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Heavy Minerals and Metals Content of Coastal Sediments between Dibba and Kalba, Eastern Coast (U.A.E.).

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HEAVY MINERALS AND METALS CONTENT OF COASTAL SEDIMENTS BETWEEN DIBBA AND KALBA, EASTERN COAST, (U.A.E.).

BY

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Faculty of Science
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Abstract

The present project deals with the study of coastal sediments along the Eastern Coast of United Arab Emirates (U.A.E.), and it has two main objectives:

1. Determination of heavy mineral contents of the coastal sediments in relation to the geology of the hinterlands.

2. Trace metals studies (Zn, Pb, Ni, Cr, Cu, Co, Cd, Mn and organic carbon) as a measure of environmental pollution.

The results of heavy minerals separation (fine sand fraction) from the Eastern Coast sediments reflect that these sediments are generally rich in heavy minerals content with percentages reaching up to 78% with some areas reaching upto 98%. The opaque minerals are mainly represented by ilmenite, chromite, and magnetite, where the gabbroic and ultramafic rocks are the main rocks exposed within the drainage basins. Three areas with high concentrations of heavy minerals are delineated. These areas are located at the mouth of the main wadies (Wadi Ham, Wadi Thayb, and Wadi Ash Shamah), and to the north of the main headlands at the shoreline maximum curvature (inflection points).

The concentration of trace metals were determined in the fine sand fraction of the coastal sediments. The samples were collected in October 1992, and after March 1994 oil spill.

The levels (μg/g) dry weight) of cadmium (9.01 times), cobalt (193.23 times), chromium (38.87 times), copper (4.7 times), Mn (272.8 times), Ni (322.7 times), Pb (6.7 times) and Zn (5.6 times) where higher than their levels prior to the oil spill occurence. The increase in the levels of some trace metals could be explained in terms of heavy navigation traffic in the area.

Comparing the data obtained here after three months from the spill time to other published data in sediments collected from Saudi Arabia one year after the Gulf war oil spill one can safely conclude that the environmental impacts of the spilted oil on the east coast had minor effects in terms of trace metals levels and organic materials and the marine environment of UAE is returning back to its normal condition.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

The present project deals with the study of coastal sediments along the eastern coast of the United Arab Emirates. It has two main objectives:

1. Determination of heavy mineral content of the coastal sediments in relation to the geology of the hinterlands.

2. Trace metal studies (Zn, Pb, Ni, Cr, Cu, Co, Cd, Mn, and organic carbon) to unravel their environmental implications.

Coastal environments may be contaminated by trace metals and this may lead to deterioration of natural habitats by depleting ecologically sensitive species or by eliminating commercial species (Sadiq and Zaidi, 1985).

Trace elements in geological terms, can be defined as they occurring at level of 1000 ppm or less in the earth's crust. Based on densities they can be divided into two groups: 'heavy' (with densities greater than 5g/cm^{-3}) and 'light' (with densities less than 5 g/cm^{-3}) (Duffus, 1983).

Metals are widespread in the nature, their distribution is controlled by both geologic and biologic processes. Trace metals occur naturally as a result of normal geologic processes such as the weathering of rocks. Rocks and ores are dissolved by rain water, the dissolved materials are naturally transported to rivers, then to oceans and are precipitated as sediments (Amdur, et al., 1991). Some trace metals are considered as one of the main sources of metal toxicity in the environment. Most of the organisms are not adapted to deal with them if they occur at high concentrations (Duffus, 1983).

The biologic cycles include bioconcentration by plants and animals as they are incorporated into food cycles (Amdur, et al., 1991) of metals. Humans release more of the metals by burning fossil fuels, mining, smelting, discharging industrial, agricultural and domestic wastes. These metals are not usually removed rapidly and so they accumulate (Duffus, 1983). Therefore, the environment might be contaminated with trace metals gathered from both natural resources and human activities. There has been an increasing potential for metallic poisoning; today the danger is greater than ever before (Marquis, 1989).

Studies of heavy metals in ecosystems have indicated that in many areas near urban complexes, metalliferous mines or major road systems there are anomalously high concentration of these elements. Some recognition must be given to the fact that some metals such as chromium and lead are toxic even when found in trace amounts (Forstner & Wittman, 1981).

Placer deposits can be defined as detrital sediments with potentially economic concentration of valuable heavy minerals concentrated by hydraulic processes. They can be classified into three genetic categories. Fluvial, estuarine and beach deposits. Fluvial and beach deposits are found in modern depositional environments and in ancient beaches, in stream channels and estuaries extending onto the continental shelf. Deposits of each environment composed of one or more mineral species in various concentrations. In the coastal environment, the beach is the usual site for the deposition of heavy minerals (Teleki et al., 1987.

1.1. Location of the study area

The United Arab Emirates is located in the eastern part of the Arabian Peninsula and includes the northern part of folded and thrust foreland of the Oman Mountains.

The area under consideration lies along the Eastern Coast of U.A.E. in the Gulf of Oman and extending from Dibba town to Kalba town (Fig. 1). It is bordered to the west by the late Cretaceous Semail Ophioliotic nappes (Glennie, et al., 1974).

The climate in the area is typical of the high arid tropical zone. In such climatic conditions evaporation (1460 mm/yr) exceeds total precipitation (100 mm/yr.). The salinity of the shallow coastal water (42 - 50%) is highly variable and strongly influenced by the weather conditions particularly winds. Offshore water temperature ranges from 18-32^{o}C. The tides are sedidiurnal but their heights differ considerably. Tidal and win-driven currents and waves are locally strong (Abu-Hilal & Khordagui, 1992).

1.2. General Geology

The first description of the area was by Pilgrim during his exploratory trips to the Arabian Gulf in 1904/1905 and an account of his visit to the mountainous area between Dibba and Ras Al Khaimah was published in 1908.

A more detailed account on the geology of the mountains range is given by Lees (1928). He was the first to recognize and describe the Hawasina metamorphic complete and the Semail igneous series and to suggest the tectonic emplacement of these two major units as nappes transported from the east. Lees (op.cit) considered that the sediments of the Rus al Jibal Massif formed highly sheared zone adjacent to the more intensely thrust zone lying North of the Batinah Coast of Oman, south east of the U.A.E. border.

During the 1950's (Hudson et al., 1954) contributed to our knowledge on the northern mountains in Jabel Hagab area; in the area around Jebel Qamar, and of the Jurassic Cretaceous Musandam Limestone Group.

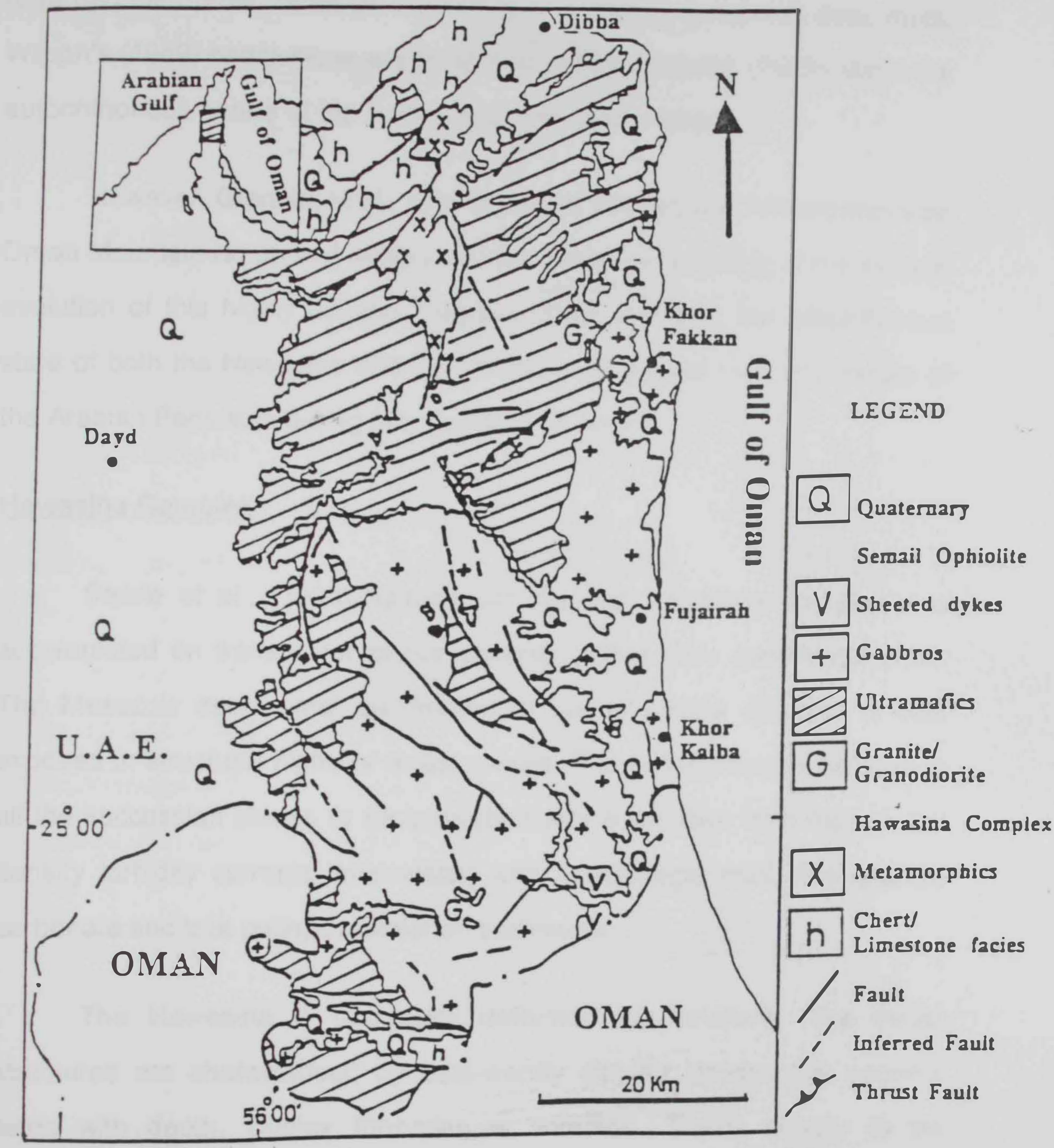


Fig.1. A Simplified Geological Map of the Northern Emirates Mountains (Modified after Hunting, 1979).

The Hawasina and Semail units are considered autochthonous by Morton (1959). He described a concordant contact between both units but mentioned "slightly sheared" to a degree not elevated to real thrusting. He regarded the Semail series as consisting of extrusive rocks with deep roots. Wilson's (1969) conclusions are in agreement with Morton (1959) about the autochthonous nature of the Semail and Hawasina rocks.

However, Glennie, et al., (1974) carried out detailed investigations on Oman Mountain range and greatly clarified the understanding of the tectonic evolution of this highly complex region. They stressed the allochthorous state of both the Hawasina and Semail rocks emplaced over the margin of the Arabian Peninsula during late Cretaceous time.

Hawasina Complex

Searle et al., (1980) pointed out that the Hawasina complex was accumulated on transitional and/or oceanic, rather than continental crust. The Mesozoic deep water succession of the Hawasina complex is now exposed in structural highs or thrust sheets. The sedimentary structures in all the succession seems to be consistent with deposition from high to low density turbidity currents, interrelated with hemipelagic mud, fine grained carbonate and true pelagic radiolarian sediments.

The Hawasina is complexly deformed by thrusting. The thrust structures are characterised by east-wardly dipping thrusts that become listric with depth. Duplex formation is common. These appear to be hinterland (eastern) dipping systems, re-thrust due to the effects of a possible oblique component of convergence.

Semail Ophiolite:

The Semail Ophiolite is one of the most extensive and well-exposed ophiolite belts in the world. It is located in the northern part of Oman Mountains, in the United Arab Emirates. Sixty percent of the mountainous area of the U.A.E. is covered by this extensive unit which includes a variety of rock types ranging from ultramafic to mafic layered sequence.

On a regional scale, the Semail rocks constitute a layered sequence which ranges from ultra mafic rocks at the base, through gabbros to sheeted diabases. The uppermost unit consists of basic volcanies. The most complete sequence occurs south of Wadi Ham where ultramafic rocks, or their serpentinised equivalents, form the foothills west of the mountains. The higher units cropout further east, culminating in Sheeted Diabase and Volcanic complex near the east coast south southwest of Khawr Kalba.

Rocks of the Semail Suite show relatively minor internal deformation. The rock assemblage and basal contact with sheared and contorted rocks of the Hawasina Series indicate that the Semail Suite is allochthonous and was emplaced as a fairly coherent slab.

The modern interpretation of these ophiolite sequences is that they represent segments of oceanic crust that has been thrust (obducted) onto the margin of the Arabian Block. (Glennie et al., 1974).

Volcanics:

This unit forms a small outcrop surrounded by Sheeted Diabase south southwest of Khawr Kalba. It consists of red, green and grey basaltic rocks with amygdales and crude pillow structure. The unit is too small in outcrop area to be recognised from the aerial photography. The volcanics are better developed to the south, in Oman.

Sheeted Diabase:

This consists of swarms of sub-parallel vertical dykes. A great variety of lithologies are represented; coarse and fine grained diabase, hornblende diabase and leucocratic porphyrite are the most common varieties. Sharp, often co-linear greenish to brown or generally dark toned ridge crests emphasize the strong north to northnortheast trend of the unit.

Gabbros and Gabbro/Ultramafics:

It is impossible to separate completely these two units photogeologically because they contain broadly similar lithologies and therefore show similar styles of weathering and photocharacteristics.

South of Wadi Ham Line the two units from most of the central and eastern zone of the mountains. In general terms outcrops of gabbroic/ultramafic and ultramafic rocks diminish in size and importance within the Gabbro Unit towards the east. North of Wadi Ham relationships are similar but the outcrop patterns are less complicated. In this area gabbros form the eastern part of the mountain range and are underlain by mixed gabbroic/ultramafic rocks and ultramafic.

The gabbro unit consists of medium to coarse grained leucocratic to melanocratic anorthositic, augitic, olivine and hypersthene gabbros. Pegmatic, agmatic and altered gabbro zones are common. South of Wadi Ham, that is in the inferred higher part of the Gabbro unit, diabases, gabbroic diorites, hornblende diorites and quartz-diorites occur. These latter rocks form darker more rounded outcrops near the coast.

The Gabbro ultramafic unit is broadly similar in photocharacteristics to the Gabbro unit but contains larger proportions of material recognised as ultrabasic in character. South west of KhawrFakkan the unit forms slightly sharper crested hills than the gabbro to the east and is locally lighter toned than the gabbros. The serpentintes , further west, are much darker toned and have even sharper crested hills. In the field the Gabbro unit contains pods, lenses and layers of peridotite and serpentinite.

The Ultramafic rocks consist of peridotites, dunites, serpentinised peridotites, and serpentinites. The general distribution of the unit sugge that it underlies the Gabbro and Gabbro/Ultramafic units. Instrusions of gabbro into the serpentinites have been noted. The lower contact of the Ultramafic Unit is with the sheared and contorted sediments and metamorphics of the Hawasina Series. Relatively isolated outcrops of serpentinized ultramafic rocks, form klippen and small thrust slices associated with the Hawasina Series, in the complex zone southwest of Dibba.

In general, the ultramafic rocks in the west are more highly serpentinized and tend to be more highly sheared. Net veining by magnesite and more rarely by chrysotile or antigorite is normal features;

angular pebbles and cobble sized fragments of peridotite or harder serpentinite occur in polished and slickensided envelopes of soften material. In its more easterly outcrops the Ultramafic Unit is more massive; in these areas shearing, net veining and intensive serpentinization are confined to rocks adjacent to fracture zones. Magnesite veins are normally larger in the more massive serpentinites and occur in zones of faulting or fracturing.

The thrust complexes are overlain by late tertiary to recent unconsolidated wadi fill areacesus sediments. Along the coast there is a narrow coastal plain consisting of areaceous beds of tertiary to recent age.

1.3. Geomorphology of the study area

The eastern coastal plain areas of the United Arab Emirates is bounded by variable groups of distinct cliffs that extend close to the shoreline. The cliffs in general have high topographic relief with steep slopes are found. by rocks of the igneous Semail ophiolite assemblage.

In the Northern sector of the study area (Ras Dibba to Dhadnah town), the cliffs that are composed mainly of peridotite and serpentinised peridotite rock types. On the other hand gabbroic types are the most common igneous rock forming the main cliffs that extend from Khor Fakhan to the southern sector of the study area (Fig. 2 a & b). The coast line is characterized by many headlands. A zone of maximum shoreline curvature occurs at a short distance to the north of these headlands.

North of KhorFakhan, severe weathering, particularly along the weak fracture zones has occurred resulting in the formation of wide valleys and flood plains covered by sheet flood sediments; as in the areas of S Dhadnah (Dhadnah town), Saih Wadi Azer (Bedia town) and Saih Al-Khor (Khorfakhan town). Gravel and very coarse clastics are common and dominate the coastal plain from Dadnah to Ras Dibba except for a few areas where remnants of sea cliffs still exist in the form of dome-like hills as in Ras Dibba area (Fig. 2).

South of KhorFakhan where the cliffs are lie further inland, tidal and marine erosion has formed a lagoonal coastal plain from Qadfak and Murbeh in the north to Khor Kalba in the souths). The coastal plain characterized by very low topographic relief (maximum height 3m). The wide flat plain is, generally covered with lagoonal and sabkha deposits (Fig.

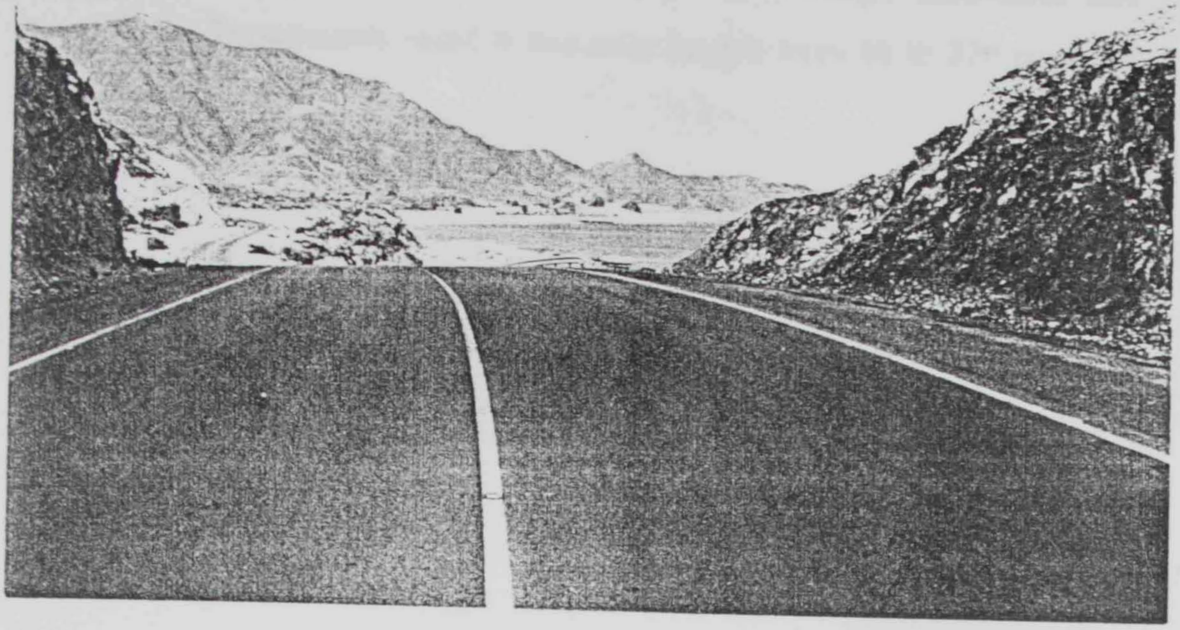


Fig. 2a. Narrow beach, sea cliffs and ultramafic rocks bordering the beach near Sharm village.

Fig. 2b. Gravelly beach near sharm village.

3) However, a very narrow coastal strip gabbroic cliffs a wave-cut bench, forming the eastern parts of Al-Ras and KhorFakhan mountains has developed. Topographic relief in this strip ranges from 90 to 220 m above sea level.

Fig. 3. The beach north of Khorfakkan port covered with lagoonal and Sabkha deposits.

CHAPTER 2

GRAIN SIZE ANALYSIS

2. GRAIN SIZE ANALYSIS

2.1. Introduction

Grain size analysis is one technique that has been widely used in the interpretation of the different ancient sedimentary environments. The technique provides a tool that can be used to differentiate between the various recent sedimentary environments such as beach, dune, aeolian and other deposits.

Uden (1914) noticed that there was a relationship between the grain size and the type of sediment. Krumbein (1934) and Otto (1939) placed stress upon the interpretation of the results of grain size analysis but Keller (1967) was the first who used grain size analysis to distinguish between beach and dune sands.

The relationship between grain size and ancient environments has been discussed by Shepard and Young (1961); Visher (1965) and Solohub and Klovan (1970). Other workers have contributed to the relation between the statistical parameters calculated from grain size distribution in different environments of deposition (Otto, Op. Cit.; Inman, 1952; Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1961 and 1967).

As this work is concerned with recent beach sediments, grain size analysis data will be used to throw light on the factors involved in the deposition of the studied sediments. For this purpose, samples are subjected to grain size analysis; and statistical parameters calculated from the cumulative curves.

It is worth mentioning that Abu-Hilal and Khordagui (1992) studied grain size distribution in the studied area but did not present any interpretations of the depositional environments.

2.2. Materials and Methods

Samples were collected along the eastern coast of U.A.E. from Kalba at the south to Dibba at the north (Fig. 4) at approximately km intervals a field description of the sampling site is given in Appendix 1). The samples are collected randomly rather than selectively. They were scooped up from the top few cms using a plastic scoop (Fig. 5). The description of the sites (stations) where sample are collected is given in Appendix 1. A total of 33 samples were collected from different sites so as to cover the studied area. Samples were taken in duplicates from each site in a plastic bag. The samples then packed in crushed-ice and transported to the laboratory where they are stored at (-18°C). The samples were then air dried being ready for sieve analysis.

Sieving is accomplished for the dried samples using the complete set. Shaking for 15 minutes was found sufficient to produce a reliable separation of the particles (Griffthe, 1967). The fraction that retained on each sieve was weighed and recorded.

Textural classes

Folk (1959) constructed a triangular diagram in which a sedimentary nomenclature can be defined according to the gravel-sand-mud ratio.

El-Sayed and Al Bakri (1993) among many others used this diagram in defining the textural class of the sediments of the Kuwait coast. They gave a sandy-textural class for a great deal of the samples.

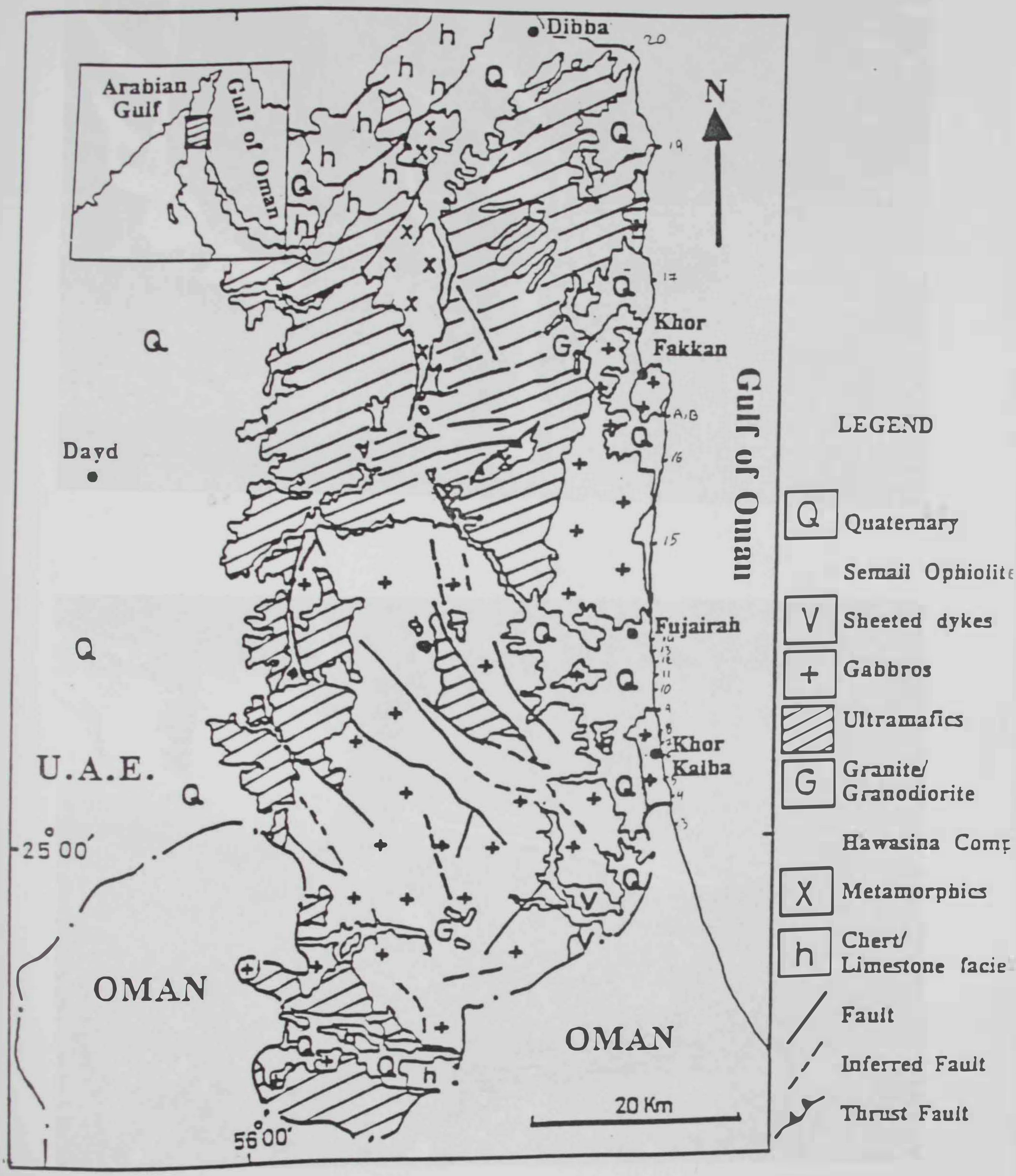


Fig. 4. A Simplified Geological Map of the Northern Emirates Mountains showing the locations of the studied samples.

