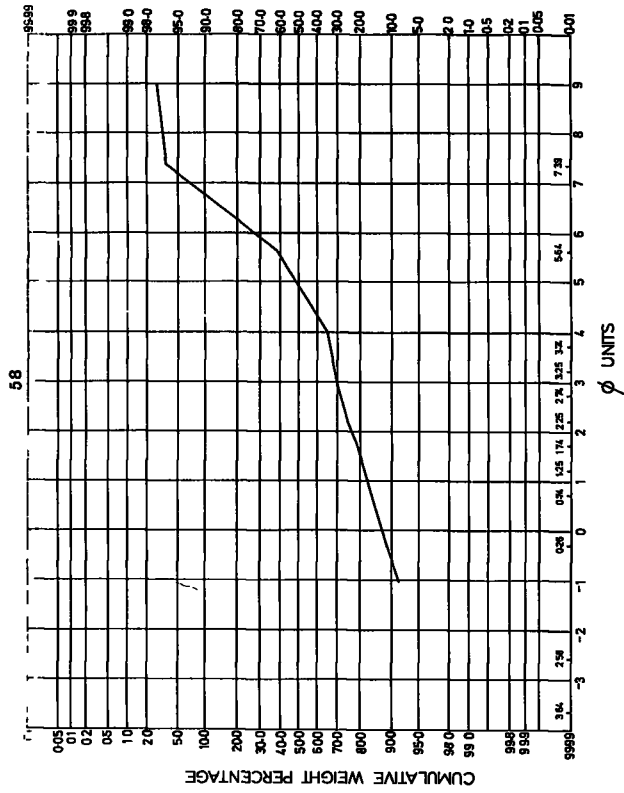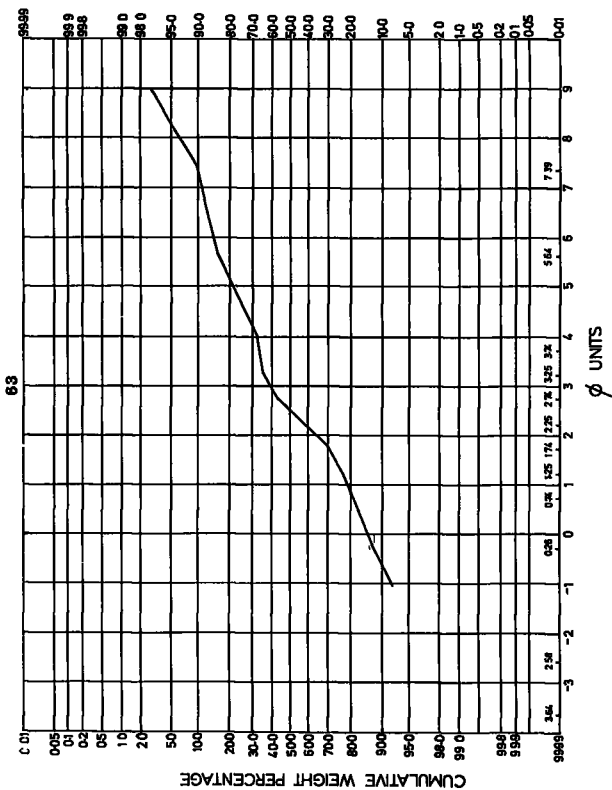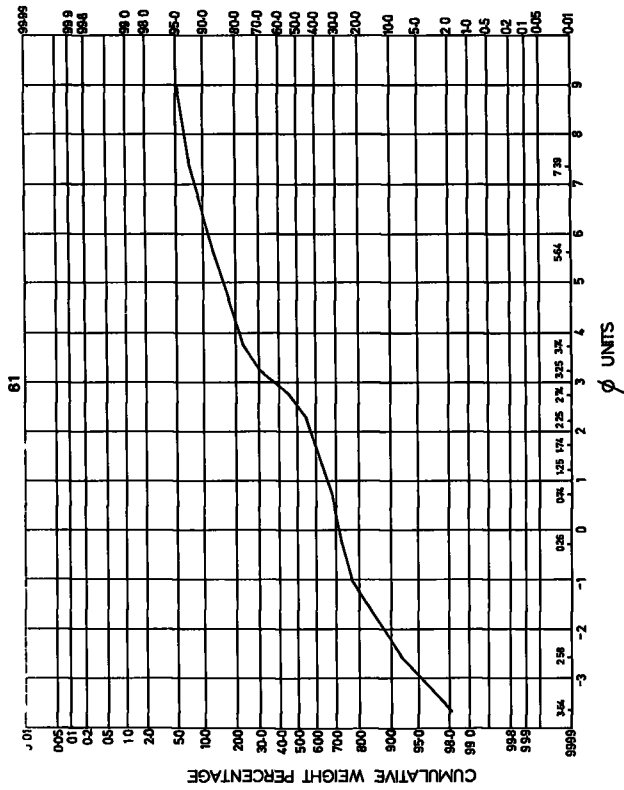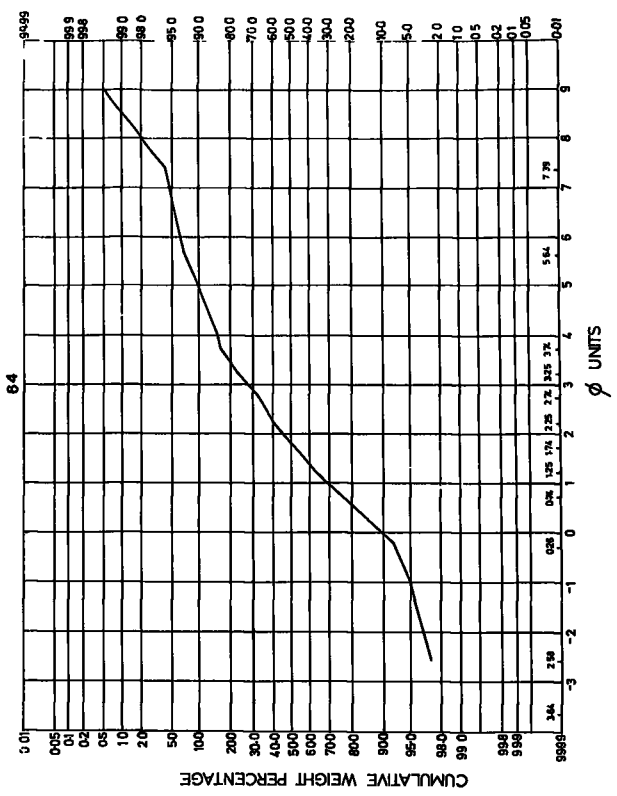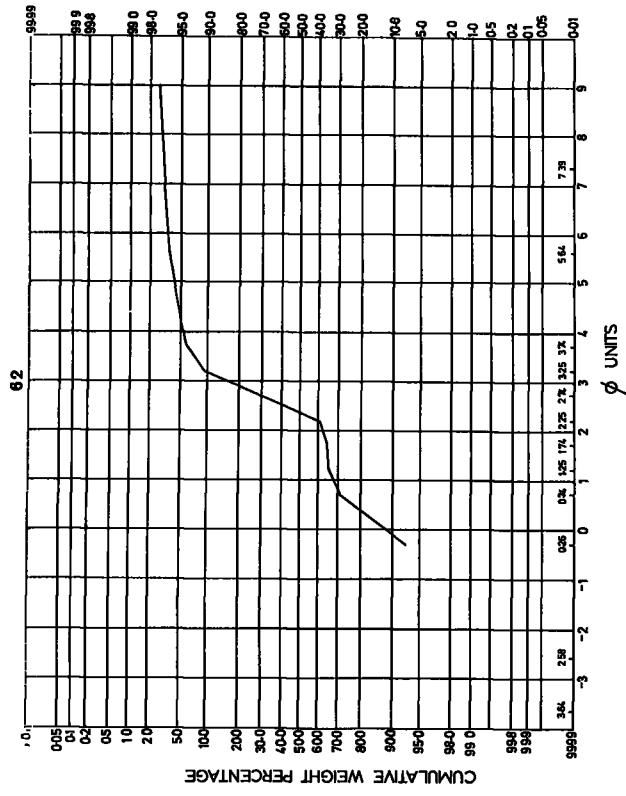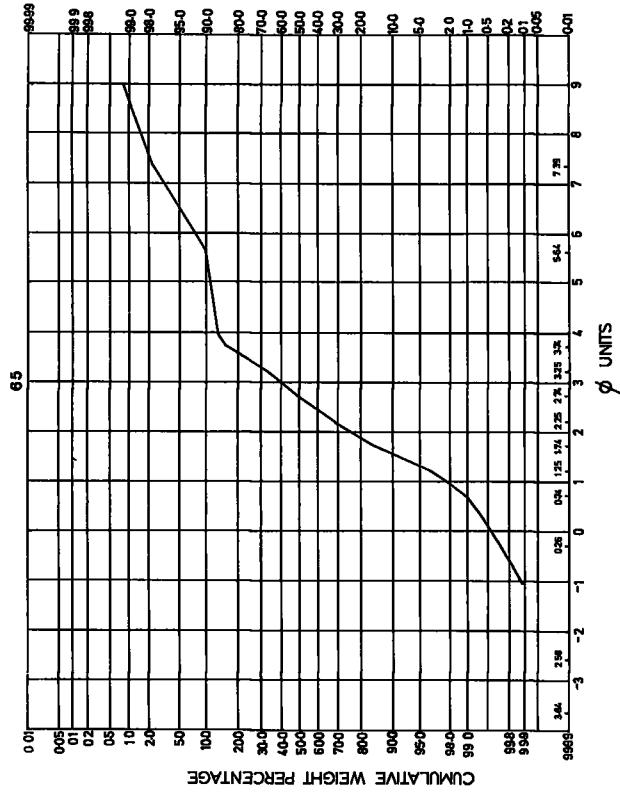
Fig. (28)

Fig. (28)

Fig. (28)

Fig. (28)

Efficiency (percentage)

Inman (1952)

$$M\phi = \tfrac{1}{2} \ (\phi16 + \phi84)$$ 74

Folk and Ward (1957)

$$Mz = \frac{(\phi16 + \phi50 + \phi84)}{3}$$ 88

McCammon (1962)

$$M\phi = (\phi20 + \phi50 + \phi80)/3$$ 88

$$(\phi10 + \phi30 + \phi50 + \phi70 + \phi90)/5$$ 93

$$(\phi5 + \phi15 + \phi25 + \phi35 + \phi45 + \phi55 + \phi65 + \phi75 + \phi85 + \phi95)/10$$ 93

Standard Deviation (sorting)

The degree of sorting in the sample is essentially a measure of dispersion. The best method is that which makes use of points representing most of the cumulative curves, as the more of a curve that enters a sorting measure, the more accurate the measure will be. Trask (1930) used the upper and lower quartiles on the cumulative frequency curve, that is the 75th and 25th on the mm scale; So $= \sqrt{Q_1/Q_3}$

Krumbein (1936) proposed a Q analogue to Trask's so the quartile deviation $QD\phi = (\phi75 - \phi25)/2$. It is clear that this formula "So" takes less note of the tail of the distribution and thus fails to give a good indication of the sorting.

Inman (1952) following Otto (1939) in suggesting a parameter called the phi diameter measure,

$\sigma\phi = \tfrac{1}{2} \ (\phi84 - \phi16)$. Inman's formula gives good results for a normal distribution but is not adequate to describe all sediments, as it is also based on the central part of the cumulative curve only and ignores at least a third of the sample at either end of the range of sizes.

To overcome this difficulty, more of the distribution curves should be included in the sorting measure. Folk and Ward (1957) suggested a sorting measure which they call the Inclusive Graphic Standard Deviation

$$\sigma 1 = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

They have suggested a verbal scale which can be used to describe sorting:

$\sigma 1$	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

McCammon (1962) proposed a new measure and compared the statistical efficiencies of various measures

	Efficiency (percentage)
Inman (1952)	
$(\phi 84 - \phi 16)/2$	54
Folk and Ward (1957)	
$(\phi 84 - \phi 16)/4 + (\phi 95 - \phi 5)/6.6$	79
McCammon (1962)	
$(\phi 85 + \phi 95 - \phi 5 - \phi 15)/54$	79
$(\phi 70 + \phi 80 + \phi 90 + \phi 97 - \phi 3 - \phi 10 - \phi 20 - \phi 30)/9.1$	87

The above formulas show that the efficiency improves as more of the tail of the sample is included in the account.

Skewness

The deviation of the frequency curve from the symmetry of a normal distribution is expressed as skewness. In a symmetrical distribution the mean and the median coincide and there is no skewness. Trask (1932)

suggested the following formula to measure the skewness.

$$Sk = Q_1 \times Q_3/Md^2$$

where Q_1 and Q_3 represent the diameter in millimetres corresponding to the 25th and 75th percentiles respectively and Md is the median diameter in mm, but since this formula does not cover the entire curve, Inman (1952) suggested two measures of skewness

$$\alpha\phi = \frac{M\phi - Md\phi}{\sigma\phi}$$

one for the central part of the distribution and the other to determine the asymmetry of the extremes and called it the second phi skewness, based on the 5th and 95th percentile diameters

$$\alpha2\ \phi = \tfrac{1}{2}\ \frac{(\phi5+\phi95)-Md\phi}{\sigma\phi}$$

Folk and Ward (1957) developed a modification to the two skewness formulae of Inman and combined them in one formula which they called the Inclusive Graphic Skewness

$$sk_1 = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$$

Symmetrical curves have $sk_1 = 0.00$, the mathematical limits are -1.00 to +1.00 and a few curves have skewness beyond -.80 or +.80.

Folk and Ward (op.cit) have suggested the following verbal limits:

Sk_1 from -1.00 to .3	very negative skewed
-.3 to -.1	negative skewed
-.1 to +.1	nearly symmetrical
+.1 to +.3	positively skewed
+.3 to +1	very positive skewed

Negative values indicate that the sample has a "tail" of coarser grain, where as positive value indicates a "tail" of finer material.

Kurtosis

Is a measure of peakness and measures the ratio of the sorting in the extremes of the distribution compared with the sorting in the central part; as such it is a sensitive and valuable test of the normality of a distribution. Inman (1952) defines the phi Kurtosis measure as

$$\beta\phi = \frac{\frac{1}{2}(\phi 16- \phi 5) + \frac{1}{2}(\phi 95- \phi 84)}{\sigma\phi}$$

For a normal distribution $\beta\phi$ has a value of 0.65, but if the curve is less peaked, the value will be greater than 0.65 and for a more peaked curve, than the normal curve the value will be less than 0.65.

Folk and Ward (1957) developed a measure of graphic Kurtosis:

$$K_G = \frac{\phi 95- \phi 5}{2.44(\phi 75-\phi 25)}$$

normal curves have $K_G = 1.00$, the mathematical minimum is 0.41. They suggested that for plotting graphs and for statistical analyses, it is better to use the normalized function

$$K_G' = \frac{K_G}{K_G + 1}$$

The following verbal limits have been suggested:

K_G		K_G'		
under 0.67	=	under 0.4		very platykurtic (tails are better sorted than the central portion of the curve)
0.67 - 0.9	=	0.4 - 0.47		platykurtic
0.9 - 1.11	=	0.47 - 0.52		mesokurtic (the sorting of the central portion of the curve is equal to that of the tails)
1.11 - 1.5	=	0.52 - 0.60		leptokurtic (better sorted in the central area than in the tails)
1.5 - 3	=	0.60 - 0.75		very leptokurtic

K_G over $3.0 = K'_G$ over 0.75 extremely leptokurtic

for the present work statistical parameters used in describing the grain

size properties of the sediments are those proposed by Folk and Ward (1957)

Parameter variations

Sixty five samples were statistically analysed by the method out-

lined before. From the cumulative curves, (Fig. 28) different weight

percentiles were obtained to calculate the different size parameters.

These percentiles are: 5, 16, 25, 50, 75, 84, and 95, and are given in

table (7). The results of the statistical analyses are shown in Table

(8). There is no significant relationship between the parameter value

of individual sampling point and their distance from the sea. Higher or

lower values are obtained in various areas. The mean size (M_z) value

of the samples shows an absolute variation from -0.61ϕ (1.53 mm) to 4.87 ϕ

(0.034 mm) which reflects the wide range of grain size present in the

area. The standard deviation (σ_I) values range from 0.82ϕ moderately

sorted to 3.54ϕ very poorly sorted. Values of skewness (sk_I) range from

very negative skewness -0.43ϕ to very positive skewness 0.63ϕ. The

transformed value of K'_G have been applied and the result shows an absolute

cariation from a minimum value of 0.43 ϕ to a maximum of $K'_G = 0.77 \phi$ which

reflects the environments prevailing in the area. However, an apparent

cariation appears when comparing all the samples from a particular terrace

with the beach samples. The mean size value was obtained by averaging

the results of the four parameters from each of the six terraces in the

areas as well as those from the top of the escarpment and the beach samples

(Fig. 29, Table 9). The results show that:

Mean Size (M_z)

The mean size fluctuates from $M_z = 0.90 \phi$ on the top of the escarpment

to a value of 0.78 ϕ on the First terrace. These high values reflect the

dominant mode of grains on them as a result of the presence of gravel of

medium and small size. A gradual decrease in the size appears towards

Table (7) Percentiles used for the calculation of the mean, standard
deviation, skewness and kurtosis.

Location	Sample No.	5	16	25	50	75	84	95
Kathma I	1	-2.60	-1.65	-1.15	1.40	3.25	4.20	5.55
	2	-2.75	+1.65	-1.06	0.45	1.70	2.68	7.43
	3	-3.64	-2.84	-2.30	0.15	2.25	2.63	5.90
	4	-1.84	-0.05	-0.40	1.20	2.80	3.10	5.00
	5	0.95	1.55	1.80	2.22	3.30	4.70	9.00
	6	0.98	1.45	1.65	2.10	2.70	4.00	6.00
	7	0.76	1.05	1.17	1.72	3.05	3.00	6.32
	8	0.52	0.98	1.10	1.48	1.95	2.30	5.25
	9	-1.12	1.30	2.05	5.45	7.55	3.85	8.55
	10	0.14	0.73	0.95	1.40	1.90	2.14	3.90
	11	-1.68	0.70	1.02	1.68	2.65	3.30	5.52
	12	0.25	0.65	0.86	1.70	3.05	3.60	7.20
Kathma II	13	-3.00	-1.90	-1.15	0.64	2.05	3.14	4.85
	14	-3.20	-2.80	-2.62	-1.53	0.80	2.50	8.18
	15	-2.25	-1.00	-0.40	1.20	2.76	3.10	8.40
	16	-3.70	-2.67	-1.95	0.44	2.40	3.10	8.60
	17	-1.50	0.20	1.10	2.48	4.17	4.67	5.90
	18	0.52	1.15	1.35	1.70	2.22	2.80	7.00
	19	0.40	0.80	1.05	1.95	3.00	3.45	5.30
	20	0.36	1.02	1.38	2.60	3.52	4.25	5.60
Ghidhai	21	-2.50	-1.65	-1.25	0.00	1.15	1.90	5.50
	22	-1.60	0.05	0.40	1.10	2.25	3.20	8.10
	23	-1.60	0.80	1.25	2.05	2.95	3.53	5.64
	24	-0.22	0.24	0.44	0.88	1.40	1.95	7.45
	25	0.33	0.84	0.96	1.32	1.73	1.97	3.85
	26	-1.35	2.04	2.26	2.73	3.45	4.75	7.05
	27	-0.80	0.35	0.10	2.20	3.70	5.40	7.00
	28	-0.37	0.85	1.35	2.04	2.50	2.72	4.90
	29	-2.40	-1.00	0.20	2.70	4.70	5.50	6.80
	30	1.00	1.45	1.63	2.08	2.56	2.90	4.10
	31	0.96	1.95	2.70	4.64	5.90	6.65	8.30
Mudairah	32	-3.70	-1.74	-0.70	1.10	2.72	4.02	5.30
	33	-2.30	-0.85	0.00	1.10	2.80	4.65	7.18
	34	-1.25	0.55	1.20	1.95	2.36	2.55	3.15
	35	1.16	1.92	2.20	2.65	3.65	5.00	9.00
	36	0.52	1.18	1.45	2.05	3.10	6.35	8.70

Location	Sample No.	5	16	25	50	75	84	95
Mudairah	37	-0.63	0.52	0.95	1.90	2.87	3.22	4.20
	38	-1.40	-1.05	0.40	2.35	4.25	4.90	7.00
	39	-1.22	-0.40	-0.04	0.80	1.97	2.74	7.90
	40	0.78	1.30	1.55	2.40	3.30	3.80	5.35
Al-Bahra I	41	-3.25	-1.85	-1.15	0.65	2.15	3.46	5.45
	42	-2.65	-1.85	-1.38	-0.05	1.60	2.65	5.10
	43	-1.65	-0.30	0.20	1.05	1.65	1.95	2.90
	44	-2.80	-2.35	-1.85	-0.70	1.10	2.08	4.50
	45	-0.80	0.20	0.65	1.40	2.65	3.40	5.20
	46	ᵢ1.33	1.80	2.05	2.60	3.15	3.70	6.75
	47	-2.22	-0.55	0.65	2.20	3.35	4.24	5.40
	48	-1.10	-0.20	0.75	2.10	2.64	2.95	4.75
	49	-2.58	-0.50	0.40	2.10	4.40	5.35	6.60
	50	-0.45	0.72	1.20	2.40	3.95	5.00	9.00
	51	-1.70	-0.94	-0.55	0.85	2.60	3.40	4.90
	52	1.06	1.70	2.05	2.95	4.45	5.10	8.10
Al-Bahra II	53	-2.44	-1.14	-0.30	1.45	3.16	4.20	5.55
	54	-2.73	-2.00	-1.48	0.20	1.80	2.55	6.30
	55	-1.37	-0.06	0.50	1.42	2.38	3.10	6.40
	56	-2.45	-1.00	-0.12	1.35	2.54	3.00	3.75
	57	0.60	1.90	2.30	2.94	3.80	4.90	9.00
	58	-1.20	0.85	2.20	4.90	6.05	6.45	7.20
	59	-2.72	-1.80	0.25	1.70	3.10	5.80	8.10
Al-Bahra III	60	-3.44	-1.45	-0.65	0.52	2.18	3.50	7.15
	61	-2.90	-1.60	-0.70	2.50	3.55	4.80	9.00
	62	-0.34	0.25	0.60	2.40	3.80	3.02	4.20
	63	-1.20	0.35	1.40	2.52	4.65	5.58	8.30
	64	-0.95	0.38	0.78	1.80	3.10	3.80	6.85
	65	1.34	1.76	2.03	2.70	3.44	3.74	6.45

the lower terraces as the sediment becomes more sandy until it reaches

its finest size on the Fifth and Sixth terraces (M_z = 2.53 ϕ and 2.52 ϕ).

Mean size increases agin towards the beach samples M_z = 2.3 ϕ indicating

increases of the particle size such as may have resulted from the loss of

the fine grains which is expected for the beach sands in general.

Standard deviation (σ_I)

The solid line indicates the area of very poorly sorted sand with

stadnard deviation of 2.58 ϕ and 2.53 ϕ on the top of the escarpment and

on the First terrace. Similar poor sorting is attained on the Fifth

and Sixth terraces with values of σ_I = 2.54 ϕ and 2.68 ϕ. The second area

is concerned with the Second and Third terraces which, although character-

ised by being very poorly sorted (over 2 ϕ), is better sorted than the

first area mentioned. The Second terrace has a mean of standard

deviation of 2.16 ϕ and 2.04 ϕ for the Third terrace. From there the

line declines to the third better sorted area on the Fourth terrace,

σ_I = 1.73 ϕ where identified marine sediment has been recognised in the

field. The second area of similar better sorting is on the present

beach with a standard deviation of 1.83 ϕ.

Skewness (sk_I)

On the top of the escarpment, the sediment is nearly symmetrical

(symmetrical limit -0.1 to +0.1 ϕ). This is because a pure modal fraction

of gravel side is predominant in that area, sk_I = 0.08 ϕ. Similar to

this area is the First terrace which appears to have sediment of nearly

equal two modes (gravel and sand), but, as the two modes are mixed, with

the majority being of the coarse fraction mode, the mean of the skewness

in the First terrace attains a positive skewness. This can be noticed

as the line joining the mean of the skewness of the top of the

escarpment rises to the value of sk_I = 0.21 ϕ. Addition of small quantities

Table (8)   Results of Statistical Analysis of Particle Size Curves

Location	Sample No.	$M_z\phi$	σ_I	sk_I	k_G	$k_G{}'$
Kathma I	1	1.32	2.7	−0.01	0.76	0.43
	2	0.49	2.62	0.20	1.51	0.60
	3	−0.02	2.81	0.06	0.86	0.46
	4.	1.42	2.13	0.16	1.17	0.54
	5	2.82	2.01	0.63	2.20	0.69
	6	2.52	1.40	0.52	1.96	0.66
	7	1.92	1.33	0.48	1.21	0.55
	8	1.59	1.05	0.42	2.28	0.70
	9	4.87	3.10	−0.27	0.72	0.42
	10	1.42	0.92	0.19	1.62	0.62
	11	1.89	1.74	0.16	1.81	0.64
	12	1.98	1.79	0.44	1.30	0.57
Kathma II	13	0.63	2.45	0.03	1.01	0.50
	14	−0.61	3.05	0.61	1.36	0.58
	15	1.10	2.64	0.14	1.38	0.58
	16	2.90	3.31	0.13	1.16	0.54
	17	2.45	2.24	−0.05	0.99	0.50
	18	1.88	1.39	0.48	3.06	0.75
	19	2.07	1.40	0.25	1.03	0.51
	20	2.62	1.60	0.08	1.00	0.50
Ghidhai	21	0.08	2.10	0.22	1.37	0.58
	22	1.45	2.26	0.39	2.15	0.68
	23	2.13	1.78	0.04	1.75	0.64
	24	1.02	1.59	0.50	3.28	0.77
	25	1.38	0.82	0.29	1.87	0.65
	26	3.17	1.54	0.50	1.96	0.66
	27	2.65	2.44	0.25	0.89	0.47
	28	1.87	1.27	−0.09	1.88	0.65
	29	2.37	3.04	−0.13	0.84	0.46
	30	2.14	0.83	0.22	1.37	0.58
	31	4.41	2.29	−0.07	0.97	0.48
Mudairah	32	1.13	2.8	−0.03	1.08	0.52
	33	1.63	2.81	0.29	1.39	0.58
	34	1.68	1.17	−0.43	1.55	0.61
	35	3.19	2.65	0.57	2.21	0.69
	36	3.19	2.53	0.64	2.03	0.67
	37	1.88	1.41	−0.03	1.03	0.51

Location	Sample No.	$M_z\phi$	σ_I	sk_I	k_G	$k_G{}'$
Mudairah	38	2.07	2.76	-0.02	0.89	0.47
	39	1.05	2.17	0.40	1.86	0.65
	40	2.50	1.32	0.21	1.07	0.52
Al-Bahra I	41	0.75	2.65	0.08	1.08	0.52
	42	0.25	2.30	0.26	1.07	0.52
	43	0.90	1.25	-0.19	1.29	0.56
	44	-0.32	2.21	0.55	1.01	0.50
	45	1.67	1.71	0.26	1.23	0.55
	46	2.70	1.30	0.34	2.02	0.67
	47	1.96	2.35	-0.15	1.16	0.54
	48	1.62	1.67	-0.28	1.26	0.58
	49	2.32	2.85	0.05	0.94	0.48
	50	2.71	2.50	0.31	1.41	0.59
	51	1.10	2.09	0.20	0.86	0.46
	52	3.25	1.92	0.36	1.20	0.55
Al-Bahra II	53	1.50	2.55	0.04	0.95	0.49
	54	0.25	2.51	0.20	1.13	0.53
	55	1.49	1.97	0.17	1.69	0.63
	56	1.12	1.94	-0.20	0.96	0.49
	57	3.25	2.02	0.53	2.30	0.70
	58	4.07	2.67	-0.40	0.89	0.47
	59	1.90	3.54	0.13	1.57	0.61
Al-Bahra III	60	0.86	2.84	0.23	1.53	0.60
	61	1.90	3.40	-0.09	1.15	0.53
	62	1.89	1.39	-0.38	0.85	0.46
	63	2.82	2.75	0.19	1.20	0.55
	64	1.99	2.04	0.23	1.38	0.58
	65	2.73	1.27	0.34	1.49	0.60

of silt to the dominant sand mode produced positive skewness, which seems to justify the positive skewness on the Third and Fourth terrace. The line declines again to negative skewness of $sk_I = -0.21 \phi$ which reflects the characteristic of the sediment. It rises again to positive skewness as the sediments on the Sixth terrace contain a higher proportion of finer material (0.18ϕ) than the beach samples $(sk_I = 0.23 \phi)$ which in the case of the beach samples, may have been caused by the addition of more silt and clay from the Tigris and Euphrates river system as opposed to aeolian material on the Sixth terrace.

Kurtosis (K_G)

The mean of the kurtosis values rises from the top of the escarpment where it attains a value of $K_G' = 0.5$ (Normal curve) indicating a predominance of gravel mode. It rises to the First and Second terraces of values 0.57ϕ and 0.55ϕ (Leptokurtic) with one mode dominant. The same characteristic can be noticed in the values of the Sixth terrace $K_G' = 0.54 \phi$ and those of the beach samples $K_G' = 0.56 \phi$ indicating better sorting in the central part of the curves than of their tails. More progress in the sorting of the centre of the curves is noted in the Third and Fourth terrace values $K_G' = 0.5 \phi$ and 0.61ϕ correspondingly.

5.3.1a Student's t test

This was applied to determine the significance of the differences between the four parameters of the top of the escarpment, the six terraces and the beach samples. The differences will reveal whether there is a close relationship between their parameters and whether a correlation can be drawn between them. In the present work the probability (p) has been adopted as less than 0.5 in order for differences to be significant. As has been mentioned before, there is evidence of mixed sedimentary environments in the area. The only samples of definite known environment which were collected are those of the beach area. Accordingly,
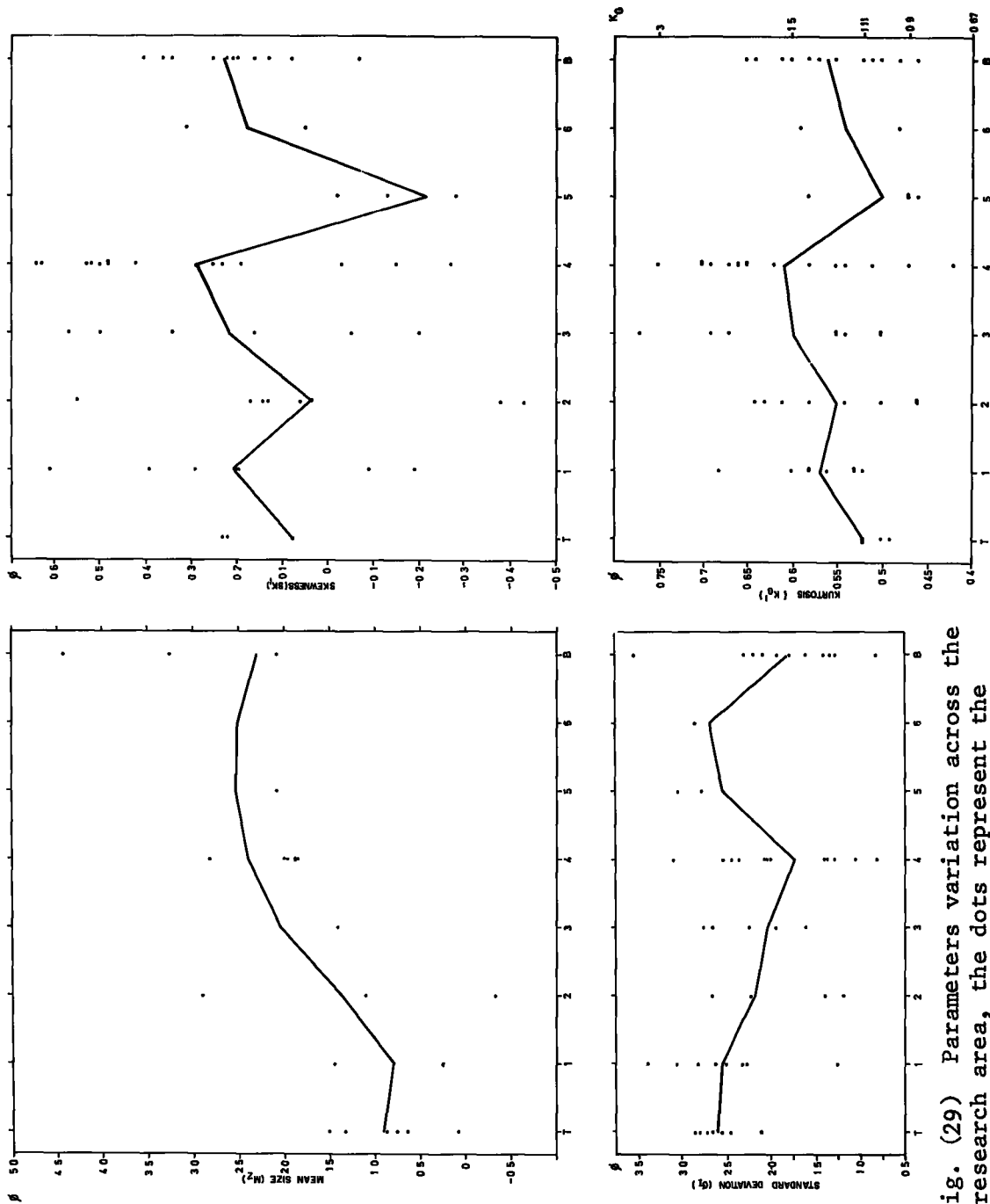
Fig. (29) Parameters variation across the research area, the dots represent the value of each analysed sample at each locality. The solid line represents the mean value by averaging the results from each of the eight locations

Table(9) The mean size values of the four parameters (mean, standard
deviation, skewness and kurtosis) for the samples from the top of the
escarpment, the six terraces and the beach.

Location	Sample No.	$M_z\phi$	σ_I	sk_I	k_G	k_G'
Top of the escarpment	1	1.32	2.70	-0.01	0.76	0.43
	13	0.63	2.45	0.03	1.01	0.50
	21	0.08	2.10	0.22	1.37	0.58
	32	1.13	2.80	-0.03	1.08	0.52
	41	0.75	2.65	0.08	1.08	0.52
	53	1.50	2.55	0.04	0.95	0.49
	60	0.86	2.84	0.23	1.53	0.60
	Average	0.90	2.58	0.08	1.11	0.52
First terrace	2	0.49	2.62	0.20	1.51	0.60
	14	-0.61	3.05	0.61	1.36	0.58
	22	1.45	2.26	0.39	2.15	0.68
	33	1.63	2.81	0.29	1.39	0.58
	42	0.25	2.30	0.26	1.07	0.52
	43	0.90	1.25	-0.19	1.29	0.56
	54	0.25	2.51	0.20	1.13	0.53
	61	1.90	3.40	-0.09	1.15	0.53
	Average	0.78	2.53	0.21	1.38	0.57
Second terrace	3	-0.02	2.81	0.06	0.86	0.46
	15	1.10	2.64	0.14	1.38	0.58
	16	2.90	3.31	0.13	1.16	0.54
	23	2.13	1.78	0.04	1.75	0.64
	34	1.68	1.17	-0.43	1.55	0.61
	44	-0.32	2.21	0.55	1.01	0.50
	55	1.49	1.97	0.17	1.69	0.63
	62	1.89	1.39	- 0.38	0.85	0.46
	Average	1.36	2.16	0.04	1.28	0.55

Location	Sample No.	$M_z\phi$	σ_I	sk_I	k_G	k_G'
Third terrace	4	1.42	2.13	0.16	1.17	0.54
	17	2.45	2.24	-0.05	0.99	0.50
	24	1.02	1.59	0.50	3.28	0.77
	35	3.19	2.65	0.57	2.21	0.69
	45	1.67	1.71	0.26	1.23	0.55
	46	2.70	1.30	0.34	2.02	0.67
	56	1.12	1.94	-0.2	0.96	0.49
	63	2.82	2.75	0.19	1.20	0.55
	Average	2.05	2.04	0.22	1.63	0.60
Fourth terrace	5	2.82	2.01	0.63	2.20	0.69
	6	2.52	1.40	0.52	1.96	0.66
	7	1.92	1.33	0.48	1.21	0.55
	8	1.59	1.05	0.42	2.28	0.70
	9	4.87	3.10	-0.27	0.72	0.42
	10	1.42	0.92	0.19	1.62	0.62
	18	1.88	1.39	0.48	3.06	0.75
	25	1.38	0.82	0.29	1.87	0.65
	26	3.17	1.54	0.50	1.96	0.66
	27	2.65	2.44	0.25	0.89	0.47
	28	1.87	1.27	-0.09	1.88	0.65
	36	3.19	2.53	0.64	2.03	0.67
	37	1.88	1.41	-0.03	1.03	0.51
	47	1.96	2.35	-0.15	1.16	0.54
	57	3.25	2.02	0.53	2.30	0.70
	64	1.99	2.04	0.23	1.38	0.58
	Average	2.40	1.73	0.29	1.72	0.61
Fifth terrace	29	2.37	3.04	-0.13	0.84	0.46
	38	2.07	2.76	-0.02	0.89	0.47
	48	1.62	1.67	-0.28	1.26	0.58
	58	4.07	2.67	-0.40	0.89	0.47
	Average	2.53	2.54	-0.21	0.97	0.50

Location	Sample No.	$M_z\phi$	o_I	sk_I	k_G	k_G'
Sixth terrace	49	2.32	2.85	0.05	0.94	0.48
	50	2.71	2.50	0.31	1.41	0.59
	Average	2.52	2.68	0.18	1.18	0.54
Beach samples	11	1.89	1.74	0.16	1.81	0.64
	12	1.98	1.79	0.44	1.30	0.57
	19	2.07	1.40	0.25	1.03	0.51
	20	2.62	1.60	0.08	1.00	0.50
	30	2.14	0.83	0.22	1.37	0.58
	31	4.41	2.29	−0.07	0.94	0.48
	39	1.05	2.17	0.40	1.86	0.65
	40	2.50	1.32	0.21	1.07	0.52
	51	1.10	2.09	0.20	0.86	0.46
	52	3.25	1.92	0.36	1.20	0.55
	59	1.90	3.54	0.13	1.57	0.61
	65	2.73	1.27	0.34	1.49	0.60
	Average	2.30	1.83	0.23	1.29	0.56

it has been decided that the four parameters (mean, standard deviation, skewness and kurtosis) of these samples are to be used for comparisons with other parameters of the samples of the seven mentioned areas (taking into consideration the original field notes of the samples).

It can be noticed (Table 10 & 11) that for the mean size parameter, the Student's t test shows that there are significant differences between the mean of the beach samples environment and those of the top of the escarpment as well as the First and Second terrace. The probability of these differences being due to chance was $p = 3.947$ for the samples from the top of the escarpment samples versus beach samples, $p = 3.951$ for the First terrace versus the beach samples and $p = 2.30$ for the Second terrace versus the beach samples, while the Third, Fourth, Fifth and Sixth terrace failed to reveal any significant differences in mean grain size between their environments. The Student's t test results are as follows from Third to Sixth terraces: $p = 0.89, 0.12, 0.234$ and 0.176.

By applying the Student's t test to the standard deviation it was found that the differences are significant between the sorting of the beach samples and other areas (terraces) and not significant in others. The probability of differences being due to chance between the beach, the top of the escarpment and the six terraces descending from the highest to the lowest one being as follows correspondingly $p = 3.904$ (significant), 3.01 (significant), 1.465 (not significant), 1.217 (not significant), Fourth terrace $p = 0.133$ (not significant), Fifth terrace $p = 2.574$ (significant), and the Sixth terrace probability values i $p = 2.479$ (significant).

The result of the Student's t test for the skewness indicate that the significant differences between the beach samples and the other areas is as follows: $p = 3.454$ for the top of the escarpment samples; the other area of significant differences coming from the Second terrace

Table (10) The results of the Student's t test of the mean, standard
deviation, skewness and kurtosis

Location	Parameter	Degree of freedom	Probability of the |t| test	Probability of the 5% level of significance	Remarks
Top of the escarpment	mean	17	3.947	2.110	Significant > 5%
First terrace	mean	18	3.950	2.101	Significant > 5%
Second terrace	mean	18	2.300	2.101	Significant >5%
Third terrace	mean	18	0.890	2.101	Not significant < 5%
Fourth terrace	mean	26	0.120	2.056	Not significant < 5%
Fifth terrace	mean	14	0.234	2.145	Not significant ⋜ 5%
Sixth terrace	mean	12	0.176	2.179	Not significant < 5%
Top of the escarpment	Standard deviation	17	3.904	2.110	Significant > 5%
First terrace	Standard deviation	18	3.01	2.101	Significant > 5%
Second terrace	Standard deviation	18	1.465	2.101	Not significant < 5%
Third terrace	Standard deviation	18	1.217	2.101	Not significant < 5%
Fourth terrace	Standard deviation	26	0.133	2.056	Not significant < 5%
Fifth terrace	Standard deviation	14	2.574	2.145	Significant > 5%
Sixth terrace	Standard deviation	12	2.479	2.179	Significant > 5%
Top of the escarpment	Skewness	17	3.454	2.110	Significant > 5%
First terrace	Skewness	18	0.625	2.101	Not significant < 5%
Second terrace	Skewness	18	2.11	2.101	Significant > 5%
Third terrace	Skewness	18	0.50	2.101	Not significant < 5%
Fourth terrace	Skewness	26	0.211	2.056	Not significant < 5%
Fifth terrace	Skewness	14	4.710	2.145	Significant > 5%

Location	Parameter	Degree of freedom	Probability of the t test	Probability of the 5% level of significance	Remarks
Sixth terrace	Skewness	12	0.656	2.179	Not significant < 5%
Top of the escarpment	Kurtosis	17	1.418	2.110	Not significant < 5%
First terrace	Kurtosis	18	0.172	2.101	Not significant < 5%
Second terrace	Kurtosis	18	0.329	2.101	Not significant < 5%
Third terrace	Kurtosis	18	1.111	2.101	Not significant < 5%
Fourth terrace	Kurtosis	26	1.563	2.056	Not significant < 5%
Fifth terrace	Kurtosis	14	1.652	2.145	Not significant < 5%
Sixth terrace	Kurtosis	12	0.826	2.179	Not significant < 5%

p = 2.11 and Fifth terrace p = 4.71. The test also shows that there

is no significant difference between the samples of the beach and the

First terrace p = 0.625, Third terrace p = 0.50, Fourth terrace

p = 0.211 and the Sixth terrace p = 0.656.

Finally, application of the Student's t test for kurtosis values

failed to point out any significant differences between the beach samples

and those of the terraces and the top of the escarpment.

Consequently, this technique has in general succeeded in revealing

the significant differences between not only the beach samples and those

of the top of the escarpment as well as the six terraces, but also shows

differences in the parameters of the terraces themselves and the top

of the escarpment with the beach. (Table 11) summarises the results of

the Student's t test (all the results whether significant or not are

related to the beach samples).

mean	+	+	+	-	-	-	-
standard deviation	+	+	-	-	-	+	+
skewness	+	-	+	-	-	+	-
kurtosis	-	-	-	-	-	-	-
location	T	1	2	3	4	5	6

Table (11) The relationship between the parameters of the beach samples
and those of the other areas. The numbers indicate their location e.g.
T. Top of the escarpment 1, First terrace etc. (+) indicate significant
differences in the parameter compared with that of the beach (-) indicate
that there is no significant difference.

This shows that for instance, the probability of differences is signi-

ficant between the mean, standard deviation, and skewness for the top

of the escarpment and those of the beach, but failed to do so with

Kurtosis.

The student's t test of the mean, standard deviation, skewness and

Kurtosis of the First terrace and the beach indicates that there is a

significant difference between their mean and standard deviation, but no significant difference in skewness and Kurtosis. The results from the Second terrace show that the probability of its mean and skewness being different from those of the beach is significant but not significant in the case of the standard deviation (the measure of sorting) and kurtosis. A close relationship exists between the four parameters of the beach samples and those of the Third and Fourth terraces. Similarity between the deposits of both have been recognised for some of the terraces in the field but were not thought to give such similarity when the test was applied.

For the Fifth and Sixth terrace, table (11) shows that they both agree with their means and the beach, which indicates a similarity between their grain size as well as with the Fourth and Third terraces, but differs from the upper three areas (top of the escarpment, First and Second terraces). Also the standard deviation of the Fifth and Sixth terraces show significant differences between theirs and the beach. For the skewness parameter, the Fifth terrace characteristic differs from the beach and the Sixth terrace, the latter having a positive relationship with three of the beach samples. Kurtosis results for the Fifth and Sixth terraces proved not to be significant. However, kurtosis so far has failed to show any significant difference between the environments existing in the area.

5.3.1b Interpretation of the four size parameters

Six basic scatter plot diagrams have been drawn for the four size parameters (Figs.30 to 35) against each other in order to find out the relationship between them and whether they add more criteria for identifying the environments of their samples. Each two size parameters of the eight areas between the top of the escarpment and the beach

were plotted against each other to show their relationship.

Fig. (30) is of the scatter plot diagram of the mean size versus standard deviation; it shows that the best sorting values are attained by medium to fine sands at mean size of 1.38ϕ (0.38 mm) and 2.13 ϕ (0.22 mm), but sorting becomes worse as the samples get either finer or coarser, which agrees with the conclusion arrived at by Inman and Chamberlain (1955); Folk and Ward (1957). Some of the samples from the top of the escarpment as well as the First and Second terraces which were found in the field to contain higher percentages of medium to fine gravels, have in the diagram high sorting values (very poorly sorted). Most of Fifth terrace samples and the two samples from the Sixth terrace are very poorly sorted, with a mean size between fine sand to silt. Several samples of the Second, Third and Fourth terraces fall in the field of the majority of the beach samples. They correspond to the area represented by medium to fine sand mean size and they are not too badly sorted with an inverted peak of moderately sorted. The result of plotting these two parameters gave results similar to those obtained by the Student's t test. Moreover, three characteristic environments seem to exist.

1) The better sorted areas which include most of the beach samples as well as others from other terraces and those of the Fourth terrace with sorting less than 2 ϕ.

2) Area of coarse grains, corresponding to the top of the escarpment, the First terrace as well as the Second terrace samples and some of the Fifth, with standard deviation value over 2.5ϕ.

3) Area of mixing between all the environments described above and attained on the Second and Third terraces.

In the scatter plot diagram of mean size versus skewness (Fig. 31)
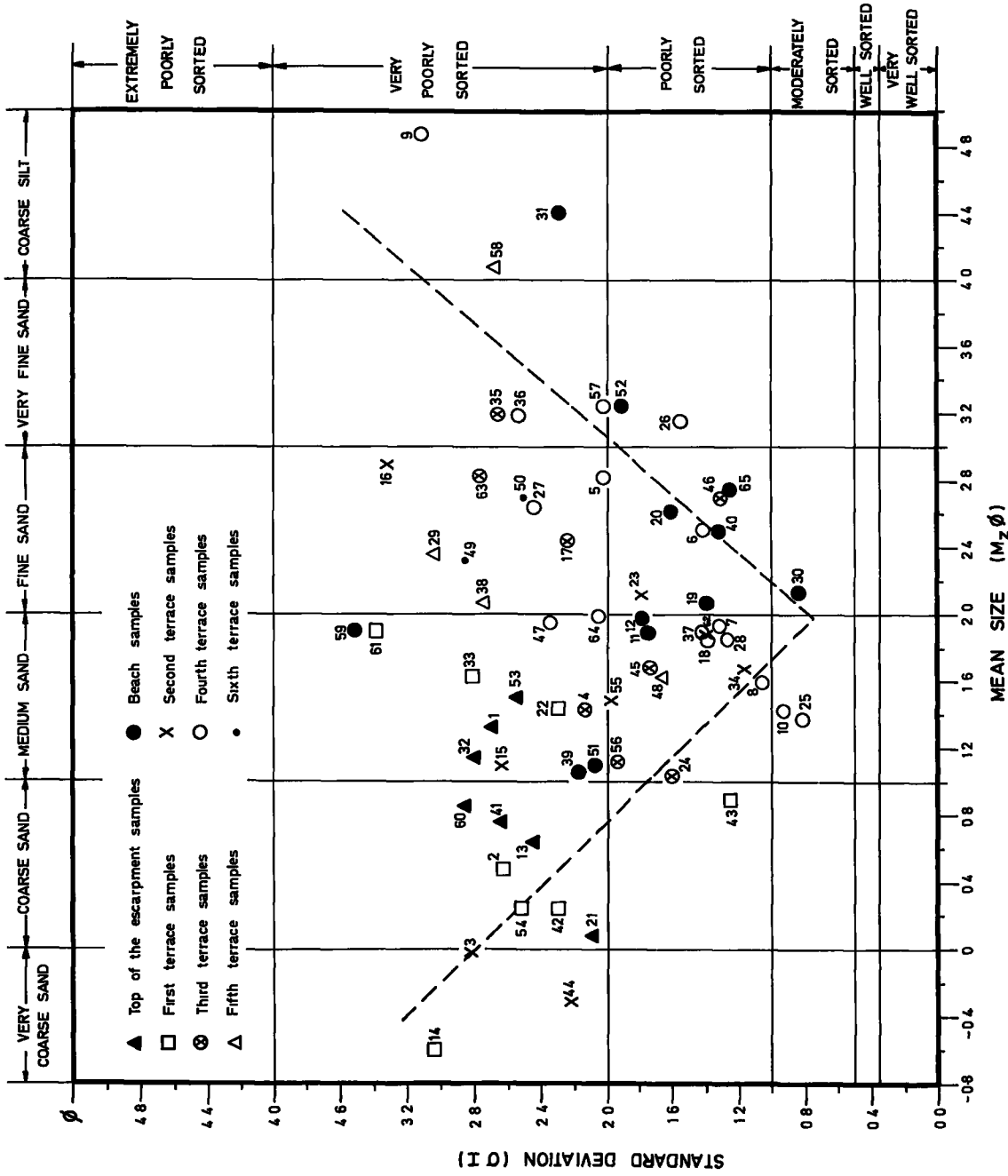
FIG (30) Scatter plot diagram of mean size versus Standard Deviation

it can be noticed that there is a good relationship between the mean

size and the skewness. A region of symmetry occurs in the pure sand

mode from some samples of the terraces as well as from the top of the

escarpment where the sands and gravels are equal. The samples attain

very positive skewness of sk_I = 0.61 ϕ at M_z = -0.61 ϕ (1.53 mm) as the

amount of gravels exceeds that of the sand in the samples. As the

mean size of the sediment decreases due to the addition of more silt

and clay, a positive skewness will result.

The mixing of the two modes with abundant sands produces negative

to very negative skewness. Folk and Ward (1957) concluded that the

pure mode fractions are in themselves nearly symmetrical, but when the

two modes are mixed negative skewness will result if the fine mode is

more abundant, and positive skewness if the coarse mode is abundant.

It can be noticed that most of the beach samples and those suspected

of being of marine origin have positive skewness. This is believed to

be due to the location of the research area close to the north of the

Gulf where there is a continuous discharge of fine particles. Khalaf

(1969) came to the same conclusion that the beach sediment here is

usually of a clay texture in composition; i.e. they have pronounced

positive skewness for samples of this area as compared with negative

skewness for those of the southern coast of Kuwait.

Fig. (32) is a scatter plot diagram of mean size versus kurtosis.

There is a general tendency for the kurtosis to change from platykurtic

to very mesokurtic which coincides with decreasing the mean from left

to right. As the kurtosis measures the sorting in the "tails" of the

distribution, it can be seen that the pure gravel or sand gives a

normal curve K_G = 1.00 (K_G' = 0.5). The addition of small percentages

of about 10% with a maximum of 20% from another mode result in good
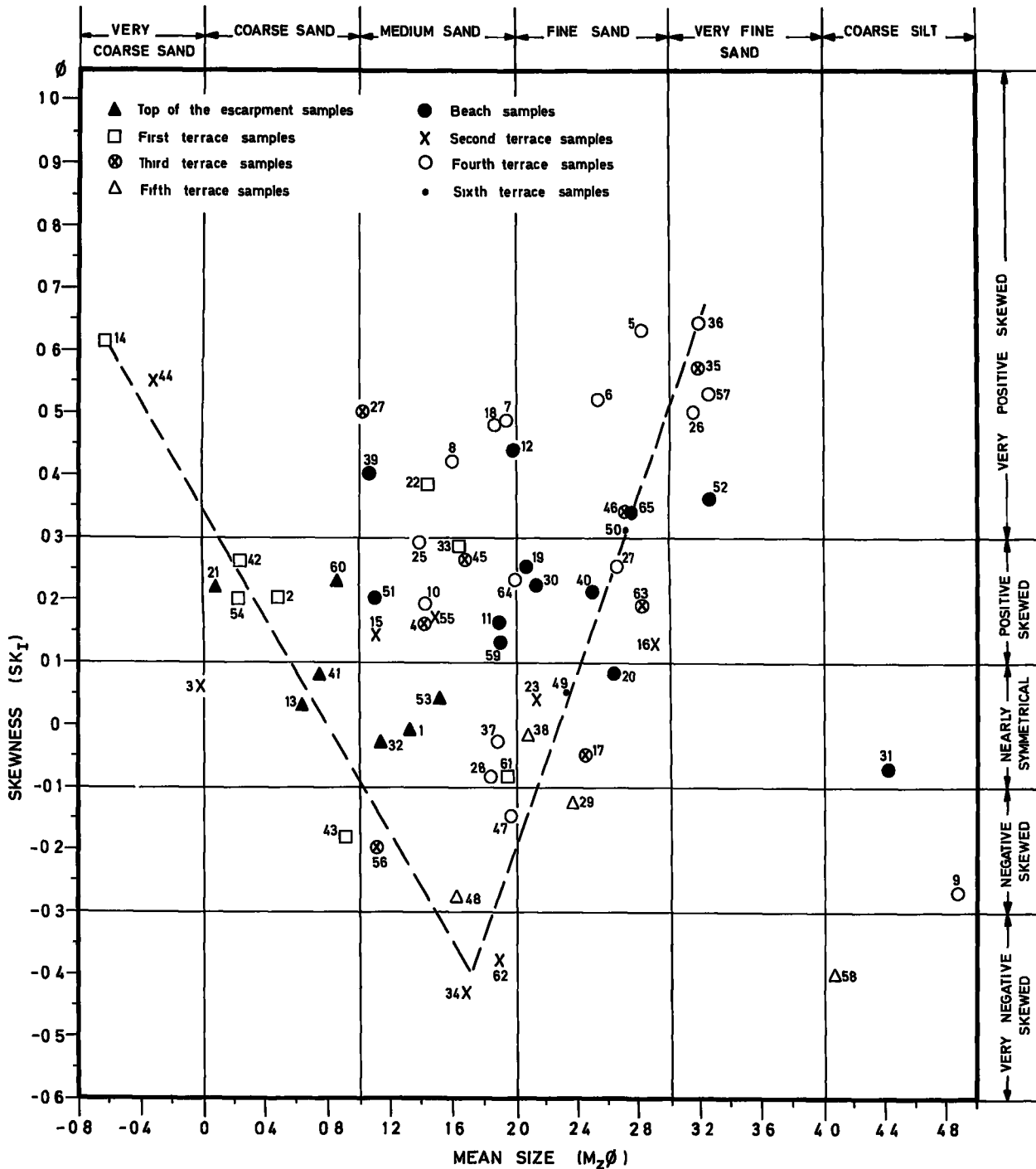
FIG (31) Scatter plot diagram of Mean Size versus Skewness

sorting in the middle part of the curves but worsened in the tails

(Leptokurtic) which characterise most of the samples except those

from the top of the escarpment and some of the other terraces and

beach samples. Further addition of another mode brings bimodal sediment

and platykurtic characteristics (better sorting in the tails than the

central curves).

After examining the mean size of all the samples versus their

sorting, skewness and kurtosis, additional information has been added

to the information already known from the field notes as well as those

from the Student's t test. It can be said at this stage that there

are three main mode characters in the sediments indicating their

depositional environments. These are 1) the gravelly sand mode,

given the symbol of (GS), 2) the sandy mode of beach samples and

samples from other terraces, given the symbol (B). Moreover, there

seems to be a third mode of aeolian environment which exists between

the two modes. It is characterised by a high percentage of fine sands

to silt, clay fractions and was given the symbol (A).

Figures (33a and 33b) are scatter plot diagrams of skewness

against kurtosis. Mason and Folk 1958 mentioned that plotting these

parameters against each other was the best way to differentiate between

the beach, dune and aeolian flat. The application of this diagram for

the samples (Fig. 33a) shows that the changes of the skewness from

very negative to very positive skewness is associated with changes

of the kurtosis from platykurtic to extremely leptokurtic. Fig. (33b) is

a scatter plot diagram of skewness against kurtosis of the same samples

but with their depositional environments. The result shows also that

most of the samples of the mode gravel exhibit mesokurtic to leptokurtic

traits. Those of the sandy mode samples have negative to positive
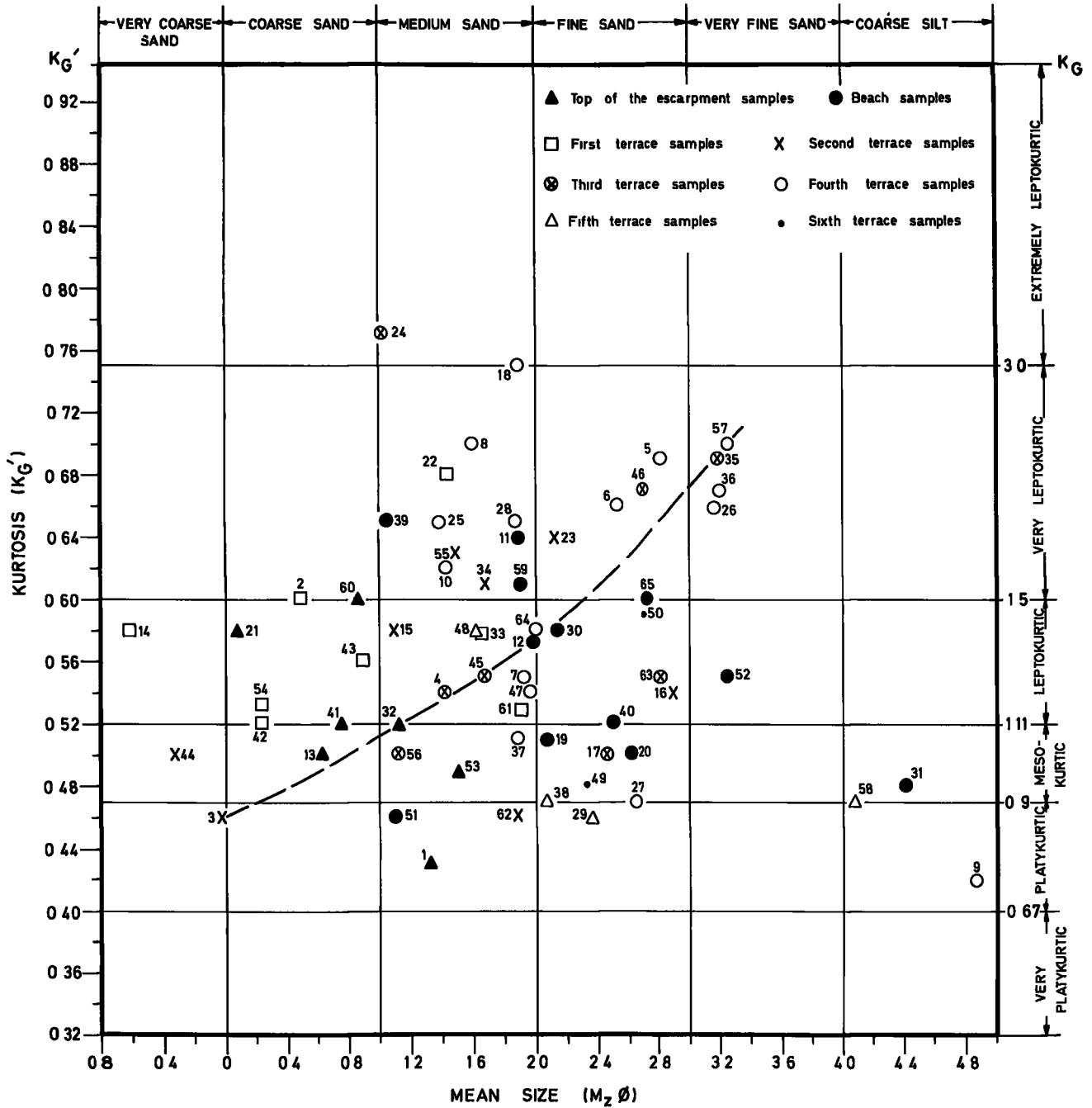
FIG (32) Scatter plot diagram of Mean Size versus Kurtosis

skewness and range from platykurtic to leptokurtic. The third mode

samples have mesokurtic to very leptokurtic. However, this diagram

does not show a clear separation of the three fields and a mixing

between them occurs in the three fields.

Figures (34a and 34b) are scatter plot diagrams of standard

deviation against kurtosis, figure (34a) shows that the sorting

decreases from moderately to very poorly sorted which is accompanied

by decrease of the kurtosis values. It can be noticed that the

three modes of environments are overlapping in some important respects.

Several other characteristics however also appear from this diagram.

Fig. (34b) which shows the depositional environments of the samples of

figure (34a) indicates that the samples from the top of the escarpment

as well as from other terraces which are characterised by gravelly sand

environments concentrate in the area between platykurtic and leptokurtic,

as well as being very poorly sorted. Samples of the aeolian environments

which come from some of the terraces are characterised by being mesokurtic

and very leptokurtic. The sorting of some of these samples and most

of the first environment- gravelly sand is very poor , but some are

slightly better by being poorly sorted. The previous characteristic

indicates that the samples from these groups are in general better sorted

in the centre of the curves than in their tails. The samples of the

third environment of the beach and those of similar characteristics

have the best sorting compared with the last two, and they are moderately

to poorly sorted with few very poorly sorted. Their kurtosis range

from platykurtic to extremely leptokurtic which indicates that the beach

samples are unimodal and bimodal mode depending on the sedimentary

supplies (silt and clay coarse sands).

Figures (35a and 35b) show the results of plotting the two
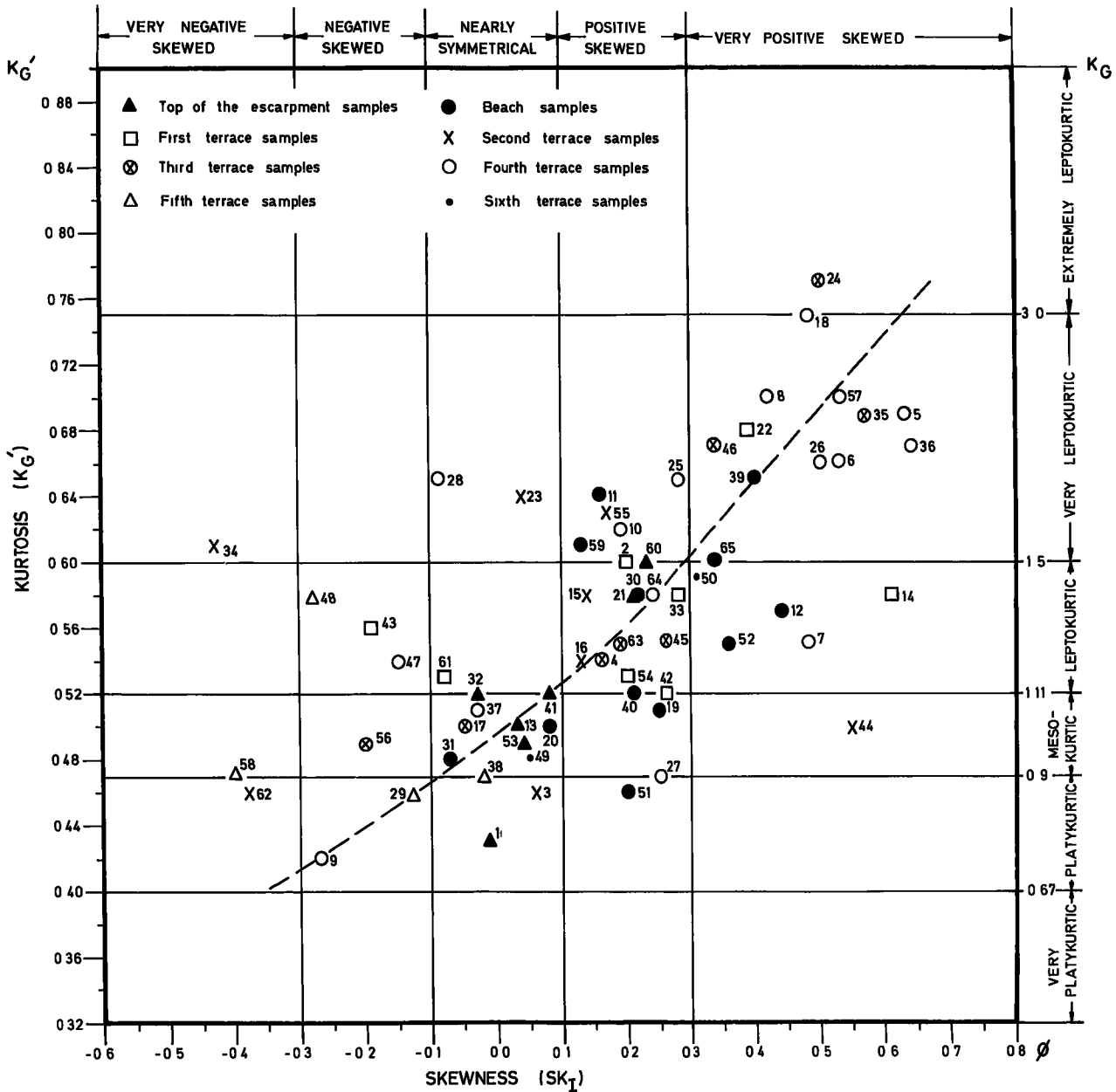
FIG (33a) Scatter plot diagram of Skewness versus Kurtosis
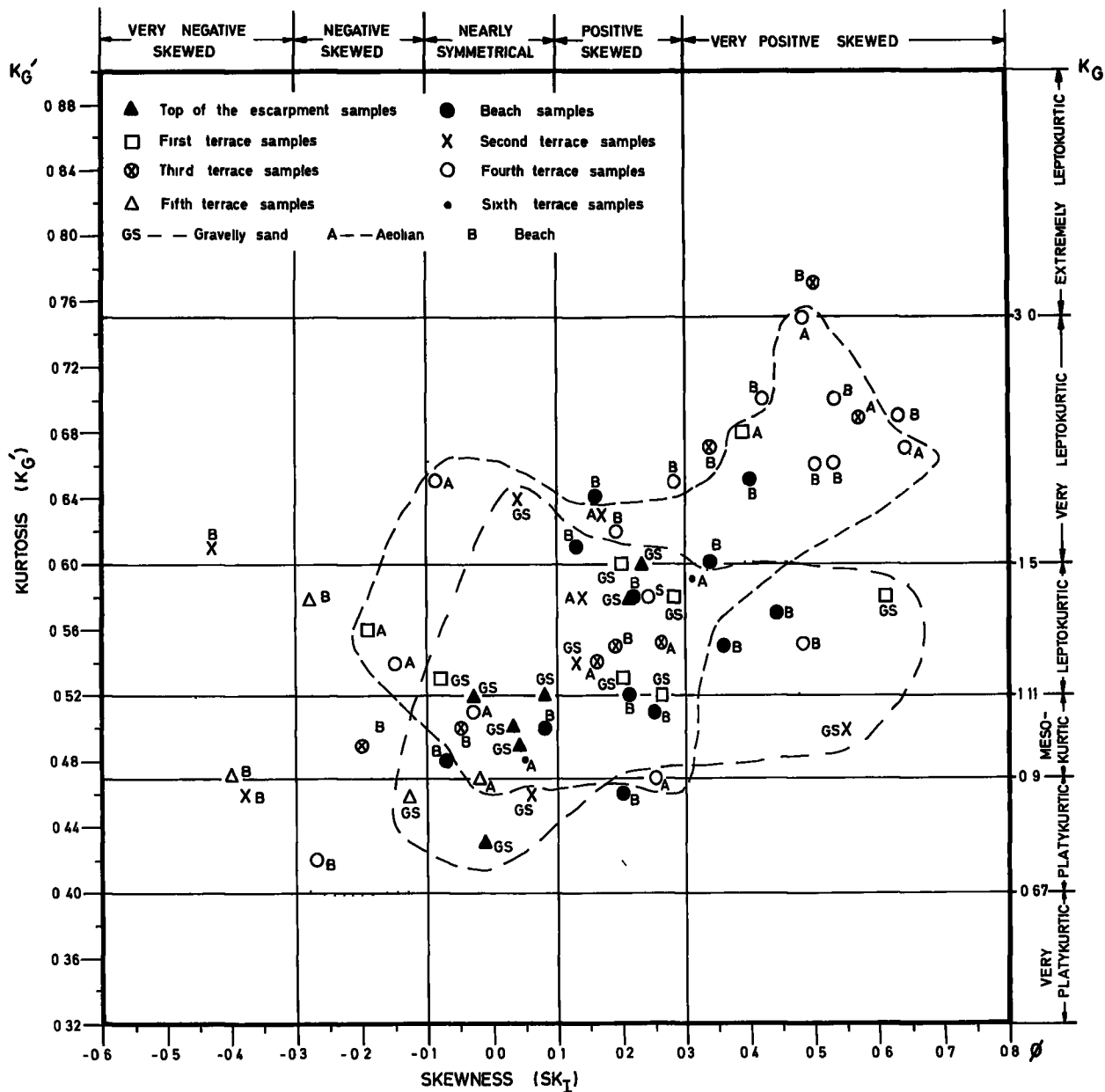
FIG (33b) Scatter plot diagram of Skewness versus Kurtosis Showing the depositional environments of the samples

parameters of standard deviation versus skewness. Figure (35a) indicates that sorting for all the samples ranges between moderately sorted to very poorly sorted and from very negative skewed to very positive skewed. It can be seen also that the plotting of the assumed environment of each sample against each other (Fig.35b), although it shows no clear separation between the fields, it has been very successful in showing that the result in general agrees with those of the Student's t test for the same parameters. It shows that most of the beach samples and those similar are moderate to poorly sorted (some samples of the Second, Third and Fourth terraces), while those from the top of the escarpment and the First and Fifth terraces (except for a few of each of them) with the Sixth terrace are characterised by also having their special characteristics: 1) The gravelly sand samples mainly from the top of the escarpment as well as the First terrace and Second terrace are in the field of very poorly sorted and range from symmetrical to very positive skewness. 2) Those of the assumed aeolian environment range between symmetrical (except two samples) to very positive skewness, but they differ from the gravelly sand by being better sorted (compared to the gravelly sands only). 3) Those of the beach samples have in general the best sorting of all the samples in the area. They range from moderately sorted to very poorly sorted. The skewness of these samples ranges from very negative skewness to very positive skewness, the positive skewness apparently being inherited from the adjacent areas to the north.