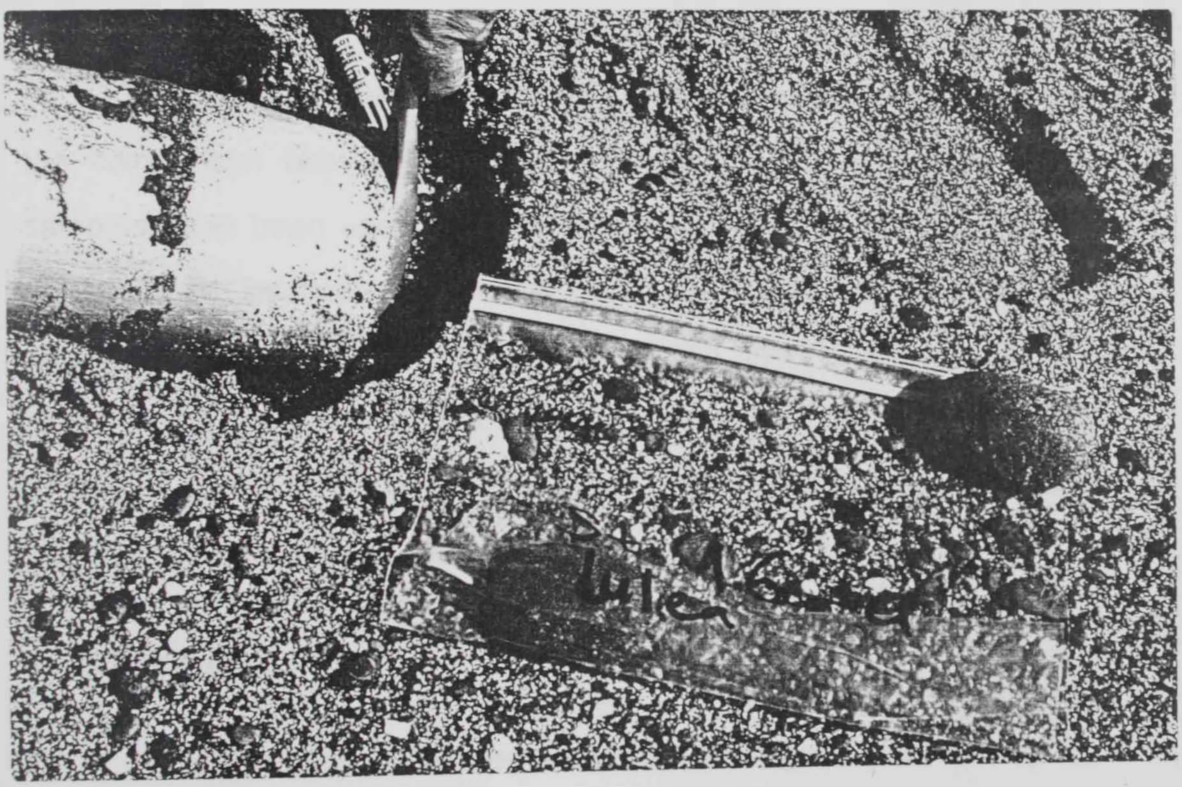


Fig. 5. Sampling of the top few Cms using a plastic scoop.

In the present work, Folk diagram is used to define the textural classes of the studied samples. From figure 6, it is clear that the samples lies mainly in the area of sand (18) and slightly gravelly sand (13) with two samples in the gravelly sand (Table 1 and Fig. 6).

Cumulative curves were constructed arithmetic probability paper using the (phi) (ϕ) scale (Krumbein, 1938) (Appendix 2). The following statistical parameters: graphic mean (Mz); inclusive graphic standard deviation (σ); inclusive skewness (Sk); and graphic kurtosis (KG), have been calculated from the cumulative curves using the formulae of Folk and Ward (1957). The following percentiles 5, 16, 25, 50, 75, 84 and 95, are listed in Table (3) while the results of the statistical analysis are given in Table (3).

The results of the four calculated statistical parameters in addition to the comparison between grain size distribution curves for the different samples have been used to decipher the source area contributing to the recent coast sediments and the dominant transporting agent. These parameters have been discussed in detail and used by many authors e.g. Trask (1932); Krumbein Otto (Op. Cit); Otto (1939); Folk and Ward (1957); Friedman (1961, and 1967); Al-Asfour (1982); El-Anbawy and Al-Aawah (1993) and Al-Sayed and Al-Bakri (1993).

1. Graphic mean (Mz)

The graphic mean (Mz) represents the average of size readings. Folk and Ward (1957) have suggested the following formulae for the calculation of the graphic mean.

Table 1: Percentages of Gravel, Sand, and Silt fractions

Sample No.	Gravel	Sand	Silt
1	11.26	86.29	2.42
2	3.27	91.92	4.79
3	2.80	92.84	5.78
4	-	99.97	0.30
5	-	99.98	0.20
6	-	99.94	0.60
7	-	99.88	0.11
8	9.72	83.31	6.88
9	-	99.99	-
10	-	99.67	0.08
11	-	99.99	-
12	-	99.99	0.02
13-A	0.21	99.78	-
13-B	-	99.98	0.01
13-E	0.11	99.86	0.01
14-A	-	99.24	0.40
14-C	-	99.94	0.05
15-A	-	99.85	0.14
15-B	0.1	99.81	0.09
15-C	0.18	99.60	-
16-A	3.38	96.29	-
16-C	3.69	99.19	-
17-A	0.67	83.37	0.12
17-B	1.64	99.90	0.20
17-C	-	99.88	0.90
17-D	0.13	99.99	-
18	-	99.99	-
19-B	-	99.99	-
20-B	2.94	97.05	-
21-A	2.70	97.28	-
21-C	-	99.45	0.53
A	-	99.99	-
B	-	99.99	-

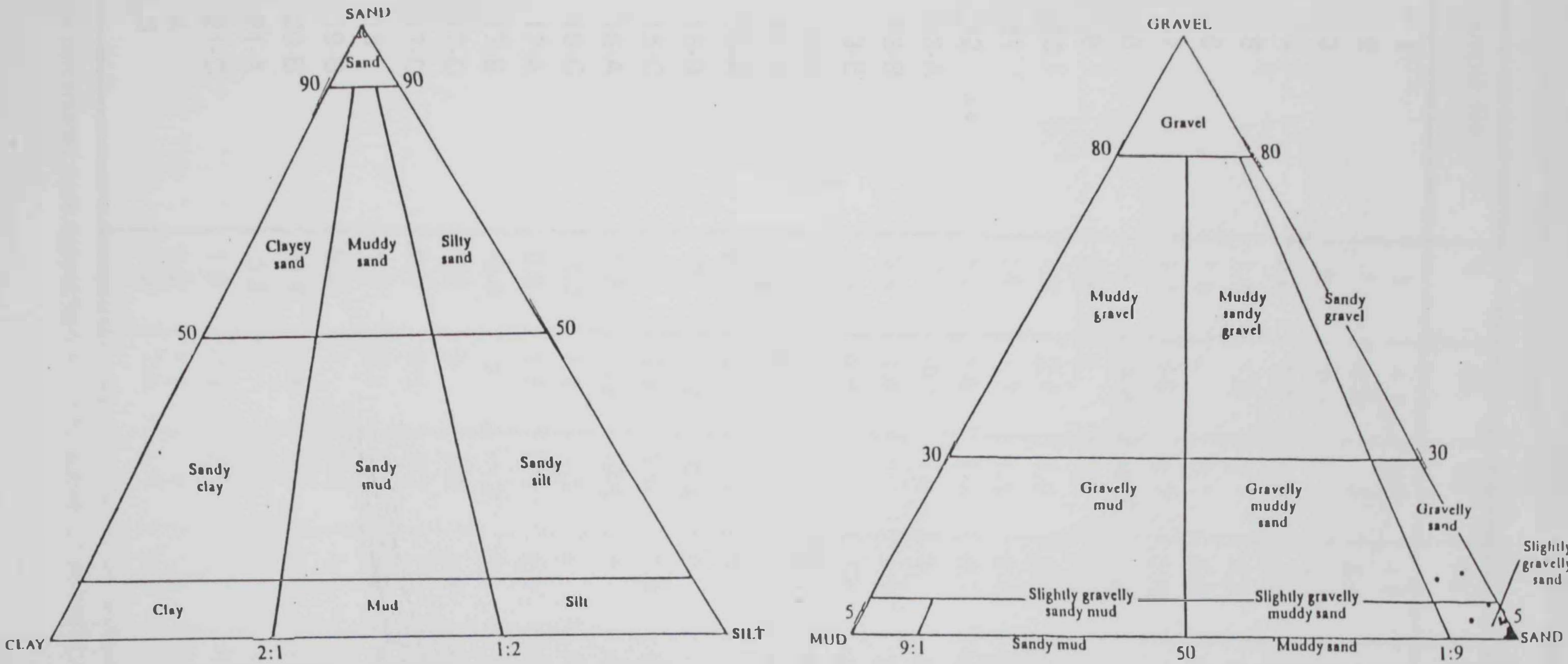


Fig. 6. Textural classification of the studied samples using Folk (1954) ternary diagram.

Table 2 The percentages used for the calculation of the statistical parameters (mean, standard deviation, skewness and kurtosis)*.

Sample No.	5	16	25	50	75	84	95
1	-3	-1.3	-0.5	0.9	1.9	2.3	3.2
2	-1	-0.4	1.3	2.4	3.1	3.4	4
3	-2.2	-0.3	1	2.3	3.1	3.4	4.2
4	1.6	1.9	2.1	2.4	2.7	2.9	3.3
5	1.4	1.8	2	2.3	2.7	2.9	3.3
6	1.8	2	2.1	2.4	2.8	2.9	3.4
7	2.3	2.6	2.7	2.8	3	3.1	3.4
8	-3	-0.6	-0.3	2.2	3	3.4	4.1
9	0.6	1	1.1	1.3	1.8	2.1	3.1
10	1.6	2.1	2.3	2.6	2.9	3	3.3
11	14	1.7	1.8	2.1	2.5	2.7	3
12	1.2	1.6	1.7	2.1	2.4	2.6	3.1
13-A	-0.7	-0.1	1.3	2	2.5	2.7	3.2
13-B	0.4	0.8	1	1.6	2.2	2.5	3.2
13-E	0.3	0.8	1.1	1.8	2.3	2.6	3.3
14-A	0.3	1.2	1.4	2.1	2.5	2.7	3.2
14-C	1.2	1.7	1.9	2.3	2.7	2.9	3.5
15-A	2.1	2.2	2.3	2.6	2.9	3.1	3.4
15-B	-3	-1.5	-0.8	0	1.3	2.2	3.2
15-C	0.1	0.9	1.6	2.9	2.7	2.9	3.2
16-A	1.7	-0.9	-0.6	0	0.5	0.5	1.3
16-C	-1.3	1.1	1.5	2	2.2	2.5	2.9
17-A	0.5	1.8	2.1	2.6	2.8	3	3.2
17-B	-3.5	-2	-1.2	0.1	1.7	2.7	3.2
17-C	1.2	2	2.2	2.6	2.9	3.1	3.5
17-D	0.1	0.5	0.7	1.1	1.5	1.7	2
18	1.7	2.1	2.2	2.6	2.8	2.9	3.2
19-B	0.7	1	1.2	1.7	2	2.1	2.4
20-B	-0.8	0.4	0.9	1.6	2.1	2.2	2.7
21-A	-0.8	1	1.4	2.1	2.4	2.6	2.8
21-C	1.9	2.3	2.5	2.8	3.1	3.3	3.6
A	0.8	1.2	1.4	1.8	2.2	2.4	2.7
B	0.9	1.4	1.7	2.1	2.4	1.1	1.9

* These percentages were derived from the cummulative curves shown in Appendix 2

Table 3 Results of statistical analysis calculated from cumulative curves.

Sample No.	MZ	SD	SK.1	KG.1
1	0.63	1.83	-0.24	1.05
2	1.80	1.70	-0.41	1.30
3	1.80	1.89	-0.40	1.24
4	2.40	0.51	0.03	1.16
5	2.30	0.56	0.07	1.11
6	2.40	0.46	0.18	0.93
7	2.80	0.29	0.14	1.50
8	1.66	2.07	-0.43	0.88
9	1.46	0.56	-0.44	1.46
10	2.50	1.36	-0.14	1.41
11	2.16	0.49	-0.20	0.93
12	2.10	0.53	0.02	1.11
13-A	1.53	1.29	-0.44	1.33
13-B	1.43	0.96	0.013	0.95
13-E	1.50	0.99	-0.09	1.024
14-A	2.00	0.81	-0.22	1.08
14-C	2.30	0.64	0.02	1.17
15-A	2.60	0.42	0.17	0.88
15-B	0.23	1.86	0.11	1.20
15-C	2.06	0.96	-0.49	1.40
16-A	0.23	0.73	-0.38	1.11
16-C	1.86	0.98	-0.42	2.50
17-A	2.40	0.70	-0.44	1.58
17-B	0.26	2.19	0.016	0.94
17-C	2.56	0.62	-0.15	1.346
17-D	1.10	0.58	-0.02	0.97
18	2.50	0.42	-0.22	1.02
19-B	1.60	0.53	-0.22	0.87
20-B	1.40	0.98	-0.35	1.95
21-A	1.90	0.94	-0.49	1.47
21-C	2.80	0.50	-0.02	1.16
A	1.80	0.58	-0.02	0.97
B	2.00	0.57	-0.23	1.17

$Mz = \phi 16 + \phi 50 + \phi 84/3$. whereas the ϕ 16 represents the average of the coarsest third of the sample, and ϕ 84 the average size of the finest third, while the ϕ 50 for the average value of the middle size third.

The present study gives mean values showing wide variation from (0.2 ϕ) to (2.8 ϕ), indicating that the sediments range between coarse gravel to medium sand and reflects the poor-sorting nature of the studied sediments. Nevertheless, the presence of about 50% of the samples having a range between 1 - 2 ϕ shows the dominance of coarse and medium sand sizes.

El-Anbawy and Al-Aawah (1993) in their study of the black beach sands at Yemen coast, they pointed out that the beach sands reflect a narrow range of mean size (1.5 - 2.4 ϕ) i.e. they are relatively medium to fine grained. On the other hand, the coastal sediments at Kuwaitstudied by El-Sayed and Al-Bakri (1993), show a wide regional distribution of mean size values ranging from 1 to 4 ϕ (coarse sand to fine silt) but with predominance of values between 1 to 2 ϕ (medium sand). However, according to Al-Asfour (1982), the north coast of Kuwait Bay has a mean size values ranging from 0.90 to 4 ϕ to 0.70 to 4 ϕ indicating the dominance of gravel perhaps of medium and small size.

2. Standard deviation (sorting σ_1)

The inclusive graphic standard deviation was proposed as a sorting measure by Folk and Ward (1957) who stated that the degree of sorting of a sample is essentially a measure of dispersion. Folk and Ward (Op. Ct.) gave the following formula:

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

In calculating the inclusive standard deviations they suggested the following scale to describe the sorting.

σ_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

The standard deviation values calculated for the studied samples shows wide range (0.29 - 2.1 ϕ) which indicate the existence of both well sorted and poorly sorted sediments.

The standard deviation of beach sediments of the Kuwait coast vary from (2.58 ϕ to 1.83 ϕ) indicating poorly to very poorly sorted (Al-Asfour, 1982) and (Al-Sayed and Al-Bakri, 1993). On the other hand, Yemen beach sands showed ranges from (0.25 ϕ to (1.31 ϕ) indicating variation from well sorted to moderately sorted.

The general characterization of sorting along with existence of some extremes, although minor, points to the fact that not only wave action was the mechanism by which our beach samples are deposited. Among a general distribution characterized by moderate sorting (Table 2).

This may be in accordance with the results obtained from the mean size (Mz). However, as Friedman (1978) in his classification of sands from various origins pointed out, most beach sands are very well sorted to well sorted. Both wave and wind action serve to capture and remove sediment particles and hence improve sorting by a winnowing action.

3. Skewness (Sk)

The deviation of the frequency curve from the symmetry of a normal distribution is expressed as skewness. If the mean and the median coincide in a symmetrical distribution, the skewness is zero. Folk and Ward (1957) developed a modification for the two formulae of skewness of Inman (1952), and combined them in one formulae called the Inclusive Graphic Skewness:

$$Sk = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 5o}{2(\phi 95 - \phi 5)}$$

The symmetrical curves have Sk = 0.00 the mathematical limits for skewness range from - 1.00 to + 1.00.

Folk and Ward (1957) have suggested the following verbal limits where the -ve values indicate "sample tailing" by coarser grains while the +ve values indicate "sample tailing" by finer grains.

Sk_1 from	- 1.0 to	0.3	very negatively skewed
	- 0.3 to	- 0.1	negative skewed
	- 0.1 to	+ 0.1	nearly symmetrical
	+ 0.1 to	+ 0.3	positively skewed
	+ 0.3 to	+ 1.0	very positive skewed

Value for the skewness obtained in the study area shows range from (0.49 ϕ) : very negative skewness to (0.44 ϕ) very positive skewness. This means that the studied samples could be classified into two groups; one with fine tail while the other with coarse tails. The percentage of the negatively skewed samples reach up to 72%. While the percentage of positively skewed ones make the rest. This means that the majority of the studied samples have tails of coarser material. This is considered to be matching with results obtained from the graphic mean (Mz).

The sediments of Kuwait coast revealed both negative and positive skewness values. (Al-Asfour, 1982). The positive skewness (0.2 ϕ) have been interpreted as due to the excess of the fine grains, while the negative values (- 0.2 ϕ) are due to the excess of coarse grains (El-Sayed and Al-Bakri, 1993). However, El-Anhawy and Al-Aawah (1993) in their study on Yemen coast regarded the skewness values they obtained as insignificant.

4. Kurtosis (K_G)

It is a measure of "peakness" in the Histograms and so is a measure of the relative sorting between sides and the central part of a cumulative frequency curve. It is considered to be a valuable test for the normality of the sample distribution. Folk and Ward (1957) developed a measure of graphic Kurtosis as follows:

$$K_G = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$$

The following verbal limits have been suggested by them (Folk and Ward 1957):

Under	0.67 -	Very platykurtic
	0.67 - 0.90	platykurtic
	0.90 - 1.11	mesokurtic
	1.11 - 1.50	leptokurtic
	1.50 - 3.00	very leptokurtic
	over 3.00	extremely leptokurtic

The values of the kurtosis obtained for the present study show a variation from a minimum value of (0.9 ϕ) i.e. mesokurtic to a maximum value of (1.3 ϕ)i.e. leptokurtic. The 67% of sample that gives meoskurtic reach up to 33%, while these of leptokurtic nature represent the rest for the leptokurtic. This means that the studied sample represent two populations i.e not subjected to good mixing as they are deposited in their new environment but kept their individual character (Friedman, 1967).

The Kurtosis values of the Kuwait Coast sediments are very platykurtic range between (0.55 - 0.57 ϕ) which means between sorting in the central part of the curves than their tails (Al-Asfour, 1982).

In addition, El-Sayed and Al-Bakri (1993) in their study on the same coast gave values of (1.58 ϕ) i.e. leptokurtic to (2.09 ϕ) i.e. very leptokurtic suggesting that these sediments consist of a predominent population.

2.3. Discussions and Conclusions

Many writers have contributed to our knowledge of different environments using grain size parameters, such as Mason and Folk, 1958; Friedman, 1961, and 1967; Moiola and Weiser, 1968; Solohub and Klovan, 1970; Moshrif, 1980; Al-Asfour, 1982; and El-Sayed and Al-Bakri, 1993. Mason and Folk (1958) and Friedman (Op. Cit.) in their investigations of modern sands, show that dune sands tend to be positively skewed, while beach sand are generally negatively skewed. Moreover, they point out that dune sands are better sorted than beach sands and, Friendman (Op. Cit.) stated that dune sands also tend to be better sorted than river sands. Moiola and Weiser (1968) stressed that a combination of size parameters was a sensitive and effective tool in distinguishing between beach, river and dune sands.

A scatter plot of size parameters have been used by Friedman (1961, 1967) to differentiate between river and beach sands and Moiola and Weiser (1968) provided scatter plots to distinguish between modern beach, dune and river sands.

In the present study six scatter plot diagrams have been constructed for the different size parameters to demonstrate the relationship between them and consequently giving information on the sediment which can be interpreted in terms of the effective transporting agent.

Discussion and the conclusions drawn were based mainly on interpretations by Friedman (1961, 1967) and Moiola and Wieser (1968) in the similar cases.

Six scatter plot diagrams are given for the studied samples in this work.

1. Mean size (Mz) versus standard deviation (σ_1)

(Fig. 7) demonstrates the relationship between Mean size (Mz) versus standard deviation In this figure Friedman (1967) distinguished three environments viz. river, dune and mixed river-dune sands. Plotting the (Fig. 7) shows that all of the samples except one are occupying the area pertaining to the mixed river-dune sands. Similarly, (Fig. 8) which represents the relation between the two parameters but constructed by (Moiola and Wieser, 1968) shows that the majority of the studied samples are occupying the river field.

2. Standard deviation(G) versus skewness (Sk)

(Fig. 9) demonstrates the scatter plot diagram of skewness versus standard deviation constructed by Friedman (1961) for distinguishing between beach and river sands.

The figure shows that the majority of the studied samples lie in the river field rather than in the beach field.

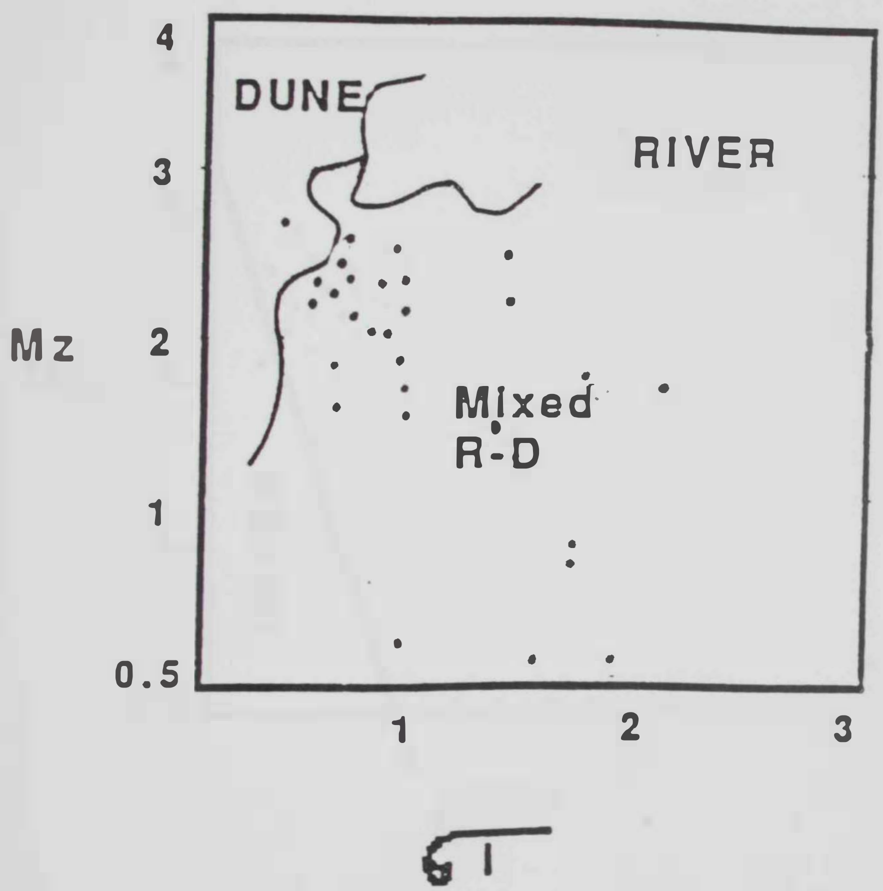


Fig. 7 . Scatter plot of standard deviation versus mean size (Friedman, 1967).

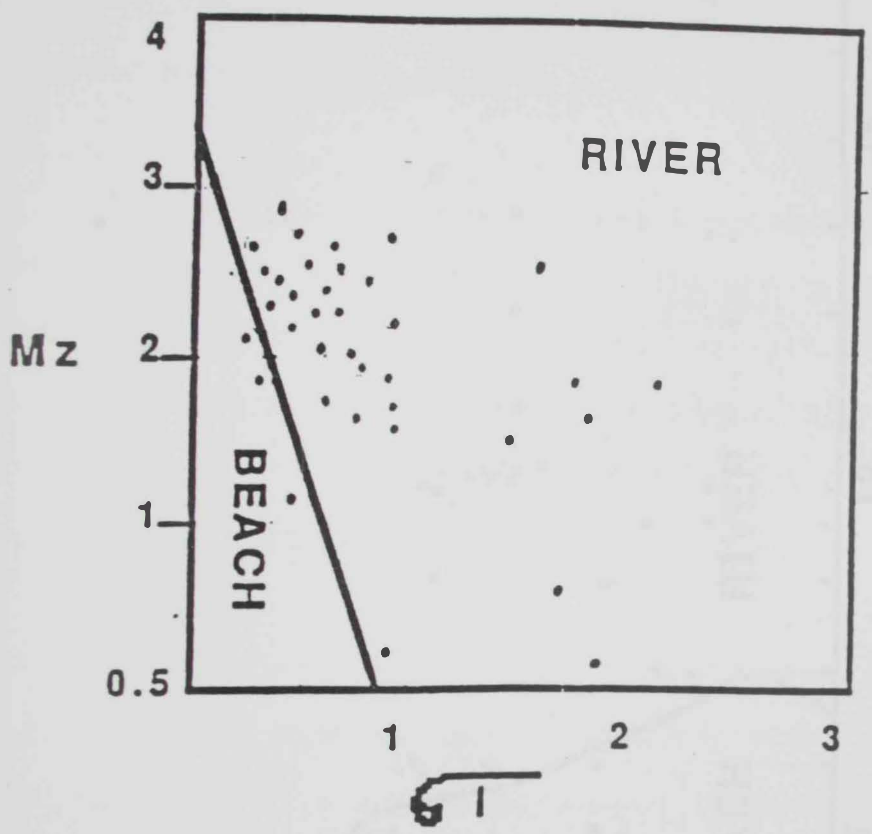


Fig. 8 . A scatter plot of standard deviation versus mean size (Moiola and Weiser, 1968).