5.3.1c. Correlation and comparison between the size distribution curves

Each size distribution curve of the analysed samples has been first studied by itself to find out the characteristic of its distributions. Using arithmetic probability papers for plotting the curves has proved
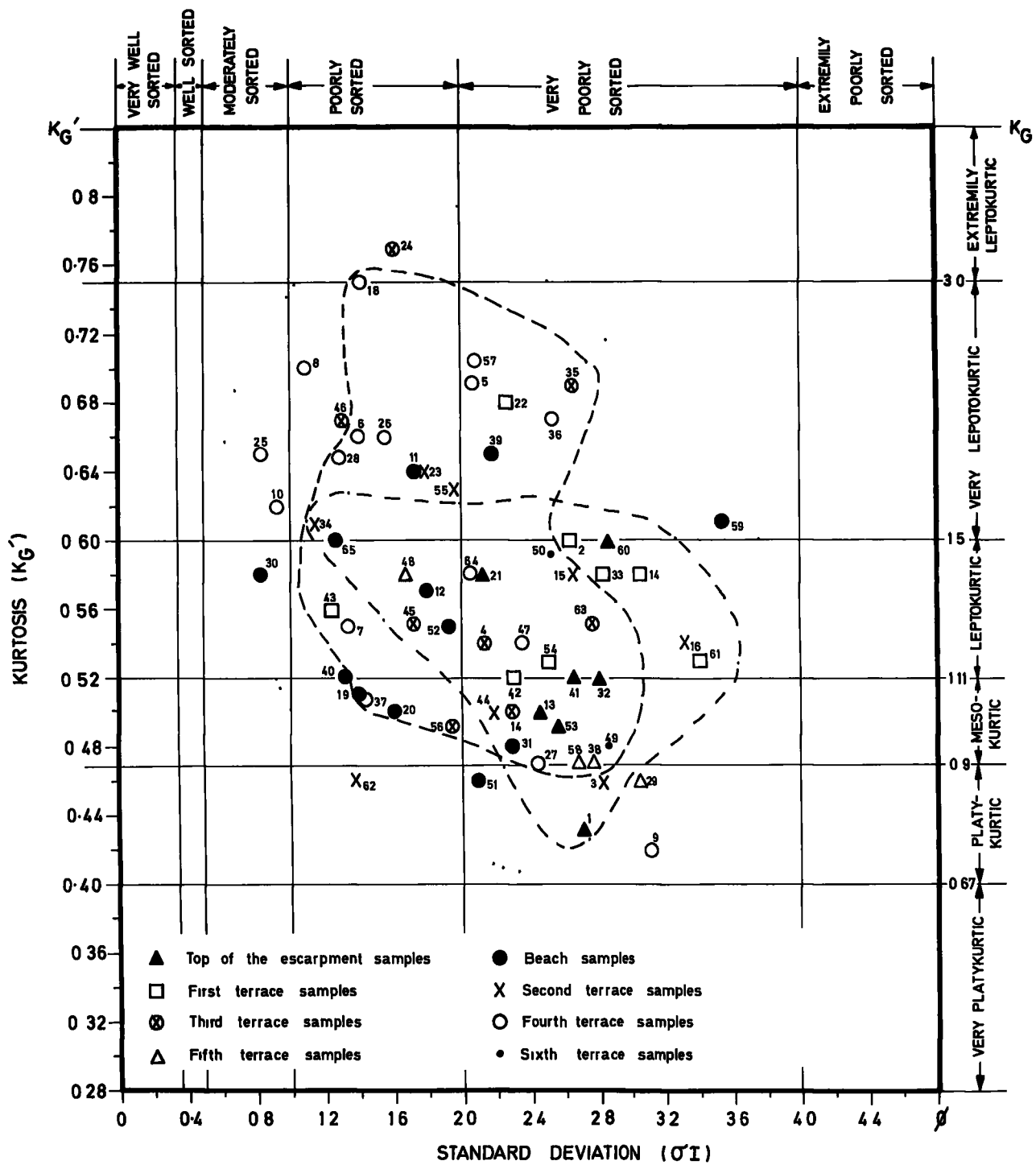
FIG.(34a) Scatter plot diagram of Standard Deviation versus Kurtosis
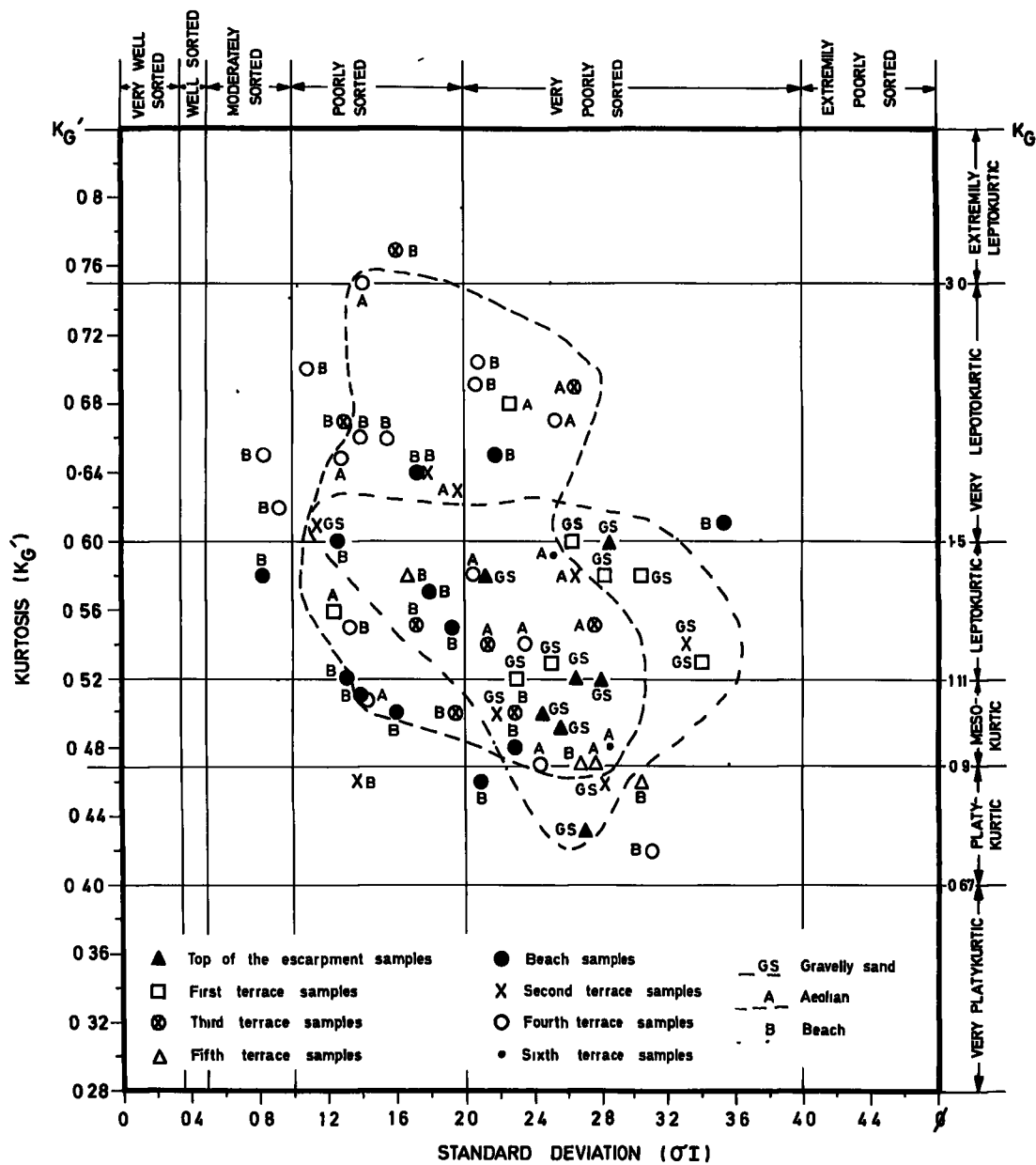
FIG (34b) Scatter plot diagram of Standard Deviation versus Kurtosis, showing the depositional environments of the samples

to be helpful in identifying the processes involved in transporting and depositing the sediments, as samples which have a more or less symmetrical size distribution will appear as a straight line when plotted on this kind of paper and any deviation from symmetrical will clearly appear. The result shows the existence of two or three populations, indicating the processes involved in its deposition. They are:

1) <u>Suspension population</u>

This includes grains smaller in size than 4.0ϕ (0.062 mm) and not exceeding a maximum size of 3.32 ϕ (0.1 mm), but mixed with another population they may exhibit sizes larger than 0.1 mm, in some cases they were found to have a size of 0.21 mm (2.25ϕ).

2) <u>Saltation population</u>

The sizes of its grains range between a minimum of 3.74ϕ (0.075 mm) and a maximum of about 1.74 ϕ(0.3 mm) to 0.74ϕ (0.6 mm) with unstable percentages.

3) <u>Rolling or Creep Population</u>

It has a grain size diameter from about 0.74$\cancel{c}$ (0.6 mm) to > 0.6 mm (0.74ϕ) coarse to fine and medium gravels. The percentage of this population varies in different curves.

The grain size distribution curves of all the samples from the eight areas, viz., the top of the escarpment, the sixth terraces and those of the beach include as before samples extending laterally from Kathma I in the west to Al-Bahra III in the east. The purpose of this replotting is tentatively to find out two main points:

1) To reveal the differences as well as the similarities between the samples collected from different transects (e.g. Kathma I and Ghidhai), but falling into one another, of the eight groups mentioned above,
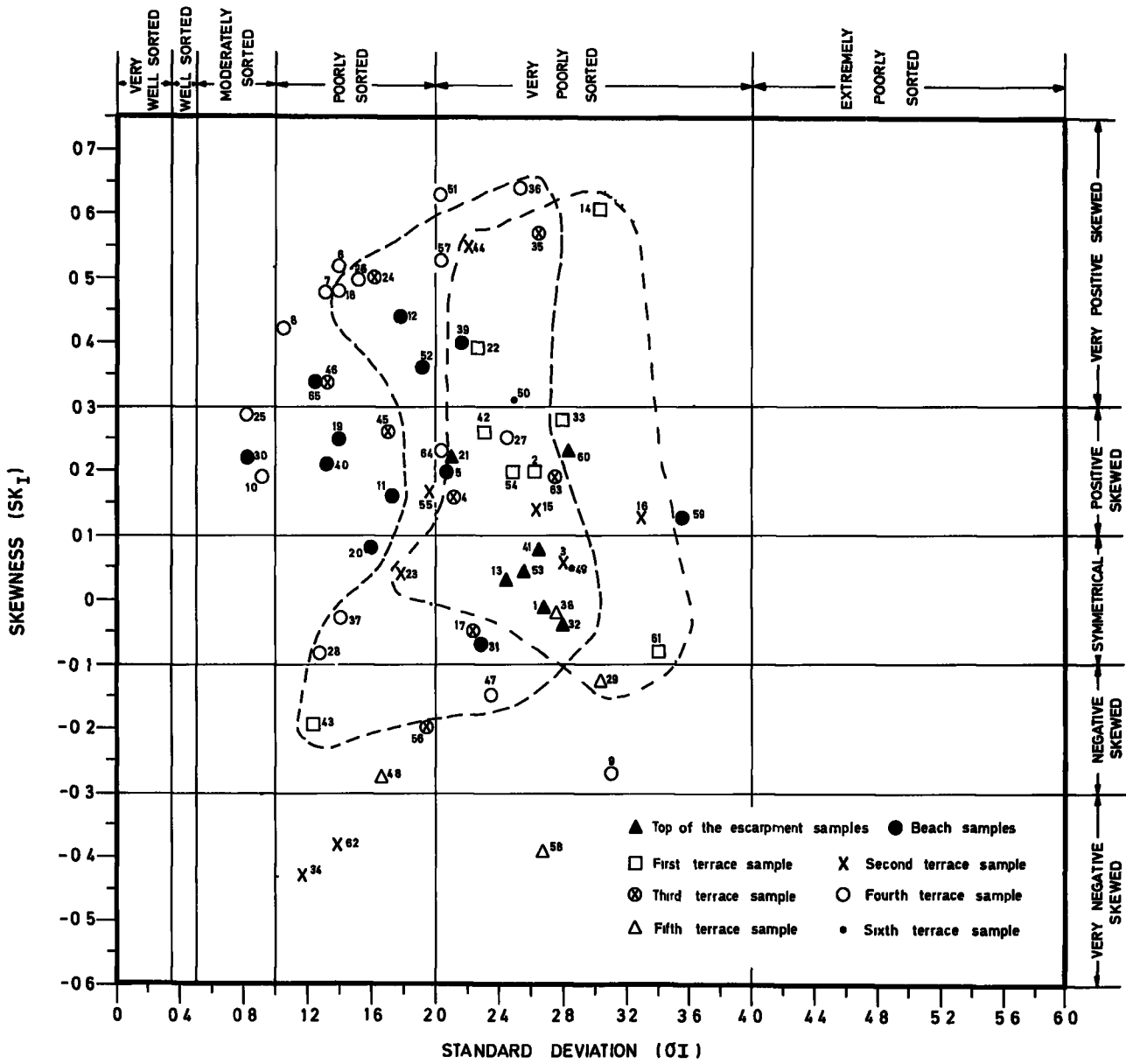
FIG (35a)   Scatter plot diagram of Standard Deviation versus Skewness
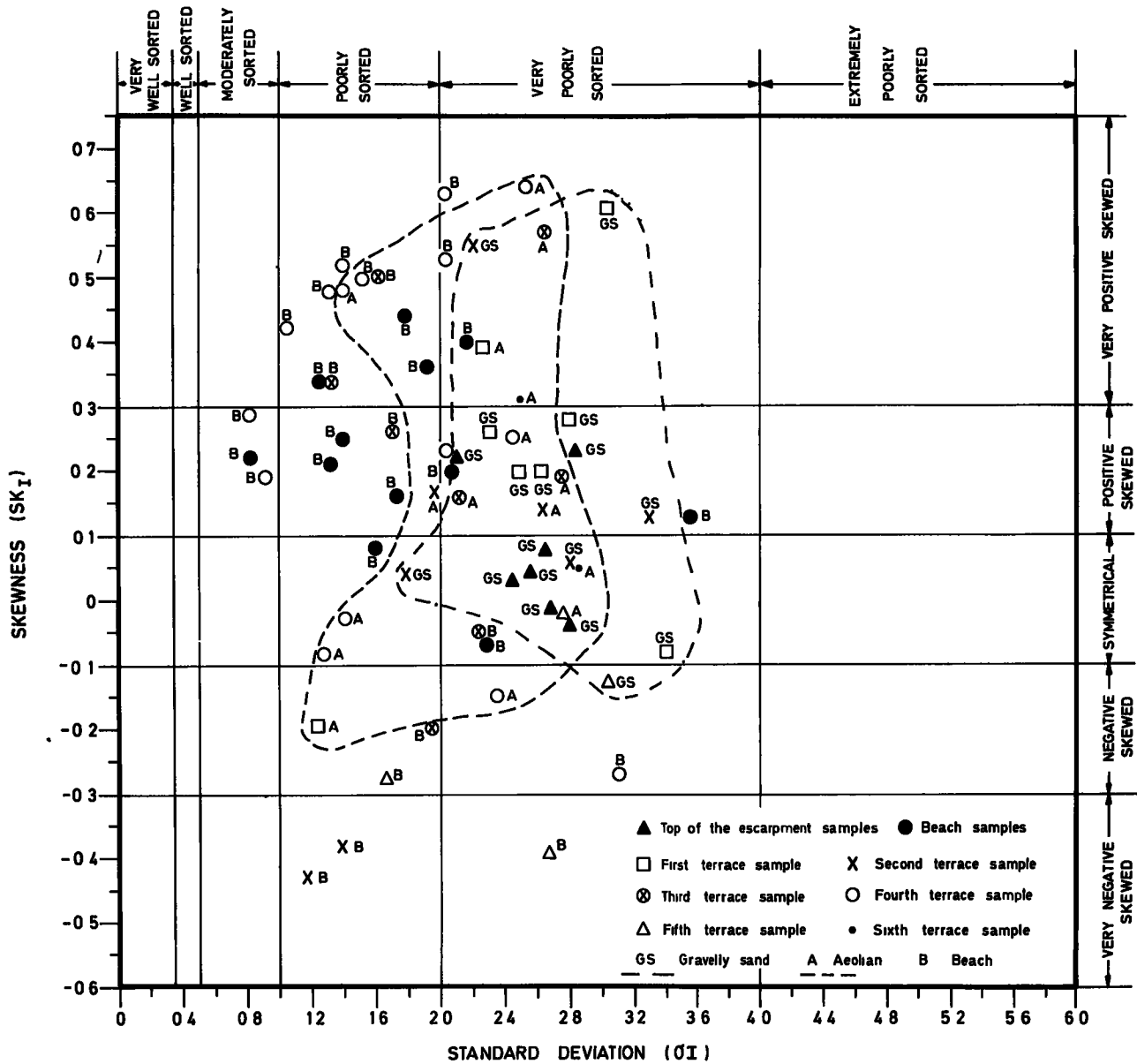
FIG (35b) Scatter plot diagram of Standard Deviation versus Skewness Showing the depositional environments of the samples

2) To find out whether plotting the curves of each group together, reflect different depositional environments, or whether they have the same characteristics which mean that they are all the result of one process of transportation and deposition.

The results (Fig. 36 to 43) show that there are areas of distinct characteristics as well as of mixing environment: For example there is a clear difference between the curves from the top of the escarpment samples, (Fig. 36) and those from the beach (Fig. 43). Some of the terraces exhibit characteristics of either one of the previous environments and some have a mixing of two. More important, a third kind of environment appears to exist between the two. The three environments are thought to be sandy gravel, aeolian and beach environments. The result shows also that in general there is a similarity between the samples collected from different areas but belonging to one group. There are also some exceptions which show the mixing of several environments on one terrace.

The three environments thought to be in the area have different characteristics

1) Gravelly sand environment; this has three well developed populations of suspension, saltation and rolling or creep populations. The truncation between the suspension population and the saltation occurs between 2.74 ϕ (0.15 mm) and 4.0 ϕ (0.062 mm). The suspension population is very distinct and consists of about 6 to 22 per cent of the distribution. Saltation population; The truncation points for the saltation population occur between 0.74 ϕ (0.6 mm) and -1 ϕ (2.0 mm) with the percentage varying between 25% and 51% of the distribution. The rolling population; is very well developed in this environment and its percentage is larger than those in the other environments, being between about 38% and 60% of the distribution.
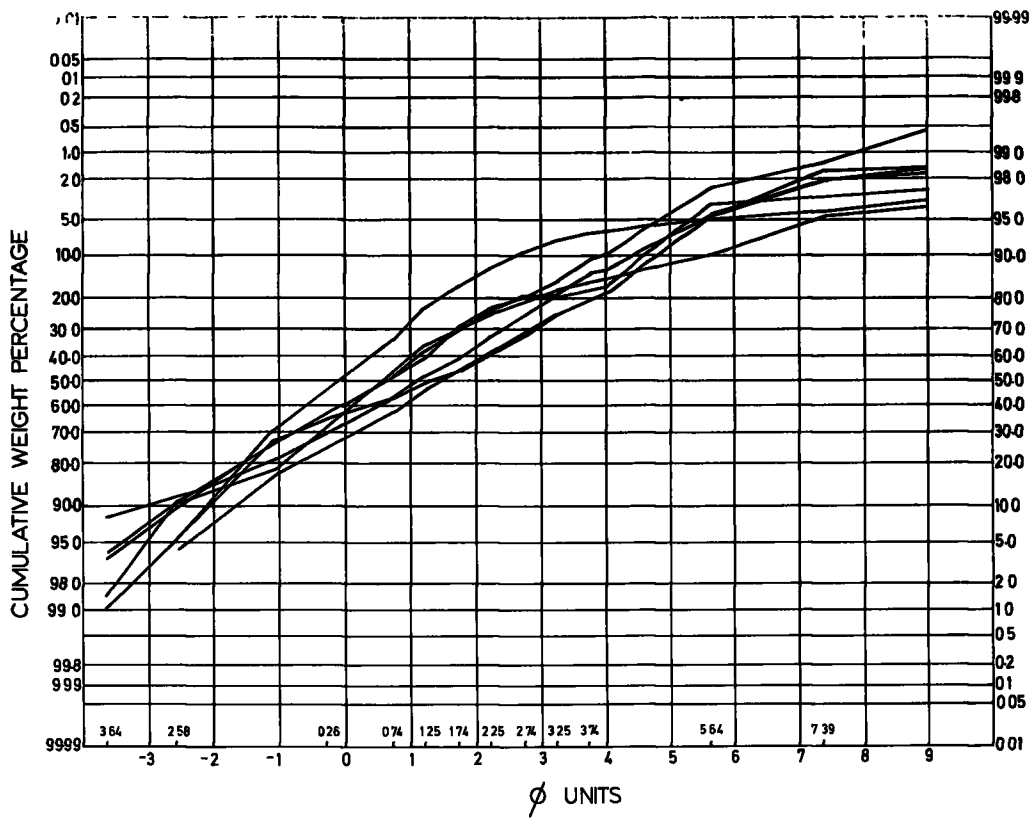
Fig. (36) Grain size distributions: Top of the escarpment
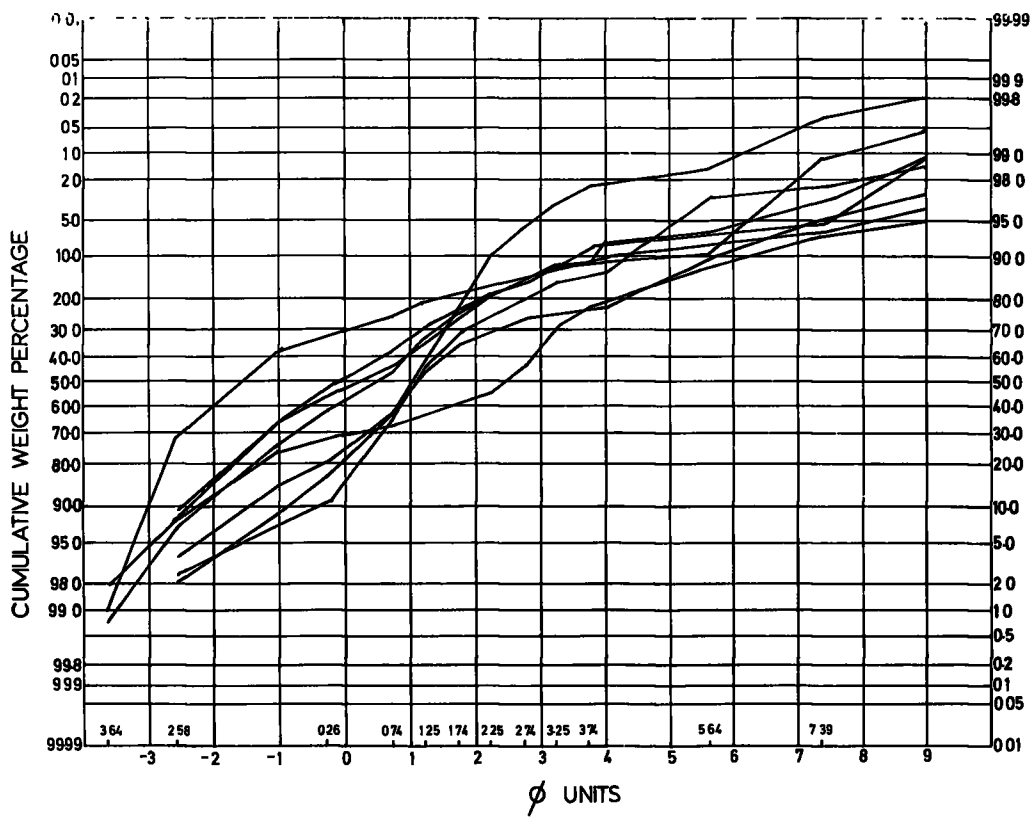
Fig. (37) Grain size distributions: First terrace

2) Aeolian Environment; this has been found in some of the samples collected from the terraces between the beach sample and the samples from the top of the escarpment. The curves are characterised by having a high percentage of suspension population, a high percentage of saltation population, but a smaller percentage of the rolling population than those of the gravelly sand curves. The truncation of the suspension population occurs between 3.25 ϕ (0.110 mm) and 3.74 ϕ (0.075 mm). The percentage is between 8% and 33% of the distribution. The distribution of the saltation population is the best, with a truncation point between 0.74 ϕ (0.6 mm) and 1.25 ϕ (0.42 mm), its slatation population being between 35% and 79% of the distribution. The curves "tail off" to the right near the suspension population because of the additions of fine particles. The percentage of the rolling population ranges between 2% and 36% with the majority at about 10% of the distribution.

3) Marine environment; the curves are distinctly different from those of the top of the escarpment and the aeolian curves. Generally, it is the nearest to a normal curve with a small percentage of the fine and coarse ends.

The majority of the percentage of the suspension population ranges between 6% and 20%, but reaches about 40%; the truncation points between the suspension and saltation populations are between 2.25 ϕ (0.21 mm) and 3.74 ϕ (0.75 mm). The second population (saltation) ranges in size between -0.26 ϕ (1.19 mm) and 1.25 ϕ (0.42 mm), the percentage being between 51% and 92% of the distribution. The rolling or creep population in the beach samples is the smallest; some samples do not have this population and the majority of the samples having percentages between 1% and 10% of the distribution, with a few exceptions.
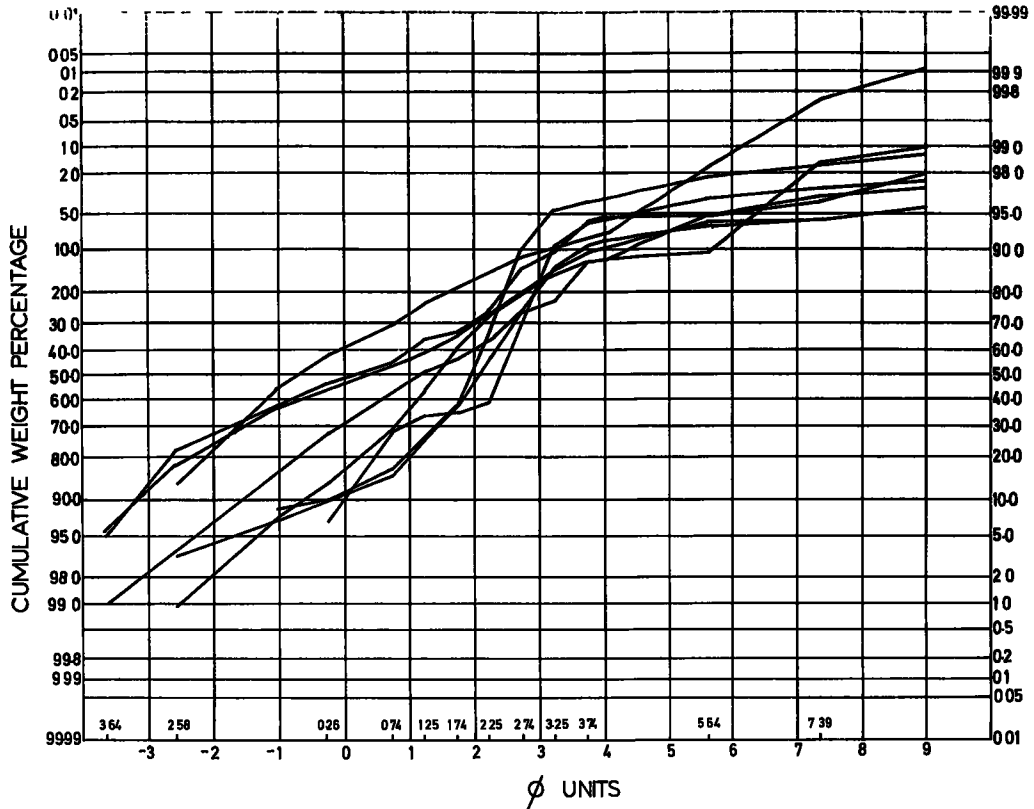
Fig. (38) Grain size distributions: Second terrace
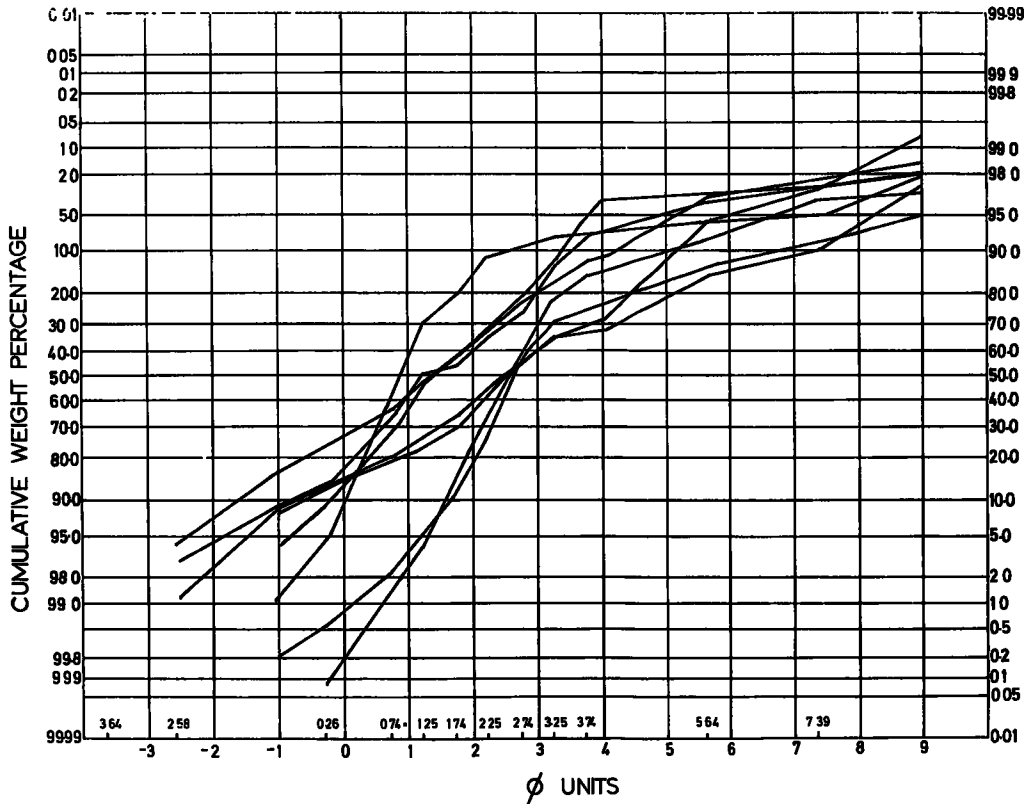
Fig. (39) Grain size distributions: Third terrace

Distinguishing the deposition environment of the curves

The results of plotting together the curves of the samples for the top of the escarpment (Fig. 36) from Kathma I to Al-Bahra III have been found to be very significant. The curves tend to be horizontal indicating the similarity between the percentages of the three populations. The curves are very similar although they come from different locations, indicating that they are of the same origin. These curves have the characteristics of the gravelly sand environment. In fig. (37) for the samples of the First terrace, the curves are in general similar to those of the top of the escarpment. There are exceptions where some of the curves seem to have a smaller percentage of the gravelly material and more of the sandy textures. Fig. (38) represents the size distribution curves of the Second terrace. They seem to be a mixture of those of the gravelly sand samples and those of the aeolian samples. However, there is an improvement in the shape of the curves as a result of the occurrence of curves with a higher percentage of silt and clay such as some of the samples which have been identified as being of marine origin.

Descending to a lower terrace (No. 3), the curves show that they are better sorted than those of the upper terrace (Fig. 39). There is a tendency towards curves of aeolian material with very small amounts of gravel, as well as curves of beach characteristics.

Terrace Four exhibits samples identified as being of marine origin and has been traced along the escarpment. The replotting of these samples as well as others collected from the same terrace in fig. (40), illustrates that they are in general similar to the aeolian curves, as all the curves have a sharp bend to the right with a horizontal extension. The high percentage of the suspension population is due to the addition of fine particles brought by the dust storms which
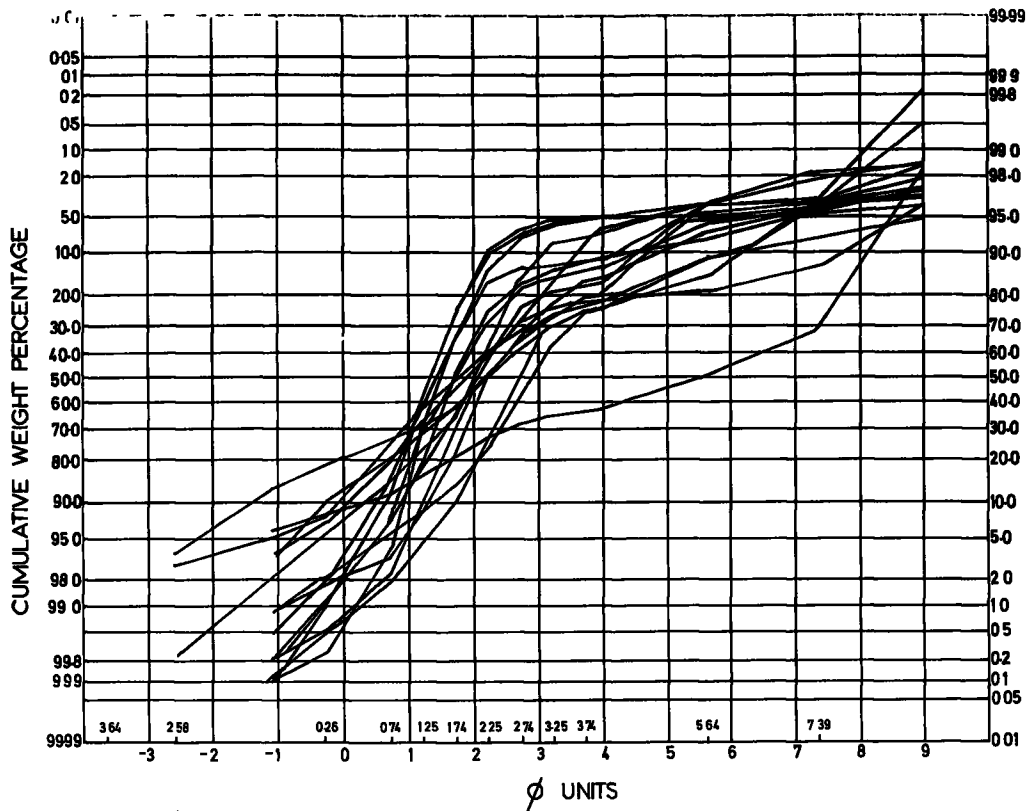
Fig. (40) Grain size distributions: Fourth terrace
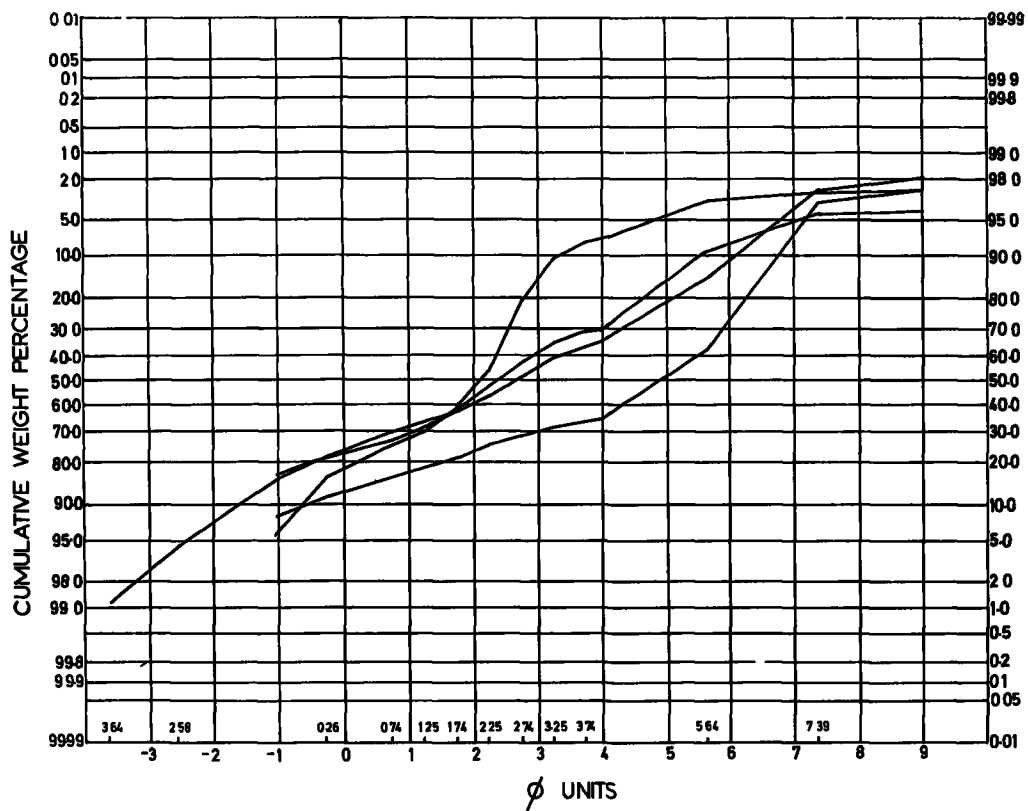
Fig. (41) Grain size distributions: Fifth terrace

prevail during the summer and especially from May to July. There
is a larger saltation population and the percentage of the rolling
population is small or negligible. As for the samples of marine
origin are concerned, while they can be distinguished from the
aeolian samples, their graphical identity is not as clear. Fig. (41)
represents the grain size distribution of the Fifth terrace. It is
an area of mixed environments and all the curves have different
shapes. The middle two curves are sandy to gravelly sand deposits,
and those of the upper and lower ones are believed to be of marine
origin. All the curves except the upper one have a high percentage
of suspension population. Fig. (42) is the grain size distributions
of two samples which came from the Sixth terrace of the Al-Bahra area.
It has been mentioned before that deposits of terrestrial and marine
origin have been found scattered in the area. The lower curve
represents the sample which is mixed with marine deposits, and the
upper one is the terrestrial sample. Both have a suspension population
of more than 30% of the distribution.

Fig. (43) illustrates the curves of the beach samples collected
from the present beach. They are characterised by having small tails
at the coarse end. The deposits are sandy or silty with varying
percentages of silt content, the percentage of suspension population
varying from about 6% to 30% but reaching to about 42% in one of the
samples. This is due to the large supply of fine particles from the
Tigris-Euphrates river system as well as to the dust storms brought by
the north wind.

The identification of the origin of the samples by comparing
their grain size distribution curves, although with clear limitations,
is reasonably successful. The occurrence of the three populations,
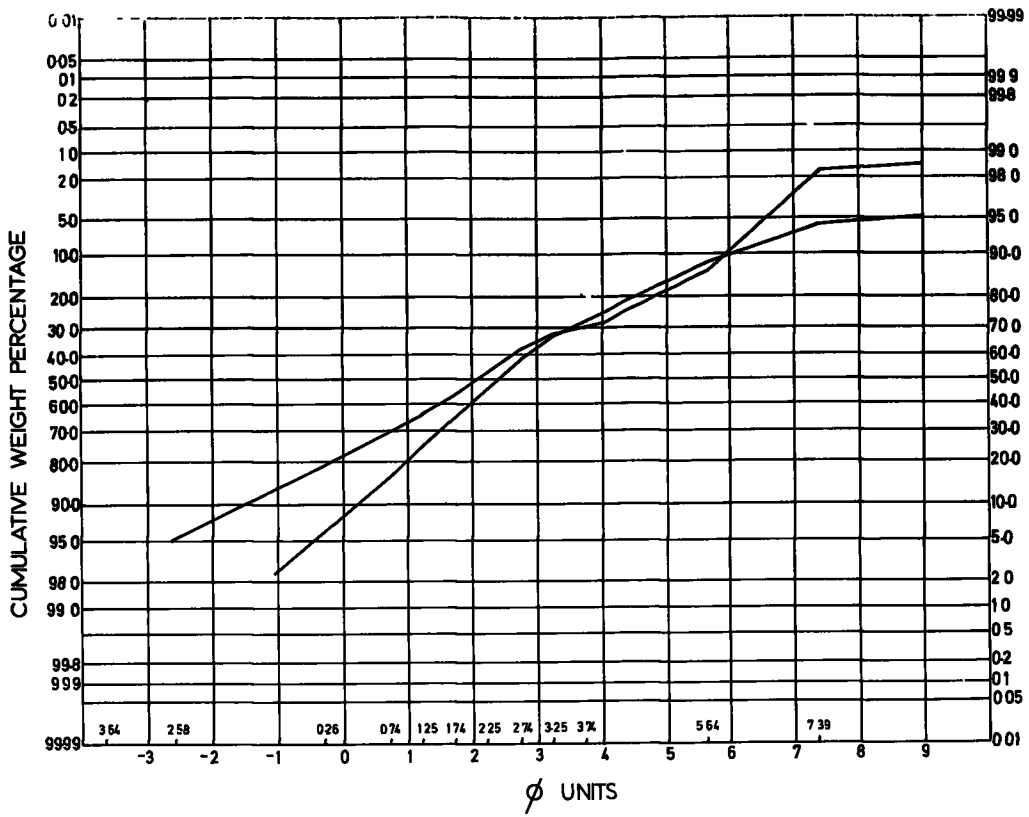
Fig. (42)   Grain size distributions: Sixth terrace
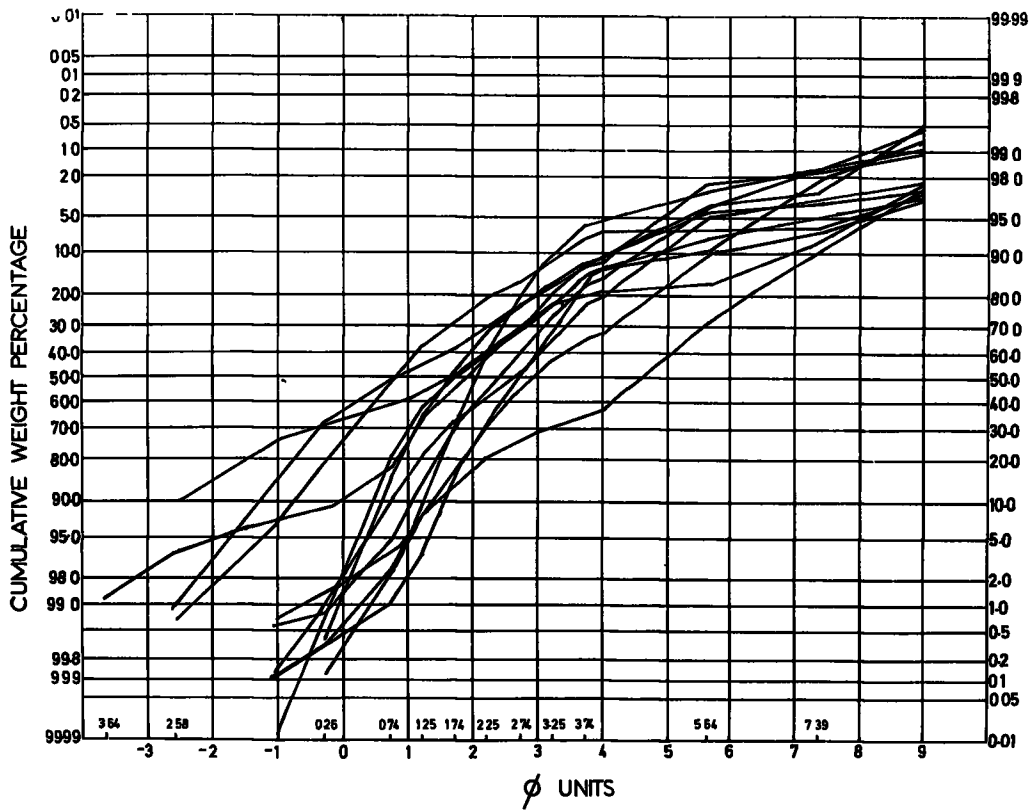
Fig. (43)   Grain size distributions: The beach

suspension, saltation and rolling with different sizes and percentages led to the identification of three main sedimentary environments and a fourth zone representing the mixing of two or more environments. These environments are believed to be gravelly sand, aeolian and marine. Identification of the origin of the six terraces as well as the top of the escarpment and the beach samples has been possible and in some cases samples belonging to one terrace but coming from different areas, showed similarity between their curves. Also, this method has proved that the area under research is an active environment, with sediments of different origin often being mixed with one another, mainly by the north wind but also the south-east wind.

Finally, its location near the head of the Gulf causes the continuous mixing of the coastal grains with those of the fine detritus of the Tigris and Euphrates river systems.

5.3.2. Interpretation of surface textures by SEM

The results of applying scanning electron microscope analysis show that the surface textures of the grains are associated either with subaqueous or aeolian environments or carry the characteristics of superimposed textures of the two environments. Krinsley and Funnel (1965), Krinsley and Donahue (1968); Krinsley and Margolis (1969) and Krinsley and Doornkamp (1973) have provided detailed information about the characteristics of each environment and this has been followed in the following interpretation. The main characteristic textures for subaqueous and aeolian environments can be summarized as follows:

Subaqueous environments:

Surfaces are characterized by V-shaped patterns which may have resulted from the collisions between grain and grain: straight or slightly curved grooves caused by the drawing of a sharp edge of a sand grain across another. V-shaped patterns may be found oriented along the axis of the grooves. Blocky conchoidal breakage patterns differ from those in aeolian environments in having regular rather than curved sides.

 Aeolian environments:

The surface textures of the quartz-grain of the aeolian environments are characterised by having upturned plates, but through abrasive action, the corners are removed and the grain tends to be rounded. According to Krinsley and Doornkamp (1973), rolling topography is produced because of the solution and precipitation which tends to modify the plates; grains from hot deserts are largely affected by this last action.

Meandering ridges are formed as a result of the impact of grains against one another during transportation which causes the wearing of the breakage blocks. The breakage patterns differ from those of the

subaqueous environment in having curved rather than regular sides.

Graded arcs occur in series and form fan-shaped patterns which may represent percussion fractures. A pitted surface is also one of the aeolian environment characteristics.

The following are the results of examining the surface textures of the sample quartz sand grains in terms of these characteristics. The locations of the samples are illustrated in figures (17, 19, 21, 23, 25 and 27).

Samples associated with subaqueous environment

Plate (19) is for sample No. 5. This is from the fossiliferous bed on the Fourth terrace west of profile Kathma I. The characteristic features of beach origin are very clearly shown on this grain. It is densely covered by V-shaped patterns of different sizes. The grain in general has rounded protruding edges, straight and slightly curved grooves with some V-shaped patterns developed along the axis of the grooves.

Plate (20) is for sample No. 6. This sample was collected from the deposits which are immediately below the fossiliferous bed (sample No. 5). It has a smooth surface as well as V-shaped patterns having a limited degree of orientation. Some grooves are partly associated with V-shaped and irregular breakage patterns.

Plate (21) is for sample No. 8. This represents a smooth surface of a portion of a quartz grain with some V-shaped depressions and irregular breakage patterns. Silica precipitation adheres to the surface. A curve depressions exists which may have resulted from aeolian environment.

Plate (22) is the surface texture of sample No. 17 from the third terrace in Kathma II; it shows V-shaped patterns with high relief, typical of beach texture. Blocky breakage patterns are also present.

Plate (23) is a portion of one of the quartz-grains; the surface

Plate References :

Plate (19)   a, V-shaped patterns; b, straight or slightly

   curved grooves; c, V-shaped patterns along some grooves

   axis.

Plate (20)   a, V-shaped patterns; b, grooves; c, grooves

   with V-shaped patterns along their axis

Plate (21)   a, V-shaped patterns; b, grooves; c, curved

   depression.

Plate (22)   a, V-shaped patterns with high relief;

   b, Blocky breakage patterns

Plate (23)   a, V-Shaped patterns, with adhering particles.

Plate (24)   a, V-shaped patterns; b, grooves

200 μ

Plate (19)

5.26 μ

Plate (20)

5.88 μ

Plate (21)

2.11 μ

Plate (22)

1.11 μ

Plate (23)

2.22 μ
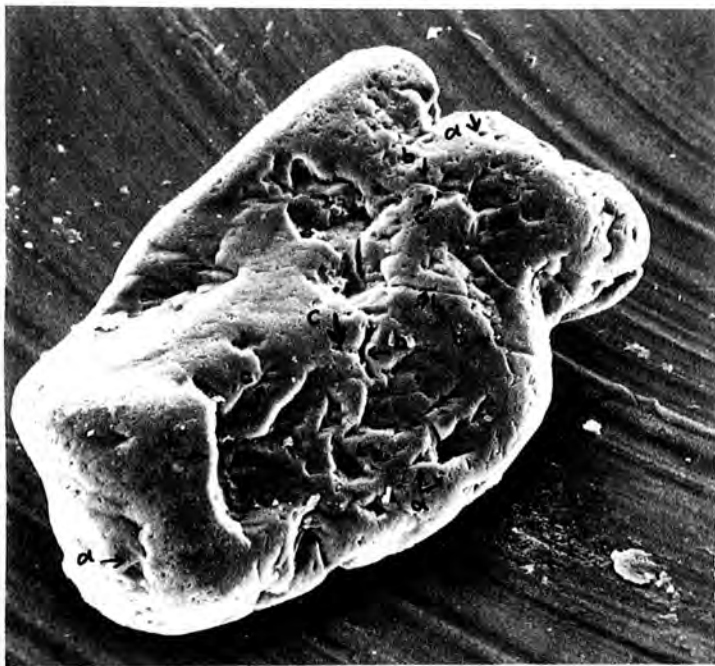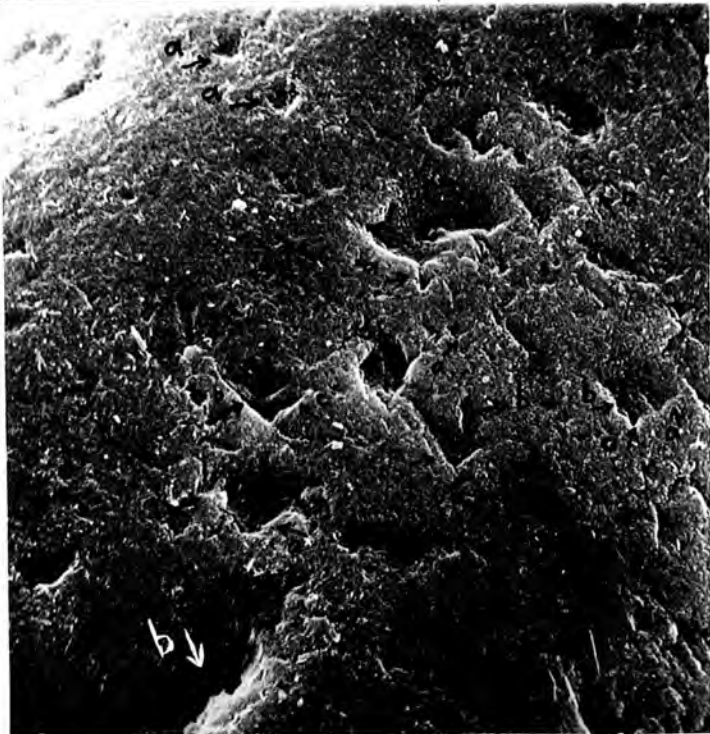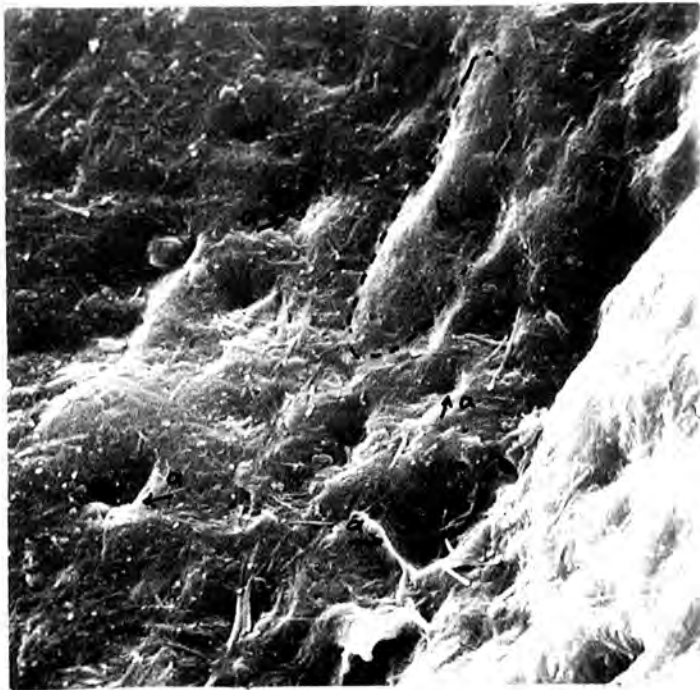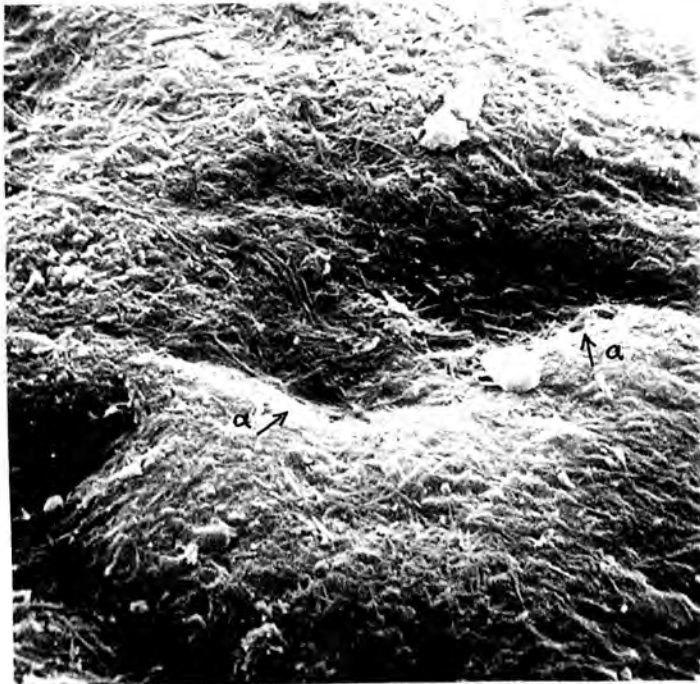
Plate (24)

texture appears to be generally smooth although this sample (25) is from the fossiliferous bed in terrace Four found at Ghidhai. Faint V-shapes can be seen on the surface.

The beach sample from Ghidhai (No. 31), Plate (24) exhibits V-shaped patterns and grooves which in some cases are associated with V-shapes. The surface has silica precipitation covering large parts of the grain.

The surface textures of high relief seen in sample 34 which come from Mudairah reflect a beach environment. The sample is from the main fossiliferous bed on the Second terrace. Plate (25) shows several blocky conchoidal breakage patterns, and V-shaped patterns. Irregular curved grooves can be seen west of the plate. These are V-shaped patterns oriented along the axis of the grooves. A little silica precipitation is also present on the surface.

Plate (26) is for sample No. 40 which was originally collected from the present beach. It shows a clear curved groove to the left associated with V-shaped depressions and upturned plates.

A typical surface texture of beach origin Plate (27) is observed from grains collected from the Third terrace at Al-Bahra I sample No. 46. The surface of the grain is almost covered by mechanically formed V-shaped depressions and irregular breakage patterns. Straight and slightly curved grooves are scattered on the surface with some of the V-shaped patterns oriented along the axis of the grooves.

The second sample of marine origin is shown in Plate (28), sample No. 48 on the Fifth terrace of Al-Bahra I; it comes from a fossiliferous bed also. Although the surface texture of portions of the quartz sand shows a smooth surface, it also has several clear V-shaped

Plate References

Plate (25)   a, V-shaped patterns; b, grooves,

c, V-shaped patterns along grooves axes; d, blocky conchoidal

breakage patterns.

Plate (26)   a, V-shaped pattern; b, deep depression;

c, blocky conchoidal breakage patterns.

Plate (27)   a, V-shaped patterns; b, grooves; c, V-shaped

patterns along grooves axes.

Plate (28)   a, V-shaped patterns with adhering particles.

Plate (29)   a, V-shaped patterns; b, grooves;

c, V-shaped pattern along some grooves axes;

d, blocky conchoidal breakage pattern;

e, Chatter marks.

Plate (30)   a, irregular depressions; b, upturned plates

4.76 μ

Plate (25)

5 μ

Plate (26)

10.53 μ

Plate (27)

10.53 μ

Plate (28)

4.55 μ

Plate (29)

22.2 μ
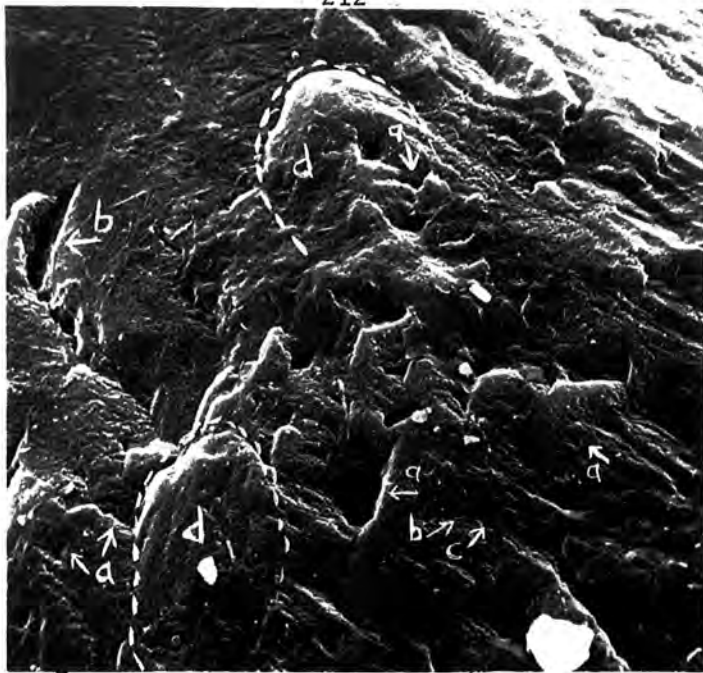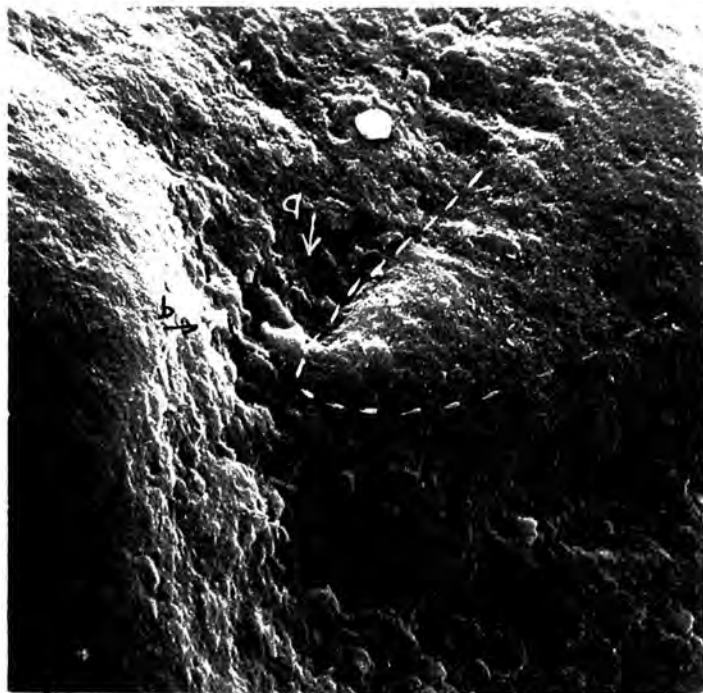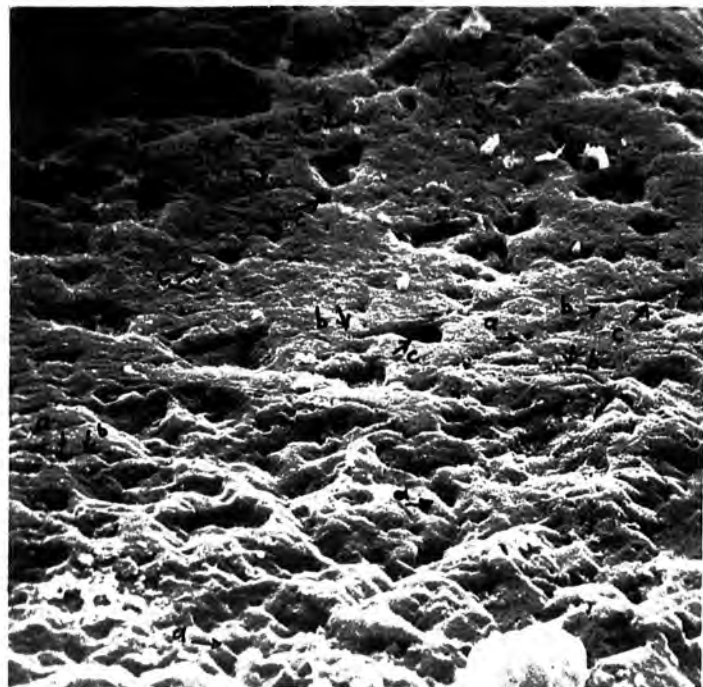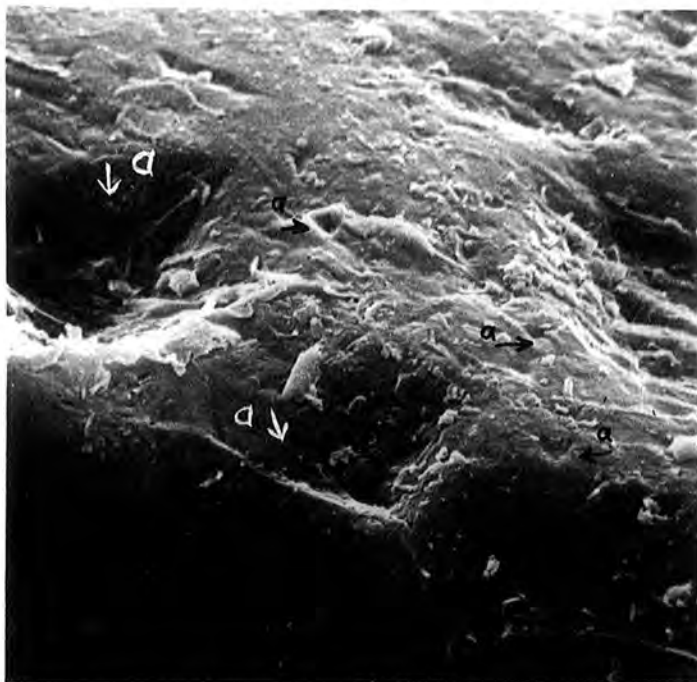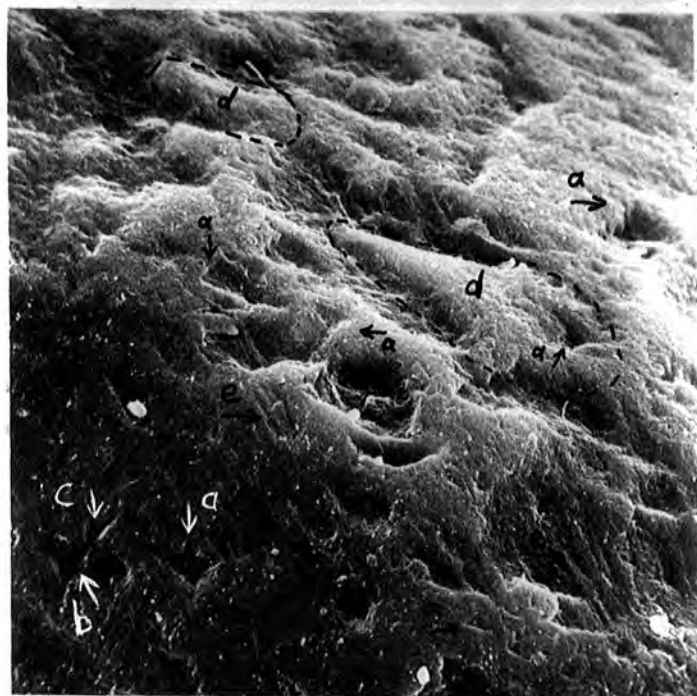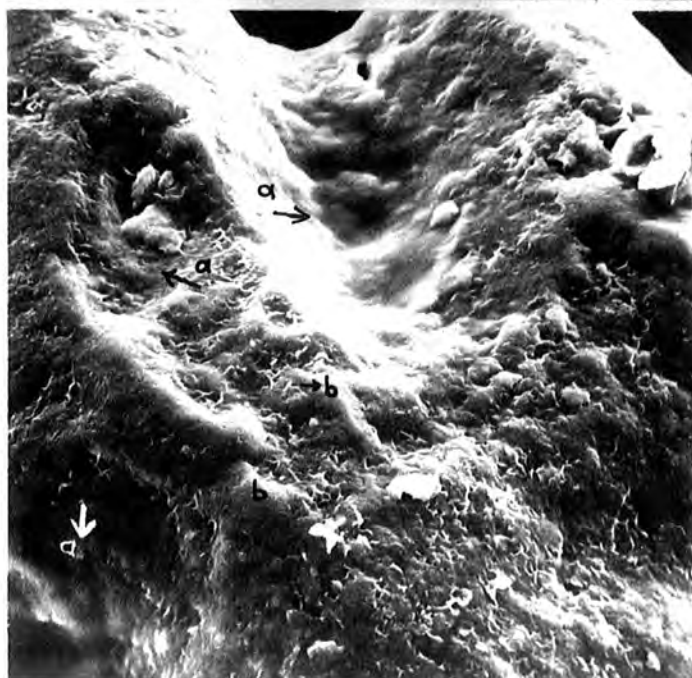
Plate (30)

patterns of different sizes scattered on the surface. Silica precipitations adhering to the surface and covering large parts of the grain indicate the hot desert environment in the area.