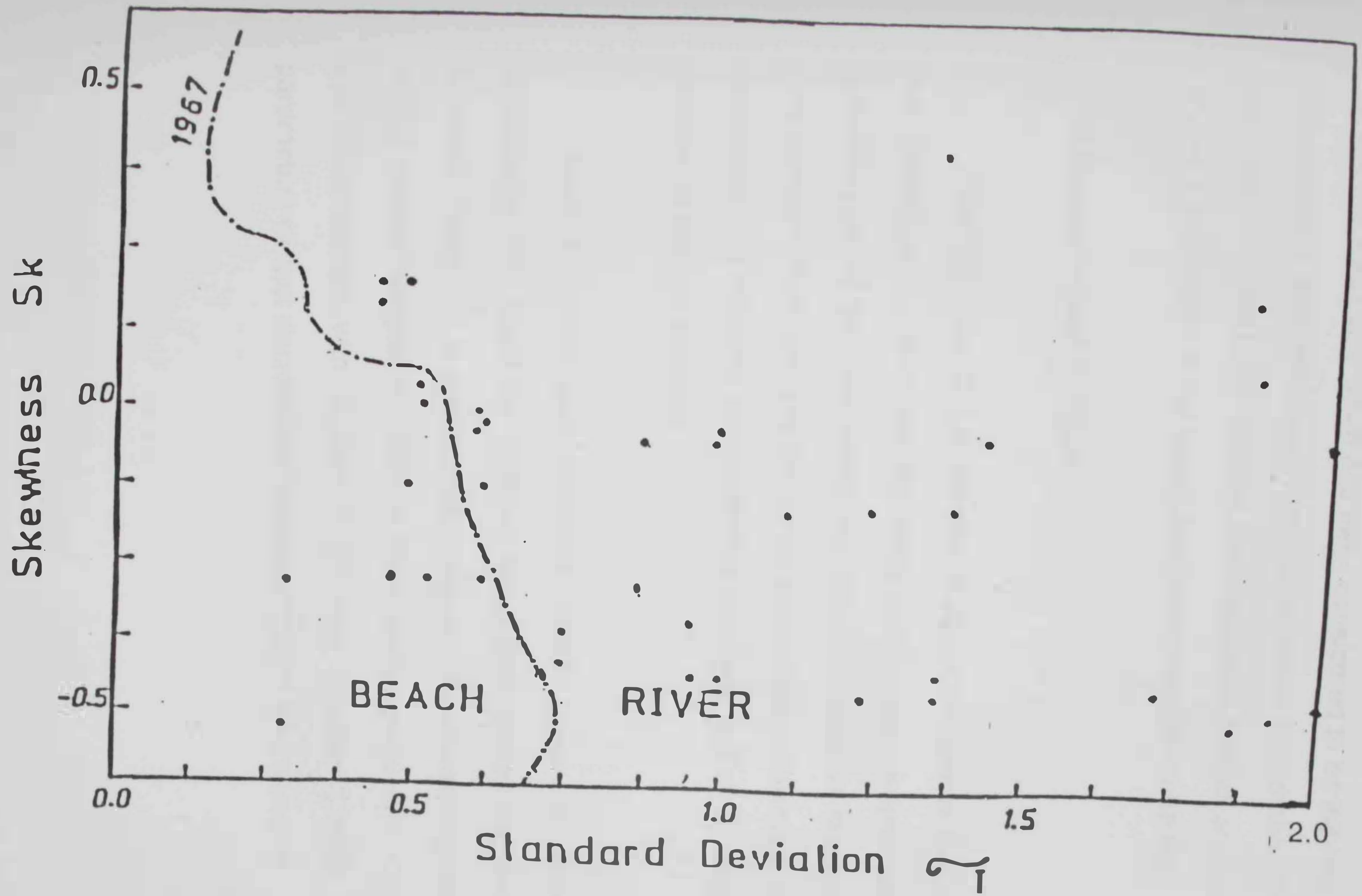


Fig. 9 . A scatter plot of standard deviation versus skewness (Fridman, 1967)

3. Skewness versus mean size:

Figure 10 and 11 demonstrate the relationship between skewness versus the mean size which has been considered to be the most effective in differentiating between beach and dune sands (Friedman, 1961, (Moiola and Wierser, 1968). The studied samples when plotted on these diagrams shows a distribution in the beach field rather than the dune field.

4. Skewness versus kurtosis:

Friedman (Op. Cit.) in his plot of skewness versus Kurtosis for river and beach sands, he found that most of the river samples gave positive skewness as did the dune sands. He related the positive skewness for river and dune sands to river and the wind transportation. However, beach sands have generally negative skewness due to waves action bringing about the removal of the fine particles.

Moshrif (1980) and Al-Asfour (1982) show no environmental significance that could be obtained when they plotted skewness versus kurtosis. Figure 12 is a scatter plot diagram of skewness against Kurtosis for the studied samples in which no trend can be discerned. Consequently and in agreement with Moshirif (1980) and Al-Asfour (1982), these two parameters cannot discriminate between different environments.

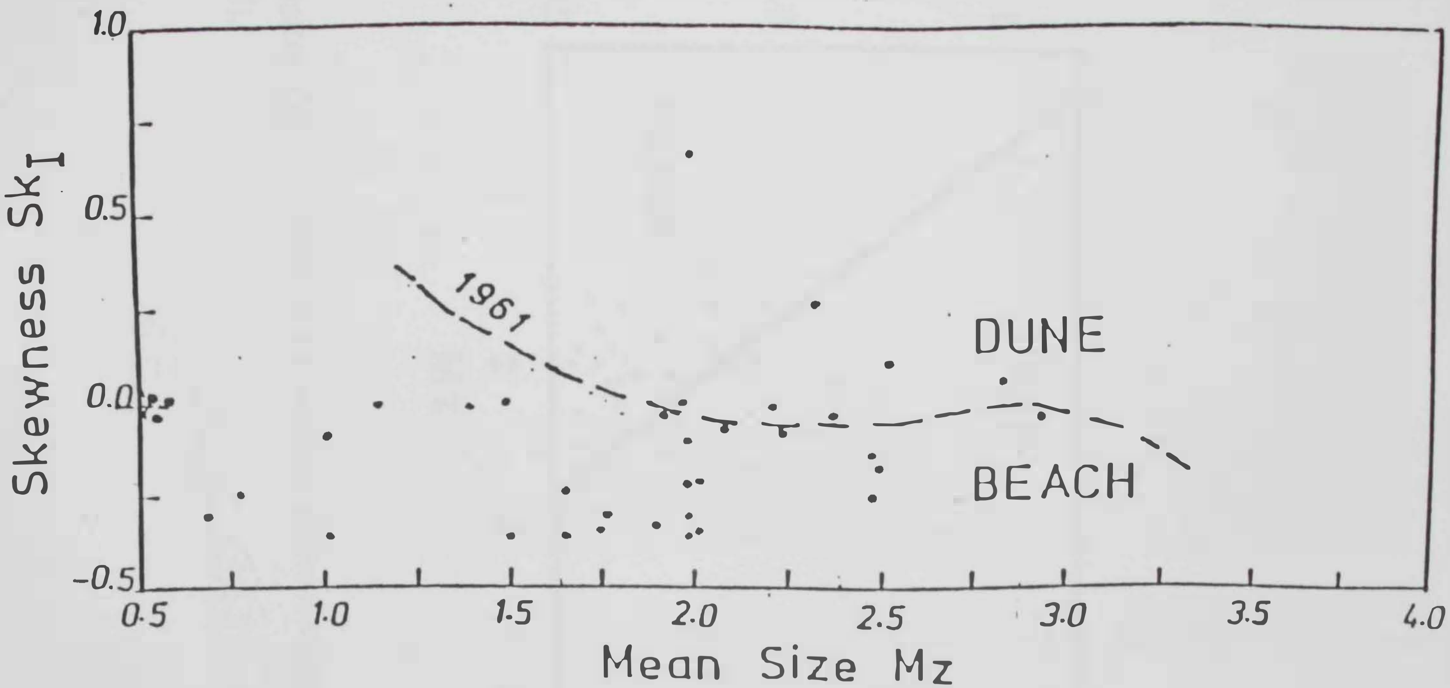


Fig. 10. A scatter plot of mean size versus skewness (Friedman, 1961).

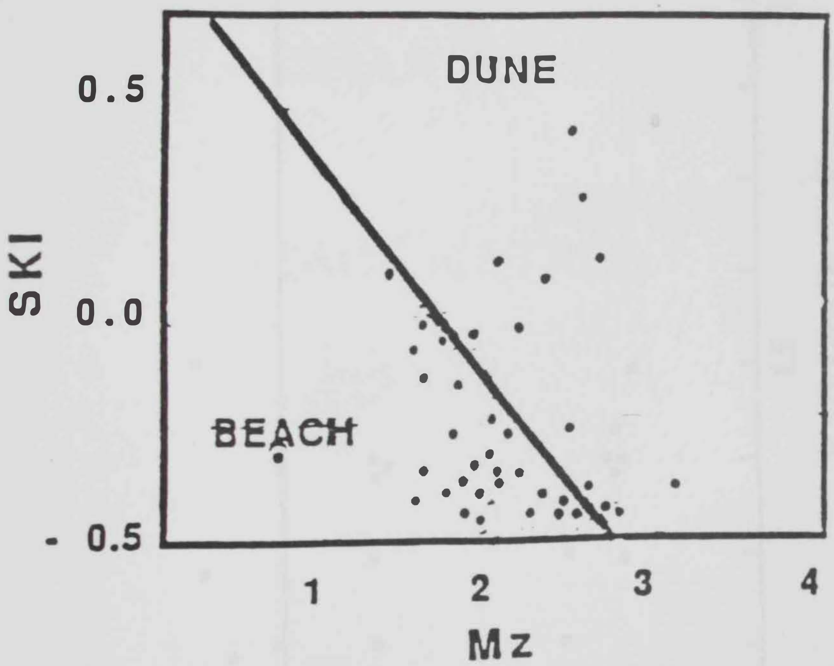


Fig. 11. A scatter plot of mean size versus skewness (Moiola and Weiser, 1968).

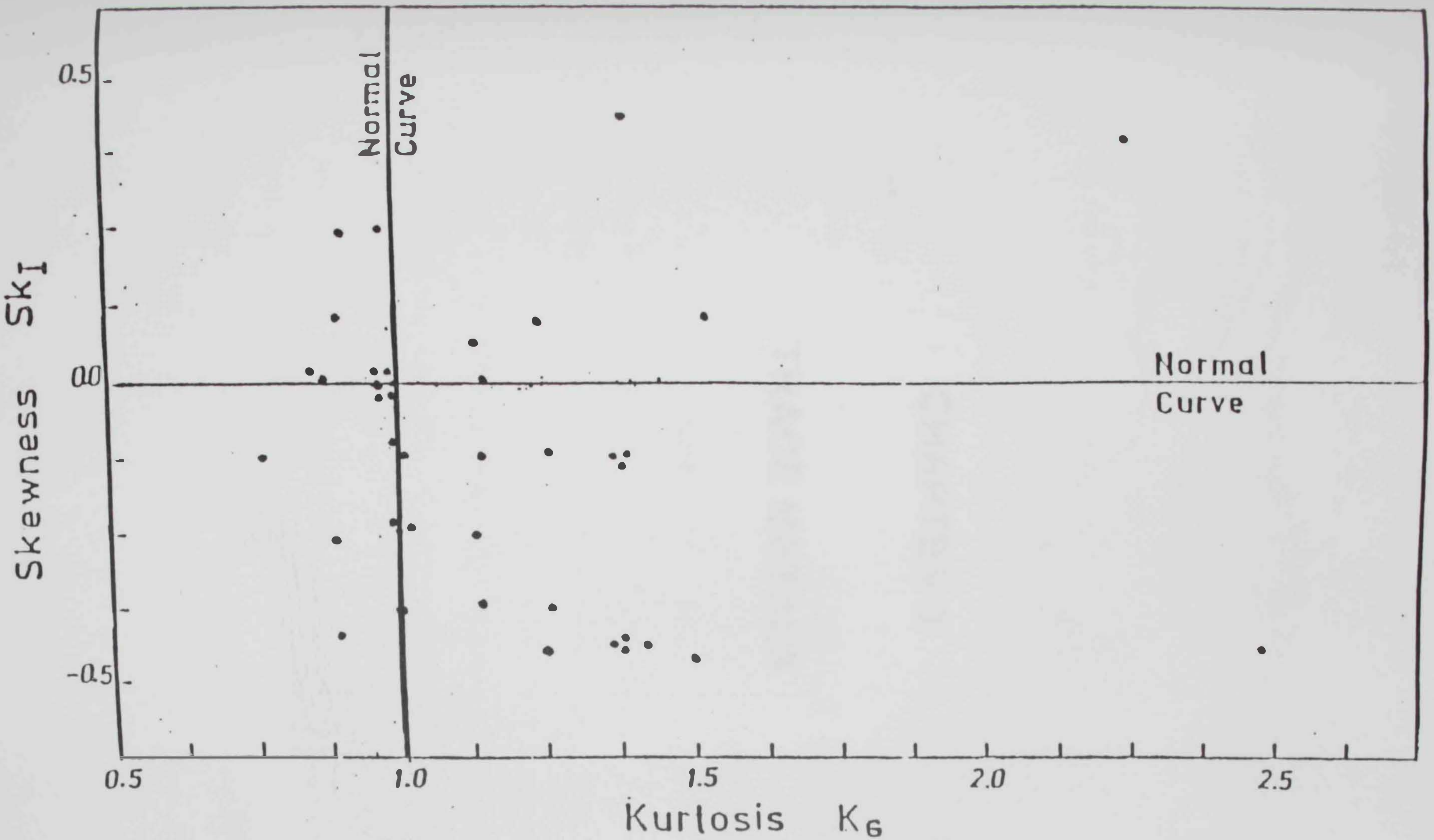


Fig. 12. A scatter plot of kurtosis versus skewness (Friedman, 1967).

CHAPTER 3

TRACE METALS

3. TRACE METALS

3.1. Introduction

Metals are natural components of the marine environment, usually at very low levels and some of them appear to be biologically essential (e.g. Fe, Cu, Zn, Ni). As a result of the accidental and intentional massive releases of pollutants into the marine environments, metal concentraitons nowadays exceed natural levels in many marine ecosystems. Metals may be introduced into the marine environment by domestic and industrial discharges, geological weathering, urban storm water run-off and atmospheric fallout. In fact, marine sediments are both carriers as well as potential sources of contaminants in aquatic systems (Baudi & Muntau, 1990; Forstner et al., 1990; Thomas, 1972).

The distribution of trace metals in sediments is fundamental to the study of environmental pollution, since metals can be toxic even if they are present in trace amounts (Cosma et al., 1979). Recently considerable interest has been shown in the accumulation of these metals in sediments. In uncontaminated marine sediments, the lowest concentrations of trace metals measured are 0.01 μg/g (dry weight), whereas in heavily contaminated sedimets the concentrations may increase to tens or hundres of micrograms per gram (Moore and Ramamorthy, 1984). High concentrations of metals particularly in coastal environments may lead to deterioration of natural habitats by reducing the number of ecologically sensitive species or by eliminating commercially important species (Sadiq and Zaidi, 1985).

Although it has been pointed out (Forstner and Wittman, 1981) that the study of metals in beach sediments is part of the study of environmental polluiton, information concerning levesl of these metals in beach sediments are extremely poor and are lacking in the beach and offshore sediments of UAE.

The main objectives of the present study are: (1) to identify precisely the distribution patterns and levels of some trace metals in order to represent zones having a high input of trace elements distant zones from the potential sources of pollution, (2) to find out relations between metal contents and other relevant parameters such as grain size and organic matter contents and (3) to investigate the environmental impact of spilled oil on levels and distribution patterns of trace metals along the eastern coast of UAE.

3.2. Materials and Methods

3.2.1. Materials

Surface sediment samples (the surface 4-5 cm) were collected from 40 stations during October 1992 and June 1994. The sampling stations were selected so as to cover the whole east coast of UAE which extends for more than 80 km from Kalba in the south of Dibba in the north (Fig. 1).

Sediment samples were stored in labelled polyethylene bags and then packed in crushed ice for transportation to the laboratory. In the laboratory, representative portions of sediments were air dried and stored in clean dry and labelled containers for analyses. As most pollutants are usually associated with the surface of the sediment particles (i.e. inorganic and organic coatings), the surface of the grain was not disturbed by grouning or crushing.

Trace metals and organic carbon analyses were done on the fine and coarse sand fraction. The fine sand fraction was used becuase it represents essentially material carried out in suspension and gives more details about pollution levels in the beach areas. It also explains the relationship between trace metals and the sand fractions (Frostner and Wittman, 1981).

In order to avoid contamination of the samples all chemicals used of were suprapure grade (Merck). All materials used were soaked for 12 hours with 5 N HCl and subsequently rinsed three times with double distilled water.

3.2.2. Methods of Analysis

1. Trace metal analysis: For trace metals deterimination of sediment samples (5.0 gm) were treated with 30 ml (30% v/v) of hydrogen peroxide for one hour and then extracted with 75-ml of diluted (0.5 N) hydrochloric acid for two hours at 90°C. filtered solutions were made up to 100-ml within the same acid solution. Filtered solutions were made up to 100-ml with the same acid solution. Filtered solutions were analyzed for Cd, Co, Cr, Cu, Pb, Mn, Ni, Zn by direct aspiration into the appropriate flame of a GBC model 906 Atomic Absorption Spectrophotometer equipped with a simultaneous background corrector, autosampler and reader. The precision of replicate samples was found to be between 5 and 10% of the lowest values obtained in this study. Blank values were negligible for all metals under consideration indicating the high purity of reagents used. The instrument was recalibrated after each fifth sample using calibration standards. A detailed method description is given by Agemian and Chau (1976), Malo (1977); Luma and Bryan (1978), Tessler et al., (1979), and Van valin and Morse (1982).

   The concentrations of the trace metals were calculated using the following equation:

$$C\ (\mu g/g) = \frac{(X-B) \times V}{W}$$

where:

C	=	Element concentration (μg/g)
X	=	Mean of two readings (μg/g)
B	=	Blank reading (μg/g)
V	=	Volume (μl)
W	=	Weight of sample (gm)

2. Organic matter:

Organic matter in terms of organic carbon percent is determined using acid dichromate and back titration method as described by Gaudette et al., (1974). The method can be summarized as follows: Exactly 10-ml of 1 N potassium dichromate solutions were added to sediment samples (0.2 - 0.5 gm) and mixed by swirling. 20-ml portions of concentrated sulphuric acid were then added and mixed by a gentle rotation for about one minute. The mixutre was allowed to stand for 30 minutes. After 30 minutes, the solution was diluted to 200-ml with distilled water, and 10-ml 85% phosphoric acid, 0.2 gm sodium fluoride, and 15 drops of diphenylamine indicator were added. The solution was then back titrated with 0.5N ferrous ammonium sulphate solution.

The percentages of organic carbon were calculated by the following equation:

% organic carbon = 10 (1 - T/S) [1.0N(0.003)(100/W)]

where:

T	=	sample titration, ml ferrous solution
S	=	standard blank titration, ml ferrous solution
0.003	=	12/4,000 = meq weight of carbon
1.0N	=	normality of $K_2Cr_2O_7$
10	=	volume of $K_2Cr_2O_7$ in ml
W	=	weight of sediment sample in grams

3.3. PREVIOUS WORK

The distribution levels of trace metals in sediments from the Arabian Gulf and Gulf of Oman have been studied by several workers. Very recently, Abu-Hilal and Khardagui (1992) studied the distribution of 14 trace metals (Ag, Cd, Co, Cr, Cu, Ni, Pb, Mo, Mn, Fe, V, Zn, Ca and Mg) in the coastal sediments of UAE. They used the relationship between metals and organic matter is the interpretation of their experimental results. Basaham and Lihaibi (1993) determined the levels of Cr, Zn, Co, Ni, Mn, Cu in the sediments of the Western Arabian Gulf. Fowler et al., (1984) studied dissolved as well as particulate trace metals in coastal water sof the Gulf and Western Arabian Sea. Al-Hashimi and Salaman (1985) analyzed trace metals in the sediments of the north-western coast of the Arabian Gulf and Burns et al. (1982) studied trace metals, in the coastal waters of Oman. Anderlini et al., (1982) detemined concentration levels of Cd, Cr, Pb, Ni, and Zn in surficial sedimetns from Kuwait Bay.

3.4. Results and Discussion

1. Levels and distribution patterns of trace metals

Trace metals concentrations reported here represent mainly the fractions removed by hydrochloric acid and point to the "anthropogenic" trace metal fraction usually listed in the evaluation of the pollution level. The hydrogen peroxide treatment removed mainly sulphides and organic matter and has a minor effect on the silicate lattice.

The levels and distribution patterns of trace metals; cobalt, cadmium, chromium, copper, manganese, nickel, lead and zinc and organic matters in fine and coarse sand fractions are listed in Tabnle (4 & 5) and demonstrated graphically in (Figs. 13 a - 13e & 14a - 14d). Table (6) summarizes the results of the present study as ranges and mean values of the different parameters.

The levels of trace metals presented in Tables 4 and 5 display significant variations from one station to another. The levels (μg/g dry weight) for cobalt, cadmium, chromium, copper, manganese, nickel, lead and zinc in the fine sand fraction are found to be scattered in the ranges (0.03 - 1.19), (0.003 - 2.87), (0.28 - 8.70), (0.02 - 14.11), (0.05 - 2.31), (0.14 - 6.58), (0.04 - 15.72) and (0.19 - 14.54), whereas in the coarse sand fraction the levels (mg/g dry wieght) fluctuating in the ranges: (0.007 - 2.44), (0.001 - 0.24), (0.09 - 6.48), (0.001 - 1.83), (0.027 - 10.1), (0.05-4.55), (0.018 - 1.50), and (0.04 - 1.15). These remarkable variations of trace metals in surficial sediments of the east coast are attributed to the differences in

Table 4 Concentration levels of trace metals (µg/g dry weight), and organic carbon (%) in the fine sand fraction (<63µm).

Sampling Site	Trace Metals (Fine sand fraction (<63 µm))								Org. Carbon %
	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
1	0.12	0.17	3.67	6.18	1.41	2.28	5.22	10.35	0.39
2	0.12	0.23	3.65	4.18	1.43	2.85	3.98	9.58	0.28
3	0.20	0.61	6.47	14.11	1.12	2.12	15.72	14.54	0.32
4	0.10	ND	3.47	1.94	0.79	1.94	0.48	5.21	0.08
5	0.09	ND	8.7	2.20	0.78	1.85	0.75	5.26	0.06
6	0.10	ND	3.56	2.04	0.79	1.81	0.58	5.62	0.05
7	0.09	0.08	5.00	2.45	1.19	2.31	1.60	5.86	0.05
8	0.14	0.08	6.41	5.80	1.25	2.62	5.70	14.2	0.79
9	0.08	ND	4.86	2.47	0.68	1.58	0.80	5.50	0.04
10	0.11	ND	3.74	2.34	0.92	2.02	1.09	6.58	0.06
11	0.05	ND	0.37	0.20	0.34	0.85	0.07	2.30	0.03
11-A	0.05	0.05	1.87	1.16	0.87	1.17	1.82	4.98	0.18
11-B	005	0.02	1.98	1.24	1.13	1.65	0.99	4.42	0.16
12	0.05	0.05	3.66	1.80	0.48	1.28	0.86	4.46	0.09
12-A	0.23	ND	0.78	1.35	2.31	3.36	2.41	2.79	0.27
13-A	0.11	ND	0.79	0.28	0.92	1.58	0.30	0.38	0.08
13-B	0.1	ND	0.52	0.38	0.94	1.82	ND	0.26	0.07
13-E	0.09	0.009	5.57	2.99	0.98	1.74	2.28	0.69	0.08
13-F	0.08	0.003	6.63	2.26	0.80	1.43	1.02	0.59	0.08
14-A	0.08	0.17	3.50	183	0.90	1.67	2.50	0.48	0.08
15-A	0.13	0.04	0.80	0.45	1.03	1.77	1.42	0.21	0.06
15-B	0.13	ND	0.98	0.24	0.95	1.68	0.43	0.23	0.09
15-C	0.09	0.03	7.66	2.74	0.98	1.80	1.49	0.58	0.07

ND : Not detected

Detection limit: Cd (0.009), Co (0.05), Cr (0.05), Cu (0.025), Mn (0.02), NiCo. 04), pb (0.06), Zn (0.008).

(Continued.............)

Sampling Site	Trace Metals (Fine sand fraction (<63 μm))								Org. Carbon %
	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
16-A	0.35	0.1	1.35	0.84	0.12	0.35	0.04	0.22	0.13
16-C	0.13	ND	2.73	1.42	0.87	2.65	0.66	0.58	0.11
17-A	0.26	ND	3.25	2.40	2.15	6.58	2.56	1.14	0.00
17-B	0.14	ND	0.73	0.29	0.85	2.10	0.95	0.24	0.11
17-C	0.12	ND	0.53	1.42	0.94	2.51	2.48	0.60	0.09
17-D	0.11	ND	0.72	0.21	0.66	1.93	0.15	0.32	0.06
18	0.03	ND	0.40	0.12	0.17	0.49	0.38	0.20	0.06
19-A	1.19	ND	0.45	0.51	0.19	0.58	ND	0.43	0.20
19-B	0.1	ND	0.50	0.02	0.13	0.43	ND	0.26	0.04
20-A	0.25	ND	0.72	0.04	0.13	0.42	0.08	0.19	0.10
20-B	0.22	ND	4.26	0.11	1.80	6.22	0.58	0.82	0.03
20-C	0.12	ND	0.80	0.02	0.78	2.51	0.55	0.26	0.05
21-A	0.06	0.62	1.12	0.24	2.03	1.37	4.58	0.61	0.06
21-B	0.1	ND	0.71	0.03	1.35	0.62	1.85	0.41	0.06
21-C	0.1	0.05	2.80	0.03	0.93	0.60	3.62	0.40	0.40
A	0.22	2.87	1.55	1.27	0.05	0.14	2.89	0.22	0.00
B	0.09	0.71	1.48	5.00	0.37	0.37	9.46	0.59	0.00

ND : Not detected

Table 5 Concentration levels of trace metals (μg/g dry weight), and organic carbon (%) in the coarse sand fraction (<500 μm).

Sampling Site	Trace Metals (Coarse sand fraction (<500 μm))								Org. Carbon %
	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
1	1.04	0.15	3.16	0.41	9.04	1.54	1.50	0.46	0.17
2	1.38	0.18	3.53	0.24	10.10	2.20	1.23	0.59	0.22
3	1.41	0.15	4.39	0.40	1.17	2.67	1.18	0.58	0.16
4	1.58	0.10	6.08	0.52	1.58	3.20	0.74	0.47	0.05
5	1.58	0.09	6.09	0.50	1.59	3.17	0.69	0.47	0.07
6	1.50	0.09	5.72	0.51	1.65	3.35	0.67	0.48	0.05
7	1.22	0.15	3.40	0.39	1.50	2.18	0.94	0.43	0.08
8	1.27	0.18	2.94	0.43	9.02	2.00	1.18	0.74	0.47
9	0.94	0.07	3.68	0.32	7.50	1.61	0.52	0.24	0.04
10	1.28	0.12	2.84	0.33	1.31	2.47	0.81	0.39	0.07
11	0.78	0.04	2.39	0.30	6.98	1.38	0.36	0.24	0.04
11-A	1.42	0.09	1.44	0.88	1.30	1.75	0.74	0.17	0.04
11-B	2.44	0.12	3.49	1.83	2.28	3.98	1.19	0.85	0.06
12	1.98	0.11	6.47	0.51	1.70	3.88	0.79	0.88	0.08
12-A	2.06	0.11	3.70	1.05	1.90	2.39	1.33	0.95	0.26
13-A	0.95	0.19	0.93	0.19	8.53	4.35	1.11	0.53	0.07
13-B	1.05	0.17	1.25	0.26	9.13	4.55	0.96	0.56	0.05
13-E	2.12	0.20	4.26	0.49	1.65	1.21	1.26	1.04	0.07
13-F	2.35	0.19	4.92	0.51	1.63	2.07	1.19	1.15	0.07
14-A	1.32	0.17	2.77	0.28	0.93	2.19	1.02	0.66	0.07
14-B	1.36	0.20	2.71	0.30	4.98	1.09	1.14	0.69	0.08
14-C	0.99	0.15	2.10	0.21	9.58	0.71	0.89	0.53	0.07

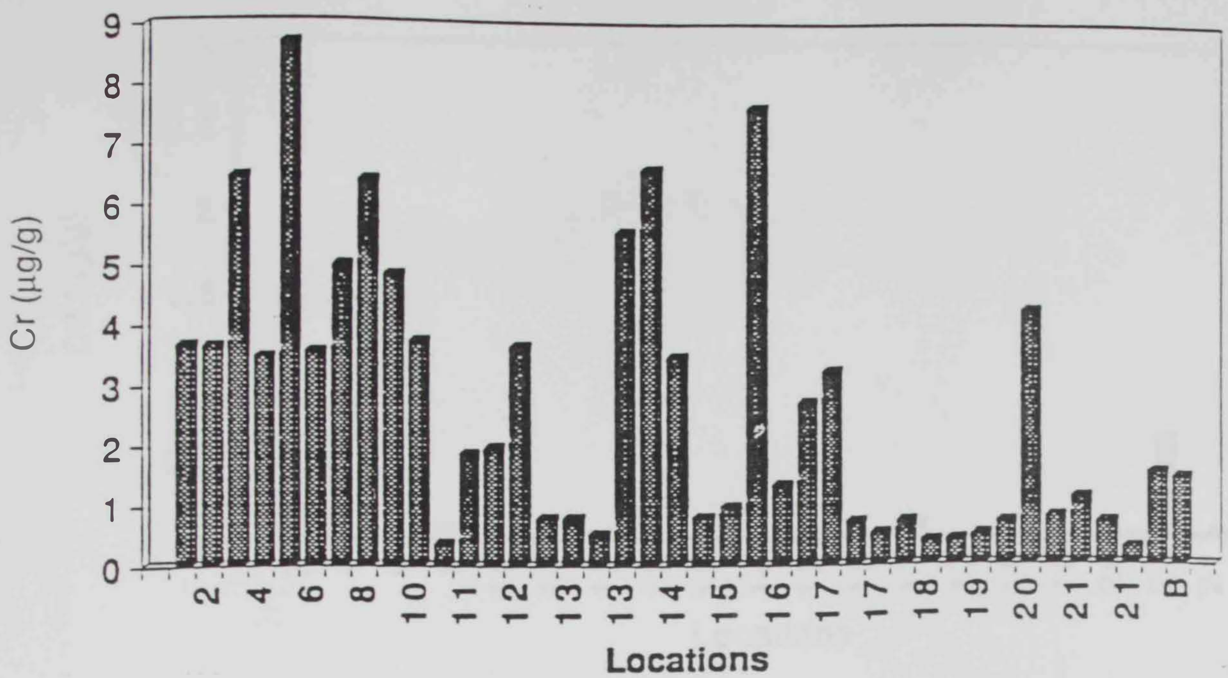
ND : Not detected

(Continued............ 2)

(Continued.............)

Sampling Site	Trace Metals (Coarse sand fraction (<500 μm))								Org. Carbon %
	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
15-A	0.01	ND	0.41	0.01	0.12	0.29	0.06	0.056	0.11
15-B	0.02	ND	0.34	0.01	0.07	0.15	0.13	0.06	0.06
15-C	0.03	ND	0.60	0.01	0.22	0.67	0.11	0.06	0.05
16-A	0.03	ND	0.40	ND	0.15	0.51	0.08	0.05	0.04
16-B	0.03	ND	0.25	0.01	0.09	0.28	0.13	0.05	0.04
16-C	0.01	ND	ND	0.01	0.02	0.05	0.12	0.05	0.09
17-A	0.02	ND	0.25	0.01	0.09	0.30	0.12	0.06	0.09
17-B	0.03	ND	0.09	0.01	0.07	0.24	0.08	0.06	0.78
17-C	0.03	ND	0.55	0.01	0.19	0.71	0.12	0.06	0.09
17-D	0.01	0.11	0.91	0.03	0.12	0.28	0.06	0.07	0.02
18	0.53	ND	0.70	0.02	4.52	1.08	0.34	0.31	0.02
19-A	0.13	0.01	0.64	0.03	0.04	0.08	0.02	0.06	0.09
19-B	0.02	0.02	ND	0.01	0.05	0.17	0.14	0.05	0.04
20-A	0.02	ND	0.67	ND	0.05	0.25	0.02	0.05	0.04
20-B	0.04	ND	0.57	0.01	0.08	0.49	0.05	0.04	0.05
20-C	0.02	0.01	0.43	0.02	0.04	0.15	0.10	0.05	0.03
21-A	0.02	ND	0.55	ND	0.14	0.194	0.13	0.06	0.11
21-B	0.03	0.04	0.25	0.03	0.08	0.114	0.07	0.06	0.09
21-C	0.03	ND	0.23	0.02	0.09	0.14	0.07	0.06	0.09
A	0.02	0.01	0.28	0.04	0.03	0.14	0.12	0.06	0.00
B	0.01	ND	0.54	0.01	0.06	0.38	0.04	0.05	0.00

ND : Not detected



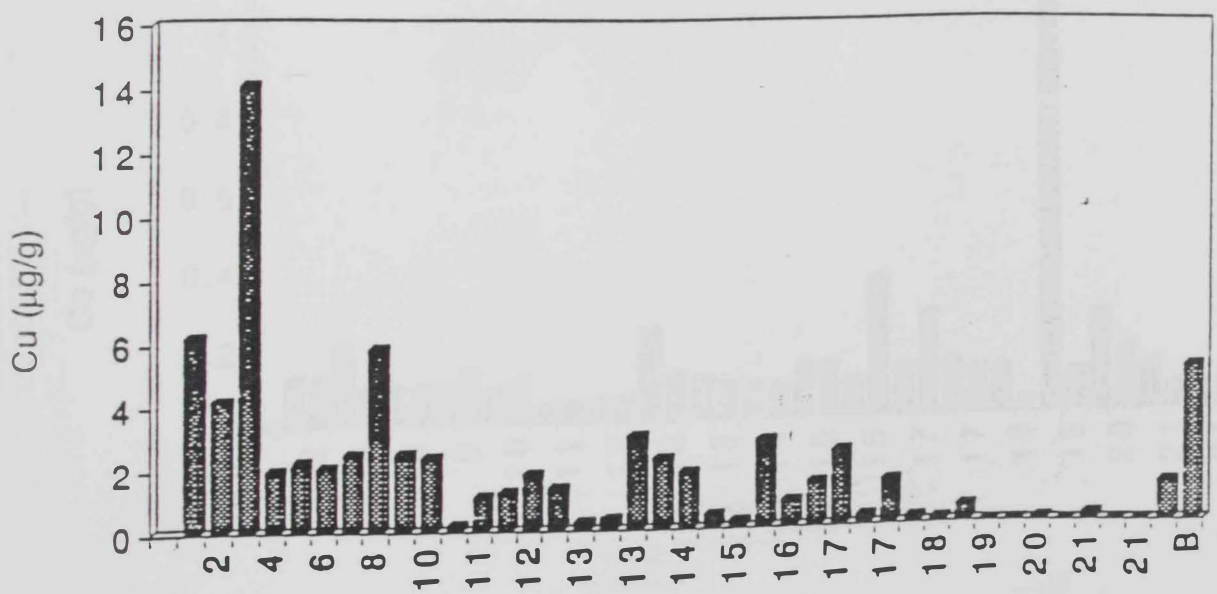


Fig. 13a . The concentrations of chromium and copper (µg/g dry weight) in the fine sand fraction of the surface sediments from the east coast of U.A.E., before pollution.

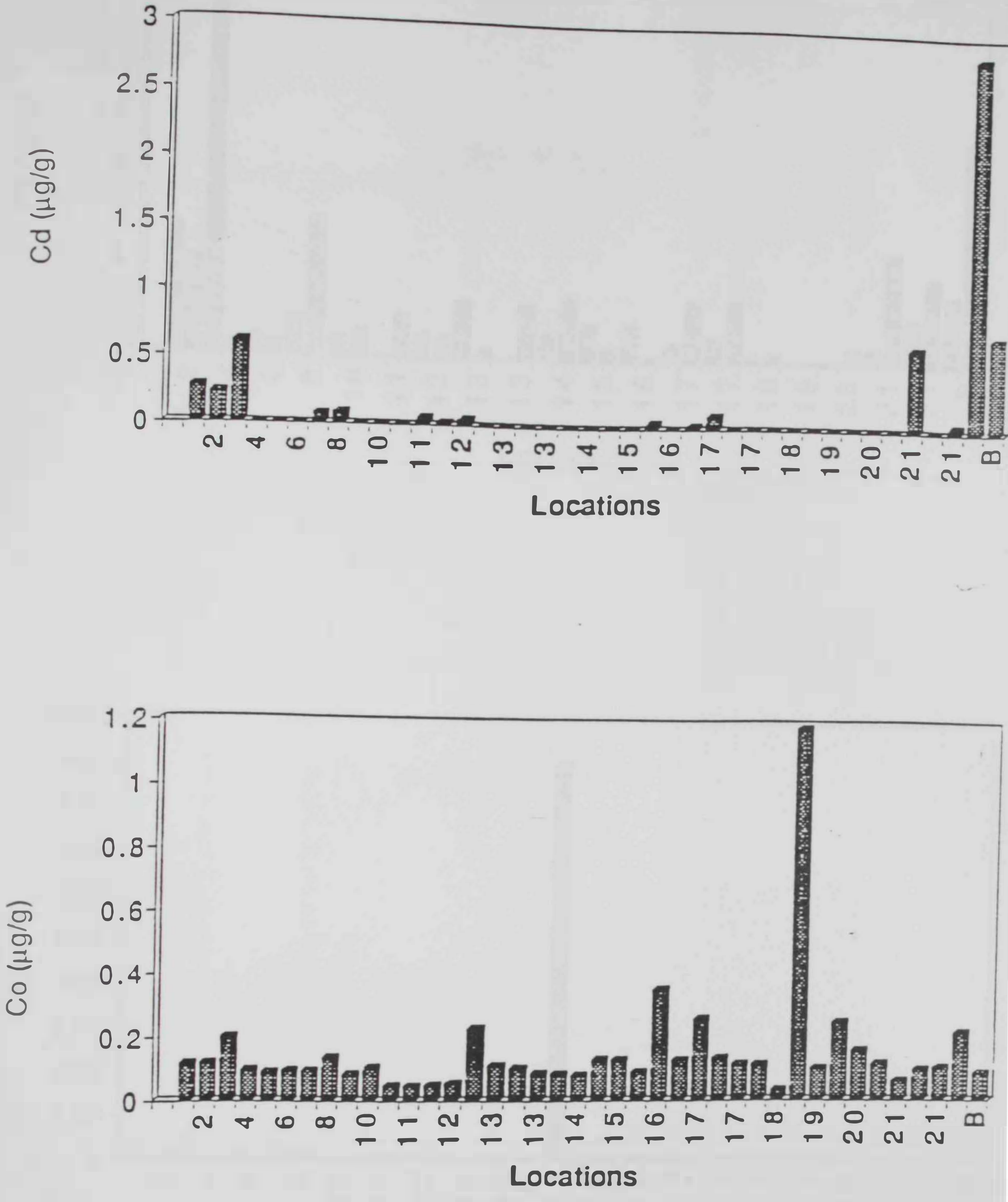
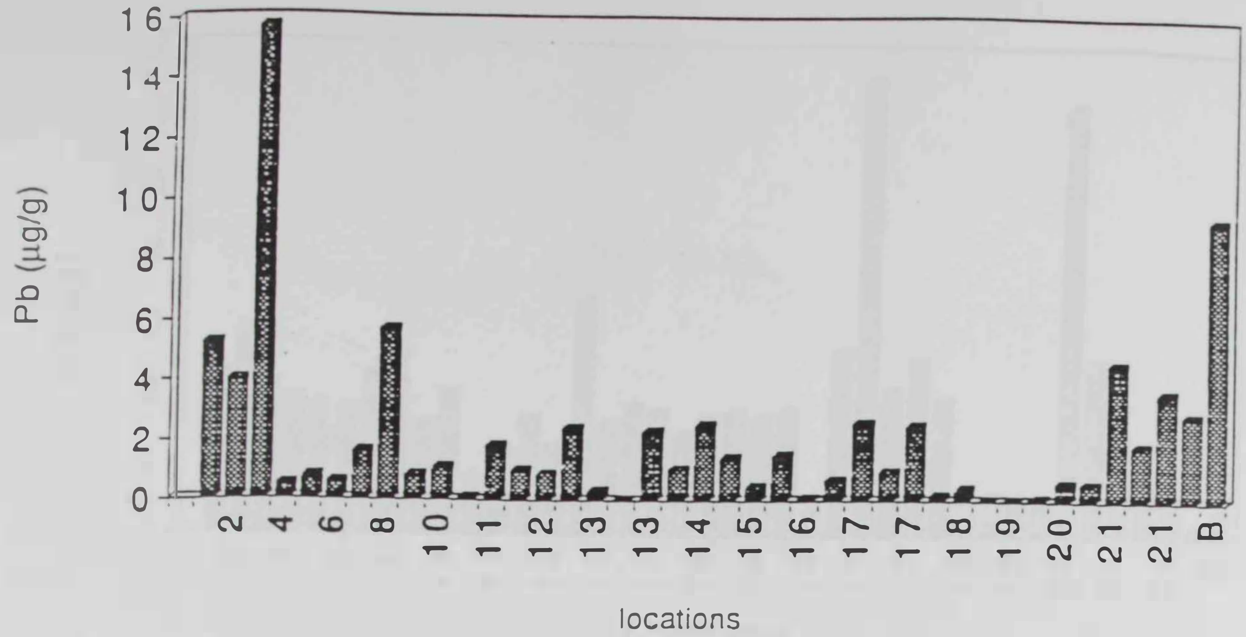


Fig. 13b : The concentrations of cadmium and cobalt (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E., before pollution.



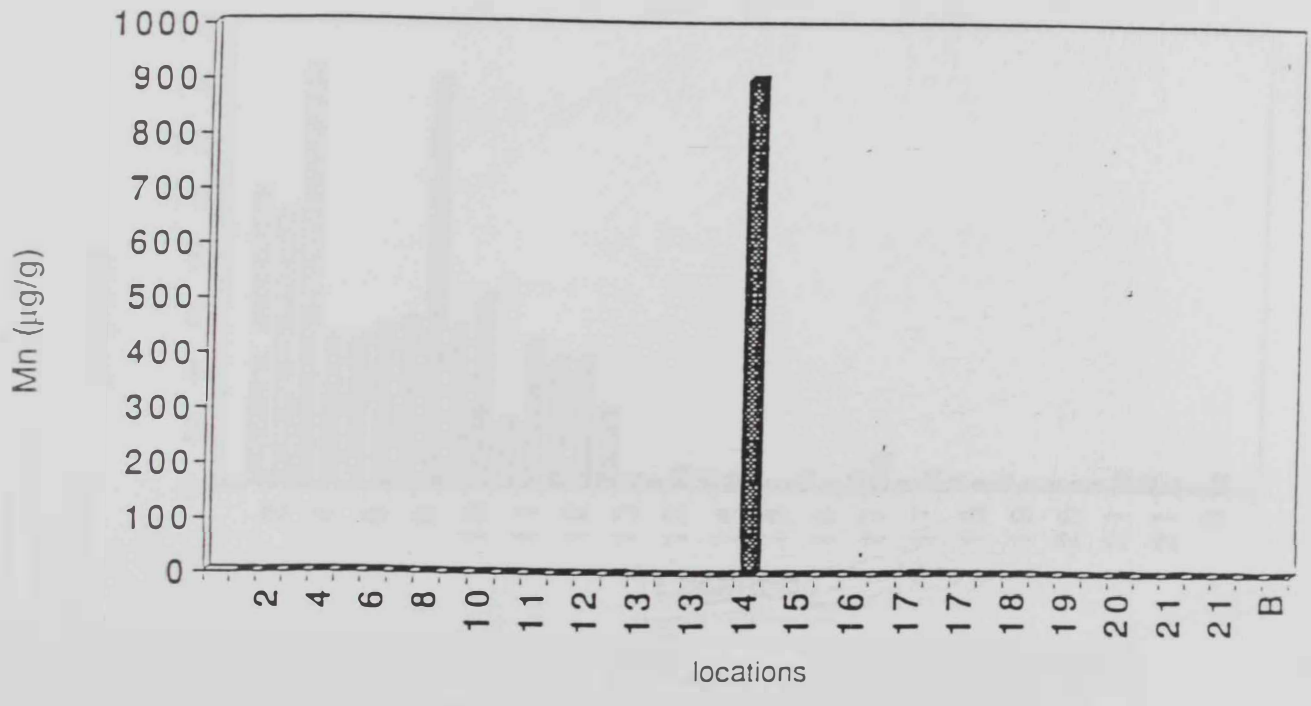
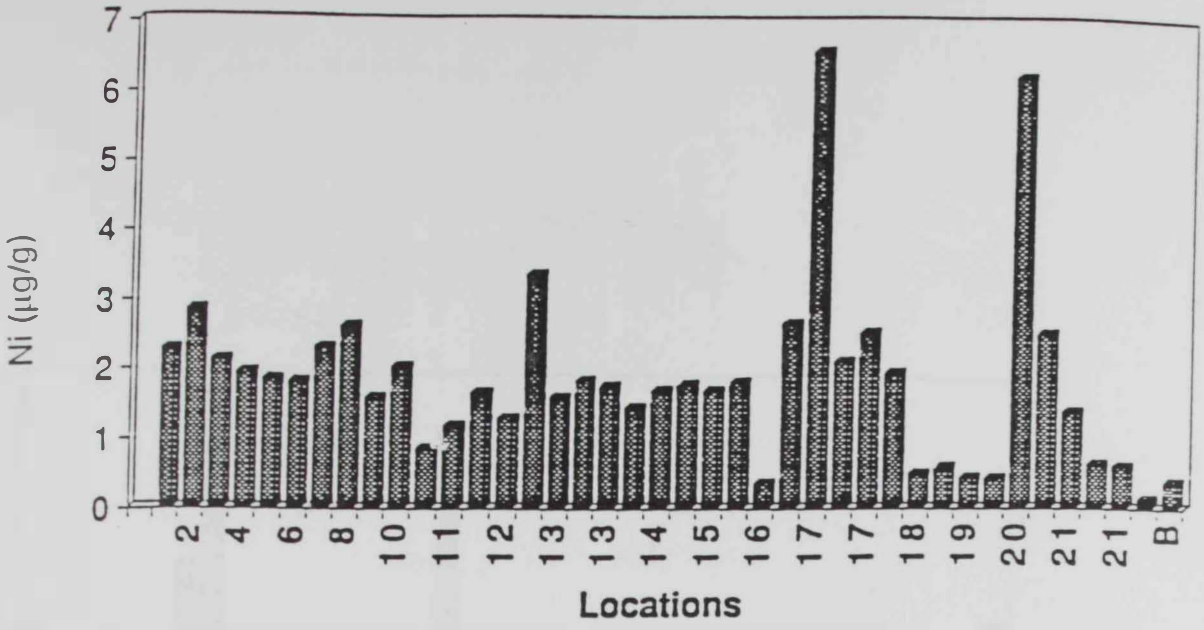


Fig. 13c . The concentrations of lead and manganese (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E., before pollution.



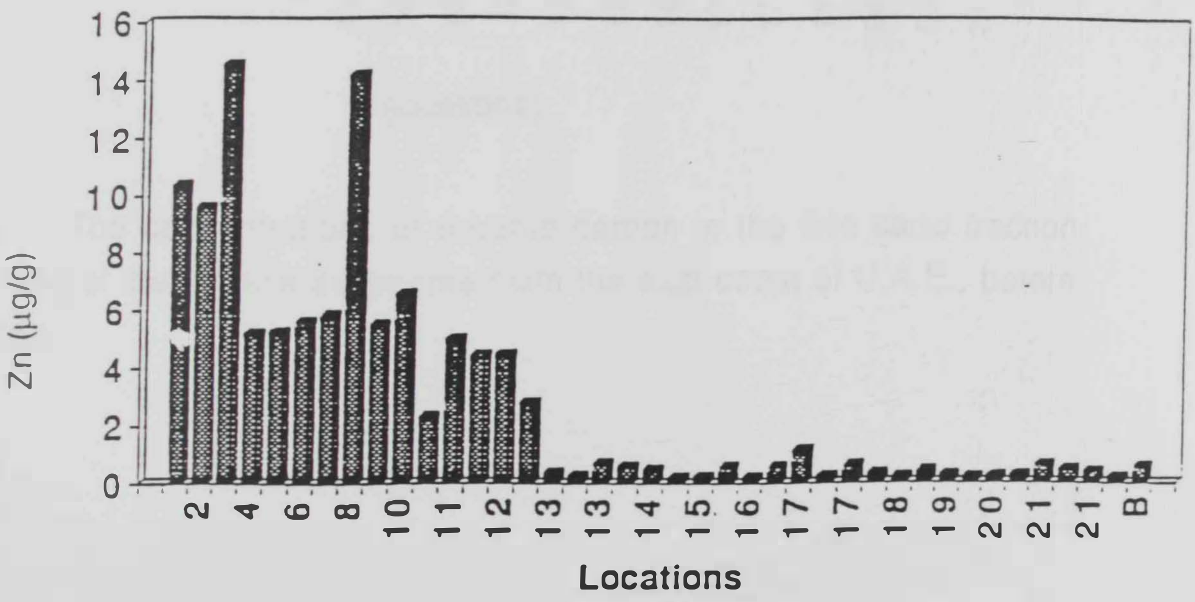


Fig. 13d. The concentrations of nickel and zinc (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E., before pollution.

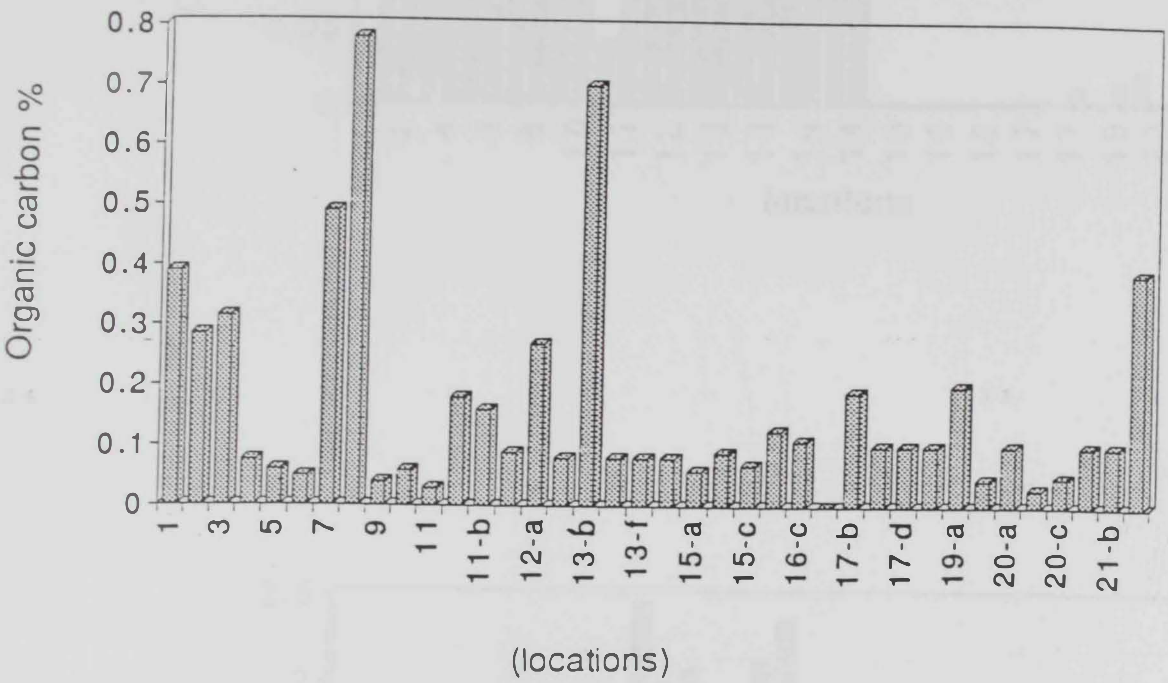
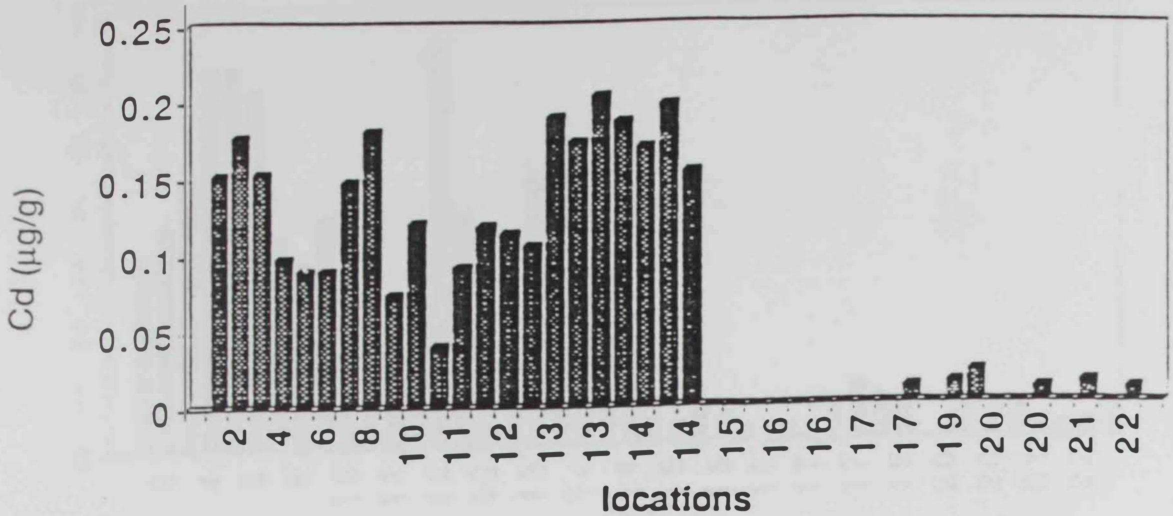


Fig.13e . The concentrations of organic carbon in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E., before pollution.