The last sample revealed by SEM of beach origin comes from the Fourth terrace in Al-Bahra II sample No. 57. Plate (29) shows V-shaped patterns of various sizes and a generally smooth surface. Blocky conchoidal breakage patterns are present and what seem to be "chatter marks", originating from the skipping of a portion of one grain across another.

Samples associated with aeolian environment

Quartz-sand grains which have been investigated under the scanning electron microscope and indicate aeolian environments, have surface textures including all those characteristics of that environment which has been discussed before, e.g. Plate (30), the surface texture of a sand grain from sample No. 18 in Kathma (profile II). It shows the dish-shaped concavities with a deep one in the middle, a certain amount of solution and precipitation occurring on the surface. According to Kirnsley and Doornkamp (1973) the dish-shaped forms probably resulted mechanically during periods of violent abrasion related to strong wind storms.

Plates (31, 32, 33) are typical examples of quartz-sand grains of aeolian environments; Plate (31) represents a group of aeolian quartz grains. Although not all of them are smooth round grains, most of them are fairly rounded or in the process of rounding and many show the upturned plates. Plate (32) is of the middle grain in the upper part of the plate. The grain is very smooth with rounded edges which show that this grain may have undergone mechanical abrasion for a considerable time. There is silica precipitation adhering to the surface, with a

Plate References :

Plate (31)   A general view of aeolian sand grains at different

stages of development.

Plate (32)   smooth rounded aeolian grain.   a, adhering particles;

b, irregular depression.

Plate (33)   another example of aeolian grain.   a, upturned plates.

Plate (34)   aeolian grain with smooth. surface and dish-shaped depression (a).

Plate (35)   surface of another grain with faint V-shaped patterns (a).

Plate (36)   a, V-shaped patterns; b, depressions- c, groove;

d, V-shaped along groove axis.

111.1 μ

Plate (31)

22.2 μ

Plate (32)

21.1 μ

Plate (33)

54.1 μ

Plate (34)

5 μ

Plate (35)

71.4 μ
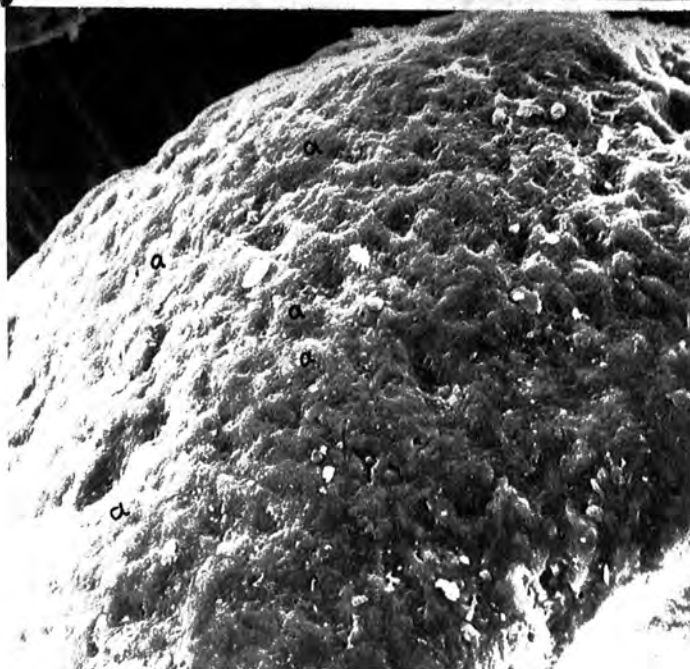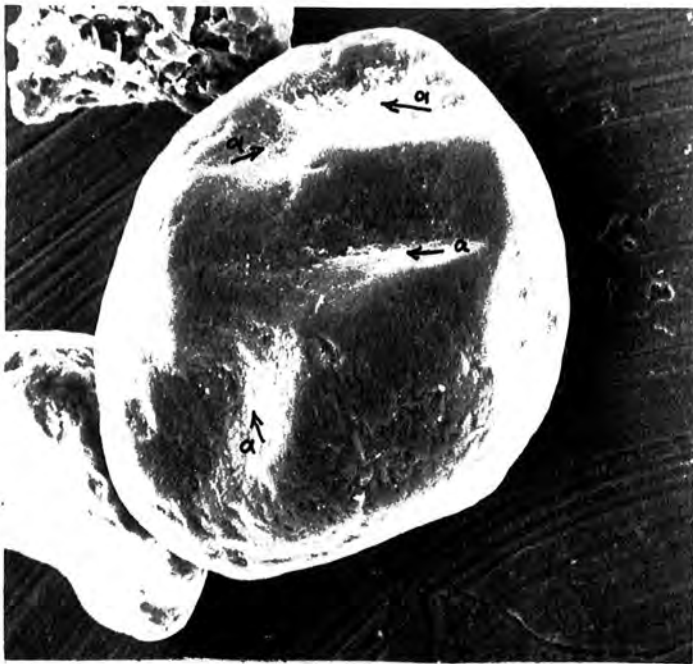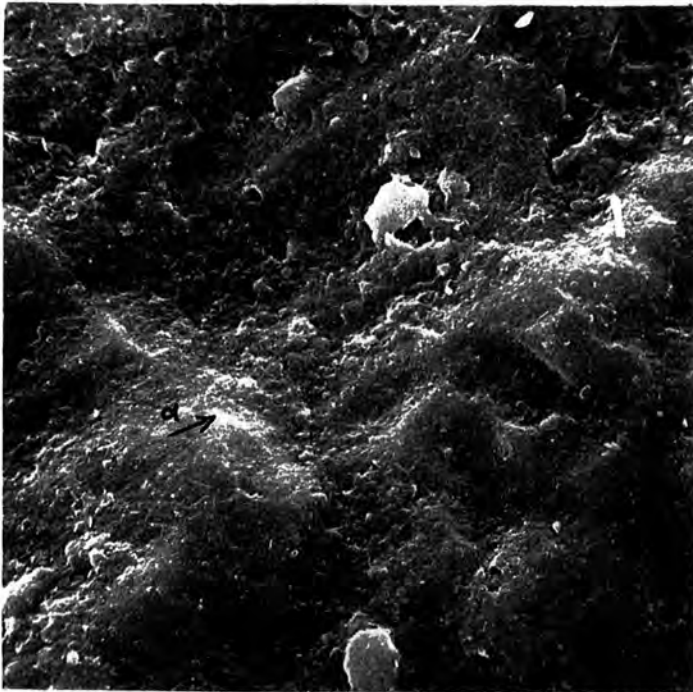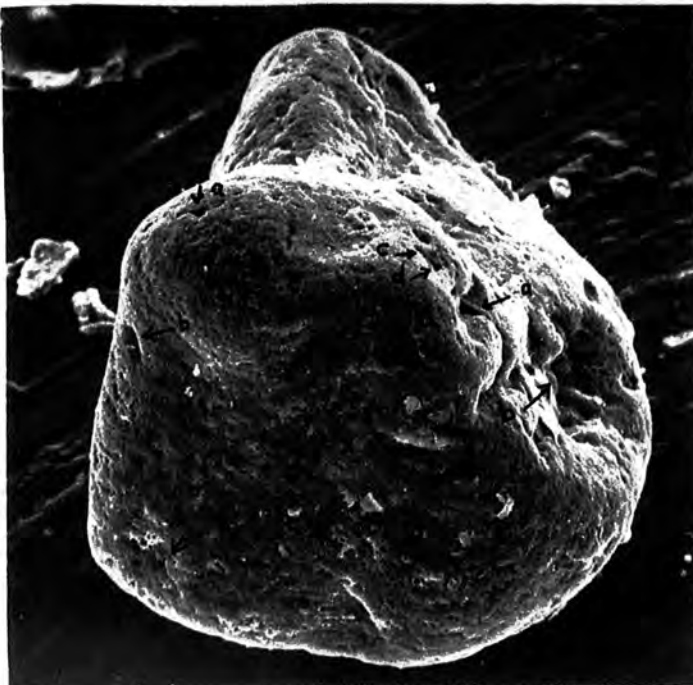
Plate (36)

larger part on the upper surface of the grain. Plate (33) is a close-up
of the large grain on the right of the plate. The upturned plates have
been subjected to solution precipitation which leads to smoothing of the
surface; rolling topography is predominant in this portion of the grain.
It is possible that the second rough part of the grain which can be seen
also in the lower right corner of Plate (31), may achieve the rolling
characteristic after a longer period of time. This sample, No. 37,
comes from the Mudairah area, on the Fourth terrace.

Superimposed environments

Plate (34) and Plate (35) are from sample No. 11.
Although this sample has been collected from the present beach, it shows
characteristics of aeolian environment as well as littoral i.e. Plate (34)
is a well rounded grain with several dish-shaped depressions of aeolian
environment. Plate (35) is a detailed surface of another grain from the
same sample with faint V-shaped indentation and upturned plates. There
is silica precipitation adhering to the surface which may further smooth
the surface. This mixing of the characteristics of the grain may be
explained by the fact that these grains are originally of aeolian
environments but have been carried to the beach by the wind storms
which usually blow actively in Kuwait during the summer.

Plates (36 and 37) are of quartz-sand grains from sample No. 42,
Plate (36) is a single grain showing the rolling and smooth topography
of the grain. Several irregular depressions are developed on the right
side of the grain. There are also upturned plates with smooth surfaces.
Plate (37) is a close-up of the upper left portion of the grain. The
general characteristic features indicating aeolian environment are the
dish-shaped features and the smooth surface, but a close examination
shows also characteristics of subaqueous environment such as V-shaped

Plate References :

Plate (37) V-shaped pattern; b, grooves; c, dish-shaped

   feature.

Plate (38) aeolian grain with rounded smooth surface and

   irregular depressions (a).


Plate (39) a, V-shaped patterns; b, grooves; c, grooves

   with V-shaped patterns.

Plate (40) a, V-shaped pattern; b, grooves, and adhering particles

   cover the surface.

Plate (41) a, faint V-shaped pattern; b, adhering particles

   cover most of the surface.

10 µ

Plate (37)

66.7 µ

Plate (38)

10 µ

Plate (39)

11.11 μ

Plate (40)

2.16 μ
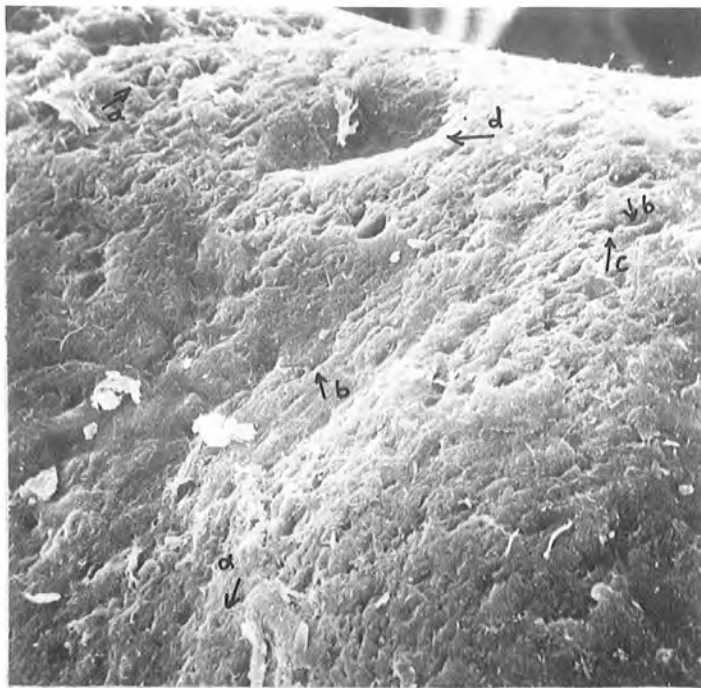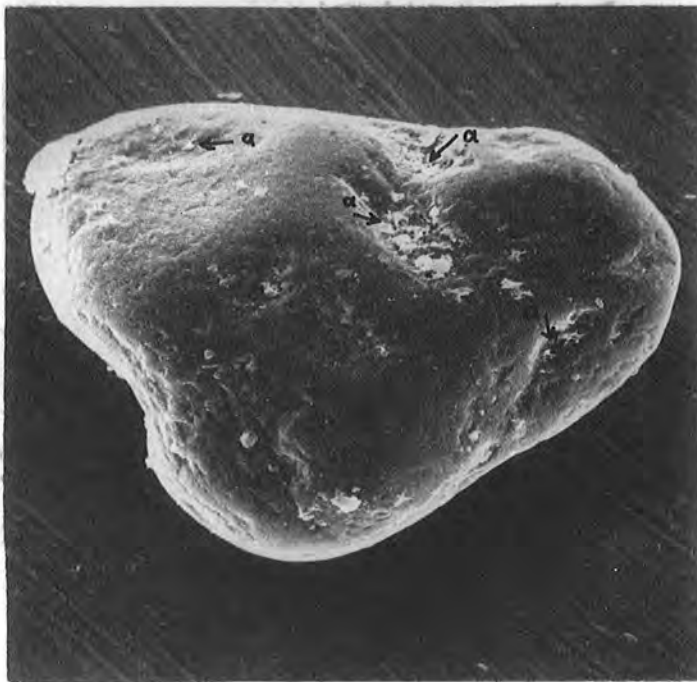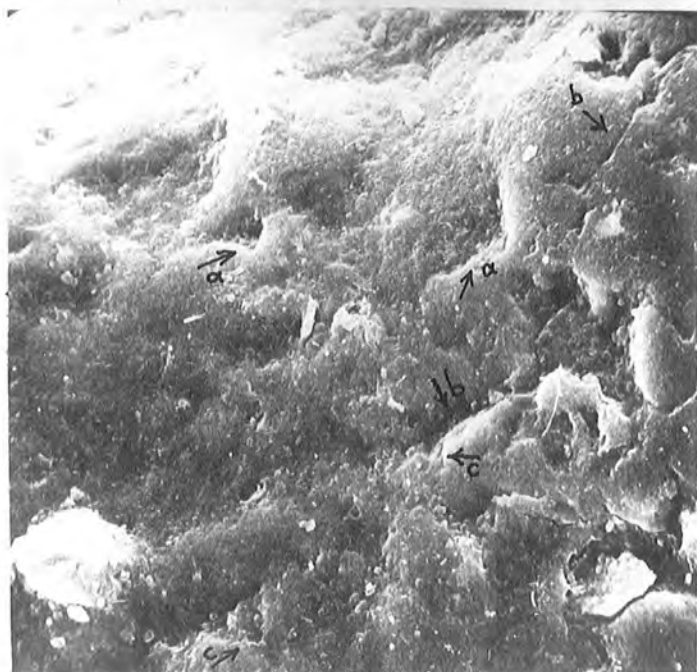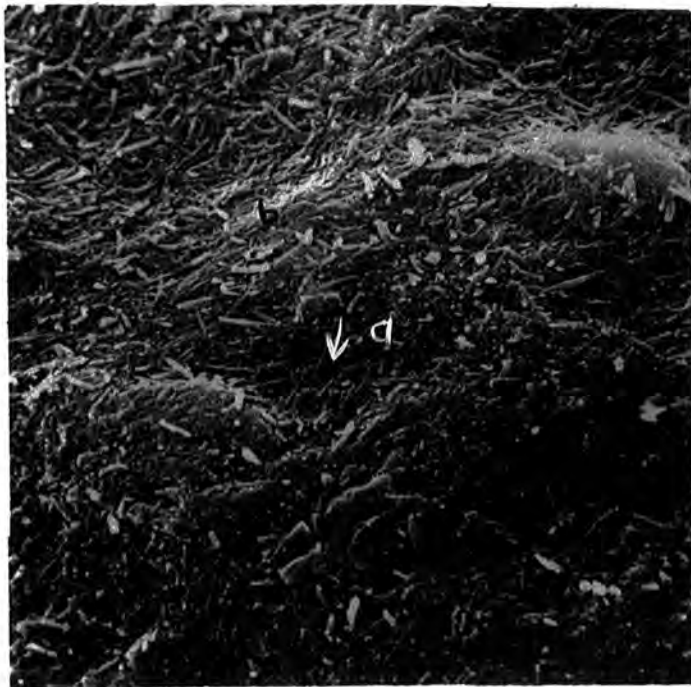
Plate (41)

patterns, straight or slightly curved grooves which in some cases are associated with V-shapes. It appears that this grain has superimposed environments of subaqueous and aeolian with the first being the original then giving way to the aeolian.

Plates (38 & 39) are for a quartz-sand grain from the top of the escarpment sample No. 13; here is another example of superimposed environments. Plate (38) is a single grain which carries the characteristics of the aeolian environments e.g. smooth surface and round edges, irregular depressions which may have resulted from mechanical chipping and solution-precipitation action, silica precipitation in the depressions and adhering to the surface (especially top left) which will help in smoothing and rounding the surface. Plate (39) is a close-up of the southern portion which in fact indicates subaqueous environments with V-shaped depressions and grooves with V-shaped developments along the axis. A crack has developed in the lower right of the plate as a result of weathering with silica precipitation helping in the weathering.

Plate (40) is a portion of sand grain from sample No. 32 from the top of the escarpment in Mudairah. It indicates subaqueous environment with V-shaped patterns and deep grooves. However, it seems that these features have been subjected to solution-precipitation which after some time may change the characteristic of the grain.

Plate (41) is a portion of a sand grain from sample No. 60 collected from the top of the escarpment in Al-Bahra III. By very careful examination of this plate, very faint V-shapes can be recognised; the original surface of the grain is almost hidden by particles adhering to the surface which changes the character of the original grain. It is thought that the previous example, plate (40), is an earlier stage than the present example. The last two examples indicate that both

samples originated from subaqueous environments, and were then subjected to aeolian environments.

The conclusions which one may draw from using the scanning electron microscope in this research are that the technique has revealed two environments of deposition; (1) Subaqueous, which according to Kinsley and Doornkamp 1973 includes all environments in which sand grains are transported, abraded and deposited by water - which includes marine and non-marine. (2) Aeolian environments. (3) Some grains carry the characteristics of the two environments with one being predominant. The results show that eleven samples are of beach origin, these include samples Nos. 5, 6, 8, 17, 25, 31, 34, 40, 46, 48, and 57, and two of aeolian environments, samples No. 18 and 37. Five samples carry superimposed environments, 11, 13, 32, 42 and 60 of which four are believed to be of subaqueous origin No. 13, 32, 42 and 60, while the last one, No. 11, is originally of aeolian environment but carried to the beach environment.

For further application of these results we have to consider them in the context of other data - see Chapter 6.

CHAPTER 6

EVIDENCE FOR CHANGING SEA-LEVEL ALONG THE NORTH COAST

OF KUWAIT BAY

6.1 Introduction

This Chapter is concerned with the interpretation of the results

of the methods which have been applied for investigating the changes in

sea-level along the north coast of Kuwait Bay. The changes of sea-

level may result from several causes but it has been generally agreed

that they have occurred as a result of the following processes acting

alone or together, and affected by the isostatic processes later

described.

1. Tectono-eustasy, which involves variation in the capacity

of the Ocean basin, while the volume of oceanic water remains constant.

2. Sedimento-eustasy, as a result of outpouring of volcanic

lava and the deposition of land derived sediments in the ocean basins which

reduce the capacity of the Ocean basin and raises the level of the sea.

3. Glacio-eustasy, results from climatic changes and is caused

by changes in the volume of ice-sheets.

All the above mentioned processes have a relative influence

on changes of sea-level as a world-wide phenomenon, while the

changing volume of ice-sheets has been the most important influence

in the Quaternary period. Emerged and submerged features all over the

world have been recorded as evidence of changes in sea-level. Accordingly,

Glacio-eustasy will be discussed in further detail as it is believed that it

has affected the present area of research.

During the Quaternary period, world-wide climatic changes produced

glacial and interglacial phases. At the time of glaciation, a considerable

volume of water was locked up as ice sheets on the land and as sea ice,

causing the sea-level to fall; during interglacial and interstadial periods water

returned to the sea and the sea-level rose. The concept of glacio-eustasy was

first introduced by MacLaren (1842) and developed in the first half of
this century by De Lamothe (1911, 1918); Chaput (1917), Depéret (1918-
1922), Daly (1934) and others who accepted the theory as an explanation
of the former strandlines and sea-level fluctuations during the
Quaternary. The amplitude of sea-level fluctuation as a result of the
melting and accumulation of ice has been estimated by several authors:
e.g. Antevs (1928) estimated a range of 93m vertical fall in sea-level
for the last glaciation, Daly (1934) suggested that sea-level was about
75m below the present for the last glaciation, while Fairbridge (1961)
put it at 100m below the present for the last glaciation. The highest
sea-water level (Sicilian) at the beginning of the Pleistocene period
was estimated by Depéret (1918) to be at 90-100m. above the present.

The Mediterranean has been the classic area for the study of
Pleistocene high stages of sea-level. The work was initiated by De
Lamothe (1911) and followed by the work of Depéret who in 1918 presented
the Mediterranean sequence of high shorelines named as: Sicilian 90-100m,
Milazzian 55-60m, Tyrrhenian 28-30m, Monastirian which is subdivided
into main Monastirian 18-20m and late Monastirian 6-8m.

However, the uniformity of the Mediterranean shorelines described by
De Lamothe and Depéret has been questioned by other workers: Baulig
(1935), Johnson (1931), and Castany and Ottmann (1957).

The beginning of the Postglacial rise in sea-level (Flandrian
Transgression) began after the melting of Würm ice-sheets with a rapid
rise of sea-level between 17,000 and 6,000 years ago with many minor
fluctuations to reach the present level. There is less agreement about
the time the sea-level reached its present level as well as its
fluctuation above and below its present level as will appear in later
discussion. Detailed account of the Quaternary changes of sea-level is
given by Zeuner (1959) as well as by Fairbridge (1961).

Although the accurate study of shorelines' movements as a result of eustatic changes of sea-level should be carried out in an area which has not been exposed to upward and downward tectonic movements, it is very difficult in many cases to find an absolutely stable region. Isostatic/tectonic movements have a principal role in determining strandline levels, many of which have been found at heights of more than 200 metres above present sea-level. These resulted not only from the eustatic changes of sea-level, but because parts of the earth's crust responded isostatically to ice formation and ice melt or were tilted or deformed by local crustal movements.

The weight of large ice caps causes localised depression of the earth's crust during glaciation, but this slowly recovers when the ice melts; The amount of the depression will depend on the thickness of the ice. The recovery and balance of a land mass from the depression caused by the weight of ice is usually a slow process, although it is believed that recovery is faster in the marginal regions where the depression is less than that near the centre which suffered from greater depression and the ice stayed longer. Evidently, in areas such as Scandinavia, the pattern of terraces and beaches is extremely complicated as it is the result of interaction of both a rising sea-level and the recovery of a land mass from its depression by an ice cap.

One element in the interpretation of an ancient shorelines is connected with certain geodetic possibilities that involve changes in the Earth's motion and shape as a whole. Fairbridge (1961) stated that "These may be related to change in the rotational rate of the Earth, and change in the gravitational forces both internal and extra-telluric. Both are intricately related. A redistribution of mass will change the moment of inertia, and hence the rotational rate, but it will also affect gravity. Also involved will be the Polar wobble, the angular velocity and its direction. Under centrifugal

force, the Earth's geoid swells at the equator and shrinks at the poles.
A change in the angular velocity would result in the hydrosphere reacting
differently from the lithosphere. Acceleration would cause a rise of sea-
level in the equatorial belt and a lowering at the poles. Deceleration
would have the opposite effect." According to several authors, these
changes have affected the level of the sea. As the geoid corresponds with
the level of the sea at any given time, accordingly, the geoid itself may
change with the cycles of world climate. The sea-level, and hence the geoid,
oscillates between three modes as illustrated by Fairbridge (1961). A
minimum dimension is assumed during the glacial period, when much of the
Earth was covered by ice sheets, and this limit is referred to as a glacial
geoid. In the interglacial stages, similar to that of today, although most
of the ice caps have melted, there is still water glacially tied up, as in
the Antarctica and Greenland ice sheets. A curve corresponding to the
interglacial geoid may be shown through the positive peaks, of Fairbridge's
sea-level curve (1961 Fig. 10. Page 133), data relating to these peaks being
well established mainly in North Atlantic regions. A complete melting of
the ice caps did not occur during each interglacial but would reach its
maximum dimension in a period when the Earth was free of ice; as a result,
the interglacial curve may not represent an accurate picture of the
deglacial geoid and hence the latter curve deviates from the inter-
glacial geoid which, according to Fairbridge (1961), would reach a point
50 metres above present sea-level to-day. (allowing for isostatic adjustment).

As most of the Pleistocene sea-level curves come from Continental
coastlines, and hence at the edge of the surface loading, it is therefore
expected that they undergo complicated movement patterns. Areas of glació;
isostatic rebound (as in the case of North America and Europe) are experiencing
larger movements than those areas which are only affected by the water level
changes. Since as with any real body, the Earth is exposed to deformation and
has a finite rigidity, accordingly any load on the surface level would cause

stress and surface displacements. The eustatic changes of sea-level which result from the shifting of loads from the ice-covered areas to the oceans, will form a redistribution of loads over the earth's surface and will cause deformation of the solid earth; this crustal sensitivity to water is called hydro-isostasy. The crustal sensitivity to ice (glacio-isostasy) as well as to water (hydro-isostasy), form the eustatic curves of sea-level recorded from different parts of the world.

There are strong arguments for a hydro-isostatic deformation of the ocean floor; Daly (1934) speculated about the effect of the changing of the Pleistocene sea-level on the isostatic adjustment of the floors of the ocean, while Jensen (1972) discussed the reasons for the differences in eustatic sea-level curves and the effect of deglaciation in changing the shape of the geoid. The glacio-isostasy which occurs as a result of the withdrawal of ice masses, is in itself a non-global effect; meanwhile, the rising of water all over the globe will create an elastic deformation of the solid earth, and also an isostatic adjustment (hydro-isostasy) both on a global base. Jensen (1972) indicated that the effect of the hydro-isostatic change is smaller than that of the glacio-isostatic, since the equivalent water is much smaller than the ice thickness. Bloom (1967) studied the effect of the hydro-isostatic changes on continental coast and oceanic islands, and indicated that the Oceanic islands record different shoreline levels to those of the continental coasts and are the best place to study glacially sea-level changes. Mörner (1970, 1972) mentioned that consideration should be given to the hydro-isostatic effect when discussing supposed eustatic curves and maintained that the decrease in Ocean volume associated with the building up of glaciers had little effect on the ocean floor. On the other hand, the transformation of water from the melted ice to the oceans would hydro-isostatically deform the ocean floor by about $^1/3$ of the thickness

of the added water body.

Walcott (1974) used several rheological models of the earth as the elastic theory and elastic parameters for the earth, which can be used to find out the quantitative relationship between surface loads and the displacement of the surface. He indicated (1972) that during and following the melting of the Pleistocene ice caps, several deformational effects are expected to occur and stated that "The actual movements at any particular point over a specific time-interval will be the sum of all three movements (elastic, hydro-isostatic and postglacial rebound)." As is noted in Chapter(2) and in the Conclusion, the Gulf during the Pleistocene period was occupied to a varying extent by oceanic water. Crustal deformation below and above present sea-level may have resulted from associated geoidal hydro-isostatic changes if not from glacio-eustasy. So far however, no quantitative measurement of the effect of these processes on the general physiography of the Gulf has yet been possible.

We now turn to the correlation of the levelled terraces and discuss them in relation to the world-wide changes of sea-level; an attempt will also be made to elucidate whether these terraces have been formed as a result of eustatic changes of sea-level or whether other factors have also played parts in their formation. The intepretation is based on the assumption that in the absence of crustal movements, ancient shorelines will be horizontal identifiable physiographic features. Hence, if the terraces exposed on land in the present research area are the result of a fall in sea-level alone, the terraces of the Al-Bahra area in the east would be of the same height or similar to the height of the terraces elsewhere, i.e. at Mudairah, Ghidhai and Kathma in the west. The problem ot interpretation becomes complicated when both localised and regional crustal as well as eustatic changes of sea-level are involved in the area. In this case, terraces of the same age may not be found at the same height in different areas, while on the other hand, the fact that the terraces are found at the same or similar heights does not necessarily mean that they are of the same age.

6.2 <u>Basic assumptions and sources of error</u>:

First, some of the basic assumptions concerning the techniques

described in the previous Chapter must be examined, with particular reference

to any source of error in the data obtained.

<u>Basic Assumptions</u>:

1) Tide range constant: It has been assumed that fluctuations of the tidal

range in Kuwait Bay were no greater in Pleistocene times than they are today.

The tidal levels now observed in the Bay are as follows:-

      Mean Higher High Water Springs   + 3.58 metres.
      Mean Lower Low Water Springs   - 0.72 metres.

Levels refer to Kuwait Land Chart Datum, which is 0.47 m. above Admiralty

Chart Datum (Shwaikh Port Authority). However, it is possible that during

the Quaternary this range varied, as the morphometry of the Gulf changed

with fluctuating sea-levels.

2) Samples taken from transect lines are representative of terrace sedimentary

environments: The number of the analysed samples has been decided according

to two factors: (i) the condition of the samples when they arrived in the

laboratory - some samples were abandoned due to breakage of their containers;

(ii) that at least a representative sample from each terrace is included.

However, although the results obtained from analysis of the samples and the

shape of their diagrams (Figs. 30-43) show general similarities, it is worthwhile

mentioning here that the samples and their results are mainly representative

of their particular locations along the levelled transects, (as indicated in

Figs. 15, 17, 19, 21, 23, 25 and 27), and hence reflect the sedimentary

environments along the transects. Nevertheless, it is believed that as the

transects themselves are dispersed in different locations in the research area,

and the results still show similarities, it can be held that the transects are

significantly representative of the type of depositional environments which exist -

not only along the transect lines, but also in the intervening areas.

Sources of error:

It is believed that all three methods are exposed to some degree of error which could affect the results obtained. The degree of error varies from one method to another, and it is believed that the radiocarbon dating results may be most liable to error, since there is no personal control over the circumstances related to the shell material used for C14 dating. Accordingly, the results presented here for the adopted methods are preliminary, and further research must be considered. However, it is also believed that correlation of the results of all three methods has reduced the degree to which errors become significant, much below the level which would be obtained if only one method was adopted.

1) <u>Levelling</u>: The error in levelling will mainly occur due to the impossibility of closing the levelled transects. The unavoidable reason, previously referred to, has been the lack of trigonometrical stations or bench marks near the closing point. However, the preliminary levelling which was carried out before the levelling began, indicates that the possible closing error of each transect is of the order of $\pm$ 1 metre, and this value is not significant in comparison with the range of terrace heights obtained in the area (Table 3, p. 126).

Another possible error arises from unequal forward and backreading distances between levelling stations, the distances were largely determined by the topography of the area, with narrow widths in the upper terraces, and increasing widths in the case of the lower terraces. As a result, the inequality of the distances between the levelling points introduced some error in the levelling results. However, this question has been referred to specialists in this field, who have indicated that although the procedure adopted would introduce a geodetic error, it is not significant in relation to the research in hand, with an error value of about 10 centimetres over a distance of about 5 kilometres. As this value is approximate,

it is suggested that the 10 centimetres can be added to the $\pm$ 1 metre

of error mentioned above in the form of a revised figure of $\pm$ 1.1 metre.

2) <u>Radiocarbon dating</u>: Sources of error in the results of the carbon dating

procedure may have occurred for several reasons, one of which is statistical,

and which may have occurred as a result of submitting the shells to several

laboratories; although the existence of this potential source is recognised,

it is not possible to determine its precise value. Accordingly, for this and

other reasons which will be discussed further, only the inner fraction of the

dated samples has been counted in calculation, and the outer fraction, which

is more exposed to contamination, has been ignored. There is a possibility

that contamination of the fossil shells may have occurred in the field before

collection, as a result of the handling of some of the species by human agencies,

as well as by intermingling of geologically older and younger species. Mollusca

add a certain proportion of radioactively "dead" carbon derived from old rocks

to their tissue, with the result that the radioactivity will be too low,

and subsequently the indicated age will be too great.

3) <u>Mixture of samples on the terraces</u>: When we come to analyse the

characteristics of the material of which the terraces, - identified by levelling

are composed, and which cover the surface of the terraces, we meet one major

problem of special importance to an interpretation of fossil materials.

During the levelling along the named transects, the nature of superficial

deposits was observed along the line and also in a wider zone on each side of

the transect line. During this process, the presence, sometimes over extensive

areas, of richly fossiliferous beds was noted, at various altitudes.

As will be seen later in this Chapter, the identification of fossil

material is of considerable importance, but in the case of the fossiliferous

beds the question which has continuously to be asked, and which cannot always

be satisfactorily answered, is whether these beds represent discontinuous

exposures of lithological material in the parent bedrock, or whether they

represent later deposition on the bedrock.

The fossiliferous beds have been correlated and examined with the aid of the cross sections which were constructed through the Jal-Az-Zor escarpment by Fuchs et al (1968). These cross sections show the occurrence of a fossiliferous formation of Tertiary age (exposed Neogene). The composition of the collected fossiliferous samples and their locations resembles those illustrated by Fuchs et al (op.cit) and accordingly some of the collected samples are thought to be of the same formation. These samples come from the First terrace in Ghidhai and from the Second and Third terraces in Mudairah as well as from some parts of the research area. As for the fossiliferous bed west of Kathma I, and that which was traced on the Fourth terrace on Ghidhai, it is probably a mixture between the old and more recent formation.

The fossiliferous marine deposits which have been found to overlie the Lower Far fossiliferous bed which is exposed in some parts of Kathma (II), are sufficiently physically distinctive to be considered as of more recent deposition. (Fig. 17 and Plate 4). The same applies to the fossiliferous rocks found on the lowest terraces in the Al-Bahra area on the three transects AI, AII and AIII (Figs. 23, 25 and 27).