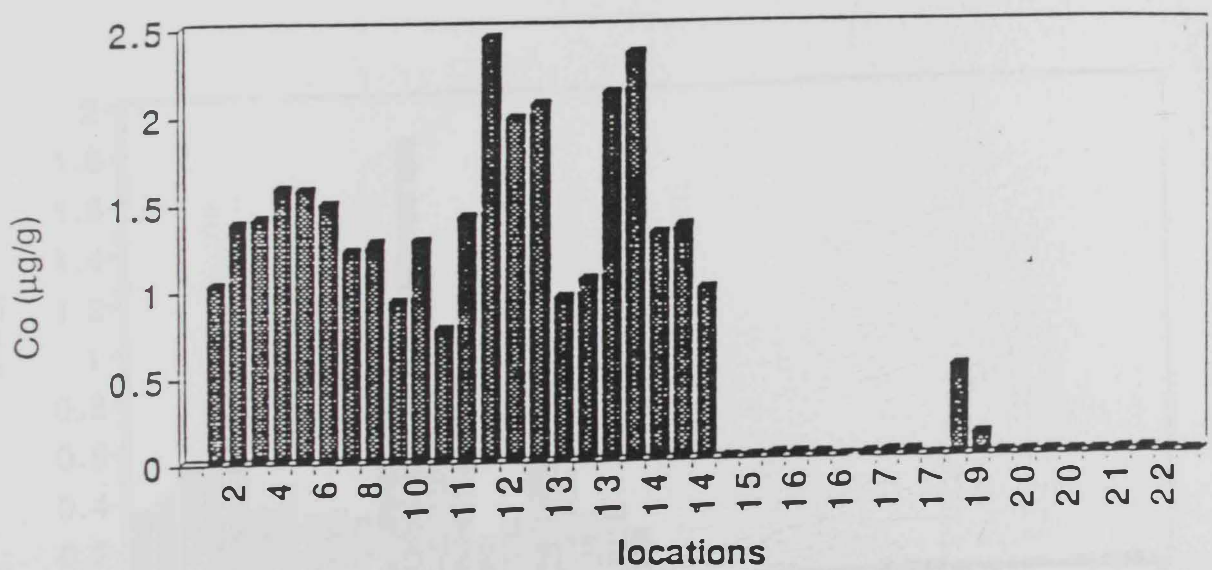
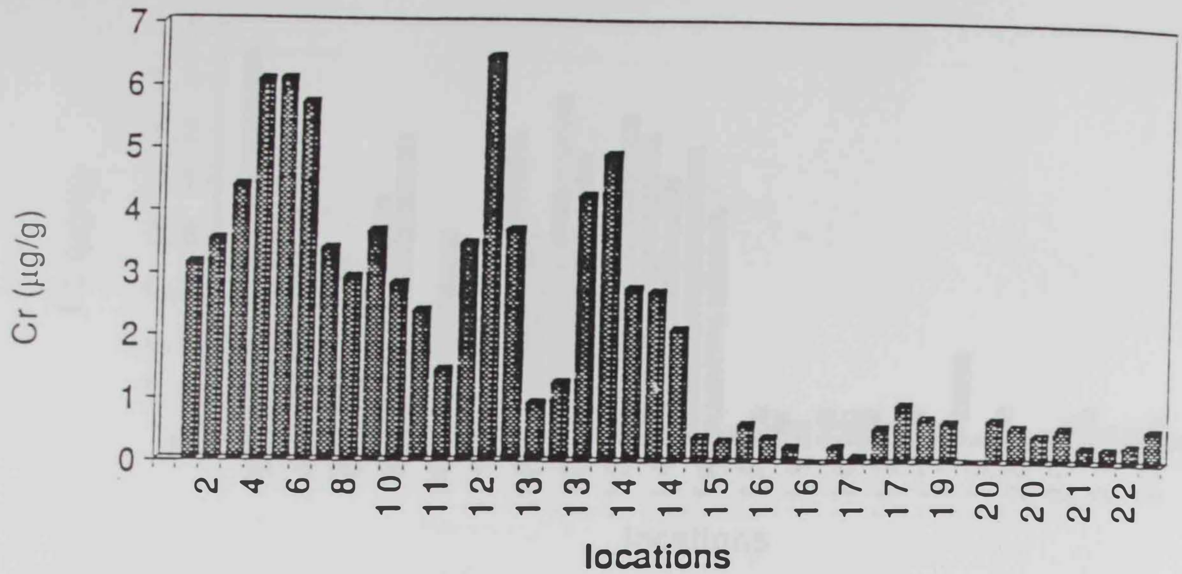


Fig. 14a. The concentrations of cadmium and cobalt (µg/g dry weight) in the coarse sand fraction of surface sediments from the east coast of U.A.E., before pollution.



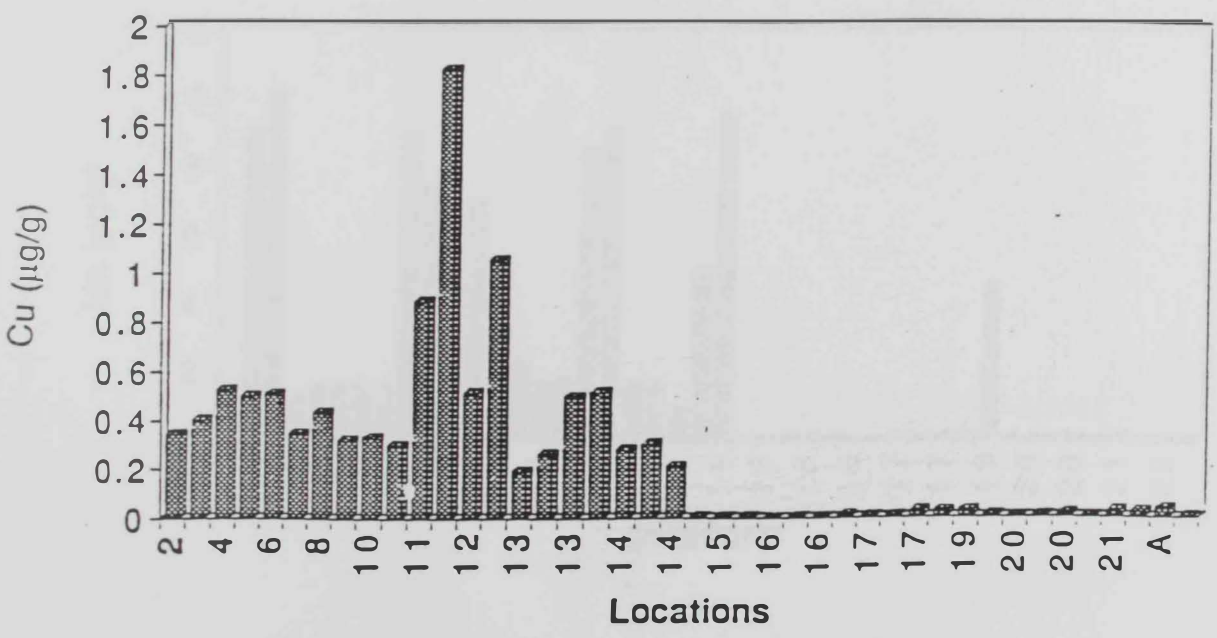
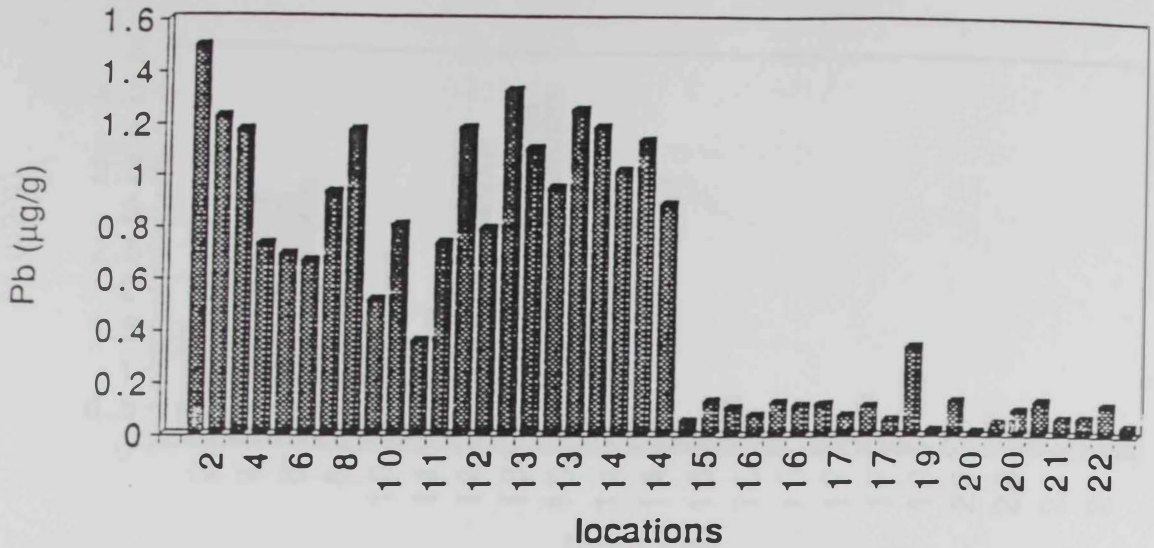


Fig. 14b. The concentrations of chromium and copper (µg/g dry weight) in the coarse sand fraction of the surface sediments from the east coast of U.A.E., before pollution.



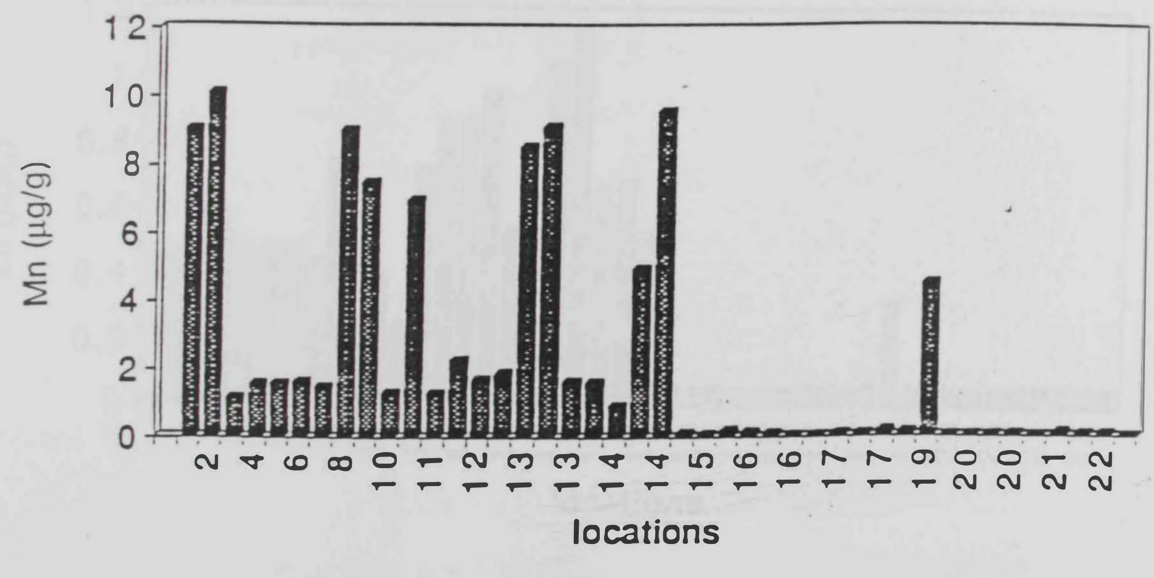
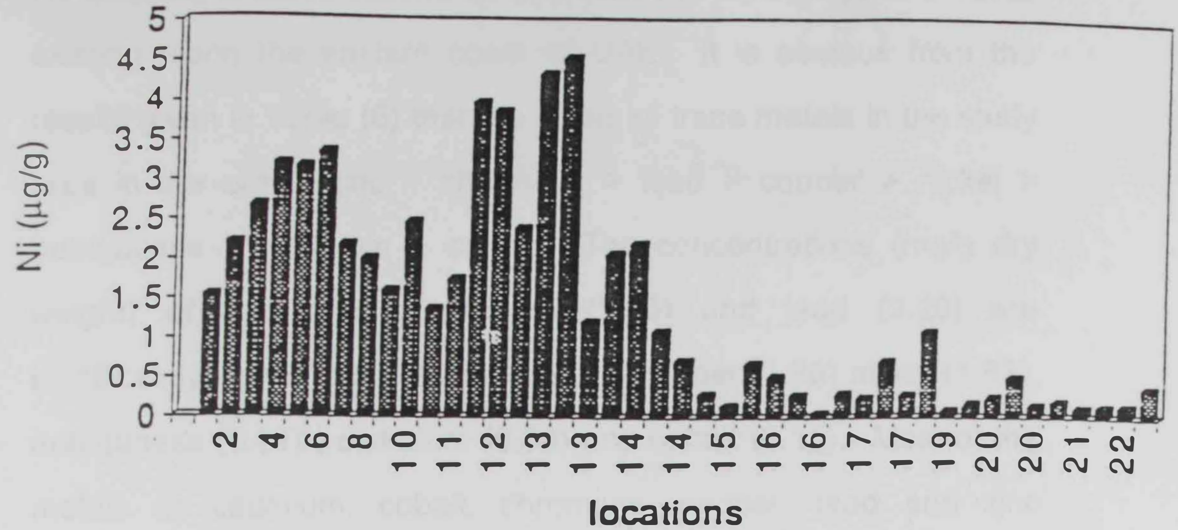


Fig. 14c . The concentrations of lead and manganese (μg/g dry weight) in the coarse sand fraction of the surface sediments from the east coast of U.A.E., before pollution.



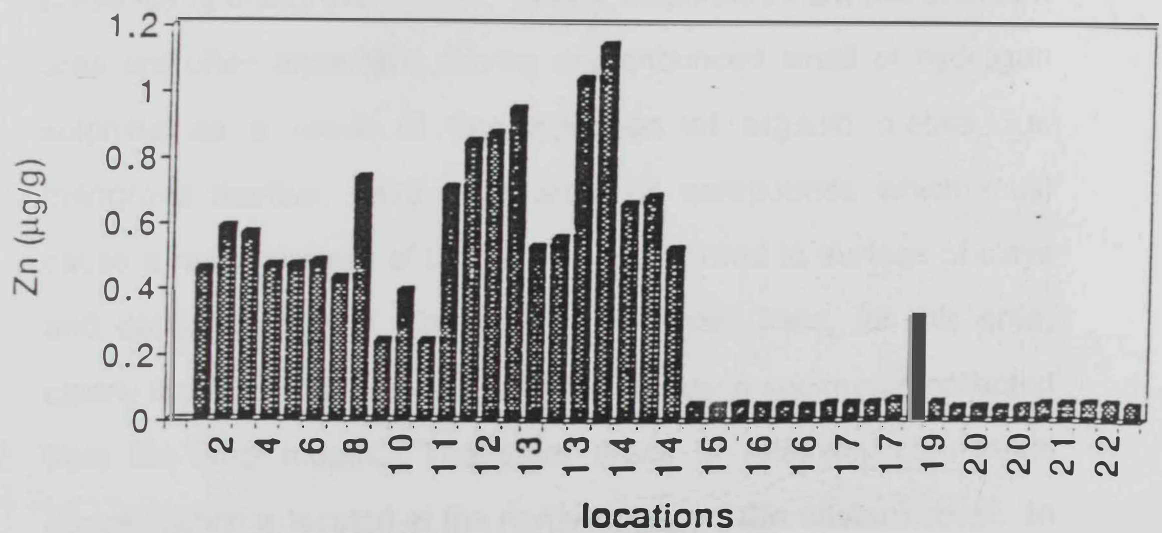


Fig. 14d. The concentrations of nickel and zinc (µg/g dry weight) in the coarse sand fraction of the surface sediments from the east coast of U.A.E., before pollution.

composition of these sediments as a result of various types of rocks existing along the eastern coast of UAE. It is obvious from the results given in Table (6) that the levels of trace metals in the study area in the order: zinc > chromium > lead > copper > nickel > manganese > cadmium > cobalt. The concentrations (mg/g dry weight) of zinc (2.81), chromim (2.66) and lead (2.20) are significantly higher than other metals, as copper (1.86) nickel (1.83), manganese (0.91) , cadmium (0.33) and cobalt (0.15). Most of the metals as cadmium, cobalt, chromium, copper, lead and zinc showed their peak concentrations at two different areas (Figs. 13a-13d), the most prominent in the southern part of the east coast. The high levels of trace metals reported in this area mainly due to a combination of factors, of which the most important are the geological nature of the area, the composition of sediments and the presence of mangrove forests. In fact, sediments from this southern area are often anaerobic, having a pronounced smell of hydrogen sulphine as a result of decomposition of organic metals, i.e. mangrove detritus, dead organisms, oil compounds which must cause a rapid removal of these metals adsorbed to surface of clays and detrital particles. The results presented here, for this area, clearly indicate higher levels for most metals in sediments collected from the wadi mouth. The other areas of relatively high metal concentration is located at the northern part of the eastern coast. In contrast to the southern zone, it is believed that the cause for relatively high levels of trace metals in the northern area, paticularly for cobalt, manganese, nickel, lead and zinc natural and mainly associated with the geological formations and not with major anthropogenic sources.

Table 6 Range and mean values (±SD) of trace metals (mg/g dry weight), and organic carbon (%) in the fine sand fraction (<63 μm) before pollution.

Trace Metals	Fine Fraction (<63 μm)		Coarse Fraction (<500 μm)	
	Range	Mean ± SD	Range	Mean ± SD
Co	0.03-1.19	0.15 ± 0.18	0.007 - 2.44	0.77 ± 0.78
Cd	0.003-2.87	0.33 ± 0.65	0.01-0.204	0.11 ± 0.066
Cr	0.28-8.70	2.66 ± 2.28	0.092-6.475	2.07 ± 1.94
Cu	0.02-14.11	1.86 ± 2.50	0.001-1.826	0.266 ± 0.35
Mn	0.05-2.31	0.91 ± 0.53	0.027-10.1	2.357 ± 3.3
Ni	0.14-6.58	1.83 ± 1.30	0.05-4.55	1.409 ± 1.33
Pb	0.04-15.72	2.22 ± 2.95	0.018-1.503	0.54 ± 0.488
Zn	0.19-14.54	2.81± 3.78	0.043-1.146	0.349 ± 0.329
Org. Carbon%	ND-0.79	0.13 ± 0.14	0.02-0.78	0.10 ± 0.13

The finding is confirmed by the significant correlations between metal pairs, i.e. cobalt and copper (r = 0.92 at ρ = 0.01), nickel and chromium (r - 0.97 at ρ = 0.01) zinc, and manganese (r - 0.92) at ρ = 0.01), and zinc and chromium (r = 0.865 at ρ = 0.01) on one hadn and the absence of such correlations with organic matter on the other hand. Generally speaking, the sediments collected fromthe northern part of the east coast contained lower metal concentrations compared to the southern part (Figs. 13a - 13d).

In a trial to compare resutls obtained for trace metal analysis in the present study with the previously published data from various marine environments along the Arabian gulf and the Gulf of Oman (Table 7), it became obvious that the levels reported here for cobalt, chromium, copper, manganese and nickel are lower than the levels reported by Abu-Hilal and Kharodagui (1992) and the others (Table 7). Regarding the levels of cadmium, our data were higher than that of Abu Hilal and Kharodagui (1992) but still lower than other results. The inconsistency in data between our results and reported ones could be attributed to many facotrs as the type, composition, grain size of the sediments, the thickness of the sediment section analyzed, organic carbon contents in addition to the extraction method used.

II. **Relationships between trace metals and other relevant parameters:**

In a trial to establish simplified correlations serving the interpretation of the different analytical data. The relationships between trace metals on one side and trace metals contents other relevant parameters such as grain-size organic matter on the other, were studied.

Table 7 Comparison of data on the concentration of trace metals in surface sediments from various marine environments (µg/g).

Reference	Area	Metal Concentrations							
		Cd	Co	Cr	Cu	Pb	Mn	Ni	Zn
Abu Hilal and Khrdagui (1992)	Arabian Gulf	0.0-0.12 (0.03)	0.0-3.4 (0.73)	1.4-26.2 (10.4)	1.8-43.0 (9.7)	0.0-38.0 (6.06)	12.2-176 (88.8)	0.4-35.4 (9.0)	0.4-142 (31.2)
	Gulf of Oman	0.0-0.2 (0.05)	9-19 (15.1)	26.4-92 (63)	4-7.8 (6.15)	0.0-0.80 (0.33)	122-208 (171)	230-492 (387)	6.6-12.8 (9.7)
Basaham and Lihaibi (1993)	Western Gulf Kuwait	ND ND	26.6-37.7 (32.2)	148.9-204.3 (170.1)	33.8-49.9 (39.1)	ND ND	551-941.2 (771.6)	149.5-209.1 (185.5)	91.4-126.7 (112)
	Saudi Arabia	ND ND	0-16.6 (6)	2.0-87 (32.3)	1.5-27.4 (9.9)	ND ND	18.8-262.3 (133.3)	3.7-116.1 (41.6)	6.2-65.3 (26.3)
	Bahrain/Qatar	ND ND	1.0-1.6 (1.2)	4.4-9.7 (7)	3.8-4.0 (3.9)	ND ND	42.8-57.2 (50.2)	0.2-12.8 (10.9)	20.4-32.2 (26.4)
	NE Qatar	ND ND	0.4-0.6 (0.5)	3-5.1 (3.8)	2.7-3.6 (3.3)	ND ND	17.7-52.5 (34.4)	4.9-6.7 (6)	12.2-13.6 (12.9)
Abayachi and Douabul (1986)	Iraq (North-West)	0.13-0.21 (0.17)	ND ND	5.2-15.2 (6.2)	4.4-12.4 (7.0)	2.3-16.7 (5.0)	590-1090 (755)	66-119 (91)	33274 (3.4)
Al-Hashim and Salaman (1985)	Iraq (North-West)	0.1-1.0 (0.26)	1-3 (2.01)	ND ND	1.5-5.3 (2.59)	3-6 (3.55)	35-78 (51.5)	5-14 (10.07)	8-28 (13.74)
Burns et al., (1982)	Sultanate of Oman	2.5-4.7	ND	16.1-115	3.6-16	29.0-63.0	35-389	21-261	11-36
Sadiq and Zaidi (1985)	Arabian Gulf (Saudi Arabia)	3.2-4.9	ND	7.7-40.4	6.8-13.8	0.7-3.0	11.6-128.9	24.2-50.4	5.6-16.4
Anderlini et al., (1982)	Kuwait (North-West)	1.2-3.9 (1.9)	ND ND	17-121 (80)	8-72 (23)	17-48 (27)	25-950 (470)	15-139 (91)	12-123 (57)
Present Study	East Coast of UAE	0.003-2.87 (0.33)	0.03-1.19 (0.15)	0.28-8.70 (2.66)	0.02-14.11 (1.86)	0.04-15.72 (2.22)	0.05-2.31 (0.91)	0.14-6.58 (1.83)	0.19-14.3 (2.81)

1. <u>Correlations between trace metals</u>:

It has been stated (Fuai and HynH-NgOc, 1976), that the appearance of local high concentration for one metal by possible contamination does not necessarily correlate with high values for other metals. Despite this fact, impressive significant correlations found between several couples of trace metals examined in this study (Table 8). e.g., copper and lead (r = 0.88), copper and zinc (r = 0-82), cadmium and lead (r = 0.80), manganese and nickel (r = 0.71). Significant positive correlations are also detected between copper and chromium (r = 0.60), copper and cadmium (r = 0.62), chromium and zinc (r = 0.54), cadmium and zinc (r = 0.45), cadmium and manganese (r = 0.41). The high correlations between trace metals studied and the virtual absence of such correlations between trace metals and organic materials suggests that the anthropogenic inputs of trace metals in the study area were minimal and may be confined to the southern area of the east coast.

2. <u>Trace metals contents relative to gain-size fractions</u>:

It is well known that various grain-size fractions contain different concentrations of trace metals (Smith et al., 1973; Clfton and Vivien, 1975; Cline and Chambers, 1977; Jaffe and Walters, 1977). Two groups of trace metals could be identified in terms of grain-size fractions. The first, and most numerous one is that including cadmium, copper, chromium, lead, nickel and zinc which show higher metal contents in the fine sand fraction compared to levels obtained in the coarse sand fraction (Figs. 13a-13d & 14a-14d and Table 4 & 5).

Table 8 Correlation between trace metals and organic materials.

	Cu	Pb	Zn	Co	Ni	Cr	Cd	Mn
Cu								
Pb	0.88							
Zn	0.82	0.67						
Co	-0.02	-0.05	-0.11					
Ni	0.18	0.15	0.14	-0.02				
Cr	0.60	0.35	0.54	-0.15	0.27			
Cd	0.62	0.80	0.15	-0.06	0.07	0.19		
Mn	0.21	0.37	0.20	-0.165	0.71	0.17	0.41	
OC%	0.46	0.50	0.64	0.07	0.01	0.20	0.27	0.21

The high level of these metals in the fine sand is attributed to the fact that most contaminants are transported as fine-grained suspended matter with relatively large surface area (Frostner and Wittman, 1981). The second group including copper and manganese have metal concentrations which showed relatively higher levels in the coarse sand fraction as compred with the fine one. It is believed that the high levels in the coarse sand fraction for these metals is probably due to the high percentages of silt in some sediment samples but not in the course sand fraction.

3. Relations between metal contents and contents of organic matter:

In general, the concentration levels of organic carbon are extremely low, ranging from0.1% to 0.2%, and below the natural background (0.7%) of organic carbon according to (Al-Ghadban and Jacob (1994). Abu-Hilal and Khordagui, 1992, determined the values of organic carbon on the eastern coast to be in the range 0.18 - 0.38% and highly concentrated in the southern part of the area.

Although the correlations between trace metals and organic matter have been investigated in many studies, e.g. Kennedy et al., (1971), Collinson and Shimp (1977), Thomas (1972), Gadow and Schafer (1974), Llchtfuss and Brummer (1977), few of them have used such relationship in the interpretation of their results. In many cases, correlations for certain metals with organic matter have been established but not for others (Piper, 1971; Mackay et al., 1972 and Lichtfuss, 1977), and, in some cases no correlation could be deduced (iskander and Keeney, 1974 and Cranston, 1976).

In the present study, we have identified two groups of metals: the first displays a significant positive correlations with organic carbon. (Table 8). This group included copper (r= 0.46), lead (r = 0.50) and, zinc (r = 0.64). The nature of these elements suggest that complexation plays an important role in the distribution patterns. (Samuel and Philips, 1988). The second group which includes metals, as cadmium, cobalt, chromium, manganese, and nickel exhibited no significant correlation with organic matter. It seems that the cause for the lack of uniform correlations between most metals and organic materials is ude to the non-conservative behaviour of the latter.

III. <u>Environmental Impacts of the spilled oil</u>:

In March 31 of 1994, huge quantities of light crude oil have been released into the Gulf of Oman after Baynnuah and Seki oil tanker accident at Al-Fujairah Emirate on the east coast of UAE. Although the change in winds and currents has trapped most of the spilled oil in Omani waters, a sizable portion of the spill was driven ashore and settled in the eastern coast of UAE, causing a major environmental diaster to marine life and environment(Shriadah and Al-Ghais, 1995).

For a contamination/pollution assessment of trace metals in sediments, a comparison carried out between the levels of trace metals originally present before the oil spill occurrence and those enhanced by contributions from anthropogenic sources. Because most contaminants are transported as fine grained suspended matter, metal concentrations of sediments are tested by their concentrations in the fine sand fraction.

The results of the levels and distributions of cobalt, cadmium, chromium, copper, manganese, nickel, lead and zinc in addition to organic carbon as an indicator of pollution of the contaminated coastal area are given in Table (9) are presented graphically in (Figs. 15a-15e). Table (10) sumarinzes the analytical data in the form of ranges and mean values.

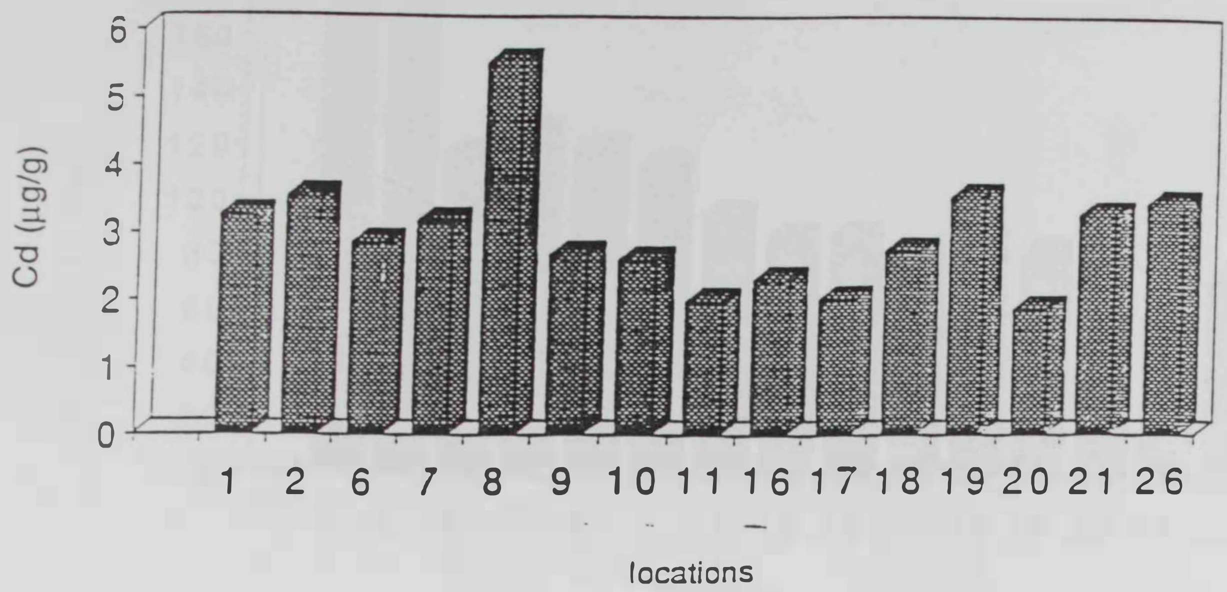
The study indicates clearly that the levels (μg/g dry weight) of cadmium, cobalt, chromium, copper, manganese, nickel, lead and zinc fluctuate in the ranges: (1.86 - 5.52), (23.26 - 39.76), (50.5 - 168.90), (5.65 - 20.9), (197.4 - 325.3), (471.6 - 854.9), (5.28 - 26.8), and (12.7 - 23.7), respectively. The results indicated a considerable increase in the levels of some trace metals concentrations, particularly in heavily contaminated areas (Fig. 15a - 15e). The levels (μg/g dry weight) of cadmium (9.01 times), cobalt (193.23 times), chromium (38.87 times), copper (4.7 times), Mn (272.8 times), Ni (322.7 times), Pb (6.7 times) and Zn (5.6 times) were higher than their levels prior to the oil spill occurrence.

(Figs. 15a - 15e) shows the distribution of trace metals after more than three months of the spill time. The figure show the clearly different distribution patterns of these metals from that found prior to the oil spill as manifested by the elevation of the levels of some metals particularly in the most inundated areas.

The results shown in Table (9) suggests that levels of organic materials measured as organic carbon exhibited, after three months from the spill time, more or less similar levels. Shriadah and Al-Ghais (1995) found that more than 95% less oil could be extracted from sediment samples after about one week from the incident. He

Table 9 Concentration levels of trace metals (µg/g dry sediment weight) and organic carbon (%) in the fine sand fraction (<63µm), after oil spill.

Sampling Site	Trace Metals								Org. Carbon %
	Co	Cd	Cr	Cu	Mn	Ni	Pb	Zn	
1	32.85	3.23	168.9	20.9	280.7	698.2	26.8	18.5	0.30
2	33.86	3.52	168.6	11.1	299.7	725.7	15.05	19.8	0.40
6	38.46	2.84	119.3	8.13	305.1	795.8	10.29	17.4	0.20
7	39.76	3.16	127.4	13.00	325.3	854.9	12.78	18.98	0.30
8	32.70	5.52	122.06	8.00	278.7	649.4	10.29	14.01	0.20
9	25.11	2.66	116.5	7.40	224.9	513.4	10.80	12.6	0.40
10	23.26	2.58	97.64	6.76	205	471.6	9.34	11.8	0.20
11	28.46	1.98	90.12	6.20	234.4	586.8	5.28	11.7	0.12
16	26.56	2.3	91.24	6.67	210.3	494.9	7.08	13.4	0.12
17	25.27	2.01	83.83	6.08	218.8	521.7	6.08	23.4	0.30
18	25.45	2.72	89.69	7.17	218.9	491.7	19.89	13.4	0.24
19	27.12	3.53	85.42	8.39	256.6	545.15	26.40	18.13	0.42
20	25.56	1.86	50.5	5.65	197.4	482.2	13.20	13.61	0.40
21	25.54	3.26	62.66	7.89	241.9	522.1	23.90	14.6	0.30
26	25.41	3.43	77.16	8.17	228.3	523.7	25.49	12.93	0.30



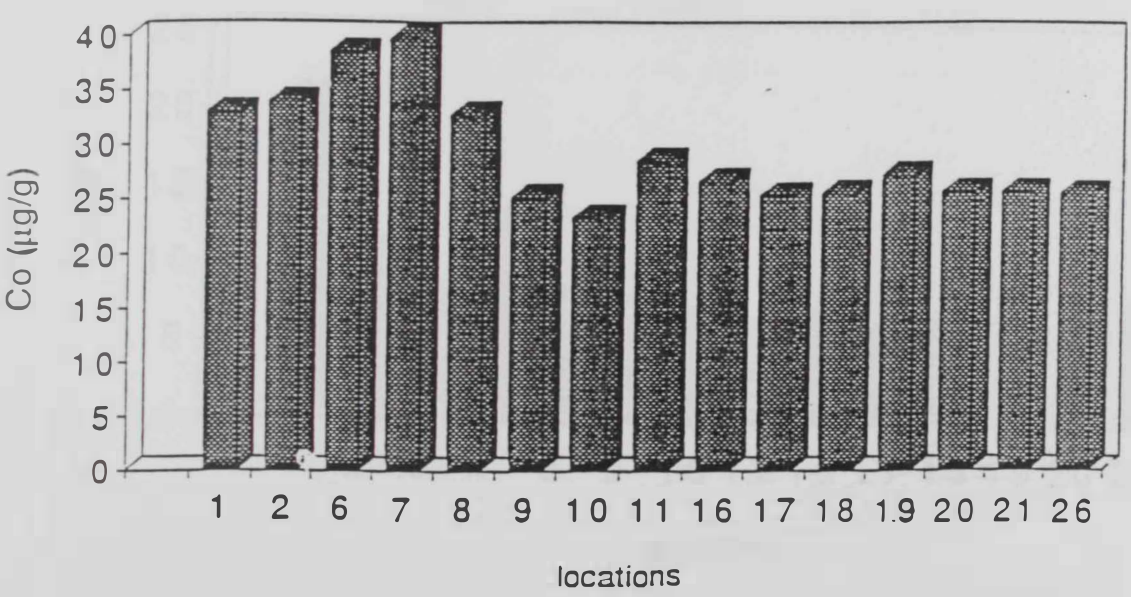
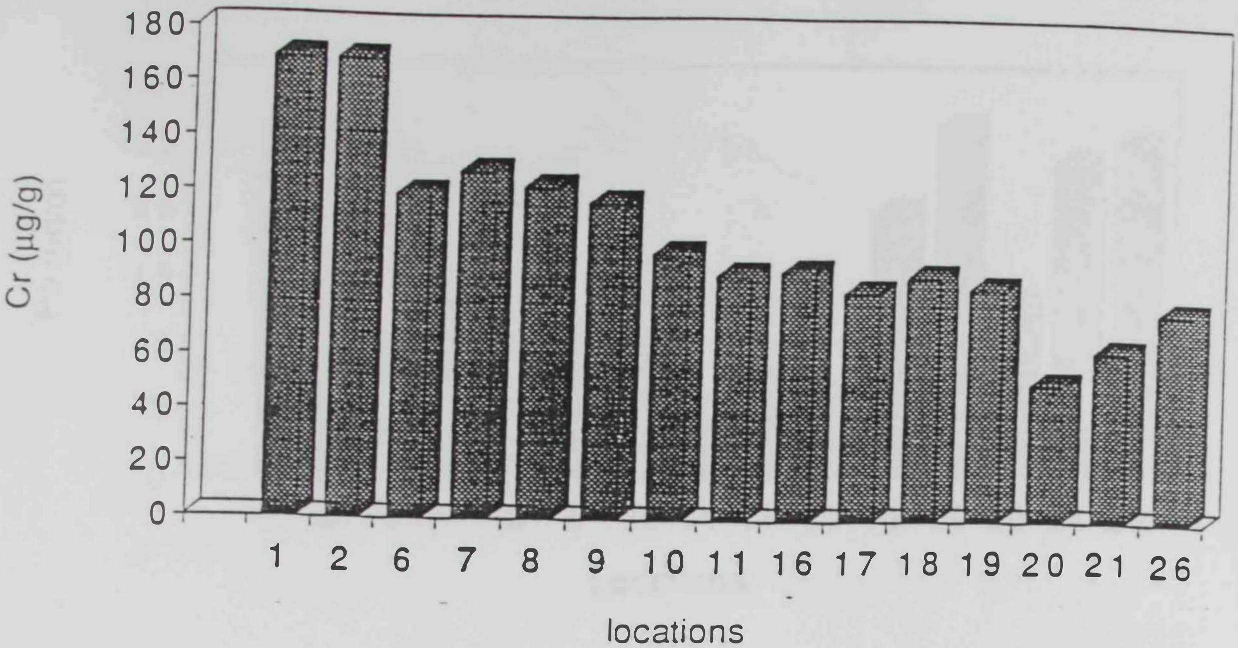


Fig. 15a . The concentrations of cadmium and cobalt (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E. After oil spill



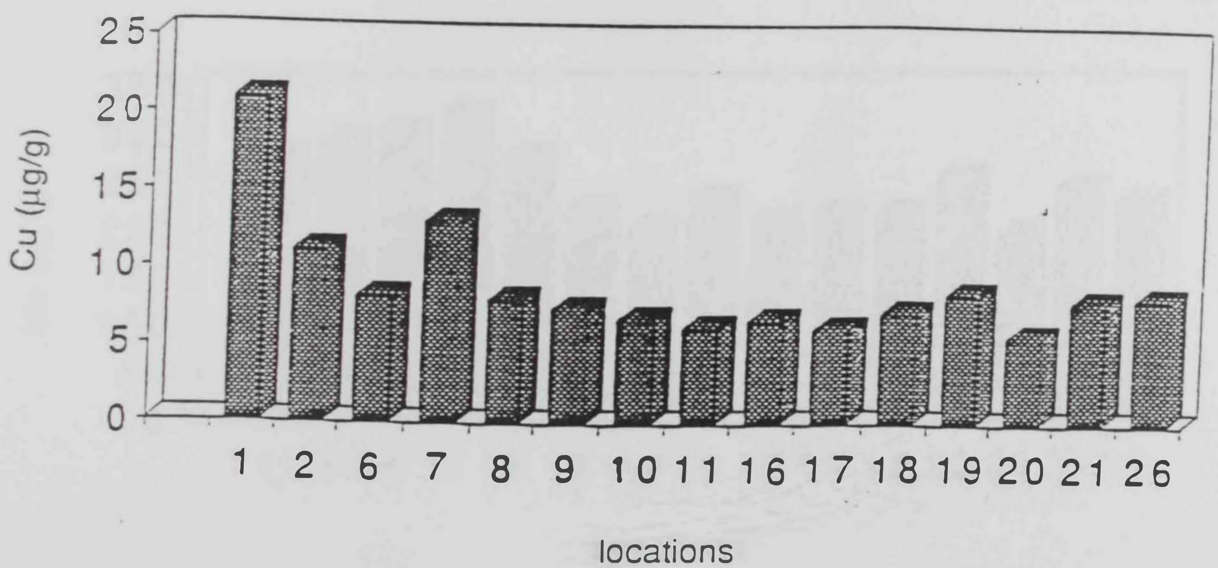
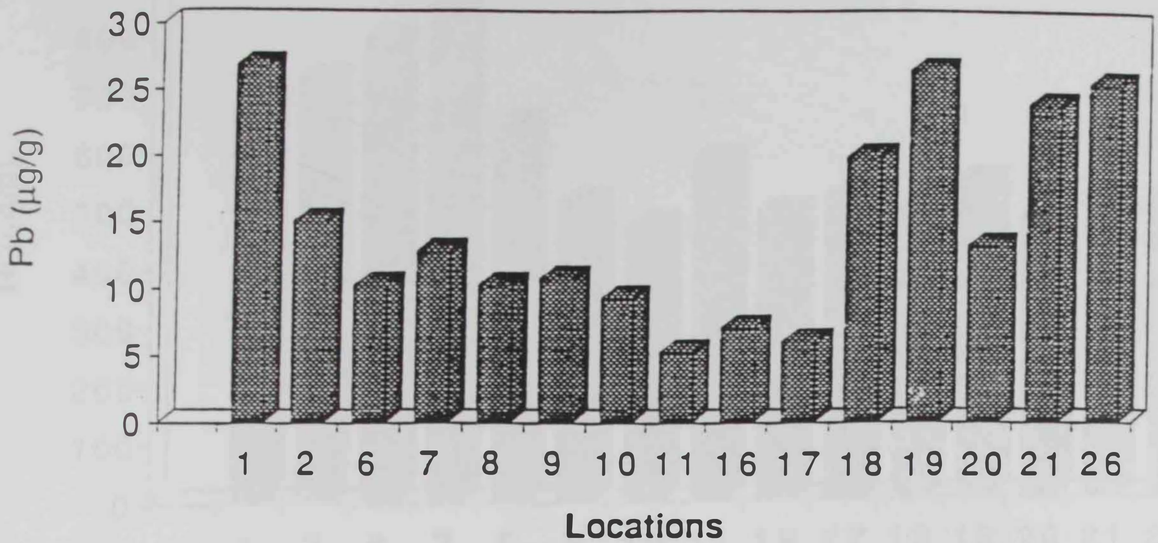


Fig. 15b . The concentrations of chromium and copper (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E. After oil spill



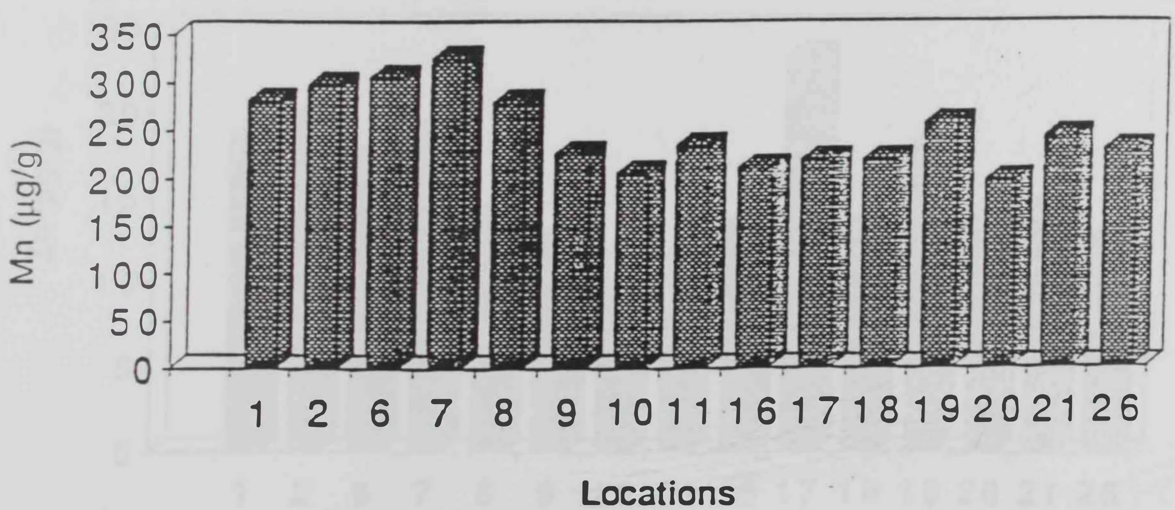
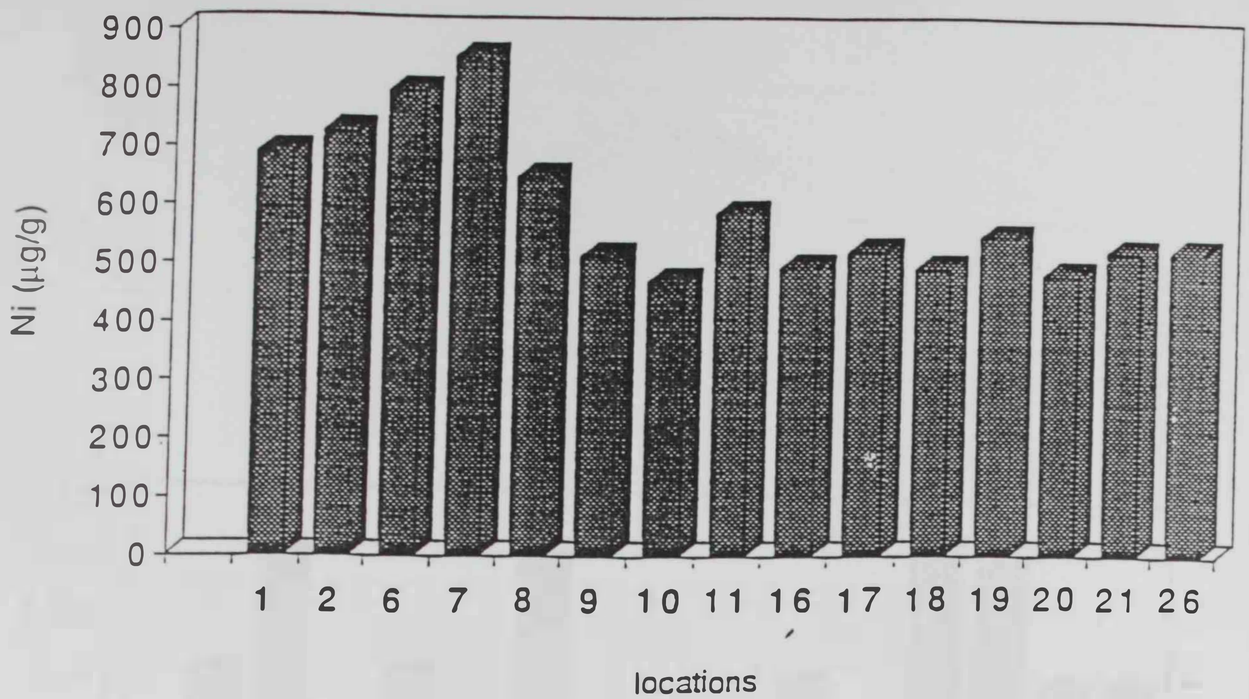


Fig. 15c . The concentrations of lead and manganese (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E After oil spill



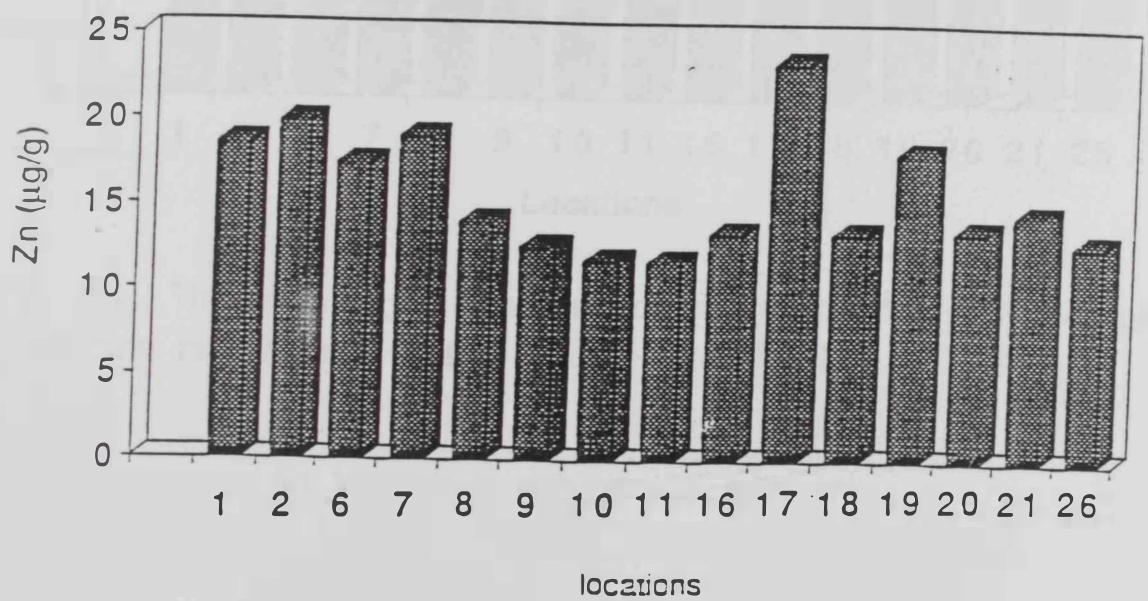


Fig. 15d . The concentrations of nickel and zinc (µg/g dry weight) in the fine sand fraction (<63 mm) of the surface sediments from the east coast of U.A.E. After oil spill

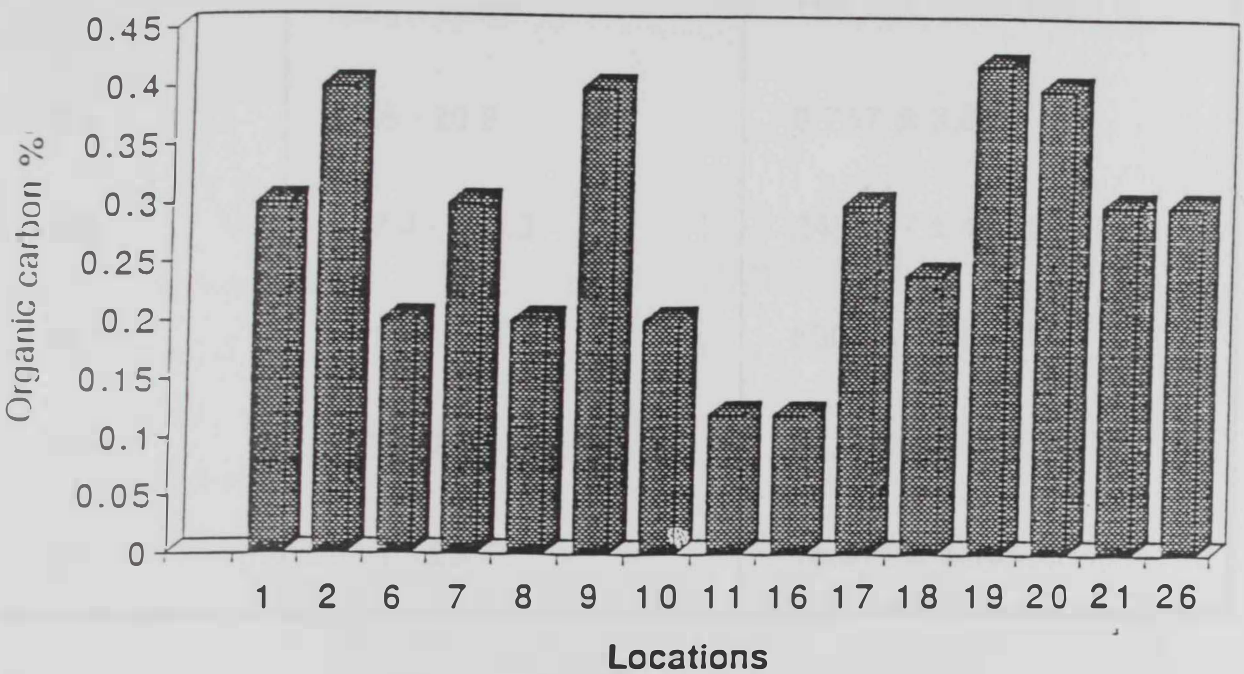


Fig. 15e. The percentages of organic carbon in the fine sand fraction (<63 mm) from the east coast of U.A.E. After oil spill

Table 10 Ranges and mean values (±SD) of trace metals (µg/g dry weight), after oil spill (fine sand fraction).

Trace Element	Fine Sand Fraction	Mean ± SD
Co	23.26 - 39.76	28.985 ± 5.162
Cd	1.86 - 5.52	2.973 ± 0.903
Cr	50.5 - 168.9	103.401 ± 34.109
Cu	5.65 - 20.9	8.767 ± 3.866
Mn	197.4 - 325.3	248.267 ± 40.057
Ni	471.6 - 854.9	590.537 ± 122.984
Pb	5.28 - 26.8	14.793 ± 7.675
Zn	11.7 - 23.7	15.617 ± 3.494

attributed this to the great water dynamism of the area in additon to different clean-up operations. The higher levels reported here for some metals such as chromium, manganese and nickel after about three months fromthe accident were due to the solublization of metals from the surfaces of clays and detrital particles. It has been stated that (Preseley et al., 1972), microbial degradation of petroleum compounds at the sediment surface results in lower pH, the release of hydrogen sulphine and carbon dioxide must cause a rapid removal of these metals absorbed to the surfaces of clays and detrital particles.

Comparing the data obtained three months after the spill time to other published data in sedimetns collected from Saudi Arabia (Fletkamp and Krupp, 1994) one year after the Gulf war oil spill (Table 11), one can safely conclude that the environmental impacts of the spilled oil on teh east coast had minor effects in terms of trace metals levels and organic meterials and the marine environment of UAE is returning to its normal condition.

Table 11 Comparison of trace metals concentrations in surfacial sediments with sediments of similar pollution episodes.

Area	Trace Metals								Reference
	Cd	Cr	Co	Cu	Pb	Mn	Ni	Zn	
East Coast (U.A.E)	0.003-2.87	0.28-8.70	0.03-1.19	0.02-14.11	0.04-15.72	0.05-2.31	0.14-6.58	0.19-41.54	Present Study (1992)
South of Arabian Gulf	2.5-5	3.4-5.3	ND	ND	0.6-4.2	ND	20.5-64.6	4.2-22.6	Al-Arfaj & Alam (1994)
Arabian Gulf Abu-Ali Area	0-6.41	4.76-25.04	0-7.01	0-7.98	0-35.81	27.58-167.84	3.21-39.11	2.41-20.15	Al-Arfaj & Alam (1994)

3.2. Recommendations:

Based on the present study, the following recommendations can be made:

1. Although the present study could shed some light on levels and distribution patterns of trace metals along the eastern coast of UAE, more comprehensive studies are required to get more information particularly on the levels and distributions of trace metals in different parts of the marine environment as seawaters, sediments and marine organisms along the eastern coast of UAE.