In addition, over thirty fossiliferous rock samples have been further examined by several geologists, Dr. G.A.L. Johnson of the Geology Department of the University of Durham, Dr. J.D. Taylor and Mr. C.P. Nuttal of the British Museum (Natural History), and by Mr. C.C.S. Davies of British Petroleum (formerly Kuwait Oil Company). Dr. G.A.L. Johnson examined some of the samples collected from the Kathma area, and indicated that no precise age can be given to them, but they are probably Tertiary to Recent. Dr. J.D. Taylor and Mr. C.P. Nuttal examined a wide number of samples and concluded that the material is very poorly preserved, but that the age probably ranges from Pliocene to Recent. As for the samples examined by Mr. C.C.S. Davies, no definite conclusion could be drawn due to their state of preservation. Purely from lithological and palaeontological examination

of the fossiliferous samples collected from selected sites, we can go no
further than the conclusion reached in Chapter 5 (pages 68-126). In this
section, and in Chapters 4 and 5, the methods adopted, the data obtained
and the interpretation approaches used have been examined, and the order
of magnitude of error arising from these and from basic technical assumptions
are noted later in this Chapter and in the Conclusion. Working hypotheses have
been put forward, bearing in mind these possible errors, on the basis that
sufficient support for a general hypothesis can be obtained from the
correlated use of the various methods adopted.

6.3 The terraces as physiographic features

In Chapter 3, it was noticed that the area north of Kuwait Bay is
structurally unstable, but the intensity of this instability is not
known exactly as there has been insufficient detailed study of this topic.

The detailed levelling of the various transects not only helped in
the identification of the terrace but also gives indications of the
degree to which crustal changes have affected the area.

The number of the levelled terraces between Kathma and Al-Bahra
district varies between six in Al-Bahra (profile AI) to four terraces
east of Al-Bahra (AIII) as well as in Kathma. (Fig. 44), which has
been drawn from the combined results of the field survey and from
information constructed by the help of aerial photographs and topographic
maps, shows that throughout the area, there is clear evidence of several
breaks of slope representing remnants of terraces; the bedrock of these
terraces are mainly of Miocene and Pliocene age which are found either exposed
on the surface or overlain by Pleistocene and Holocene marine
and terrestrial deposits.

Fig (44) TENTATIVE GENETIC CORRELATION OF TERRACES NORTH OF KUWAIT BAY
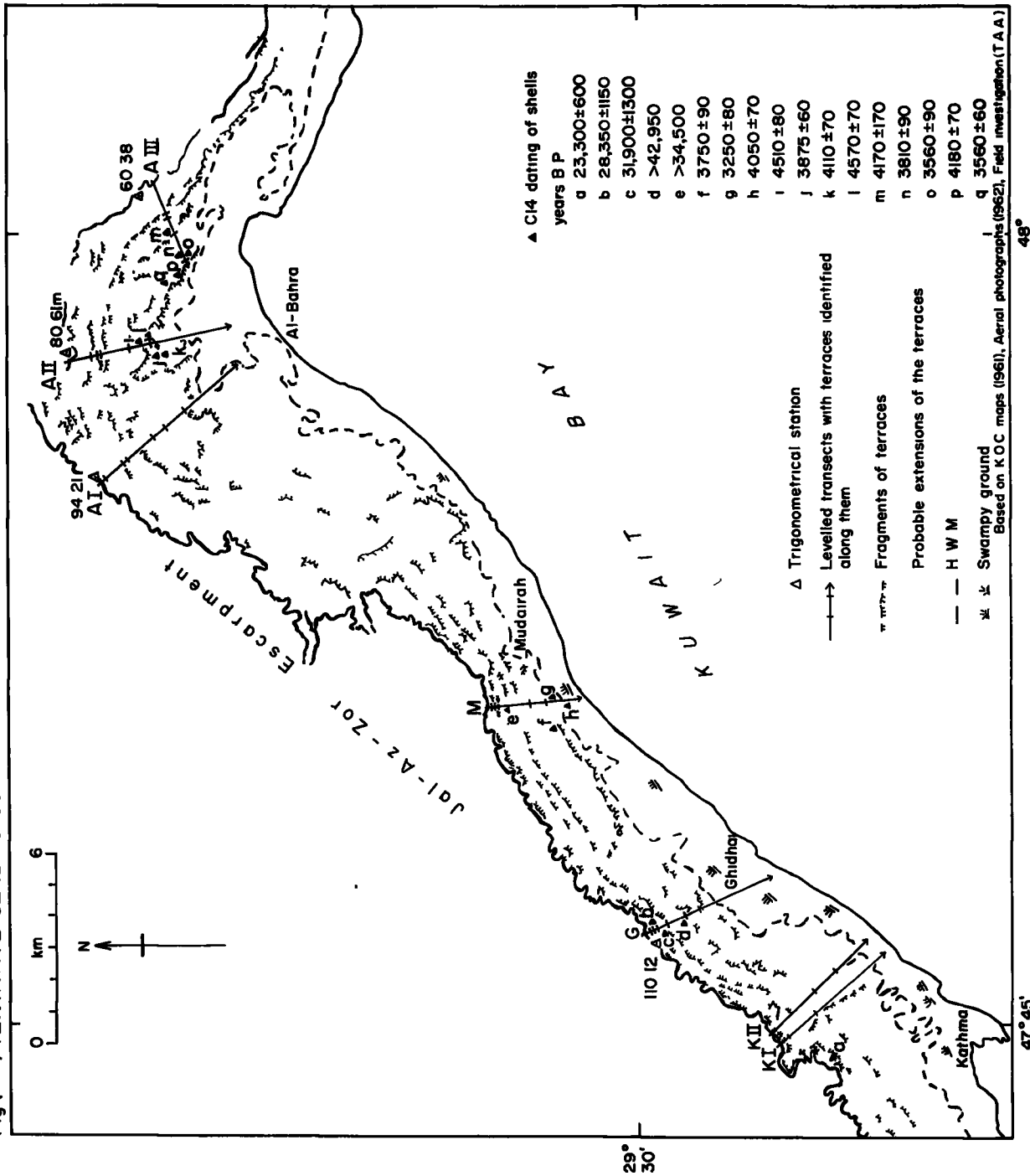
The mean heights of the levelled terraces range between a maximum of 92.62 metres for the highest terrace found in Ghidhai and a minimum of 5.99 metres above K.D.* for the lowest height of terrace in Al-Bahra III. Table (3) gives the mean height of the surveyed terraces; it clearly indicates that from Kathma in the west to Al-Bahra in the east, the mean heights of the terraces above K.D. not only decrease, but also there are local decreases and increases in height. This can be noted from the heights of the First terrace where as in Kathma, it has a mean height of 90.60 m above K.D. in KI and a mean height of 81.53 m above K.D. in KII, whilst in Ghidhai area, the First terrace exhibits higher elevation from that in KII and KI. East of Ghidhai and at the border of Mudairah, the mean height decreases to a level of 71.12 metres above K.D. In Al-Bahra district, the First terrace in AI rises in height to 79.85 m above K.D., and then gradually decreases to 63.72 m above K.D. in Al-Bahra AII until it reaches a mean height of 33.11 m above K.D. in Al-Bahra AIII. Similar characteristics are found for the other terraces in that from Ghidhai the height of the terraces gradually decreases until they reach the lowest level in Al-Bahra III. The height of the Fifth terrace which has been levelled in Ghidhai, Mudairah and Al-Bahra (profile I and II) has its highest mean elevation in Ghidhai 33.60 m above K.D., then it decreases to a mean height of 11.61 m in Mudairah. In Al-Bahra I, it rises to a mean height of 22.32 m above K.D and has an elevation of 14.43 m in the middle of Al-Bahra (AII).

The levelling results indicate that:

1. There are six terraces observable between Kathma and Al-Bahra

2. These terraces do not have a constant height, but generally decrease in height from west to east

3. Beside the general eastward decrease of their elevation, there are

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*K.D.: Kuwait Land Chart Datum

indications supported by the differences in heights that the area

in the middle between Ghidhai and Al-Bahra has suffered from

some local structural warping

Therefore, it seems that although the levelling has thrown some

light on the existence of the terraces and their distribution in the

area, it has meant alsothat it is impossible to correlate them solely

according to their height and the results of the other methods applied

in this research are necessary to a better understanding of the

relations between the terraces.

C14 dating correlation

During field investigation, several fossil shells species were found

either scattered or cemented onto the surface of the terraces in

different areas and different heights (Figs. 15, 19, 21, 25, 27).

The shells have been identified and some of them submitted for

radio-carbon dating. They have been identified for two reasons:

1. To investigate whether they are of marine or freshwater origin for

   the reasons explained already on page (127)

2. To find out whether they correspond to those species described by

   Cox and Rhoades (1935) and Fuchs et al (1968) as being of the

   fossiliferous Lower Fars Formation which is exposed in some places

   between Kathma and Al-Bahra, or whether they correspond to more

   recent deposition. The species which belong to the Recent period

   have also been described by Cox and Rhoades (1935), Perry and Al-

   Refai (1957) and Steininger (1968). Although, it is known that

   complete separation between old and new species during geological

   time is not possible for some species, as they may have existed

   longer before the Pleistocene and may be still flourishing in

   present seas, it is possible to locate some of the species which

lived here for a limited period of time. An attempt has been carried out to compare the shells which have been collected and partly submitted for C14 dating with those referred to by the previous authors as belonging to the fossiliferous Lower Fars Formation of Miocene age.

The results indicate that the shell samples include both the old and the more recent species, the older group including *Ostrea sp.,* *Spondylus sp.,* and *Turbo sp.,* has been found at different heights. The *Ostrea sp.,* have never been found on the lowest terraces (i.e. terrace 6) but have been found in Kathma west of the levelled line of KI on the Third terrace and the upper part of the Fourth terrace. They have been also found in Ghidhai on the Third, Fourth and Fifth terraces. In Mudairah, they are scattered on the Second, Third and Fourth terraces and at some places on the higher terraces in Al-Bahra.

The *Turbo sp.,* have been found in Ghidhai on the Third terrace and on the First terrace east of Al-Bahra (AIII) and have not been found near the present coastline. *Spondylus sp.,* have not been found on the higher terraces as have the previous two species and only found in Mudairah below the Fifth terrace,(Fig. 21). However, the last two species *Turbo* and *Spondylus* although thought to be only of Miocene age of the Lower Fars Formation, Steininger (1968) has reported them on the southern coastal area of Kuwait and on some of the adjacent islands. Therefore, one is left with only the *Ostrea sp.,*which has not been reported as Recent in the available literature. The rest of the species must probably be thought of as Recent as well as of earlier provenance and similar to some of the other Recent species described by Steininger (1968) and to those which have been found by the author on the coastal area of Al-Dhba 'iyyah (Table 4). Those which are reported by Steininger (1968) include *Barbatia sp., Cerithium sp., Dosina sp., Glycymeris sp.,*

Plicatula sp., and *Spondylus sp.,* Of the supposedly Recent shells

species, a few of them are located on the higher terraces such as

Cerithium sp., Dosina sp., and *Pitar hagenowi sp.*

The question is whether these old and Recent species which are

found in the area are helpful in indicating the age of the terraces on

which they were found. On the other hand, are they spread throughout

the area without any regularity in age, and is the C14 dating able to

indicate whether they belong to old or more recent deposition? Also,

the dating of the shells will be helpful in correlating those terraces

already identified by levelling but which cannot be correlated solely

according to height. For example, can a terrace fragment in the Al-Bahra

area be correlated with other fragments, sometimes at different heights

in Mudairah, Ghidhai and Kathma?

Two samples of *Ostrea sp.,* which at the moment are thought only to

belong to Miocene formation, have been submitted for dating. The first

from the Fifth terrace in Ghidhai at a height of 46.51 metres above K.D.

(Fig.19) gave a C14 dating result age of > 42,950 BP. The other sample

from the Fourth terrace in Mudairah at a height of about 40-42 metres

above K.D. gave an age of> 34,500 BP. From a higher level (63.30 m

above K.D.) a *Cerithium sp.,* of shells has been dated and the C14

dating gave an age of 28,300±1150 BP., the sample came from the Third

terrace in Ghidhai.

At similar heights, two further shell samples have been identified;

they are composed of broken indeterminate shells of mixed species and

were collected from the top of a clear Fourth terrace covered by a

fossiliferous bed. This terrace No.4 and the fossiliferous bed has

been earlier described in Chapter 5 and both field investigation and

aerial photographs have confirmed its location at the foot of the

Jal-Az-Zor escarpment. These two samples were collected from two

different areas, the first from Kathma west of the levelled line KI,
and the second from the Fourth terrace in Ghidhai (Fig. 15 and Fig.19).
The results were 23,300±600 BP. for the sample in Kathma at elevation
of about 48 m above K.D. and 31,900±1300 BP. for the sample in Ghidhai
at a height of about 52 m above K.D.

The other samples have all come from the lower terraces and gave a
maximum age of 4570±70 BP. and will be discussed later.

The result from the higher terraces indicates several points. First,
that although the *Ostrea sp.*, samples do not come from the highest
altitudes, they gave the oldest age (>42,950 BP. and >34,500 BP.) for the
heights of 46.51 m and 40-42 metres above K.D. By contrast, some
younger dated samples were taken from higher altitudes e.g. (SUA-86)
28,350±1150 BP., height 63,30 metres above K.D. and sample No. (I-7610)
31,900±1300 BP., height about 52 m above K.D. and sample (I-7609)
23,300±600 BP., at elevation of about 48 m above K.D.

Secondly, the dated *Cerithium sp.*, which have also been found in the
southern coast of Kuwait and are still living at present, has an age of
28,350±1150 BP. which is younger than the *Ostrea sp.*, samples although the
former come from much higher elevation (63.30 m) than the *Ostrea sp.*,
(Height 46.51 m and 40-42 m above K.D.)

Thirdly, the two samples (I-7610 and I-7609) which came from the
Fourth terrace have given disappointingly different results, 31,900±1300 BP.
for that from Ghidhai and 23,300±600 BP. for the Kathma sample. They
also gave different ages from those of the *Ostrea sp.*, and the *Cerithium sp.*

Fourthly, the *Ostrea sp.*, samples, derived from the small amount of
evidence now available, would seem to be of the fossiliferous Lower
Fars Formation which is recorded here and elsewhere as being exposed on
the surface and accordingly, although they were found at lower altitudes,
they have the oldest age.

Fifthly, the fossil shell bed found on the Fourth terrace and from which samples (I-7610) and (I-7609) have been collected, although from a terrace clearly identifiable physiographically in the field, gave a different age. These differences may have resulted from the mixing of old and recent species to various degrees. Hence, the fossiliferous bed (Lower Fars Formation) which have been washed down by water and different kinds of erosion, mixed with products of deposition associated with later marine transgression in the area which has deposited more recent sediment and reworked the two at the same time. Lastly, the C14 dating indicates that the age of the higher terraces is possibly Pleistocene or older, two of the samples are older than 34.500 and 42.950.

In the case of the Lower terraces which are close to the present coastline, all the species found are associated with periods more recent than the Lower Fars Formation. The sample dated came from Mudairah and Al-Bahra, and C14 dating results give similar age and are generally close to each other. The ages range between a maximum of 4570 ± 70 BP. (T-1056) from a sample in Al-Bahra AII (Table 5) and fig. (44) and a minimum of 3250 ± 80 BP. (T.1062) in Mudairah which would indicate a Holocene age. Twelve samples have been dated, three from Mudairah (T-1062 to T-1064); four samples from the middle of Al-Bahra (AII), numbered T.1054, HV.4770, T.1055 and T.1056) and five samples from east of Al-Bahra (AIII), numbers (T-1057, T-1058, T-1059, T.1060, T.1061).

Most of these dated shell samples are thought to be in situ due to their occurrence in dense masses and in some cases they are cemented on to the terraces. Exceptionally, those collected from the Third terrace in AIII were found scattered sporadically in the area. As pointed out

earlier in this study, the terrace sequence One to Six refers to physiographically identifiable terraces in each transect and there may not necessarily be a firm correlation between individual terraces in different transects. In the case of the Third terrace however, levelling, other field survey and an analysis of aerial photographs does not suggest a continuity between transect AIII, AII and AI. In Kathma, Ghidhai and Mudairah C14 dates for the Third and Fourth terraces were all older than 23,300$\pm$600 BP. From the Al-Bahra transects, (T-1057) is the only shell sample which could be found different from those found on AI, AII and AIII lower terraces (Fourth and Fifth) in its site but was similar to them in age. The C14 dating for this sample is 4170$\pm$70 BP. and is totally different from the Third terrace sample dates from Kathma and Mudairah equivalents. It is believed, therefore, that the age of this sample is too young for this terrace and may have resulted from human activity as, although this area is not inhabited at the present time, there are small groups of people who move in the area collecting surface gravels to sell them for building purposes. These groups may have carried shells from lower altitudes and left them in their present location. Fig. (44) shows the distribution of C14 dating for the lower terraces; it indicates that the ages of the samples for the middle of Al-Bahra are generally close to those in AIII, their ages ranging between a maximum of 4570$\pm$70 BP. (T.1056)and a minimum of 3560$\pm$60 BP. (T.1059). Similar dates have been obtained for the samples in Mudairah, where the C14 results range from 4050$\pm$70 BP. (T.1064) and 3250$\pm$80 BP (T.1062). The above samples of Al-Bahra and Mudairah include four samples which were collected below the lowest terrace in the two areas. Two of the samples, No. (HV.4770) age 3875$\pm$60 BP. and (T.1055) dated 4110$\pm$70 BP. come from the lowland embayment within the Fifth terrace in AII, while the other two (T.1062) 3250$\pm$80 BP. and (T.1064) 4050$\pm$70 BP. have been collected from below

the Fifth terrace in Mudairah. Although these last four samples came
from lower altitudes than those on the adjacent terraces, they do not
have different ages and they probably belong to the terraces lying at
a slightly greater height but have been carried down either by human or
physical agencies, or both.

The shell samples located on the lowest terraces in Mudairah and Al-Bahra
are at the following heights: about 11 m in Mudairah, 15.18 m and
9.77 m above K.D. level in AII (middle of Al-Bahra), at 8.87 m, 8.27 m,
7.44 m and 4.60 m above K.D. to the east of Al-Bahra (AIII). This
difference in heights agrees with the general results of the levelling
which proved that there is no regular change in the heights of the sets
of terraces between one area and another but there is a general decrease
in height from west to east. Fig. (44) shows that there is a con-
tinuation of part of the levelled terraces from Al-Bahra AIII to AII,
AI and another continuation in Mudairah as well as west of Mudairah.
The dotted line represents a probable extension of the fragment of the
terraces in the area.

As the dating results, with one or two obvious anomalies, gave
similar sequences in all the terraces and since gradation in heights is
expected, it is possible to hypothesise that the fragments of terraces
observable between the transects are remnants of one continuous terrace
which extended from Al-Bahra in the east at least as far as Mudairah;
it may also extend further west to Ghidhai (aerial photographs evidence) and
even to Kathma but this latter extension cannot be identified from available
aerial photographs and has not been identified by C14 sampling.

The result of fossil identification and correlation with the old
and more recent marine shell species as well as the C14 dating of the
shell samples implies;

(1) that there is a noticable mixing between shell species of the Lower

Fars Formation exposed in the area and those presumable of younger age, this particularly applies to the Upper four terraces,

(2) that the age given for the higher dated terraces (above 40 m) suggests Pleistocene age at least,

(3) the other result determined by C14 dating suggests that the lower terraces in each of Mudairah and Al-Bahra are remnants of one terrace dated between $4,5701^{+}_{-}70$ BP. and $3,560^{+}_{-}60$ years BP. The mean heights of this terrace in each of the previous areas are 11.61 m in Mudairah, 14.43 m in the middle of Al-Bahra (AII) and 5.99 m above Kuwait Datum east of Al-Bahra (AIII).

It is probable that the samples of shells (SUA.85) which came from Al-Dhbai yyah area and gave a date of $940^{+}_{-}80$ BP. has been introduced by human agencies. Fossil shells have been noticed covering vast parts of the coastal area of Al-Dhbai'yyah at different levels. Recently, this area has been covered by an almost continuous belt of seaside cottages and buildings. Hence, the age obtained by C14 dating for the sample which comes from an elevation of about 5m above K.D. has given a younger age compared with other samples collected from the research area at a similar height. However, a definite explanation can not be given until further dating and investigations have been carried out in this area.

Interpretation of sediment investigation

Until now, it has been possible to identify the number of the terraces in the research area as well as their heights which, together with some radio carbon evidence, positively proved that the area is not stable. Marine shell dating has suggested possible ages for two groups of the levelled terraces, the higher and the lowest terraces, which correspond to different heights.

The origin of these terraces is not definitely known and we now turn to studying the deposits covering the terraces to see whether this

will indicate their origin, although there is a possibility that they, or some of them, may have been cut by different agents than might be indicated by the superficial deposits. In this section therefore some sediment analysis results are discussed in the context of other research results already noted and of other geological studies.

The result of the application of sediment research by particle size analysis and to a limited degree by scanning electron microscope seem, in general, to provide a good indication of the origin of the deposits covering the terraces and the adjacent areas at the top of the escarpment and on the present beach. The Student's t test (Table 11) has shown that there is no relationship between the samples from the top of the escarpment and the beach samples, with regard to sediment mean size, standard deviation and skewness. The results of the plotting of the parameters against each other have shown that samples from the top of the escarpment fall in the gravelly sand category. Also, the composition of the particle size curves (Figures 36 - 43) show that the curves of sediments from the top of the escarpment (Fig.36) are different from those of the six terraces and from those of the beach curves. The results of three samples from the top of the escarpment which have been examined by scanning electron microscope (samples 13, 32 and 60) from Kathma,Mudairah and Al-Bahra, indicate the occurrence of subaqueous environment as well as aeolian with the former being the dominant agent of deposition. Krinsley and Doornkamp (1973) indicated that the subaqueous environments include both marine and non-marine water. The literature relevant to the whole region refers to fresh water deposits of gravels covering the north and west of Kuwait, (Moody 1947 , Higginbottom 1954 and Fuchs et al 1968), these deposits being laid down by active rivers which originated from the interior of Arabia during the Pleistocene. The evidence thus given concerning the origin of sediments on the top

of the escarpment fits with the results of this investigation which indicate that the deposits covering the bedrocks of the top of the escarpment are mainly of fluviatile origin.

As far as the First and Second terraces are concerned, the results seem to show that their deposits are similar to each other but that the First terrace is closer in character to the top of the escarpment than to the Second terrace. The mean size of the sediments on the First and the Second terraces are different from that of the beach sediments indicated by the Student's t test which agree with the result of the field investigation. The sorting of the sediments of the First terrace seems to be worse than that of the Second terrace and of the beach and is similar to that of the top of the escarpment. As for skewness, the situation is reversed; this can be understood when one remembers that some of the beach samples have positive skewness. The difference in skewness results may have been obtained because some parts of the Second terrace carry marine deposits which may have influenced the results of the skewness. The result of plotting the parameters of the First and Second terraces samples (Fig. 35b) shows that all the First terrace samples except one fall in the gravelly sand category with the top of the escarpment samples. The same applies except for 3 samples to those of the Second terrace. The combined curves of the First and Second terraces (Figures 37 and 38) illustrate that the curves of the First terrace, although generally similar to those of the top of the escarpment, in some cases have higher percentages of the suspension population which distort the shape of the graphs. The graphs of the Second terrace are more uniform as they include samples of marine origin. Sample 42 from Al-Bahra (Fig. 23) indicates a superimposed environment when examined by scanning electron microscope. The sample (Plate 36 and 37) was first deposited by water and later exposed to aeolian action; sample 34 (Plate 25) which comes

from the Second terrace in Mudairah is of beach origin. It can therefore be stated that the First terrace exhibits deposits similar to those of the top of the escarpment, with indications of both fluviatile and aeolian origin. As for the Second terrace, traces of marine deposits have been found in the area (Figures 19, 21, 23 & 27) and hence one would expect to find more evidence of marine origin than would be found in the First terrace; it also carries sediments of fluviatile and aeolian origin.

The Third and Fourth terraces have been observed to contain fossiliferous beds of possibly old and more recent deposits, and extends from Kathma to Al-Bahra. The Student's t test (Table 11) shows that there is a complete agreement between the four parameters of the samples of these two terraces and those of the present beach. These parameters, when plotted against each other, show that some of the Third terrace samples fall into the gravelly sand field as well as the aeolian and beach environments, a result which does not completely agree with the Student's t test (Fig 35b). The samples of the Fourth terrace have all fallen in the beach field and in the aeolian field except one sample in the gravelly field. The investigation of the origin of the samples according to their shape characteristics and the three populations (Rolling, Saltation and Suspension) indicate that the Third terrace (Fig.39) shows characteristics of aeolian curves. As for those of the Fourth terrace, they have special characteristics with a higher per- centage of suspension population indicating mixed environments. The results of scanning electron microscopy on two samples, one from Kathma No.17 and No. 46 from Al-Bahra agree with the result of the particle size analysis and show that they are of marine origin. Samples No.5, 6, 8, 18, 25, 37, and 57 have been collected from the Fourth terrace between Kathma and Al-Bahra. The features on these grains indicate marine origin. In conclusion, one can say that the Third and Fourth

terraces show that there is a mixing of the three environments on the Third terrace, although there are only very limited samples of gravelly sand deposits of fluvial origin.

Only four samples have been analysed for the Fifth terrace and two from the Sixth terrace. The Student's t test shows a close relationship with the parameters of these samples and those of the beach, especially of the Sixth terrace, but the mean size and skewness correlation is negative. The result of plotting the parameters for the Fifth and Sixth terraces shows that two of the samples of the Fifth fall in the beach field and one in the aeolian field, while the fourth has gravelly sand. Those of the Sixth terrace sample have all fallen in the aeolian field.

Thus, the distribution of the sediments covering the bedrock of the terraces and the study area can be described as follows:

1. The gravelly sand deposits are concentrated on the top of the escarpment, the First, Second and parts of the Third terraces; they are also found sporadically on some of the Lower terraces.

2. The sediments of the aeolian environment are in fact very difficult in some cases to separate from the other two environments because they were deposited during all periods and hence they will be widespread in the whole area. However, the aeolian material is most noticeable in the middle zone between the higher terraces and the H.W.M. i.e. on the Third, Fourth and on a fragment of the Sixth terrace.

3. The third and last environment of deposition is that of the beach and this, as well as being found on the present coastline where samples exhibit characteristics of the adjacent area's sediments to the north of the Gulf, has been also identified on the Third, Fourth and Fifth terrace, as well as having a very limited distribution on the Second terrace, especially in Al-Bahra area.

4. The fossiliferous beds found on some of the terraces, e.g.

below the First terrace in Ghidhai, are of Miocene age (Lower Fars

Formation); the same applies also to those in the Mudairah area on the

Second and Third terraces, and to some of the exposed fossiliferous beds

in between the previous areas and Al-Bahra. The problems arising from

the presence of this non-Recent material were considered earlier in this

chapter.

It is now proposed to give a first tentative statement on the possible

origin of these terraces in relation to sea-level changes. The small

amount of relevant literature which exists and has been available to the

author, together with information provided by geologists in Kuwait -

partly in the form of personal communication - has indicated: first that

this area of research is tectonically unstable and that this instability

has affected the general topography of the area. Secondly, the Bahra anti-

cline has been associated with the Kuwait arch which extends to the south of

Kuwait and is possibly still active. Thirdly, a general dip towards the

north-east has been noticed, which may accord with a general subsidence of

the northern part of the Gulf. Fourthly, a probable northward block tilting

as suggested by C.C.S. Davies. Fifthly, there are indications of marine

fossils of recent species on higher levels than would be expected either in

the absence of positive vertical movement of land or of a general falling

of sea level. The existence of several levels of terraces at the foot of

the escarpment reflecting sea-level changes during the Pleistocene has

already been postulated (Fuchs et al 1968 and personal communication).

In addition to these basic observations one may cite the widespread

occurrence of fluviatile materials on the northern and western land surface

of Kuwait, which have been interpreted as being deposited by rivers during

the Pleistocene and possibly late Pliocene (see p.33 and p. 36). The

fossil remnant of one of these rivers is the Wadi Al-Batin in the west of

the country and possibly the Al-Musannat in the south-west of the country.

The sedimentological results embodied in the present research support the

view that fluviatile materials are present in this area, e.g. the gravels
at the top of the escarpment and on the upper terraces. The sediment
evidence for marine action becomes stronger as one proceeds down the
terrace sequences from the escarpment.

On the basis of these points a tentative correlation of the origin
of the terraces in terms of present knowledge is as follows. The terraces
in the area seem to be attributed to two main agents of erosion and dep-
osition, these agents being marine and freshwater action. The latter of
these agents is more evident on the higher two, and possibly three terraces,
while marine action has been responsible for the cutting and deposition
of the lower terraces (which include the Fourth and other lower terraces).
This correlation is based on the types of deposition found on the terraces
even though there is a general mixing of the minds of deposits. Terraces
One, Two and Three together with the top of the escarpment carry sediment
deposits of gravelly sand and are dissected by several dry drainage systems.
The fossiliferous beds found on some of the First terrace in Ghidhai and
on the First and Second in Mudairah, are partly of Miocene age, while those
of the lower altitudes carry marine deposits of more recent age which rest
upon the Miocene fossiliferous formation, which in turn represents the
bedrock of these terraces.

The probability that the upper terraces have been partly formed by
rivers is strengthened when one accepts all the evidence for past
widespread fluvial action in the area. Whether this fluvial system was
a previous alignment of the Wadi Al-Batin or a quite separate system which
deposited the gravels in the north and west of the country is not known.

The alluvial agents of freshwater deposition no longer exist under
present conditions, as annual rainfall totals do not exceed 195.8 mm.
Accordingly, it is probable that the sediments covering those terraces
with incised wadis originated during past periods of heavier rainfall,

coinciding with global climatic changes (during the Pleistocene) and fluctuations of sea-level along with regional and local tectonic movements.

At this stage, a brief consideration of ancient climates and their development in the surrounding areas is worthwhile. The present climate does not justify the existence of several morphological features, as for example, the dendritic wadis in Arabia, the higher advance of sea-level to more than 150 m. above present sea-level at the early stages of the Pleistocene periods as indicated by the height of old deltas of wadi Al-Batin and wadi Sahbah (Holm, 1960), as well as the existence of Sabkhahs and east facing cliffs at about 150 m in height in eastern Saudi Arabia. The raised beaches of 373 m. in Oman (Lees, 1928) which carry marine fauna in a state of preservation similar to that of sub-Recent raised beaches, may have been formed during the high stages of sea-level during early Pleistocene periods. Other indications have been discussed by Lees (1928) and others (see Chapter 2).

The effect of climatological variations and their associated features has made it possible to clarify the factors involved in the development of the present topography of the research area. Butzer (1968) indicated that during the late Tertiary the climate of Egypt was semi-arid, accompanied by concentrated runoff. Chapman (1971) referred to the climatic history of the Eastern Province of Saudi Arabia during the Pliocene as having a temperature approximately the same as at the present time, being considerably moister in mid-Pliocene and semi-arid in the late Pliocene. As for the Pleistocene, the main relevant feature was the great development of glaciers, when millions of cubic kilometres of ocean water were locked in the Continental ice masses, with a resultant lowering of the sea-level. During the warmer interglacial periods, when water was released, the sea-level rose. Schwarzbach (1963) reported that in the period of glaciation, particularly in the Northern Hemisphere, the west wind belt was forced

equator-ward; consequently, at least the poleward limits of the deserts received a more abundant rainfall, and a glacial phase in a polar region corresponds to a "pluvial" with reduced temperatures, near the equator. During the inter-glacial stages, Schwarzbach (1963) believes that the climate was drier, and either as warmas or slightly warmer than at present, while the higher latitudes were subjected to glaciation and deglaciation and the arid lands were exposed to moister (pluvial) and drier (inter-pluvial) periods. The pluvial periods were characterised by cooler temperatures, and considerable rainfall, and by the formation of terraces and wadi cutting.

The inter-pluvial, on the other hand, were warm and semi-arid with short periods of appreciable rainfall alternating with longer periods of drought. The pluvial period was defined by Butzer (1961) "as a phase of widespread, long-term rainfall increase, of sufficient duration and intensity to be of geological significance". Penck (1913), Büdel (1939) and Fairbridge (1961) have discussed this phenomenon, and put forward two hypotheses to explain it. The first is the uniform migration of climatic belts, equator-wards, in glacial periods and towards the pole in the inter-glacials. The equatorial belt was narrowed down during the cold periods and expanded during the warm periods. The second hypothesis is the pluvial-arid alternation, during which the glacial phases were characterised by almost complete suppression of arid zones, and extensive increases in precipitation, while wide desert belts were developed during the inter-glacial phases.

Schwarzbach (1963) indicated that every present-day desert area has been influenced by pluvials. In North America, during the glacial period, the Great Basin area was flooded by extensive lakes such as Lake Bonnevile, the former high feature level is indicated by the old lake terraces. In Asia, the Caspian, Aral and Black Seas were connected, while in the Dead Sea the water level was 400m. higher than it is today, with fifteen raised beaches. In Arabia, several examples have been presented regarding the climatic changes which occurred, one of which is the occurrence of several

wadi drainages in areas which are now desert and relics of wetter climates
such as the wadi channels and fluvial gravels which occur on the southern
edge of the Rub al-Khali of Saudi Arabia, an area which at present lacks
a permanent flow of water. According to Glennie (1970) these features
originated at periods of increased wadi flow, e.g. during the Pleistocene
pluvial periods.

Correlation between pluvial and glacial periods has been broadly
suggested on the basis of sea-level correlations, although exceptions do
occur, as in the Mediterranean area, where it has been found that only the
early parts of low sea-level periods were moister, while later parts were
much drier. Also, while some periods were generally dry, other periods
were warm and moist (Butzer, 1963). The glacial periods were associated
with marine regression and river degradation, while the inter-glacials
were accompanied with marine transgression and river aggradation.

For the Holocene or Recent period, Butzer (1961) indicated that the
Sahara experienced a full aridity about 8,000 B.C., and between about
5,500 B.C. and 2,350 B.C., the climate was more moist than today, this being
indicated by faunal, botanical and geological evidence. The period between
2,350 - 800 B.C. was intensely dry with evidence of sand dunes invading
parts of the Nile valley, and the decline of the Nile floods associated
with famines. In south-west Asia, there was a similar climate to that
of the Sahara, with fluctuations of markedly greater humidity and aridity
(Butzer, 1961). The evidence of climatic changes of postglacial periods
in the Gulf are recorded in the submarine terraces at different levels,
Houbolt (1957); Kassler (1973). Godwin et al (1958), Evans et al (1969)
and Taylor and Illing (1969) also refer to marine transgression of that
period.