2. Impact of pollution sources as land-based industrial, domestic wastewater and oil pollution on levels and distribution patterns of trace metals should be subject to continuous monitoring programmes to identify their levels and accumulation in sediments, fish and seafood paticularly in case of toxic metals.

3. To establish the relative importance of the various contributing sources, it is recommended that a distinction be made between the detrital fraction and the non-detrital fraction to measure the input due to human activities in the surrounding area.

4. A supplementary information concerning the relationships between levels and distribution patterns of these metals and other parameters as grain size, organic carbon be obtained as an indication of their assoication with organic detritus probably as absorbed ions, in addition to calcium carbonate which is considered a good indication of their association with biologically derived skeletal materials.

5. In order to fully understand the distribution of trace metals in sediments, their association with clay minerals as well as with ferro-manganese hydrogeneous phases should also be studied.

CHAPTER 4

HEAVY MINERALS

4. HEAVY MINERALS

4.1. Introduction

During the last two decades a great attention has been given to the ocean and sea floor to assess their mineral potential. Studies have led to the discovery of a large number of marine sulphide deposits and renewed interest in other marine mineral resources, e.g. manganese nodules, phosphates and placer deposits (Teleki, et al., 1987). From these marine resources, only lacer deposits are currently mined because they are located in shallow waters and their mining technology is well known.

The techniques usually used for the benefaction of placer minerals include hydrogravimetric, electrostatic, and magnetic separation (Teleki, et al., op. cit.). Placer deposits are clastic sediments which contain economic concentrations of heavy minerals concentrated by hydraulic processes.

Placer deposits may have been formed on the continental shelf and to assess this potential one should start with the study of heavy minerals distribution along the coastal areas.

In the coastal environment, beaches are usual site for heavy minerals deposition. Due to the differences in the density of heavy and light minerals, they show different hydraulic properties. The grains of heavy minerals are less easily transported by currents as those of light minerals, especially if they are the same size and shape. In any sand sample, because of density differences the grains of heavy minerals tend to be smaller than grains of light minerals (Kurdass, 1987).

This chapter deals with the study of the heavy mineral contents of recent surface coastal sediments along the eastern coast of United Arab Emirates (U.A.E.) between Dibba and Kalba. The aims behind studying the heavy minerals in these sediments are: (1) determination of heavy minerals content present in the coastal sediments, (2) define their source areas, and (3) delineation of coastal locations bearing heavy mineral concentrations of possible economic value, and if so, areas in the hinterlands with possible occurrence of mineral deposits.

4.2. Previous Work

In the last decade, numerous studies have been carried out on beach sediments to assess their content from heavy minerals, particularly the Pacific Coast of U.S.A. and that of Greece and Cyprus.

Among the numerous papers that have been published on heavy minerals in beach sediments on the Pacific Coast of U.S.A., are Stinson (1957) stated that black sands of the Pacific Coast contain ilmenite and magnetite. He pointed out that magnetite is the most abundant mineral, followed by ilmenite whereas the latter is related to igneous intrusion. Kulm et al., 1969 show that Oregon beaches contain occurrences of placer deposits enriched in ilmenite, chromite and magnetite with trace amounts of gold and platinum. Moreover, Mertie (1969) has pointed out that platinum in the northern beach at Washington is thought to be deposited with gold.

The Klamath mountains bordering the Washington coast are composed of peridotites of the Josephine and Pearsoll peak ophiolites which are considered to be the main source of podiform chromite deposits (Carlson et al., 1985).

Placer potential of the continental shelf of Alaska and Pacific Coast was described with more details including the geologic framework of each coast by (Clifton and Luepke, 1987). Later, Luepke (1989) studied the placer potential on the West Coast of the U.S.A. He found that this parts of coast have a high potential for gold and chromite placers. Also, he described the occurrence of placer deposits based on the presence of known heavy minerals occurrences in adjacent beach placers and bedrock sources.

From the literature, it appears that this work can be considered the first approach to the distribution, concentration of the heavy minerals present in the studied sector along the Eastern Coast of the U.A.E.

4.3. Materials and Methods

Thirty five samples of recent coastal sediments were collected and mechanically analyzed using the dry sieving method adopted by Folk (1974). Generally, the samples were collected from the supratidal zone, but at some sites, samples across the beach from the tidal (A), intertidal (B) and supratidal zone (C) and (D) were taken in order to study local variations. The locations of the samples are shown in (Fig. 16) 250 gm of each dry sample was sieved and almost 50 gm of the fine sand fraction (2.0 ϕ - 3.0 ϕ) was used for heavy mineral separation. The fine sand fraction is usually used by many workers for heavy mineral separation because it represents a large proportion of the total sediment budget (Nakhla, 1985; Dasilva, 1979; Al-bakri *et al.*, 1984; and Metra *et al.*, 1992).

Bromoform with 2.85 gm/cm^3 density was used in the separation, and the results are presented in Table (12) and depicted graphically in (Fig. 17).

The heavy minerals fraction is further subjected to magnetic separation, particularly samples with high yield of heavy minerals. The magnetic separation was carried out at 0.1, 1.0 and 1.5 amperes. Magnetite was first separated at 0.1 A, followed by ilmenite at 1.0 A, and then chromite at 1.5 A. The non-magnetic fraction is found to be mainly composed of silicate minerals, e.g. pyroxenes and amphiboles. The percentages of the magnetic fractions in each sample are presented in Table (13) and graphically plotted as histograms in (Fig. 18).

In addition, polished sections for twelve magnetic fractions were prepared and examined by ore microscope for mineral identification and as a trial for seeking the potential presence of platinum group minerals.

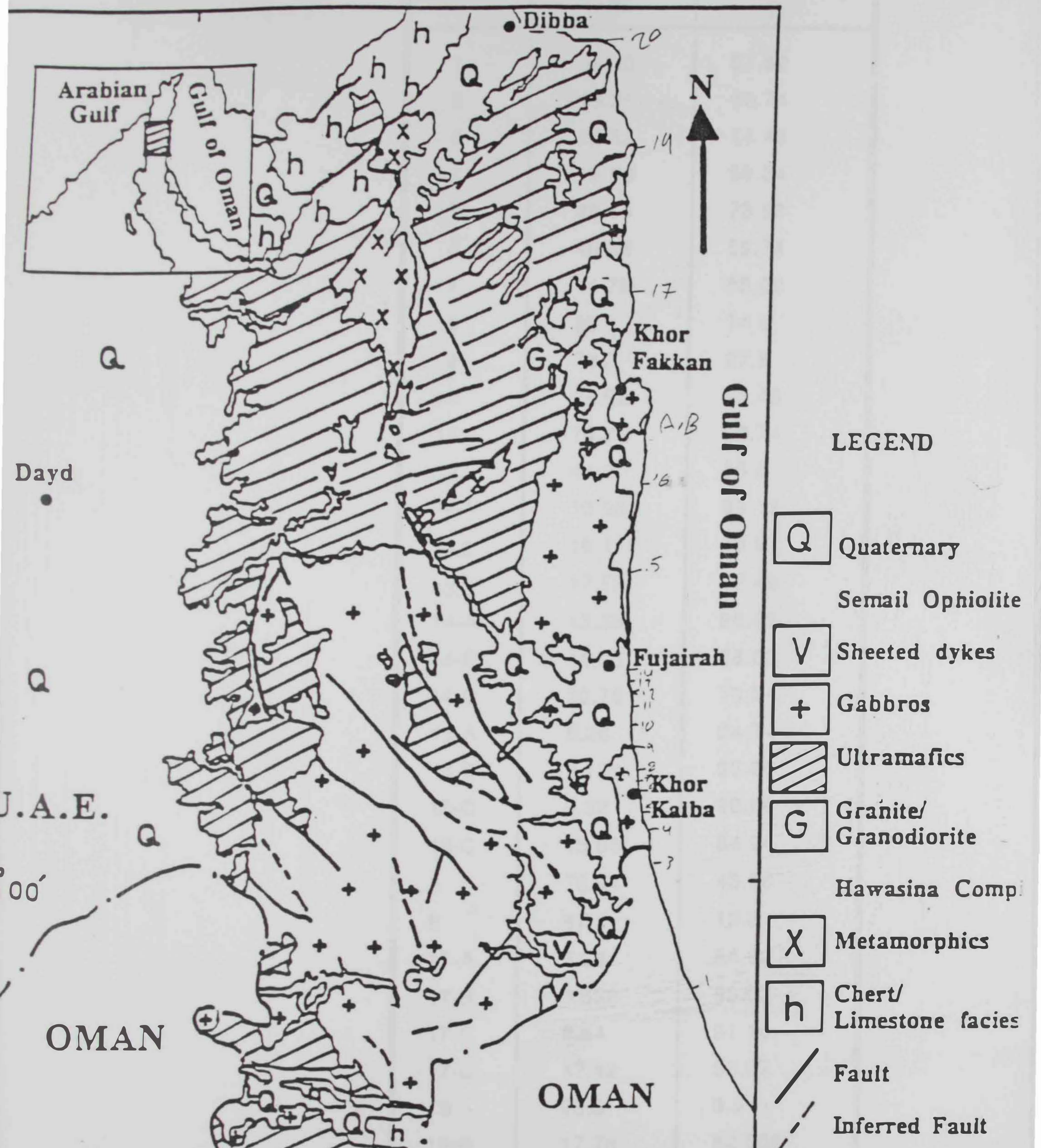


Fig. 16. A Simplified Geological Map of the Northern Emirates Mountains showing the location of the studied samples.

Sample No.	Heavy %	Light %
1	42.20	57.89
2	13.2	86.74
3	25.52	74.48
4	19.66	80.34
5	26.14	73.86
6	40.26	59.74
7	14.78	85.22
8	25.4	74.6
9	72.2	27.8
10	26.52	73.48
11	70.26	29.74
12	44.2	55.8
13.1	10.88	89.12
13.2	19.1	80.9
13.3	17.52	82.48
14-A	13.38	86.62
14-B	11.98	88.02
14-C	20.76	79.24
15-A	5.26	94.74
15-B	4.131	95.86
15-C	9.32	90.68
16-C	15.06	84.94
A	76.94	43.06
B	87.2	12.8
17-A	5.98	94.02
17-B	3.538	93.02
17-C	8.84	91.16
17-D	47.42	52.57
18	98.5	3.5
19-B	17.76	82.008
20-A	15.12	84.87
20-B	8.06	91.94
21-A	0.44	99.56
21-B	0.511	99.82
21-C	1.1	98.9

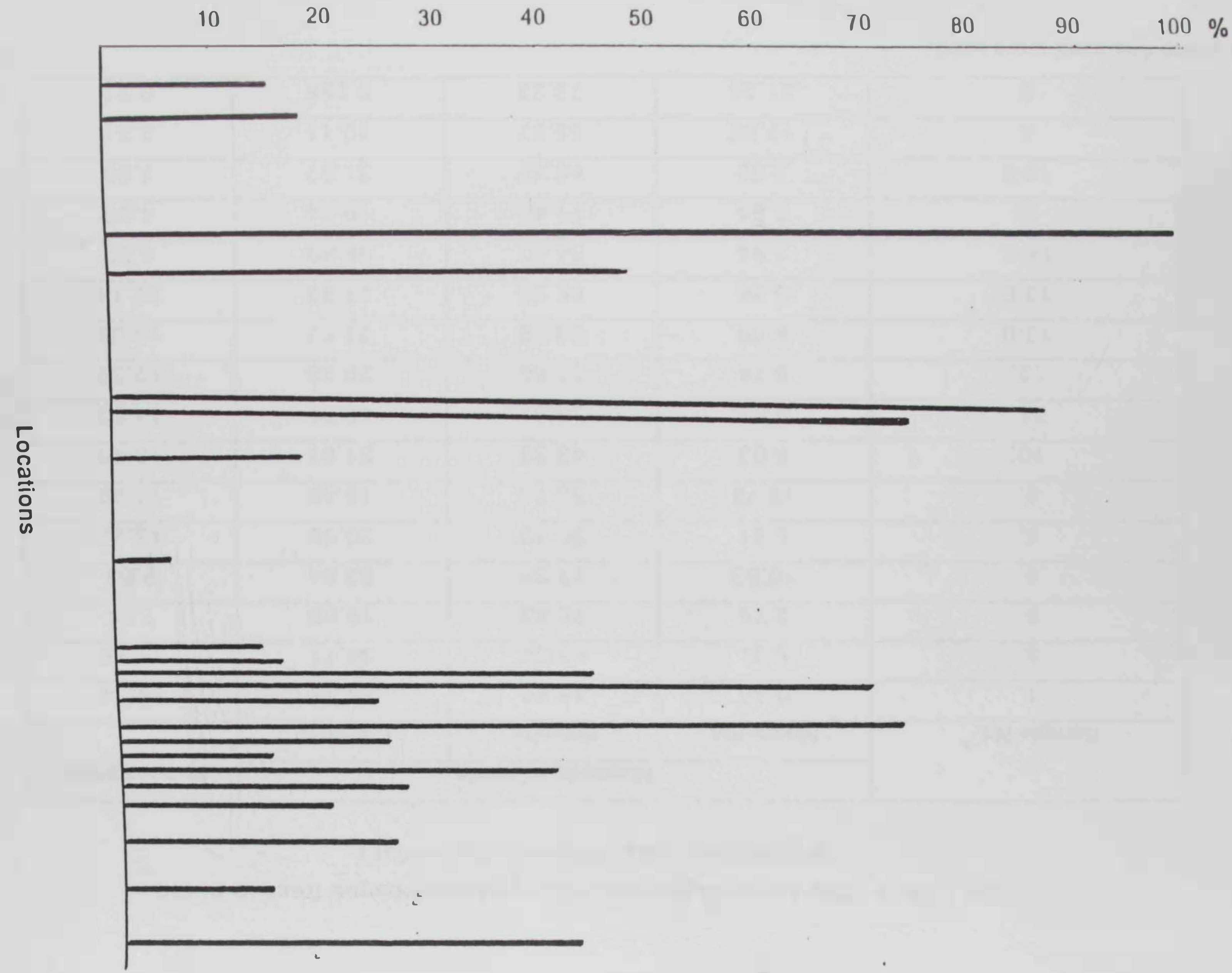


Fig. 17 Heavy minerals distribution along the eastern coast.

Table (13). The percentages of opaque and non-opaque fraction of the different samples (Magnetic separation).

Sample No.*	Magnetic minerals			Non-magnetic
	Magnetite	Ilmenite	Chromite	
1.	0.36	45.99	35.28	18.34
3.	5.01	45.37	34.71	14.89
5.	2.75	75.43	19.89	1.91
6.	10.53	17.38	62.54	9.53
8.	5.51	50.70	30.55	13.22
9.	18.78	53.76	15.45	11.99
10.	6.03	43.89	31.67	18.40
11.	9.87	33.61	42.61	14.00
12.	6.74	51.62	29.23	12.39
13-B	8.69	59.58	21.67	10.05
13-E	0.34	59.58	17.92	22.14
14-C	3.94	54.52	36.89	4.52
18	5.54	71.41	19.04	4.00
19-B	3.69	56.47	31.97	7.85
A	17.59	69.97	10.11	2.31
B	21.26	73.23	5.288	0.21

* 50 gm of the fine sand were used.

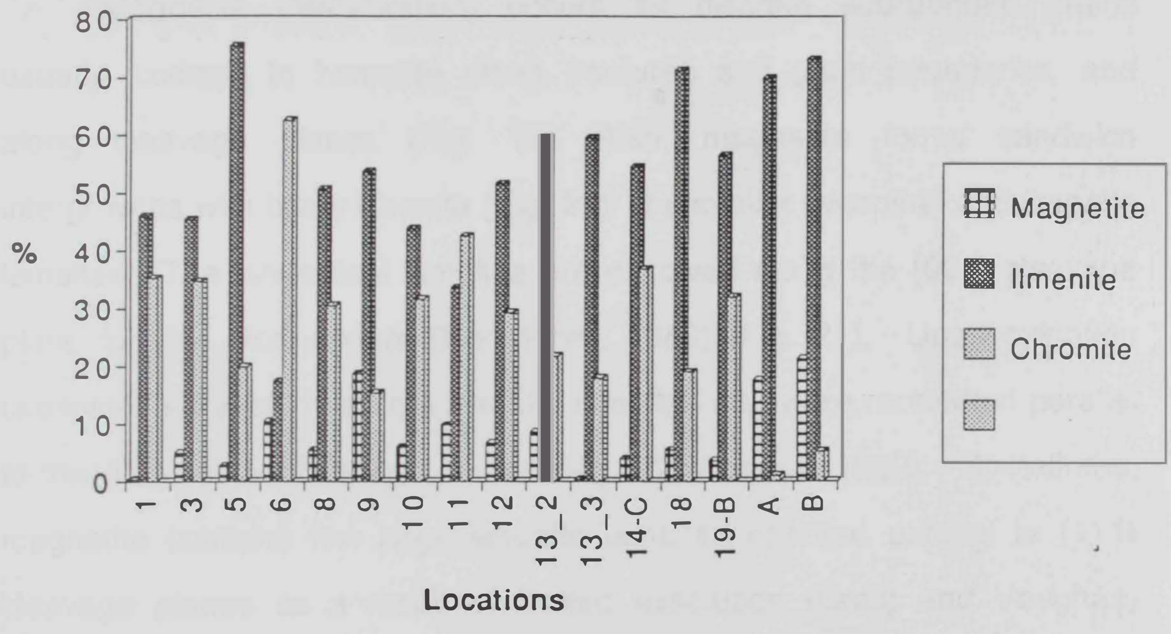


Fig. 18 Distribution of ilmenite, chromite, and magnetite.

4.4. Ore Microscopic Study

Examination of 12 polished sections of the magnetic fraction of the sampels reveals that the abundant opaque minerals are: magnetite, chromite, and ilmenite with, in addition to few sulphides and platinum group minerals.

1) Magnetite:

Magnetite (Martitization) occurs as discrete subrounded grains usually oxidized to hematite along fractures and grain boundaries, and along cleavage planes (Fig. 19). Also, magnetite forms sandwich intergrowths with blady ilmenite (Fig. 20) It contains uvospinel and ilmenite lamallae. The ullvospinal lamallae are exsolved along the (001) cleavage plane forming cloth-texture (Ramdoher, 1980) (Fig. 21). Upon oxidation uvospinel is transformed into ilmenite lamallae that were reoriented parallel to the (001) cubic cleavage planes (Fig. 22) (Ineson, 1989). Sometimes, magnetite contains few large ilmenite lamallae oriented parallel to (111) cleavage planes as a result of limited exsolution (Craig and Vaughan, 1981).

2. Ilmenite:

Ilmenite is present in the form of discrete elongated grains, that are usually altered to sphene, and/or rutile; as well as sandwich intergrowth with magnetite (Fig. 20). Some ilmenite contains exsolution lamallae of spindle-shaped hematite oriented parallel to (0001) cleavage plane (hematite-ilmenite exsolution texture) (Fig. 23). These textural relations between hematite and ilmenite are the result of continuous solid solution between the

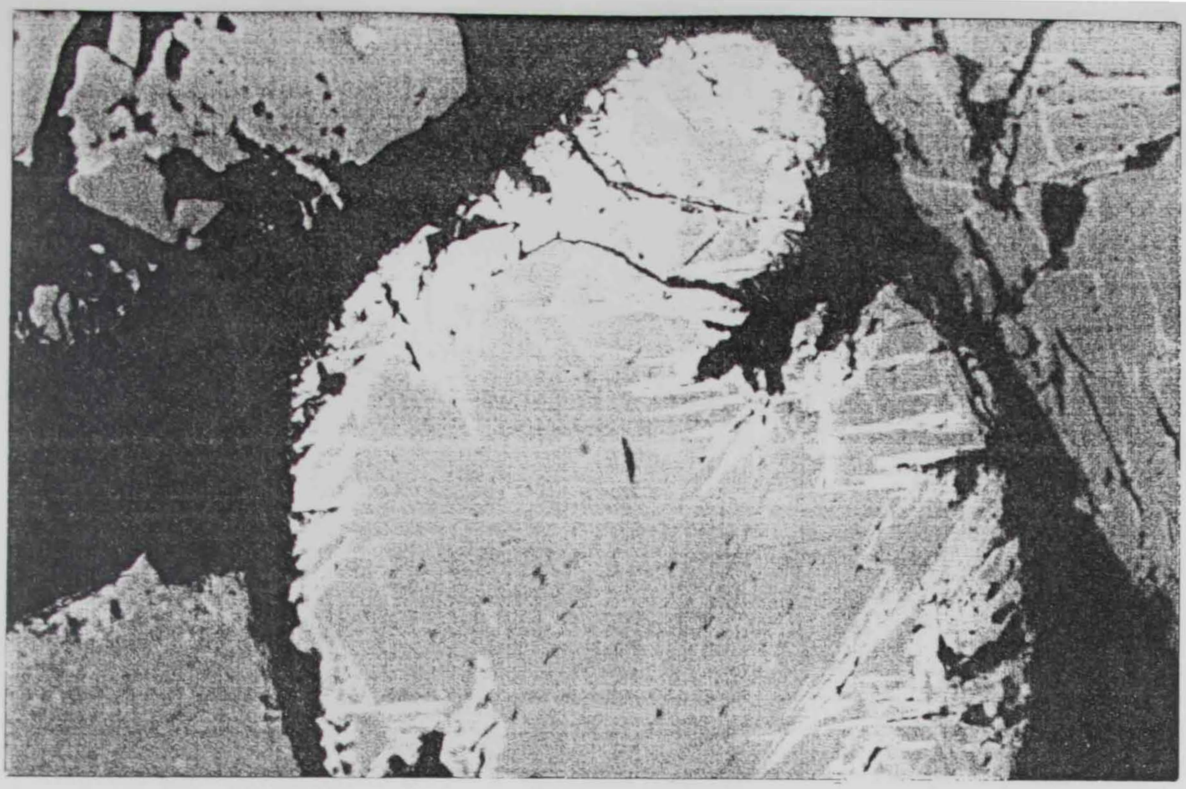


Fig. 19. Magnetite oxidized to hematite (Martitization) along cleavage planes and grain boundries.

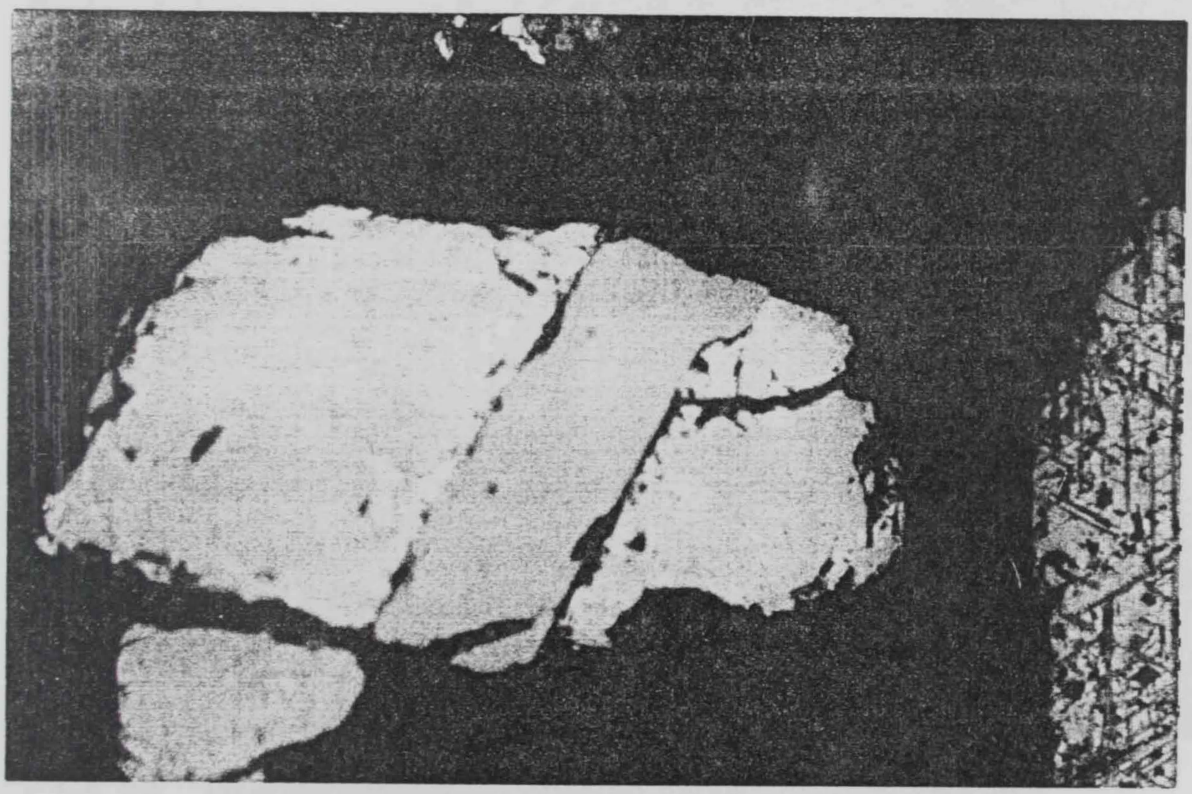


Fig. 20. Sandwich intergrwoth between magnetite (M) and Ilmenite(I).

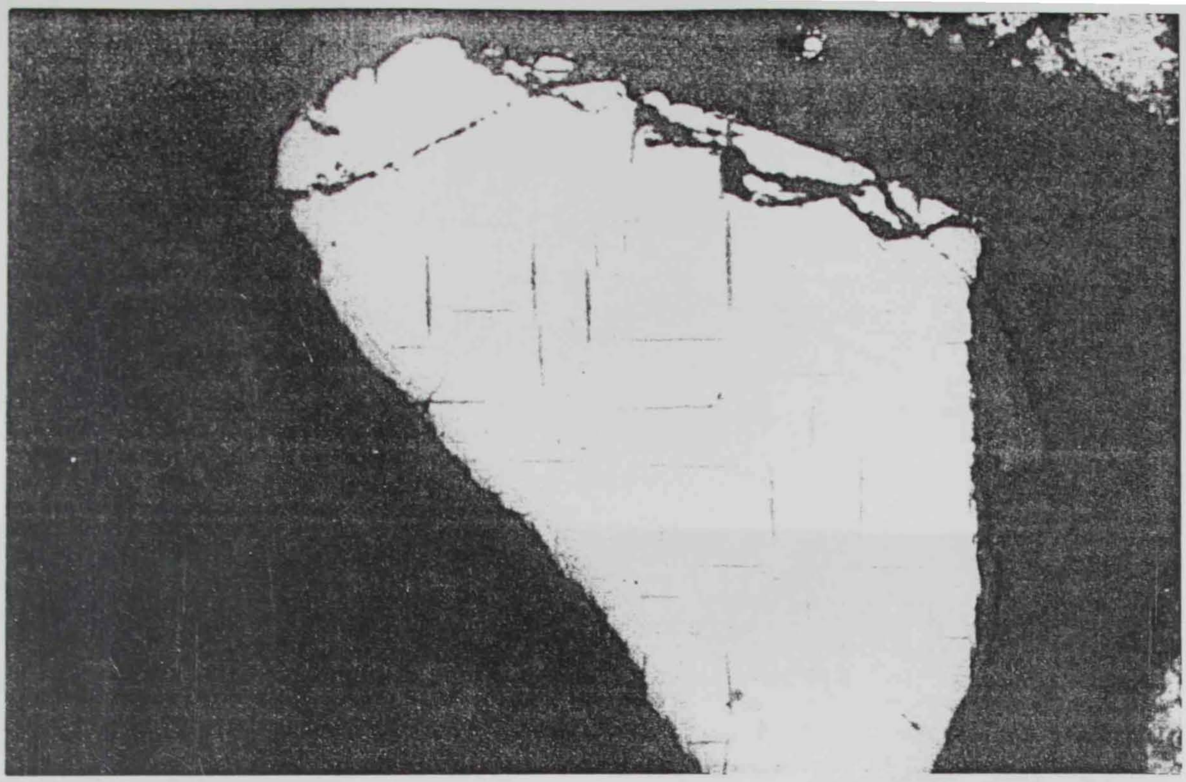


Fig. 21. Ulvospinel lamallae (black) oriented parallel to (001) cleavage planes of magnetite (M).