After considering the climatic change in the macro-region of which
Kuwait is part, it may now be possible to add further possibilities of

the origin of the terraces beside those already obtained from the applied methods of investigation, by returning to the question of land surface alluvial deposition.

When one examines the topography of Kuwait (Fig. 10), one notes the existence of channels of gravels aligned south-west to north-east in the area between the Jal Az-Zar escarpment and Wadi Al-Batin in the west. This phenomenon is not observable between the escarpment and the coastline, instead, marine deposits cover some of the terraces at different altitudes.

The north and west of Kuwait is dissected by several drainage systems and as the present climate does not permit the existence of such drainage, it is obvious that they originated during some of the pluvial periods of the Pleistocene or possibly earlier The edge of the escarpment is dissected by wadis which are most prominent in the west. Their channels cut through the terraces and represent periods of rejuvenation of erosion and deposition influenced by repeated regional tectonic movements and sea-level changes. The present staircase topography which is most prominent between Kathma and Mudairah and the deposits covering them and the dissection, in particular show evidence that the terraces may have been formed as a result of land and sea movements since at least the beginning of the Pleistocene. It is possible therefore that the terraces were first cut by marine action during high stages of sea-level. As the sea-level dropped to a lower level, stream erosion would have been increased and streams would be deeply incised, with the heavier rains washing down the fluvial deposits from the top of the escarpment on to the lower altitudes. If the sea-level rose again, stream erosion would decrease and streams would tend to aggradate their loads. These changes occurred either due to a eustatic drop of sea-level, or by a local and/or regional tectonic movement, or both.

From Kathma to Mudairah, the upper two or three terraces have narrow widths in comparison to those of the Al-Bahra area. Usually, if the sea

maintained its level for a long period, the original cliff would retreat
inland and the wave-cut terrace would be broad. But, if the sea-level
was not maintained for a long time, or if a sudden change of coastal
movement occurred, the width of the wave cut would be small. Hence it
is possible that the upper two and possibly the third terraces between
Kathma and Mudairah, had a different tectonic history from those in Al-
Bahra; they may have been exposed to local positive movement during
which the sea-level dropped to a lower stage, while the area of Al-Bahra
had a generally quiet tectonic history or had been rising very slowly in
accordance with the movement of the Bahra anticline. The indication that
the area between Kathma and Mudairah up to the border of Al-Bahra was
exposed to a different tectonic history is first given by the results of
topographic levelling and by the clear phenomenon of wadis which are cut
straight into the terraces. The other possibility is that an increasing of
stream erosion and the even better preservation of the higher terraces from
Kathma to Mudairah (which are also higher than those of Al-Bahra) may relate
to the general subsiding of the north of the Gulf, and as the Al-Bahra area
is closer to that area, it is possible that Al-Bahra, especially the eastern
part, is affected by that movement. Lees and Falcon (1952) have suggested
that the northern part of Bubiyan Island which is close to the Al-Bahra
area is undergoing subsidence because of the general movement at the north
of the Gulf. More recently, Kassler (1973), quoting an unpublished oil
company report written by V.S. Colter, indicated that the latter observed
the subsiding of the Kuwait part of the delta by as much as 37 metres below
sea level in the last 5,000 years (but see p.15-16).

It seems that the Fourth terrace, which clearly extends along the foot
of the escarpment from Kathma to Mudairah and appears discontinuously in
the Al-Bahra area, was probably cut by marine action only. It carries
fossiliferous beds of old and younger ages. It may have originated during
the last stages of the Pleistocene when the world climate became warmer

and the sea-level consequently rose, a change in accordance with which
the climate of Arabia including Kuwait tended to become less moist. As
a result there would have been a decrease of the amount of rainfall and
possibly the ending of the alluvial action which originated from the
highlands of Arabia, leaving the area affected by marine transgression
only. Another reason for the end of the freshwater deposition in this
area and particularly on terrace Four, may be due to the block tilting
towards the north, as C.C.S. Davies suggested. That tilting was accompanied
by stream migration from an original Musannat-Kuwait Bay to the more
recently developed channel of wadi Al-Batin. However, the C14 dating of
fossil shell samples from the higher terraces, which are believed to be
younger than the shells of the Lower Fars Formation, have age ranges
between a maximum of $>$ 42,950 BP. for sample No. C5/I from Ghidhai (at a
height of 46.51 metres above K.D.) and a minimum of 23,300 $\pm$ 600 B.P. for
sample No. I-7609 from Kathma (at an elevation of about 48 m above K.D.),
while the sample which was collected from Mudairah at a height of 40-42 m.
above K.D. (Birm. 285) gave an age of $>$ 34,500 years BP. The fourth
sample (SUA.86) at a height of 63.30 m above K.D., gave an age of 28,350 $\pm$ 1150 BP.
from the Third terrace in Ghidhai

At present, little is known about the eustatic changes of sea-
level during the period between 80,000 and 20,000 years BP. Fisk (1959)
reported an age of 23,400 BP. for the shells 50 feet (15.24 m) below
sea-level on Padre island, off the coast of southern Texas. Frye and
Willman (1961) mentioned that there was an interstadial at 25,000 BP.
called Farmdalian with an ice advance before and after. Fairbridge (1961)
estimate the level to be about - 40 m around that date, while Curray (1961)
thought it was about -15 metres as indicated from remnants of shoreline
deposits, off Freeport, Texas, which gave an age of about 30,000 years.
McFarlan (1961) reported that the sea-level rose to its present level
about 3,000 years ago in two stages; the sea-level was about -450 feet

(-137.2 metres) more than 35,000 years ago, it then rose from -450 feet

to -250 feet (-76.2 m) and stayed at that height until 18,500 years ago.

The second stage started 18,500 years ago and continued to rise until

about 3,000 years ago. In 1963 Shepard declared the existence of an

interstadial sea-level which may belong to the Farmdalian. The evidence

was obtained from terraces at levels of between 1.5 and 3.7 m in Oahu

(Hawaii) and New Caledonia. He dated shells from these terraces in Oahu

and the ages obtained were 24,140 and 26,640 years BP. for the 1.5 m

terrace, while the shells from the 3.7 m terrace gave ages of 31,540 and

31,840 years BP. The study of the coral reef terraces along the north-east

coast of Huon Peninsula, New Guinea (Bloom et al, 1974) indicate that since

about 125,000 years ago, a · time of higher sea-levels than at present,

five stages of sea-level maxima occurred, but none of them is above

the present level. The terraces record the succession of relative

transgressions and regressions which reflect the oscillations of glacioeustatic

superimposed on a relatively smoothly rising land. Fairbridge (1961)

revised the dates of major late Quaternary events as presented by vast

numbers of researchers. He referred to the Gottweig interstadial which

is dated about 50,000 - 30,000 and the Main Würm Emergence as being

between 30,000 - 17,000 years BP. None of these ages correspond with

evidence from the study area.

Also the correlation between the present terraces and those of

Deperet in the mediterranean, which have been referred to in this Chapter,

is rather difficult because of terrace height variations found within

the study area. In addition the Pleistocene terraces are beyond the

limits of the radiocarbon method dating; it has been suggested by

Zeuner (1959) that the approximate age of the Pleistocene interglacial

terraces - Sicilian, Milazzian, Tyrrhenian and late Monastirian are

between 825,000 and 125,000 years BP. The ages of the late and Epi-

Monastirian terraces (the last was named by Zeuner, 1953) which attain

heights ot 6-8 m and 3-5 m, have been revised by Fairbridge (1961), who

indicated that extrapolation to Emiliani's curve (1955), suggests that

the age is of 95,000 to 90,000 years BP. for the late Monastirian and

80,000 years BP. for the Epi-Monastirian.

From this and previous reviews, it can be said that there is general

agreement that for the time period obtained tor the Kuwait higher terraces

(between $>$ 42,950 years BP. and 23,000 $\pm$ 600 years BP.), sea-level fluc-

tuated without being higher than at present. Exceptions rarely occur, and

are referred to by Shepard (1963) and Shepard and Curray (1967).

Consequently, it seems that the heights of the Kuwait dated terraces are

very much higher than other workers have estimated for the same periods

in other parts of the world.

The present ages and heights of the terraces and their relationship

with the general trend of sea-level changes in the Pleistocene period

can be summarized as follows:

(1) Although the heights of the terraces of the study areas

are in the range of the Mediterranean sequence of high

sea-level, none of the terraces can be definitely

correlated with any particular terrace of the Mediterranean

because of the considerable height variations within the

study area.

(2) Although a correlation between the ages of the available

shells collected from different heights of the terraces,

agrees in general with dates obtained by other workers

for the late Pleistocene, they are distinctly different

in their heights above sea-level.

(3) The samples which have ages of 23,300 $\pm$ 600 years BP. and

over may either confirm their association with the Lower

Fars Formation or they may represent more recent

Pleistocene contamination

With regard to the lower terraces, for which young C14 ages are obtained,

- (between 4,570 ± 70 BP. and 3,560 ± 60 years BP.) - the ages suggest

that they are Holocene and particularly related to that stage which

occurred from about 6,000 to 3,000 years ago. There is less agreement

between the various researchers about the trend of sea-level during the

last 6,000 years. Shepard (1964) indicates that there are three schools

of thought concerning the changes in sea-level during this period:

1) sea-level fluctuated from about -1.5 m to +3 m above the present.

2) constant sea-level since the present level was reached about 3,000

to 6,000 years ago. 3) continuing slow rise of sea-level after about

5,000 to 6,000 years ago up to the present level. Fairbridge (1958, 1961)

maintained that the sea-level fluctuated with four higher level stages.

The first occurred about 5,000 BP. when the sea-level rose to +3 to +5

metres, but the actual elevation may be greater in some areas than others.

The second rise reached to about + 3 m in the period from 4,000 to

3,400 BP. The third was about 2,300 BP. with a positive rise up to

+1.5 m while the last rise was between 1,600 to 1,000 BP. during

which the sea-level rose by 0.5 to 1 m. Shepard and Suess (1956)

believed that sea-level was never above the present in the postglacial

period; McFarlan (1961) held the same opinion, but believed that the sea

reached its present level about 3,000 years ago. A similar result to

McFarlan's has been obtained by Jelgersma and Pannekack (1960). More

recently Tooley (1974) recorded three or four stages of higher sea-level

above the present during the last 4,000 years. It is therefore suggested

that the lower terraces may represent one of the higher stands of sea-level

during the last 6,000 years, especially since there is world-wide as well

as regional evidence from the Gulf of stages of higher sea-level. The

only problem is that the height of the terraces varies from a minimum

mean height of 5.99 metres above K.D. east of Al-Bahra to a mean height

of 14.43 metres above K.D. in the middle of Al-Bahra, and a mean height

of 16.10 metres west of Al-Bahra, to a mean height of 11.61 metres above

K.D. in Mudairah. However, the most noticeable characteristic of these

terraces is that they are better preserved than the higher terraces further

inland and the marine fossiliferous deposits here lie directly on bedrock

of Miocene to Pliocene age. The lowest terrace also has its highest

elevation in the west and the middle of Al-Bahra, a fact which fits with

the movement of the Al-Bahra anticline, which is possibly still active.

Further, there is clear observable continuity of the lowest dated

terrace, especially in the Al-Bahra area (see Fig. 44). The above

conclusion has been supported by the sample dating of the shells material.

In other words the present height above K.D. does not represent the original

higher stand of sea-level because the area has been disturbed by the

action in Bahra anticline and possibly by the tilting towards the north and

subsiding towards the north-east.

The only dated shell sample (SUA. 85) from the southern coast of

Kuwait which comes from Al-Dhba'iyyah area at a height of about 5 m above

K.D. (940 ± 80 years B.P.), proved to be too young to be correlated with

the dates obtained for the lowest terrace in the research area. However,

it is doubtful whether it represents the true age of the terrace from

which it was collected because of its location beside an inhabited area,

but the height is close to that of the uplifted cliffs further south in

Al-Jlayah which stand at an elevation of about 6 m above K.D. and were

referred to by Perry and Al-Refai (1957). Khalaf (1969) referred to a

marine terrace which varies in height from a few centimetres near Al-

Sabbiyah to about 4 metres at Ras-Ashairij and Al-Khiran. All the last

three examples referred to by the author, Perry and Al-Refai (1957) and

by Khalaf (1969) contain shells such as those which are found on the beach
at the present time. Further correlation will need an extension of the
area of detailed investigation, and also additional detailed studies
within the area.

CHAPTER 7

CONCLUSION

7.1 Methods of research and correlation of Kuwait data.

Sea-level changes along the north coast of Kuwait Bay have been investigated by examining the coastal terraces in the areas of Kathma, Ghidhai, Mudairah and Al-Bahra. "Staircase" topography has been observed everywhere between the Jal-Az-Zor escarpment and the present coastline. In some cases, the terraces are clearly continuous for long distances, while in others they are represented by isolated terrace fragments. In general, the bedrock strata dip to the north and are frequently exposed between surfaces of more recent unlithified sediments. A complicating factor in the reading of the superficial geology arises from the outcropping of fossiliferous beds which belong to Lower Fars Formation of Miocene age and are exposed on the surface. As well as material derived from this formation, fossiliferous marine deposits, presumably younger in age, in some cases overlie the Lower Fars Formation and have also been found on some of the terraces, e.g. Terrace Four between Kathma and Mudairah and the Lowest terrace in the Al-Bahra area.

Three methods of investigation were adopted in the study of the terraces and the origin of the surface materials viz: a. levelling, b. Radiocarbon dating of shells, and c. Sediment analyses, including particle size analysis and scanning electron microscopy. Each of the methods was selected in order to deal with particular problems and, consequently, each has furnished independently valuable results which can also be evaluated collectively.

1. Levelling:

This technique was adopted to determine the number and heights of the terraces in the area, and also provided essential data for the understanding of the structural stability and instability of the research area.

This part of the work consisted of surveying seven lines of levelling transverse to the alignments of the coast and the Jal-Az-Zor escarpment, two in Kathma, one each in Ghidhai and Mudairah and three lines in Al-Bahra. Whenever possible, the lithology along the transect was recorded in detail along with the nature of the superficial deposits. Soil samples and available fossil shells were in most cases collected during the levelling procedure. The overall results of the levelling indicate that the total number of terraces or fragmentary lines of terraces do not seem to be more than six in number and these are identified as Terraces 1 to 6 in downward succession. The six terrace lines where everyone of them is identifiable in a single transect - Ghidhai lie between 92.62 metres and 13.0 metres above Kuwait Datum, the first height being the highest point at which Terrace 1 can be identified in the Ghidhai transect and the lowest point at which Terrace 6 can be identified also in the Ghidhai transect.

The area as a whole has been considerably affected by structural deformation since the terraces were formed and this has resulted in a general tilting downwards from west to east. Since the terraces are not completely continuous morphological features, their numerical classification along each levelling transect line was obtained from the sequence in which they could be topographically identified independently along each transect. Thus the sequence 1 to 4 on Kathma II transect refers solely to that transect and does not necessarily correspond to the sequence 1 to 4 in Ghidhai transect (see table 3 p. 126). The use in this way of the uninterpreted levelling data exposed some clear alignment correlations as in the case of terraces 1 and 2 in all transects except the most easterly (Al-Bahra II and III); the height variations being explicable by later warping.

In the case of Terrace 3, the levelling data and/or field morphological observations showed clear correlation over the four most westerly terraces,

with the exception of the Third terrace in KII which seems to correlate

with the Fourth terrace elsewhere, height variation being only explicable

in terms of later warping; Terrace 4 is basically of the same type but with

larger height variation. In the cases of Terraces 5 and 6 any correlation

between particular sequence numbers could only be made after analytical

methods were used.

The levelling data and morphological observations when displayed

uncorrected, as in Table (3) p.126, also indicated that the Al-Bahra area

as a whole could not simply be regarded as an eastward continuation of the

same terrace features as were observed in the west. Within the Al-Bahra

area it was also clear that the three transects could not simply be

correlated on the basis of height and physical conformation.

Given the apparent anomalies in the topographic data, sediment

and fossil analyses were then applied to samples from the uncorrected

terrace sequences, so that any first observational bias would be

avoided. The most significant facts to emerge from the first level-

ling and topographic observations were (a) the recognition of a set

of terraces, up to six in number, and (b) evidence of structural

instability during and after the period of terrace formation.

2. Radiocarbon dating:

This was applied to shells, the only fossil material, in order

to determine the age of the fossil material which was collected from

different heights either along the transect lines or occasionally

off-set from the levelled lines. Ideally, their ages would indicate

the approximate ages of the terraces involved. However, the results

have to be treated very cautiously as the shells are subject to the

sea-water affect, for which empirical data are not available from the Gulf and

therefore any sea correction is not possible. The shells themselves may have

been exposed to contamination or may have been handled by human agencies.

A particular problem has arisen here because of the exposure of the
fossiliferous Lower Fars Formation of Miocene age from which some
shell material now on the surface may have been derived. The shell
species were tentatively compared with the available literature on the
mollusca of Kuwait. The C14 dating results show that there are two main
groups of ages represented. The first includes those which range
between $>$ 42,950 years BP and 23,300^{+}600 years BP. and without a simple
direct relationship between the height above datum and age. For example,
the highest dated sample in Ghidhai had an elevation of 63.30 metres
above K.D. and the age obtained is 28,350^{+}1150 years BP. The second group
of dated samples has a maximum age of 4570^{+}70 years BP. and a minimum age of
3,250^{+}80 years BP. The samples of this second group come from and below
the lowest and last terraces in Mudairah and Al-Bahra areas.

3. Sediment analyses

The third method of investigation used was the study of the
origin of the deposits covering the terraces by applying two methods
of sediment analyses; particle size analyses as the main technique and
scanning electron microscope as a subsidiary method. The results
of the mechanical anlysis have been plotted as cumulative curves
from which several percentages have been chosen to determine the mean,
standard deviation, skewness and kurtosis. The characteristics of
the four parameters of each sample as well as all the samples from a
particular location, e.g. top of the escarpment, First terrace, have
been studied and compared with the present beach samples.

The Student's t test was applied in the sediment investigation
to see whether there are significant differences between the parameters
of the present beach samples and those of the top of the escarpment
as well as with the other six terraces.

The results show that there are significant differences between
the samples from each of the different levels i.e. the top of the

escarpment, the six terraces and the beach.

The sedimentation environments in which the sample materials were shaped have been identified by plotting the four stated parameters against each other. The results show that there were three kinds of sedimentary environments dominant in the historical geomorphology of the area, fluvial, aeolian and marine beach environments.

However, the results do not define a sharp separation between the environments as there is often a mixture of environment-type material on a single terrace. In general, the conclusion which has the highest probability is that the fluvial environment is represented mainly on the top of the escarpment, and on the First, Second and parts of the Third terrace. The aeolian environment is the most difficult one to separate from the other two and is represented everywhere, especially in the middle zone. The marine-beach environment is mainly represented on the present beach as well as on the Fourth terrace, especially in Kathma, Ghidhai and Mudairah. It is represented also by material on the Sixth, Fifth and Fourth terraces in Al-Bahra (AI, AII, AIII respectively).

The particle size analysis has also shown that a large number of samples, especially those of the present beach have positive skewness indicating the influence of the freshwater sedimentation of the Shatt-al-Arab.

The third method of investigating the origin of the sediments which is derived from the result of the particle size analysis is the comparison between the grain size distribution curves of the samples. The results show that there is a clear difference between the curves obtained from material on the top of the escarpment and the curves from the present beach material. The degree of simi-larity between each sample as well as between each group of terrace

samples depends upon the origin of the samples involved. The result broadly supports the conclusions reached from the earlier mentioned analyses.

As for the second technique used to reveal the origin of the sediment (scanning electron microscope), although the number of samples was limited, the results obtained from the genetic classification of the micro-morphological features imprinted on the quartz grains of sand show that the results of most of the samples correspond with those of particle size analysis.

The collective evaluation of the results of the three methods of investigation indicates that the terraces were not only formed by sea-level changes but that the First, Second and probably the Third terraces originated because of sea-level changes and freshwater action, changes in the location of which probably accompanied crustal movements. This is particularly clear in the case of the terraces between Kathma and Mudairah.

Some terraces certainly appear to have been formed by changing of sea-level only and were accompanied by tectonic movements either during their formation or after. This is probably true of the Fourth, Fifth and Sixth terraces.

The simple correlation between each individual terrace identified in each area with others similar in numerical sequence is certainly not possible for the whole area. Problems appear especially in Al-Bahra, where the main difficulty is that heights of fragments of what is apparently the same terrace vary from one place to another. It is suggested that the reasons for altitudinal variation within the area can be attributed to one or more of the following disturbances, (a) instability associated with the Bahra anticline which is probably still going on, (b) possibly long-continued

but not necessarily regular subsidence at the head of the Gulf as suggested

by Lees and Falcon (1952), and (c) by the possible north tilting of the

area as suggested by C.C.S. Davies,(recent work in personal communication.)

If all the research results are utilised, it is possible to suggest a

highly tentative correlation of marine terrace alignments. Table (12)

which is a projection from Table (3) indicates such a hypothetical correlation

which however must remain unproven until further field investigation is

possible.

The heights of the terraces fall within the range suggested for

the Pleistocene high shorelines of the Mediterranean, also they are broadly

similar in height to those which have been tentatively suggested for the

Gulf. However, these can not with certainty be identified in detail with

any particular research area because of the problem caused by variability

in terrace heights.

The terraces cannot either be certainly correlated as the result

of the radiocarbon dating undertaken in this study; this is particularly

true for the earlier dates. A larger and longer-term investigation involving

a much larger number of samples than could be taken in this research is

clearly required. There would still remain the problems caused by the

exposures of old fossiliferous beds of Lower Fars Formation from which

fossil material has been mixed with younger shells. The resulting

contamination affects C14 dating very considerably and has made it difficult

at this stage to differentiate with certainty between bedrock-derived

fossil shells and those of presumably younger sediments.

Accordingly, it is possible that the older dated terraces are

not younger than Pleistocene period in age. As for the more recent dates which

come from Mudairah and Al-Bahra, these still create a correlation problem with

terrace height variation from a mean height of 13 metres above K.D. in Ghidhai, 11.61

metres above Kuwait Datum in Mudairah to a mean height of 16.10 m above K.D.

Table (12)

Tentative genetic correlation of the terraces (all heights in metres above Kuwait Datum)*

Location / Terrace Number	Kathma I	Kathma II	Ghidhai	Mudairah	Al-Bahra I	Al-Bahra II	Al-Bahra III
1	90.60	81.53	92.62	71.12	79.85	63.72	33.11
2	77.92	69.65	79.27	59.57	56.10	47.82	18.58
3	67.38		65	52.30	40.39	39.45	11.72
4	50.76	40.55	52.94	31.23	31.79?	29.86	5.99
5		10.70?	33.60		22.32?	14.43	
6			13	11.61	16.10		

- - - Separation between two main sub-areas (see text)

* Recorded heights might be exposed to some source of errors (see text)

west of Al-Bahra, 14.43 m above K.D. in the middle and a mean height of 5.99 m above K.D. east of Al-Bahra.

The other evidence of recent and continuing coastal movement may be used for providing some explanation of apparent anomalies. For example, the anomalous height in the middle of Al-Bahra probably results from Bahra anticlinal movement, the close grouping of C14 dates suggesting strongly that these samples represent a single terrace which extends between Mudairah and Al-Bahra and is of Holocene in age.

However, the fossiliferous surface deposits covering the terrace need to be reconsidered in detail before firmer conclusions can be reached about the age of the terraces.

7.2 Implications of the Kuwait Bay findings and the Geomorphic evolution of the Arabian Gulf.

The correlation between the results of work on the present area of research and those relating to the adjacent areas in the Gulf cannot be definitively made at the present stage, mainly due to the absence of sufficient other research data related to the topic under investigation. Most of the research work concerned with the physical environments of the Gulf has only been carried out during the past fifteen years and has mainly been concentrated on the study of the Holocene sedimentation. Other studies of the Pleistocene and associated features, especially those related to sea-level fluctuations, are very limited. The difficulty of correlation has been particularly felt in dealing with the higher terraces of the research area, which gave ages of 23,300 $\pm$ 600 years B.P. and over. These terraces suggest a Pleistocene age about which information from other parts of the Gulf is sparse.

To correlate each individual terrace with similar phenomena from other areas in the Gulf is a difficult task for several reasons. First, general studies of similar features elsewhere in the Gulf area lack

detailed scientific descriptions. Most studies of geomorphological

features generally refer to their height and occasionally to the kind

of deposition, but there is no precise dating or levelling. Secondly,

with regard to the research area, so far the results obtained from the

levelling indicate that the area under investigation has been exposed

to regional and local upward and downward movements, and the possible

effect of local disturbances was referred to in Chapter 3. As well as

being affected by local movements, the research area is close to the

Mesopotamian and the head of the Gulf area, over which argument still

continues concerning crustal movements. However, it is felt that at

this stage a general correlation can be achieved in the context of

understanding the tectonic framework of the Arabian Gulf as well as the

palaeoclimate of the area.

The structural evolution of the Gulf and surrounding areas has

already been referred to in Chapter 2, and this can be summarised by

identifying the Gulf as a tectonic basin, whose general form was largely

established in the late Pliocene to Pleistocene times. The Iranian coast

is topographically controlled by Zagros orogeny. A close relationship

exists betwwen the Zagros and Oman mountains, and it is possible that

the uplift of the Oman mountain continued well into the Quaternary.

Recent investigation has shown that the Musandam Peninsula of Oman

is undergoing subsidence, and that the amount of subsidence during the

last 10,000 years has exceeded 60 metres (Vita Finzi, 1973).

In Chapter 2, two other points of view were discussed with reference

to the head of the Gulf; that of the archeologists who, supported by a

geologist (De Morgan, 1900), claimed that the advance of the shoreline

at the head of the Gulf towards the south, was due to the continuous

silting up caused by the accumulation of sediments brought down by the

rivers Karun, Karkeh, Tigris and Euphrates. The second point of view, that of geologists who have emphasised the structural instability of the area, is mainly presented by Lees and Falcon (1952); Mitchell (1957a and 1958) and Colter (quoted by Kassler, 1973). Recently however, Larsen (1975) has argued in favour of structural stability at the head of the Gulf. Kassler (1973) maintained that the effect of Quaternary tectonic movements only produced local adjustment of existing features, but that an exception exists in the Gulf of Salwa where small vertical movements considerably affected the topography.

First, a re-examination of the scattered evidence of high stands of sea-level of Pleistocene age around the Gulf will be presented. As with those of the Post-glacial, an attempt will also be made to postulate their possible morphological development as a result of sea-level changes.

According to Fairbridge (1961), at the end of the Pliocene the level of the sea was about 150 metres above its present level. Holm (1960) has indicated that inland sabkhas on the coast of Saudi Arabia are found at the same height. The retreat of the sea to its present level left its mark on the coast of the Arabian Gulf in the form of marine terraces, high deltas and inland sabkhas. In the Gulf area however, it has been found difficult to correlate the available evidence according to the height at which features are now found. For example, the marine terraces of Oman, which occur at an elevation of about 373 metres were claimed by Lees (1928) to be sub-Recent, this is on the basis of evidence of marine shells claimed to be of this age. However, the problem of correlating these terraces with other areas in the Gulf raises two questions. First, what was the precise height of these beaches at the time of their formation, noting that the Oman mountains have been exposed to uplift movements since before the Pleistocene; the second question is how certain is the dating of the

shells to the sub-Recent (apart from their similarities to present-day species). A similar question faced the author when the results of the C14 dating of shells from the research area were examined, where the sediment analysis indicated Quaternary marine deposits as well as Pleistocene fluvial deposits, the latter being laid down during the wetter periods of the Pleistocene. Suspicions have been declared of the possibility of the shells being Tertiary in age, since the species identified are not solely Recent or Quaternary in provenance, or contaminated either by mixing with other species or by handling.

Certainly the height correlation between the raised beaches found in Kuwait, with elevation over 15 metres in Qatar (Kapel, 1967), in Saudi Arabia and Oman (Hölm, 1960 and Lees, 1928) as well as those found in the Makran Coast and referred to by Snead (1970), Falcon (1947) and Butzer (1958), others found in Das, Zirko, Ardhana and Qarnain islands (Kassler, 1973) is not completely feasible because of the crustal movements in most of these areas. However, it is possible to indicate the weight of the evidence for high sea-levels from that presented from the present area of research, as well as from the sporadic evidence discussed at length in Chapter 2. Mitchell (1958) described recent marine fauna near Najaf in Iraq at a height of between 40 to 41 metres, pointing out possible higher sea-levels during the Pleistocene. Voute (1957) also referred to the occurrence of recent marine fauna in the Abu Dibbis depression; according to Larsen (1975) a high sea-level of about + 25 metres is necessary in order to connect Abu Dibbis with the sea. These levels are similar to those found for the Fifth terrace in Kuwait (Table 12); and these heights also fit well with the Qatar raised beaches at +25 to 30 metres, which were reported by Kapel (1967) to have an age of > 39,800 years. Raised beaches at similar elevation (30 metres and higher than 80-90 metres)

in the Makran coast of Iran, were reported by Falcon (1947) who attributed them to uplift movements; Butzer (1958) has later suggested that eustatic changes of sea-level have played a part in the formation of these beaches. Moreover, Butzer (1958) added a 60 metre level and suggested that the whole sequence corresponded to the altimetric sequence from Sicilian to Monastirian, he also referred to the raised beach of 30 metres on the Kharag Island, Qishm, as well as in the Bushire.

The 60 metres raised beaches can be followed on the Makran coast as well as in Kharag Island (Butzer, 1958). Glennie's (1970) inland sabka of Umm as Samim in Oman, suggests a relic of an arm of the sea at a height of less than 70 metres, and evidence of similar heights has been reported by Kassler (1973).

However, as noted in Chapter 6, even the features associated with early Quaternary high sea-levels in the Gulf must also be regarded in the light of recent work on local and regional deformation of the Gulf basin by hydro-isostatic forces, as well as by the more general geoidal changes associated with varying distribution of oceanic water. As well as being affected by the world-wide eustatic changes of sea-level, the Arabian Gulf has responded to the load of water transferred to and from its basin. The Pleistocene was a period of repeated glaciation and deglaciation phases associated with periods of low and high sea-levels, from which point the volume of water in the Gulf basin alternately fell and rose, producing hydro-isostatic changes. At the end of the Pleistocene, the sea began to rise from its minimum level of -100 metres (according to Fairbridge 1961) or -120 metres to -130 metres (according to Guilcher, 1969) to reach its present level. It invaded the Gulf basin through the Strait of Hormuz and marked the newly coastal areas with several morphological features, one of which is the formation of submarine platforms and drowned valleys.

Since then, the Gulf has experienced the pressure of the load of water on its surface and is undergoing stress and surface deformation. However, at present, there are no published detailed studies regarding such processes in the Gulf area, and one may note for consideration that any results of work on eustatic changes of sea-level in the Gulf must be concentrated on the consideration of hydro-isostasy in the area.

Apart from the evidence provided for higher sea-levels during the interglacial periods, represented by raised beaches or higher sabkhas, it is evident that they occur at different heights, according to the steps followed by the sea until it reached its present level. The possible ancient climates in the area have been referred to earlier in Chapter 6. During the glacial period, several wadis in the Arabian Peninsula flowed into the sea. Holm (1960) referred to two main rivers, the Nisah-Sahbah, which flowed towards the south-east of Qatar and Rimah Wadi al-Batin which extended from Najd, and followed the western border of Kuwait until it reached the Tigris-Euphrates valley. These water flows were active during the pluvial periods of the Pleistocene and carried gravels, cobbles and pebbles which were deposited as deltiac material. Chapman (1971) indicated that the wadis and gullies of the Shedgum Plateau of Saudi Arabia were cut by running water during a wetter climate. During the pluvial periods, wadi cutting was active, even if not continuous, while during the drier intervals, wadi cutting ceased, or at least became very intermittent. He referred to the important role of sea-level fluctuation on the development of these wadis and to the fact that the falling sea-level had resulted in the formation of fluvial terraces by increasing wadi gradients. The dry rivers and wadi channels found inland or along the coast, may extend below the present sea-level. These landforms were mainly cut by rivers in a variety of climates, and their development has been influenced by both sea-level changes and repeated regional uplifts. The drowned river

valleys offshore of Abu Dhabi (Kassler, 1973) and those of the Musandam
Peninsula (Lees, 1928 and Vita Finzi, 1973) which were of fluviatile
origin, may have been drowned by the rising sea-level during the post-
glacial. Kassler (1973) indicated that the drowned river valleys can be
mapped down to the deepest platform, indicating that the channels may have
been formed during a single eustatic sea-level period. Consequently, it
appears that alluvial landforms are common geomorphological features, both
above and below the present sea-level, noted by several researchers and
related by all of them to the Pleistocene development of glacial and inter-
glacial periods, which in general coincide with the occurrence of Pluvial
wet periods and interpluvial dry or semi-dry periods.

At this stage, it seems reasonable to believe that similar developments
have taken place in the research area as part of the climatic succession
of the area. The present area of research is characterised by the
occurrence of several wadi systems (Plate 1), and although these seem
to be smaller in size than those described by other authors in the
surrounding area, a general similarity is implied. The west and north
of Kuwait, as well as the upper part of the Jal Az-Zar escarpment are
covered by fluvial deposits, laid down by running water. The remnants of
these main channels, represented for example by Wadi al-Batin, were
referred to by Holm (1960) as being active during the pluvial periods
of the Pleistocene, and Davies (1973, and personal communication), who
has also referred to similar drainage (see Chapter 3); another wadi
channel on a smaller scale is the Al-Musannat in the south-west of the
country. As well as these, several wadi drainage areas in a variety of
shapes cover the north and west of the country, and these river channels and
wadis have responded to both climatic and sea-level changes in the area.
The lowering of the sea-level during the glacial periods would have resulted

in considerable active eroding, as well as lowering the base level of the

wadis. During the drier periods - which may coincide with high sea-level,

active wadi cutting would decrease and tend to aggradation, and give way

to further subaerial erosion.

The general correlation seems reasonable at present in the light of

the available results from both the research area and from other areas

around the Gulf, any further correlation needs more detailed investigation.

During the late Würm glaciation, the sea reached its minimum level at

-100 or -120 metres, and as the maximum depth of the Gulf does not exceed

100 or 110 metres near the Strait of Hormuz, the Gulf would have then

remained a dry basin, except for the flow of the water of the Tigris and

Euphrates rivers. Sarnthein (1972) believed that the Shatt al-Arab at

that time reached the shelf margin in the Gulf of Oman, which at present

stands at -110 metres. During the glacial maximum (about 70,000 to 17,000

years B.P. according to Fairbridge, 1961), the Gulf experienced continental

conditions and the climate of the whole area was more arid than today,

Kassler (1973), quoting personal communication with M.S. Thornton,

indicated that Pleistocene limestone in cores taken from a depth of some

37 metres has undergone leaching, which probably shows sub-aerial exposure

of the rocks. On the other hand, Sarnthein (1972) declared that during

the post-glacial transgression, aragonitic sediments dominated the north-

east area of the Gulf. At present, these carbonates can only be found

along the south and south-west coast, where no rivers enter the Gulf, while

those sediments in the north-east are covered by calcareous, clayey, terrigenous

sediment deposited by Zagros rivers. This suggests that the climate of the

Zagros mountains must have been much drier than that of today, indicated

by the lower activity of Zagros rivers. The climax of development of the

drowned rivers offshore of AbuDhabi and/the Musandam Peninsula occurred during

the maximum retreat of sea-level of the Pleistocene. Vita Finzi (1973)
indicated that the drowned valleys of the Musandam Peninsula are the
result of subsidence of the coastal areas and the Flandrian transgression;
he estimated that the vertical displacements of the north-east of this
coast have exceeded 60 metres during the past 10,000 years.

The aeolianite of Makhus formation which Vita Finzi (1973) inter-
preted to be of coastal dunes, were formed during that period, and
accord with the last major regression. As there was no "evidence for a
subsequent transgression above present sea-level", Vita Finzi suggested
that the onset of the aggradation of Makhus deposits may have occurred
after approximately 35,000 years ago. The raising of the sea-level from
-130 metres to -40 metres, about 11,000 or 9,000 years ago, eliminated
most of the major sources of littoral sediments, and also indicated that
the age of the upper crust of the calcareous deposits is about 10,000 years.

Coinciding with the maximum sea-level retreat of the Pleistocene
glaciation, river channels and wadi degradation became active, and
those facing the coastal areas of the Gulf would have experienced con-
siderable lowering of their base level to correspond with the decrease
of the water level of the Gulf. Kassler (1973) reported the occurrence
of a network of channels which represent drowned river valleys, appearing
most clearly in the steps between submarine terraces. According to his
interpretations, these river valleys were formed when the climate was wetter
than today.

The so-called "Flandrian transgression" began about 20,000 to 17,000
years ago, and reached its present level in stages. In the following
review, a correlation of the Post-glacial sea-level will be suggested
between the available data, which include erosional and depositional
features from the Arabian Gulf, and Fairbridge's (1961) eustatic curve
of changing sea-level (see Fig. 45). However, it must be mentioned here

that although most researchers have indicated structural stability of the
Gulf during the transgression period, the possibility of small movements
cannot be entirely eliminated. Examples of such movement have been presented
from the north coast of the Gulf, the Iranian Coast and the Musandam Peninsula,
as well as from the Gulf of Salwa. Along with these examples is the effect of
the hydro-isostatic movement on the deformation of the Gulf floor and coasts.
Nevertheless, the correlation is tentative and will show the possibility
of the simultaneity of events in the Gulf with those from different parts
of the world, which were presented in Fairbridge's curve.

The maximum retreat of the sea-level to a level of about -120 metres
is recorded by Kassler (1973) in the form of eroded submarine platform in the
Gulf of Oman and the Strait of Hormuz, formed while the Gulf floor stayed above
the level of the sea. As the sea rose eustatically to a higher level of
-100 metres, or Main Würm, according to Fairbridge (1961), it formed
(Kassler, 1973) a submarine platform at a depth of -100 metres; this
platform extends along the Gulf of Oman as well as in the Arabian Gulf.
A rapid rise of sea-level began about 17,000 years B.P. and is characterised
by the formation of several wide submarine platforms, such as the -65
metres platform described by Carrigy and Fairbridge (1954) on the stable
west coast of Australia. In the Gulf area, it is possible that this
coincides with the formation of Kassler's-66-80 metres platform. Houbolt
(1957) was one of the first to put forward evidence from the north and east
of Qatar to show the Post-glacial rise of sea-level in the Gulf. The deepest
submarine terrace to which he referred is at -55 to -73 metres (-30 to -40 fm).
Meanwhile, Sarnthein (1972) believed that the rising sea-level transgressed
the area, which at present lies at depths of between 100 and 65 metres. He
presented depositional evidence to show   the transgression still-stands
in the Gulf at -64 to -61 metres, and-53 to-40 metres. The transgression
is indicated by the frosted quartz and ooid concentrations embedded in

lithified aragonitic mud. These are interpreted by Sarnthein to be
drowned sand dunes associated with a fossil ridge and trough system of
dunes. He correlated his results with those of Van Andel et al (1967),
who described similar formations at the same depths on the Sahul Shelf
of Australia. Meanwhile, Sarnthein (1972) believed that at that time, the
entire Arabian Gulf coastal region attained a morphological maturity,
indicated by several features - among which is the break of slope along
the longitudinal profile of the Gulf at a water depth of approximately
50 metres. According to Sarntheim, this feature can be followed around
the entire Gulf. This does in fact, correspond also (see Fig. 45) to the
depth of the "Second offshore terrace" of Houbolt (1957), which occurs at
—31 to-51 metres (-17-28 fm.)

Towards the end of the last glaciation, evidence from other parts of
the world recorded warm phases dated approximately 12,000 to 10,800 B.P.
(Fairbridge, 1961). Marine platforms at -32 - 40 metres (-18-22 fm.) have
been recorded from all over the world. It is expected that such platforms
were formed simultaneously in the Gulf, at similar levels. Houbolt (1957)
referred to a submarine terrace "The first off-shore terrace" at -20-31 metres
(-11-17 fm.), which is broadly developed east and north of Qatar. Also,
and from a similar depth (Fig. 45), Kassler (1973) recognised a submarine
platform at -29-37 metres (-16 - 20 fm.). Moreover, Kassler (op.cit),
indicated that a platform at that depth has been mapped from Abu Dhabi to
Kuwait, and used this evidence to disagree with Colter's results (quoted
by Kassler, 1973), who claimed that the Kuwait part of the Delta has
subsided by approximately 37 metres over the last 5,000 years. Kassler
(op.cit.) indicated that the more or less horizontal surface which was
identified by Colter at about -35 metres (-115 feet) and which carries
modern deltiac sediments, is in fact within the depth range of the sub-
marine platform (-29 to -37 metres, or -16 to -20 fm.) which extends

Fig.(45) TENTATIVE CORRELATION OF LATE PLEISTOCENE AND HOLOCENE SEA-LEVEL CHANGES IN THE ARABIAN GULF.
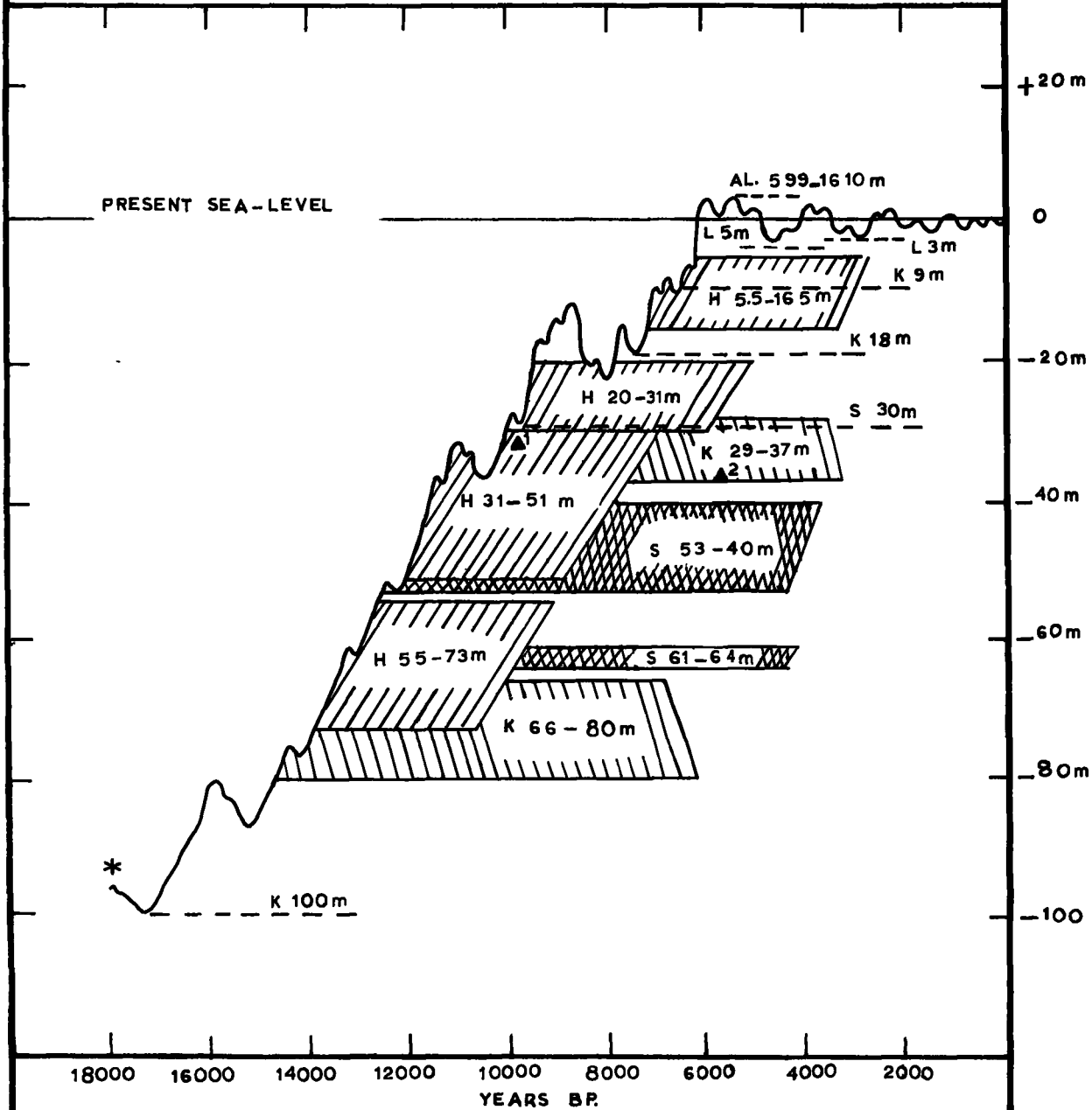
AL	AL-ASFOUR 1975	S	SARNTHEIN 1972
H	HOUBOLT 1957	▲¹	GODWIN AND WILLIS 1959
K	KASSLER 1973	▲²	COLTER (QUOTED BY KASSLER 1973)
L	LARSEN 1975	✳	SEA-LEVEL CURVE BASED ON FAIRBRIDGE 1961.

(T.A.A 1975)

between Kuwait and Abu Dhabi. Kassler (1973) suggested that correlation
with Fairbridge's 1961 scale indicates the age of this platform to be
about 9,000 to 11,000 years B.P.

On the other hand, Godwin et al. (1958) and Godwin and Willis (1959)
reported that the result of dating of a freshwater detrital mud which
represents an organic layer at a depth of about -32 metres, gave an age
of 9,910 $\pm$ 100 years B.P. However, Figure (45) shows that replotting the
sample results on Fairbridge's curve, according to its depth and age,
reveal that it comes within the depth range -29 to -37 metres, the age
of Kassler's submarine platform. Accordingly, it is possible to suggest
that the dated sample referred to by both Godwin et al (1958) and Godwin
and Willis (1959) may have come from the same surface referred to by Colter
as well as by Kassler (1973). The organic deposit was inundated by the
advancing rise of the sea in the Gulf. At a similar depth, about 30 metres,
Sarnthein (1972) provided another indication of his third standstill
transgression.

About 11,000 years B.P., at the commencement of the Holocene period,
the sea began to rise rapidly at a rate of about 20 to 30 mm, a year,
to within 15 metres of its present level; this movement alternated with
small pauses and slight reversal. Marine platforms associated with this
period are universally recorded between -15 to -24 metres (7 - 13 fm.).
In the Gulf area, it is believed that evidence for that period is provided
by the work of Houbolt (1957); his submarine terrace, or as he called it,
the "near-shore terrace" at a depth of-5.5 to_16.5 metres (3 - 9 fm.) fits
in the depth range suggested by Fairbridge's curve (1961). Another example
is also suggested by Kassler (1973), who suggested a submarine platform
at -18 metres.

During the last 6,000 years, the sea-level has fluctuated above and
below the present level, and several points of views have been presented

concerning this period (p.259). According to Fairbridge (1961), the highest recorded level of the sea in most places was about 3-5 metres (10-15) feet) above the present (older Peron Terrace, Australia), although he indicated that a higher figure could be obtained as a result of isostatic rebound, geodetic, tidal and other features. It is possible that the lowest terraces in the research area, which extend between Mudairah and Al-Bahra, and which have ages between 4,570 ± 70 and 3,560 ± 60 years B.P. corresponded to this high stage of sea-level. The difference in heights, which range from a maximum of 14.43 ± 1 metres in the middle of Al-Baha to a minimum level of 5.99 ± 1 metre east of Al-Bahra, is presumably related to tectonic movements in and around the research area.

Arguments have been presented in Chapter 2 about the various points of view relating to the structural stability of the Gulf, and Sarnthein (1972), Kassler (1973) as well as Larsen (1975) have particularly emphasised that the area at the head of the Gulf has generally been structurally stable during the last 6,000 years. In the light of this evidence, it is possible that the period of deposition which occurred in the Mesopotamia area between 4,000 and 3,000 B.C. (about 6,000 - 5,000 B.P.) is in general accord with the world-wide sea-level fluctuation of the Holocene. Accordingly, it is possible that the positive movements of sea-level to near its present level or higher, correspond to the period of river deposition during the period 4,000 - 3,000 B.C., postulated by Woolley (1938), Lloyd (1943) and Lees and Falcon (1952). The minor erosional events and later deposition referred to by Lees and Falcon (1952) correspond to minor fluctuations of sea-level, while the main erosional event, which is probably Post-Sassanian and produced the Dar-i-Khazineh evidence, has resulted from a world-wide dropping of the sea to attain its present level.

If during the Holocene general structural stability prevailed in the northern part of the Gulf in particular, and the whole Gulf in general, then

the great variation in height found among the lower terraces may indicate local movements, possibly due to Bahra anticline activity, although this question requires further investigation, both in the research area and surrounding zones.

Other dated evidence from the Gulf comes from Abu Dhabi, where a detailed stratigraphic sequence indicates marine transgression from 7,000 to 4,000 B.P. (Evans et al. 1969), while Taylor and Illing (1969) reported 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 ± 180 years B.P. However, these dated evidences, although indicating high stages of sea-level, can not be applied to any specific period of high sea-level until further research is carried out.

Evidence of undated marine transgression in the Gulf (see Chapter 2), (except for one sample from the southern coast of Kuwait), can be related to terraces in the research area or to younger stages, ranging in height from between 1.5 to 6 metres above sea-level. These features extend along the Arabian coast of the Gulf from Kuwait as far as Oman. Along the coast of Kuwait, Recent marine deposits containing shell fragments, similar to those found on the present beach have been found by the author in Al-Sha'aib and Al-Dhba'iyyah areas on the southern coast. A dated sample of shells which come from Al-Dhba'iyyah at a height of about 5 metres above K.D., gave an age of 940 ± 80 B.P., but further investigation is necessary due to the possibility of contamination. Milton (1967) referred to these marine terrace deposits, as did Khalaf (1969) who has identified a recent marine terrace with a thickness of up to 4 metres at Ras Ashairij and at Al-Khiran. Perry and Al-Refai (1957) indicated that oolitic sandstone found at Ras Al-Jlay'ah at a height of about 6 metres above sea-level, extends into the coast of Saudi Arabia, which they believe, suggests eustatic lowering of shorelines. Evidence of sea-level recession of 1.5 to 3 metres on the coast of Al-Hasa in Saudi Arabia was mentioned by Cornwall (1946), and included

the abandonment of old settlements to more recent settlements on the Gulf coast. In 1960 Holm reported the occurrence of undisturbed shell beds at heights of 1.5 to 2 metres above sea-level, and which extend from Ras al-Mish'ab to Salwah, and similar occurrences along the Trucial coast (coast of the United Arab Emirates). This level may also, as Holm (1960) suggested, correspond to the level which Cornwall (1946) had in mind when he referred to the 1.5 to 2 metre recession of sea-level. Powers et.al (1966) referred to marine terraces of 1 - 3 metres in height along Saudi Arabia, but considered them to be of Pleistocene marine transgression.

Evidence of lower sea-levels in the Gulf during the last 6,000 years, which can be correlated with Fairbridge's scale of 1961, may be found in the recent data provided by Larsen (1975). According to Fairbridge (1961) the sea level fall to -4 metres (Bahama emergence) occurred between 4,600 - 4,000 B.P. and is evidenced by buried peat-drowned forests and submarine platforms. Larsen (1975) referred to two submarine platforms at -5 and -3 metres, which are found in the deltiac area north of the Gulf. Both levels appear to cut into marine and perhaps estuarine clay or silt of Hammar formation. The -3 metres submarine platform has also been observed by Larsen off Bahrain.

In conclusion, the methods applied in this research to study the changes of sea-level along the north coast of Kuwait Bay, specifically in the area from Kathma in the west to Al-Bahra in the east, have in general contributed to reveal the processes involved in shaping the present landscapes. The changes of sea-level in the area have been the result of changes of water volume in the Gulf basin as a result of glaciation and deglaciation; they have also occurred because of local and regional tectonic movements in the research area and surrounding regions. The results of sediment investigation have also indicated that fluvial

processes have played a significant part in the area. The levelling of the terraces indicates that as well as height variation existing from one area to another, there is a general tendency for the terrace heights to decrease from west to east. Sediment investigations in the area have shown that there are three depositional environments, fluvial, aeolian and beach environments. The lateral continuity of the terraces from one area to another is not always possible or easily distinguishable, and the height variations create a problem of correlation. Radiocarbon dating of shells has made it possible to make a tentative correlation for the lowest but not for the highest terraces. However, the C14 dating of the limited number of shell samples (five) for the higher terraces, gave an age range between > 42,950 and 23,300 ± 600 years B.P., which suggests that these terraces are probably not younger than Pleistocene in age. The results from the seven dated shell samples which were collected from the extreme lowest terrace, found in Al-Bahra and Mudairah, gave an age range between 4,570 ± 70 years and 3,560 ± 600 years B.P., suggesting their formation in the Holocene period

A tentative correlation between the results of the present research and those from the Arabian Gulf has been presented. The available results from the present area of research and from different parts of the Arabian Gulf indicate that, during the last 7,000 years, the sea-level has fluctuated above and below the present level. However, these recorded values do not only include eustatic changes of sea-level, which have been recorded from different parts of the world, but local tectonic movements may have been included in the recorded values. The absolute value of the eustatic changes can not yet be decided at present. The lack of sufficient data for the interpretation has been particularly felt, especially when correlating features older than those of the Holocene. However, the evidence becomes more positive for the Post-glacial transgression, and hence the interpretation, although not completed, is more easily understood.

Although necessarily tentative, the conclusions put forward have been reached with some degree of confidence. There is, of course, no simple descriptive explanation which can as yet be given, which clearly differentiates between isostatic, eustatic or a simple climatic variation, but it is hoped that the complex hypothesis arrived at in this work will encourage further research and will stimulate interest in the study of the Quaternary problems in this region. It is further hoped that the results of this research will draw the attention of the authorities in Kuwait to the need to slow down the demolition of the natural environment of the coastal areas of Kuwait, with all its evidence of the genetic history of the country. This destruction, through the demolition of terraces, earth and beach movement and building, has already affected much of the southern coast, and it is hoped that scientific studies can be urgently organised before it becomes impossible to carry out further investigations of the type presented here.

It is perhaps of satisfaction, at least to the author, that the present rebuilding of the coast which is going on in the south, has not yet penetrated to the present area of research.

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APPENDIX

APPENDIX

Particle Size Analysis

a. Coarse Analysis

Scope

This method covers the quantitative determination of the particle size distribution in a soil down to the fine sand size.

Equipment

1. British standard sieves as follows:- $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$, 8, 14, 25, 36, 52, 72, 100, 150, 200, 240 and a receiver.

2. A balance readable and accurate to 0.001 gram.

3. A thermostatically controlled drying oven, capable of maintaining a temperature of 105 to 110°C.

4. Evaporating dishes of about 6 inches in diameter.

5. Metal trays or similar.

6. Sieve brushes.

7. Riffle.

8. Mechanical sieve shaker.

9. Sodium hexametaphosphate (Calgon).

10. Large wide necked bottles with capacities of about 2 litres.

Procedure

Samples brought for mechanical analysis were either collected dry from the inland or near the sea side. The latter were put into the oven to dry.

From these samples, sub-samples of 500 grams are obtained by riffling and placed in a wide necked bottle. A solution of sodium hexametaphosphate is added (about 20 ml) and the sample topped up to 2 litres with distilled water. The soil and water mixture is

then stirred and left to stand overnight to aid dispersion.

The sample is then washed through a No. 8 and 240 sieve and the finer material allowed to run to waste. Care must be taken not to overload No. 240 sieve with sediment.

Washing is continued until the water passing No. 240 sieve is clear. The material remaining on the sieves is carefully washed into the evaporating dishes and dried in the oven. When dry, the material is weighed and dry sieved for 15 minutes through the full range of sieves on a mechanical shaker.

Calculations

The amounts retained on each sieve are weighed and recorded. The percentage weight of the material on each sieve is calculated and the percent weight of the material passing the No. 240 sieve shall be obtained by difference.

The cumulative percentage (by weight of the total sample) passing each sieve is then calculated.

b.   Fine Analysis by Pipette Method   (Fig. 46)

Scope

This method covers the quantitative determination of the particle size distribution in a soil from the coarse sand size down.

Equipment

1.   A sampling pipette fitted with a pressure and suction inlet, and having a capacity of approximately 10 ml is so arranged that it can be inserted to a fixed depth into a sedimentation tube when the latter is immersed in a constant temperature bath.

2.   Six glass sedimentation tubes, 5 cm (2 in) in diameter and of approximately 34 cm (13 in) long graduated at 500 ml volume, with rubber bungs to fit.

3.   18 glass weighing bottles (seven for each sediment sample) of approximately 25 mm (1 in) in diameter and 50 mm (2 in) high. The weight of the bottles should be known to the nearest 0.001 gram.

4.   A constant temperature bath capable of being maintained at 25°C to an accuracy of ± 0.1 deg C into which the sedimentation tube can be immersed up to 500 ml mark. The bath must not vibrate the sample.

5.   A suitable mechanical mixer.

6.   A thermostatically controlled drying oven, capable of maintaining a temperature of 105-110°C.

7.   A balance readable to 0.001 gram.

8.   A stop clock.

9.   6 evaporating dishes.

10.   A Buchner funnel about 10 cm in diameter.

11.   A fitter flask to take the Buchner funnel (about 500 ml).

12.   1 litre conical beaker.

13.   A 100 ml measuring cylinder.

14.   A wash bottle preferably plastic containing distilled water.

15.   Filter paper to fit the Buchner funnels.

16.   pH indicator paper.

17.   A length of glass rod about 6-8 inches (15-20 cm) long and fitted at one end with a rubber "policeman".

18.   A source of vacuum, e.g. an efficient filter pump.

19.   A length of rubber to fit vacuum pump and filter flask.

Reagents

The reagent should be of recognized analytical reagent.

1.   Hydrogen peroxide. A 20 volume solution.

2.   Hydrochloric acid N solution.

3.   Sodium hexametaphosphate solution.

Calibration and sampling pipette

The sampling pipette is thoroughly cleaned and dried and the nozzle immersed in distilled water. The tap B is closed and the tap E opened.

By means of a rubber tube attached to C, water is sucked up into the pipette until it rises above E. The tap E is closed, and the pipette removed from the water. Surplus water drawn up into the cavity above E is poured off through F into the small beaker.

The water contained in the pipette and tap E is discharged into a glass weighing bottle of known weight, and the weight determined. From this weight the internal volume (V_p ml) of the pipette and the tap can be calculated to the nearest 0.05 ml. Three determinations of the volume should be made and the average value taken.

Procedure

Pretreatment of sample

20 grams of soil are weighed to the nearest 0.001 g(Wa) and placed in the 1 litre conical beaker. 50 ml of distilled water are added and the soil suspension gently boiled until the volume is reduced to about 40 ml. After cooling, 75 ml of hydrogen peroxide are added and the mixture allowed to stand overnight (this procedure applies only to samples containing organic matter). The suspension is gently heated and care must be taken to avoid frothing over and the contents of the beaker should be agitated frequently. As soon as vigorous frothing has subsided the volume should be reduced to about 30 ml by boiling.

In the case of soils containing calcium compounds the mixture should be allowed to cool and 10 ml of hydrochloric acid added.

The solution is stirred with a glass rod for a few minutes and allowed to stand for 1 hour. After 1 hour the pH of the suspension shall be checked with the indicator paper. If the pH is more than 5.0, further 10 ml of acid should be added, followed by stirring and standing until the pH remains below 5.0.

The mixture after pretreatment is filtered using the Buchner funnel. The damp soil on the filter paper and funnel shall be transferred without any loss to the evaporating dish (weighed to 0.001 g) using a jet of distilled water. The dish and contents are placed in the oven and dried at 105-110°C. They are then weighed to 0.001 g and the weight of soil remaining after pretreatment is recorded (Wb).

Dispersion of Soil

25 ml of the sodium hexametaphosphate solution are added from the pipette to the soil in the evaporating dish together with about 25 ml of distilled water and the soil brought into suspension by stirring with a glass rod. The mixture is warmed gently for 10 minutes and then transferred to the dispersion cup using a jet of distilled water. Dry soil adhering to the dish is rubbed off with the rubber policeman. The amount of water used should not exceed 150 ml. The soil suspension is then agitated for 15 minutes by means of the mechanical mixer.

The suspension is transferred to the No. 240 sieve placed on the receiver, and the soil washed on the sieve using a jet of distilled water from a wash-bottle. Particular care should be taken to wash off all traces of suspension adhering to the dispersion cup and baffle wires. The amount of distilled water used during this operation should not exceed 150 ml. The suspension

that has passed through the sieve is transferred to the graduated

sedimentation tube using a glass funnel and the volume of liquid

made up to 500 ml with distilled water.

Sedimentation

25 ml of sodium hexametaphosphate solution is transferred from

a pipette to a graduated 500 ml sedimentation tube and diluted with

distilled water to exactly 500 ml. This sedimentation tube,

together with the sedimentation tube containing the soil suspension,

is transferred to a constant temperature bath and the rubber bungs

inserted and allowed to stand up to the 500 ml graduation mark

until they have reached the temperature of the bath. They are then

thoroughly shaken by inverting several times and are replaced in

the bath.

At the same instant as the tube containing the soil suspension

is replaced in the bath, the stop watch or clock is started. The

rubber bungs shall be removed carefully and laid lightly on the

top of each tube.

The pipette with the tap E closed is lowered vertically into

the soil suspension until the end is 100 $\pm$ 1 mm below the surface

of the solution. It must be lowered with great care some 15 seconds

before the sample is due to be taken. Approximately 10 seconds

is taken to complete this operation.

The tap E is opened and a sample (V_p ml) drawn up into the

pipette. The pipette and base in the tap E is filled with the

solution and tap E then closed. This sampling operation will take

10 seconds to complete. This procedure shall be carried out at

the following times. 4 min 5 sec, 46 min, and 6 hours 56 min.
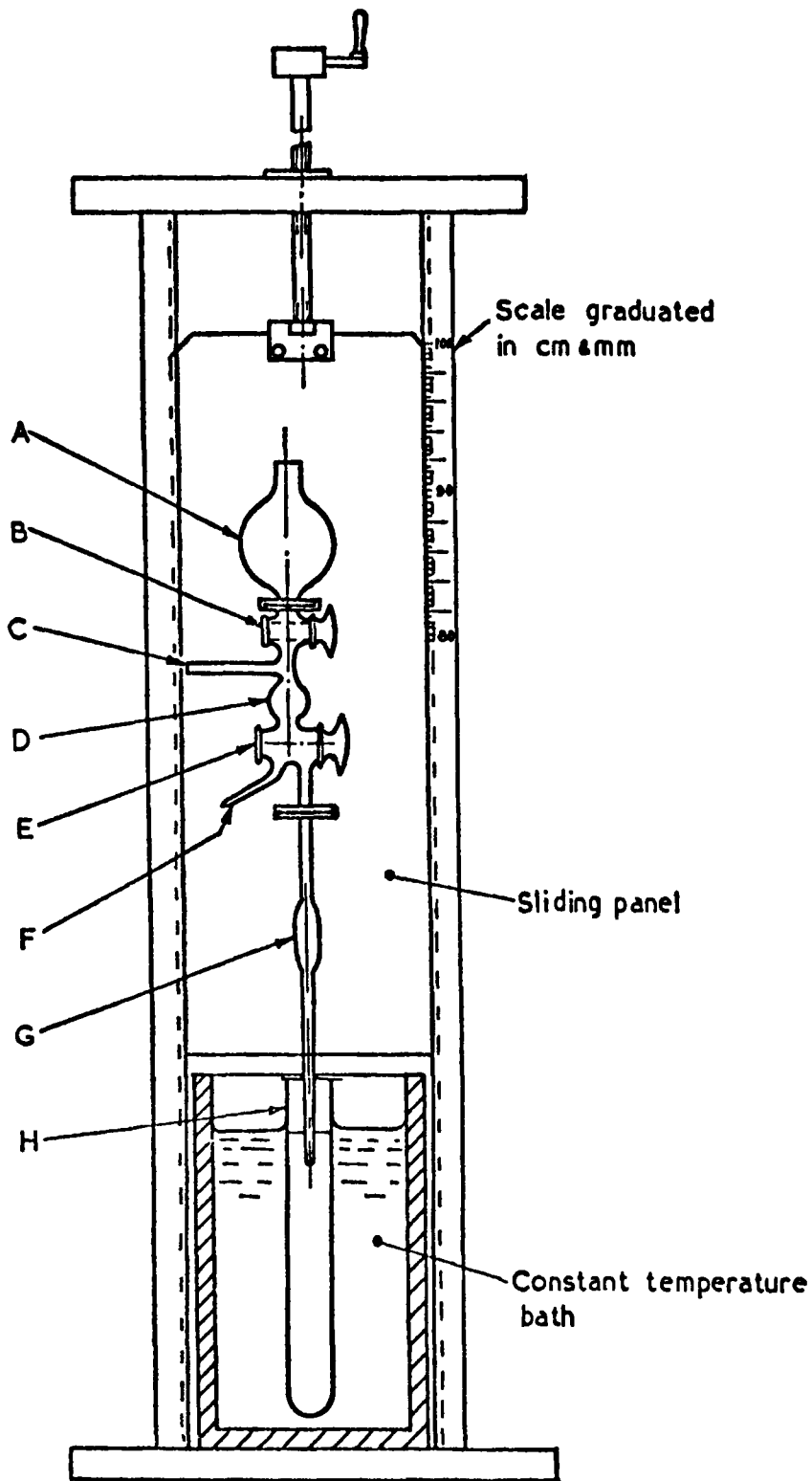
A & B. 125 ml bulb funnel with stopcock.
C. Safety bulb suction inlet tube.
D. Safety bulb.
F. Outlet tube.
G. Sampling pipette.
H. Sedimentation tube.
D, F & G are joined to three-way stopcock E.

Fig. (46) Diagram showing an arrangement for lowering the sampling pipette into the soil suspension

From British Standard No. 1377 (1967)

During the sampling a small amount of the suspension may have been drawn up into the bulb D above the base of the tap E. This surplus is washed away into the beaker down the outlet tube F by opening the tap E in such a way as to connect D and F. Distilled water is then allowed to run from the bulb funnel A into D and out through F until no solution remains in the system.

A tared weighing bottle shall be placed under the end of the pipette and the tap E opened so that the contents of the pipette are delivered into the bottle. Any suspension left on the inner walls of the pipette is washed into the weighing bottle by allowing distilled water from bulb A to run through B, D and E into the pipette. The weighing bottle and contents are placed in the oven maintained at a temperature of 105-110°C and the sample evaporated to dryness. After cooling in a desiccator the weighing bottle and contents are weighed to the nearest 0.001 gram and the weight of the solid material in the sample determined (W_1, W_2 and W_3 for each respective sampling time).

Between any of the times in which the above sampling is taking place a sample (V_p ml) is taken from the tube containing the sodium hexametaphosphate solution. The weight of solid material in the sample shall be determined (W_4).

Calculations

Loss in pretreatment

The percentage loss in pretreatment (p) is calculated from the weight of air-dried soil used (W_a) and the weight of the soil after pretreatment (W_b) from the formula:

$$p = 100 - \frac{W_b (100)}{W_a} \text{ percent}$$

The weight of the pretreated soil (W_b) is used to calculate the percentage below.

Sedimentation

The weight of the solid material in 500 ml of suspension for each respective sampling time is calculated from the fomula:

$$M_1 \text{ or } M_2 \text{ or } M_2 \text{ or } M_4 = \frac{W_1 \text{ or } W_2 \text{ or } W_3 \text{ or } W_4}{V_p} \times 500 \text{ g}$$

Where M_1 = weight of material in 500 ml from the first sampling

M_2 = weight of material in 500 ml from the second sampling

M_3 = weight of material in 500 ml from the third sampling

M_4 = weight of sodium hexametaphosphate in 500 ml

V_p = calibrated volume of the pipette in ml

The percentage of medium silt in the original sample is calculated from the following formula:

$$\text{Medium silt} = \frac{M_1 - M_2}{W_b} \times 100$$

The percentage of fine silt in the original sample is calculated from the following formula:

$$\text{Fine silt} = \frac{M_2 - M_3}{W_b} \times 100$$

Where W_b = weight of pretreated soil.

The percentage of clay in the original sample is calculated from the following formula:

$$\text{Clay} \quad \frac{M_3 - M_4}{W_b} \times 100$$

The percentage of coarse silt in the original sample is obtained by graphical interpretation.

The percentage obtained is expressed as cumulative percentage of the total sample.