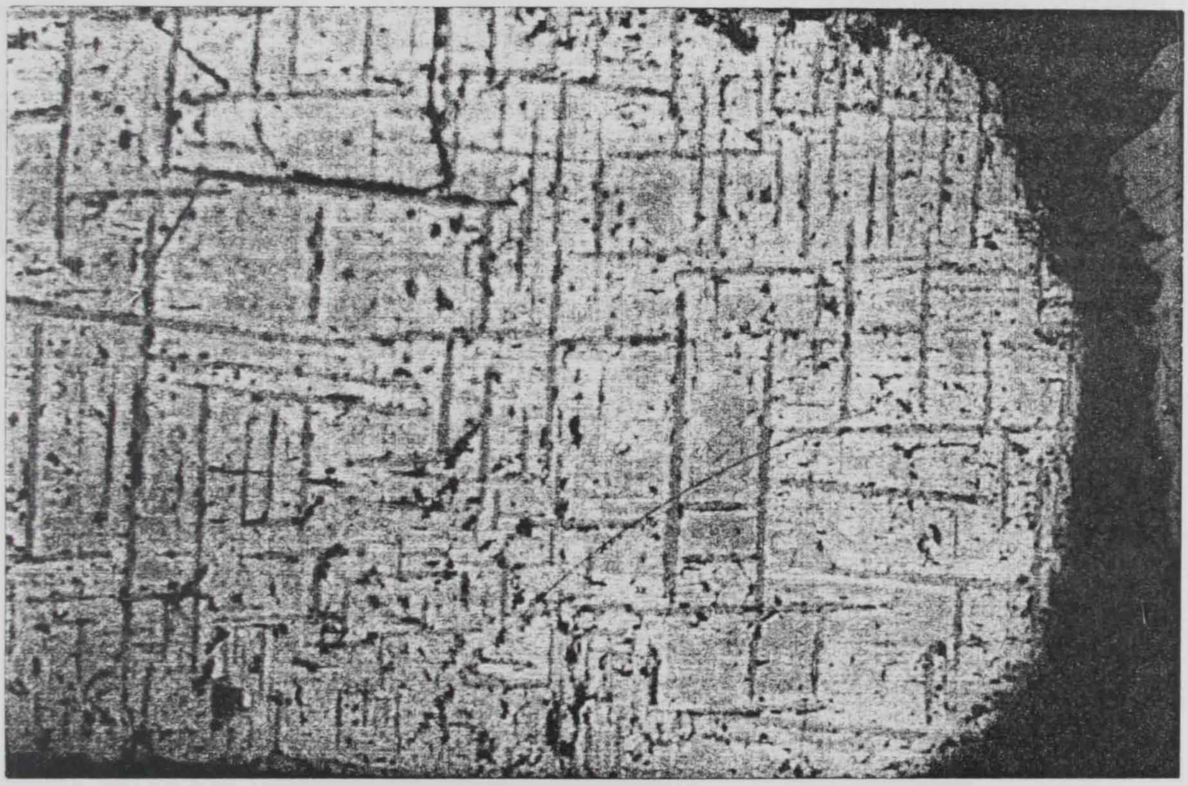


Fig. 22. Ilmenite lamallae (I) oriented parallel to (001) cleavage planes of magnetite. Notice martitization of magnetite.

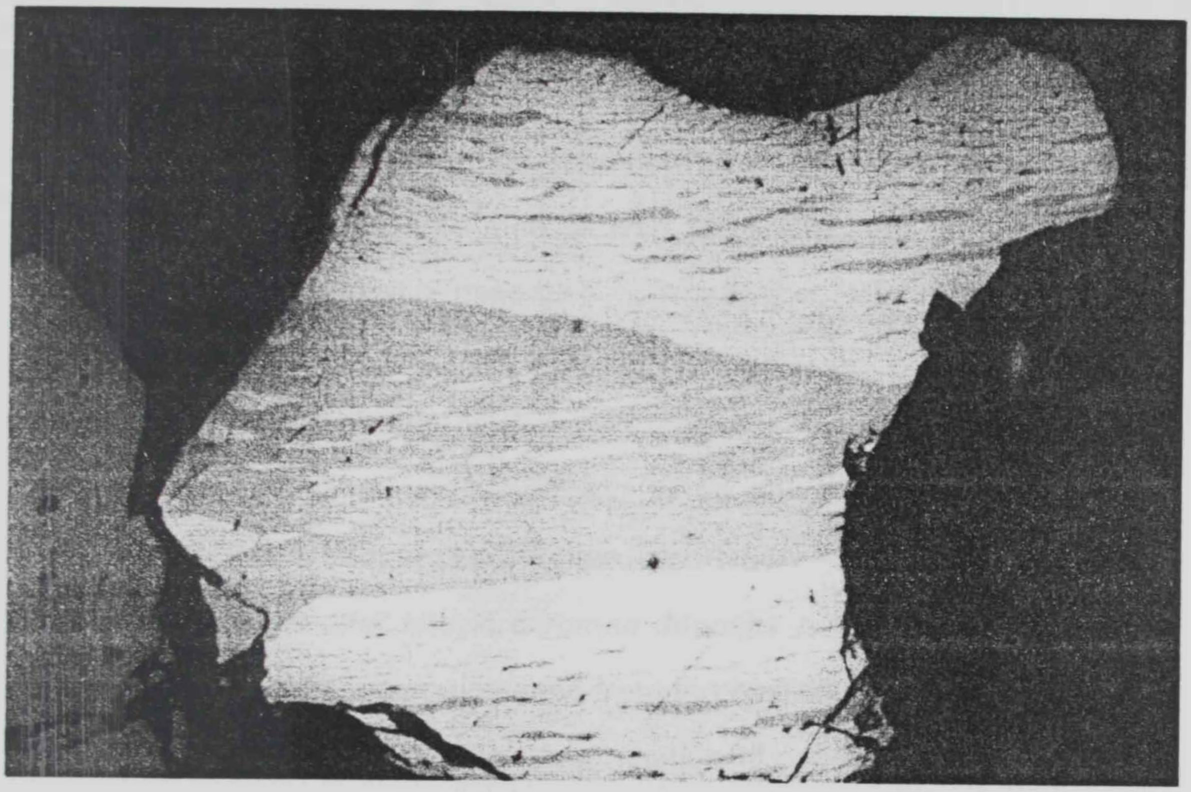


Fig. 23. Ilmenite (I) - Hematite (H) exsolution texture : Notice : hematite contains ilmenite lamallea (i) and ilmenite contains hematite lamallea (h).

two minerals (Ineson, 1989). The exsolution textures described above are characteristic as described from magnetic ores associated with mafic igneous rocks (Craig and Vaughan, 1981).

3. Chromite:

Chromite usually occurs as angular to subangular grains due to its breakdown along the fracture planes commonly found in chromite. Some chromite grains are highly brecciated into finer chromite grains (Fig. 24). Some grains show oxidation rim of magnetite surrounding a core of fresh chromite (Fig. 25). It was observed that some chromite grains contain some inclusions of white a coloured mineral with high reflectivity most probably one of the platinum group minerals. In addition, few pyrrhotitte and chalcopyrite grains are not uncommon.

4. Platinum Group Minerals:

Platinum group minerals are said to be associated with Chromite deposits in ophiolitic sequences (Prichard and Neary, 1985). It is reported that wadi sediments near known chromite deposits in U.A.E. contain up to 1.2 ppm platinum, and a chromite sand from the eastern coast assayed 0.55 ppm platinum (MPMR, 1977). The examination of polished section reveals the presence of few fresh grains characterised by their tin-white colour and high reflectivity. Some serpentinite grains contain euhedral crystals with optical properties which identify them as one of the platinum group mineral (Fig. 26). However, these grains need further work for proper identification using more sophisticated techniques.

This heavy mineral assemblage is always considered as typical of the ophiolitic ultramafic and mafic rock of the ophiolite sequences.

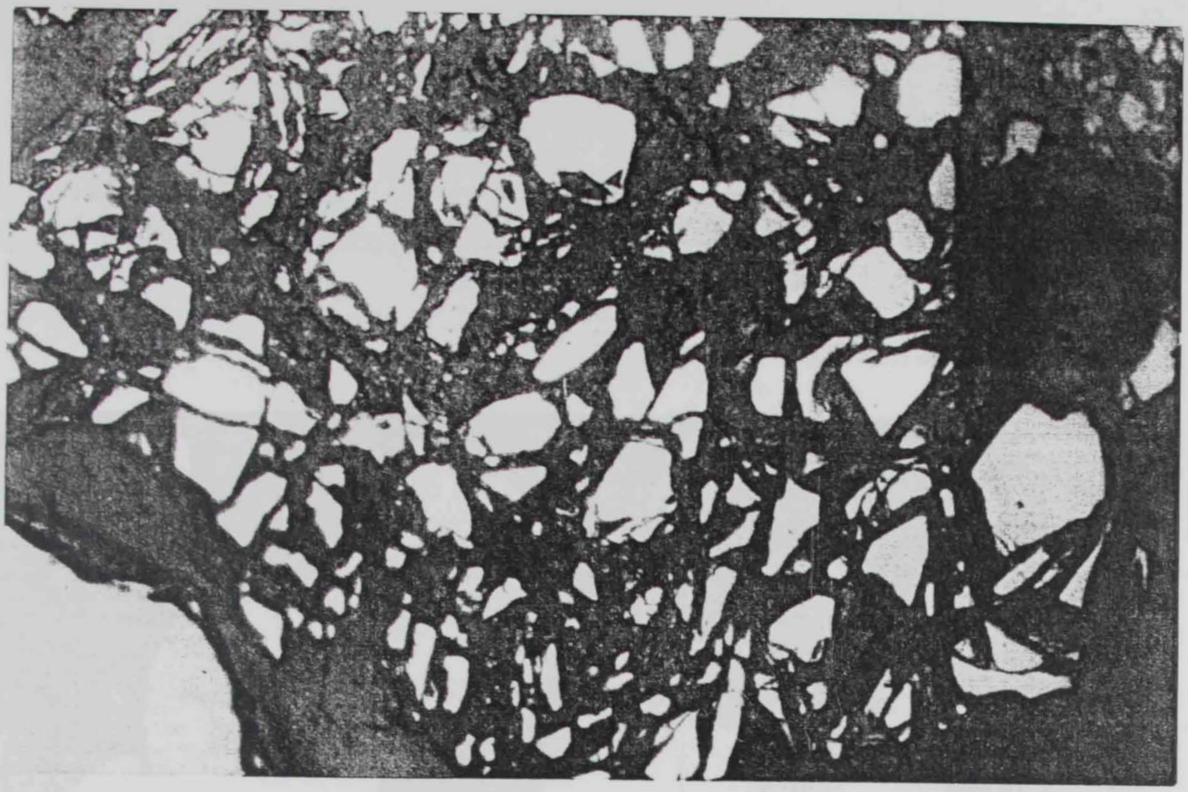


Fig. 24. Brecciated chromite in serpentinite (S).

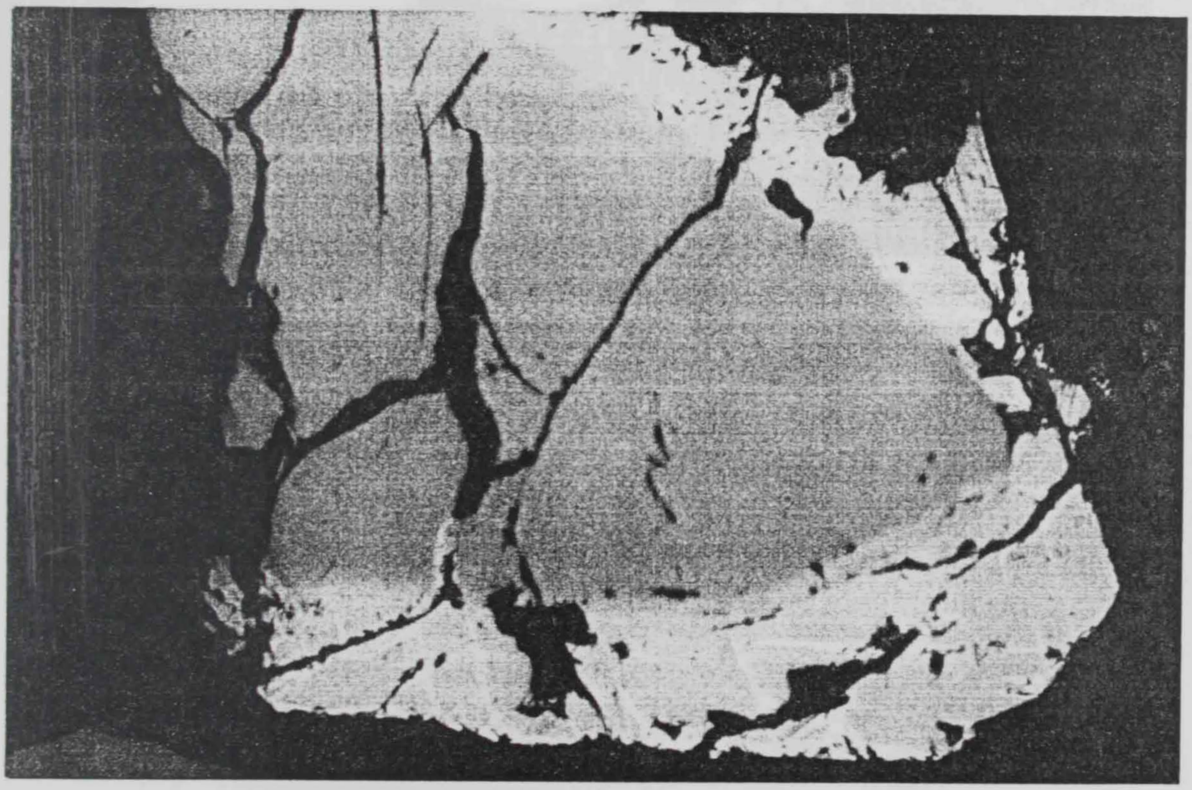


Fig. 25. Chromite (C) oxidized to magnetite (M). Notice martitization of magnetite.

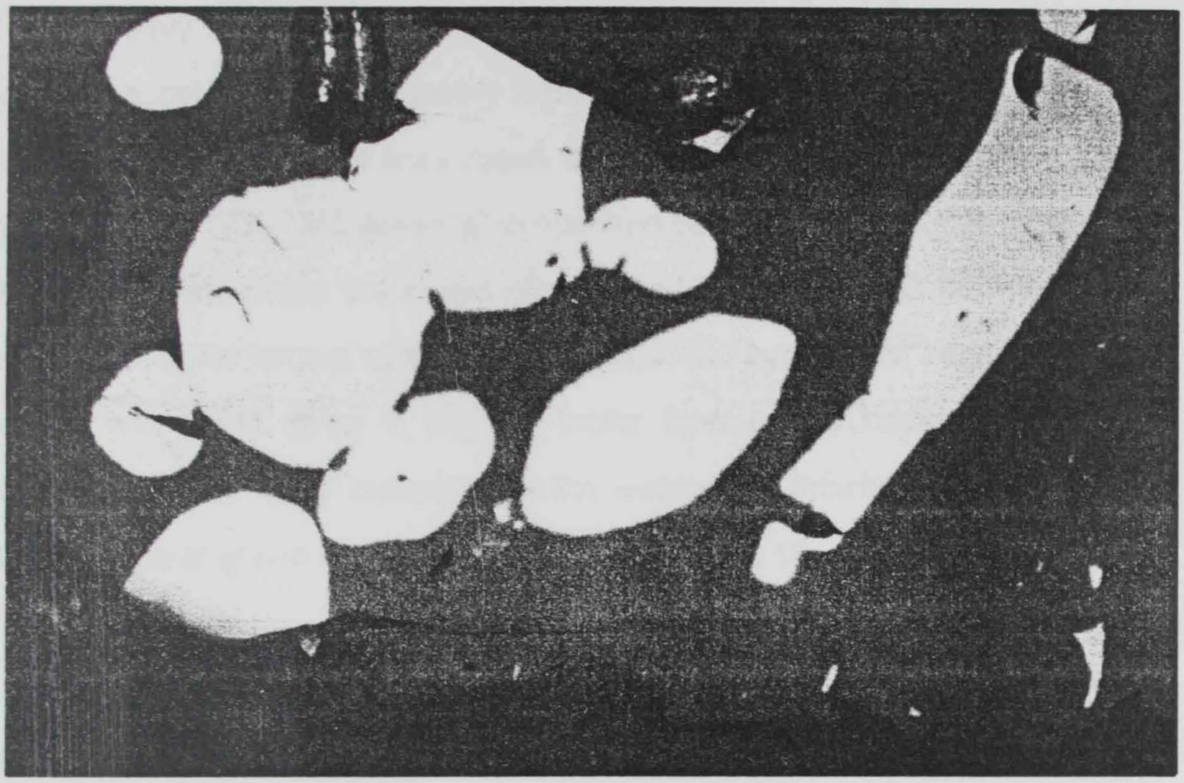


Fig. 26. A platinum group minerals (?) enclosed in serpentenites.

4.5. Results and Discussion

Heavy mineral separation revealed the general richness of the eastern coast sediments in heavy minerals. Their percentage were found to be as high as 78% and may reach 98% in some sites. Range = 0.4 to 98.5%, mean 36%. Moreover, a comparison between the samples collected from traverses across the beach (designated A, B, C and D in Table 12), showed that the largest concentration was in the superatidal zone because of the winnowing effect in the thin water layer of the backwash current where velocities fall of steeply near the water-sand interface removing the lighter mineral grains (Fig. 27) (Seibold and Berger, 1982).

In addition to the density difference between light and heavy minerals, other factors which improve the sorting process are the higher rolling ability of the light minerals (Veenstra and Winkelmolen, 1976) or shear sorting by which larger grains are pushed upwards in a stirred-up sand flow (Sallengen, 1979) .

The enrichment in ilmenite is usually accompanied by a decrease in chromite content (samples 5, 9, 13B, and 8) in only a few samples the chromite increase relative to ilmenite (samples 6 and 11) in front of Wadi Ham. The relative proportion of ilmenite, chromite, and magnetite in the samples was attributed to the type of rocks exposed in the drainage basins.

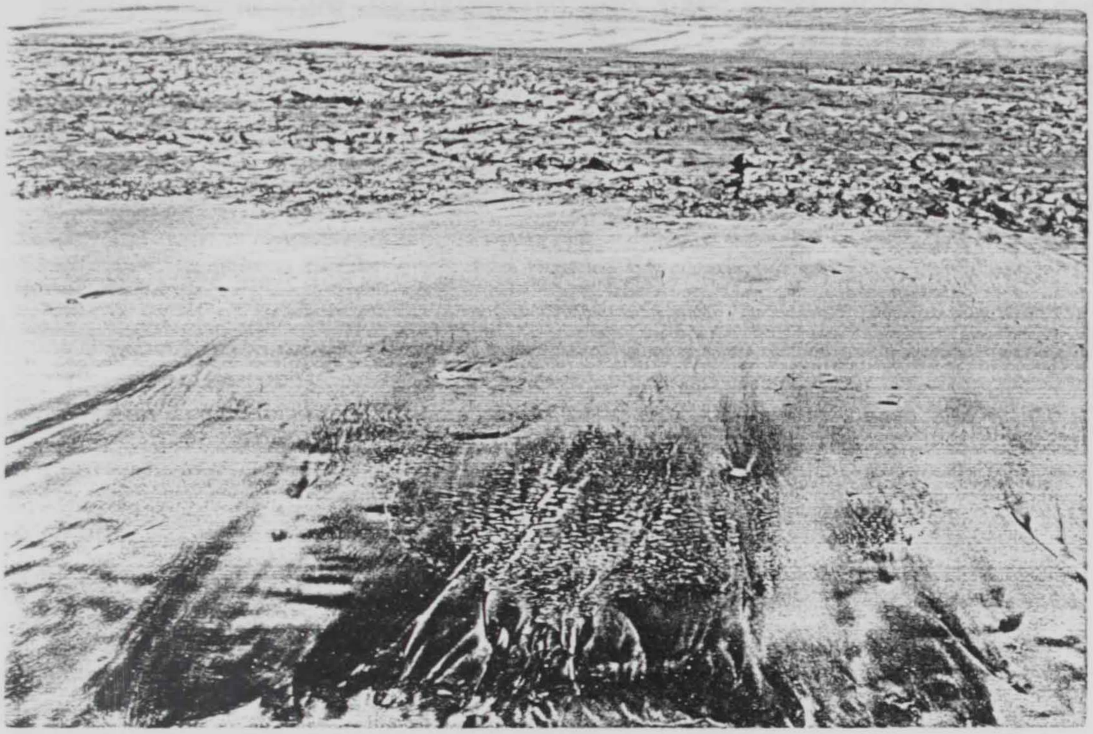


Fig. 27 Concentration of heavy minerals in supratidal zone.

However, these grains need further work for proper identification using more sophisticated techniques.

Worthy to mention this heavy mineral assemblage, mentioned above, is always reckoned to the ophiolitic ultramafic and mafic rock of the ophiolite sequences. This, in turn, prove that this heavy mineral assemblage is mainly derived from the ultramafic and mafic rocks of the semail ophiolite forming the eastern mountaineous area of the U.A.E. Moreover, considering that the main source of the heavy mineral content in the studied beach sediments is the Semail ophiolitic sequence render conclusion reached before that these sediments are mainly formulated by stream (river) agent of transportation is quite plausible.

Heavy minerals distribution

Along the studied coastal area three locations showed pronounced high concentrations of heavy minerals. These are; south of Fujairah town, north of the oceanic hotel (KhorFakhan) and the beach area of Bedia village (Fig. 16, 17, 28, 29, 30 & 31). These three areas were found to be characterized by the occurrence of heavy minerals in the form of lenses and streaks up to 10 cm thick (Fig. 32). The areas characterized by heavy minerals enrichment render their situation in front of large drainage basins is a matter of self explanatory (Fig. 28). In general, the heavy mineral distribution along the coast was found to be increasing along with increasing proximity to areas suffered from major shoreline inflection points (Fig. 28, 29, 30 & 31). It is obvious that the source is the large basins drainage and the relative concentration is attributed to the deceleration of the longshore currents at the inflection points.

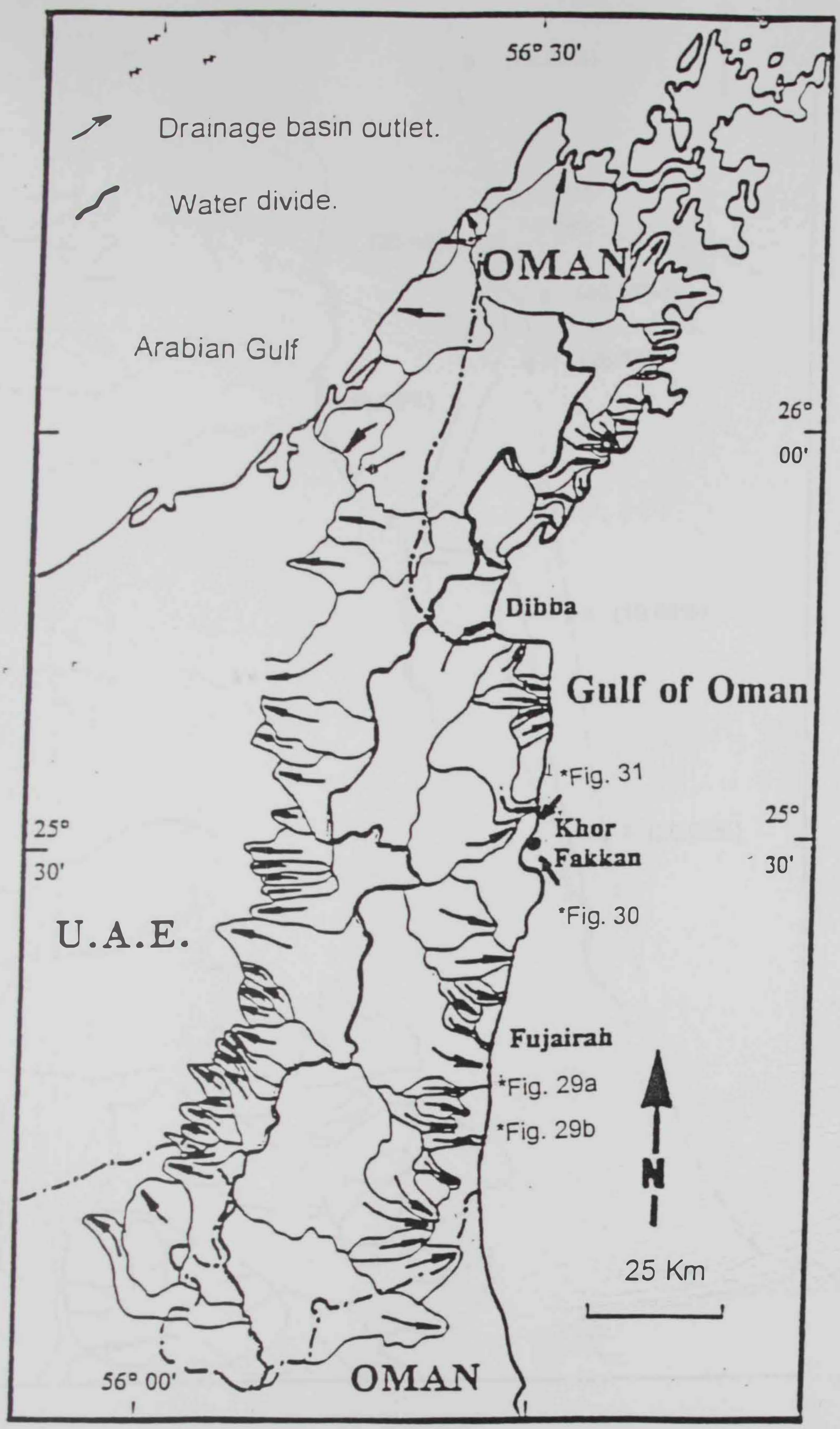
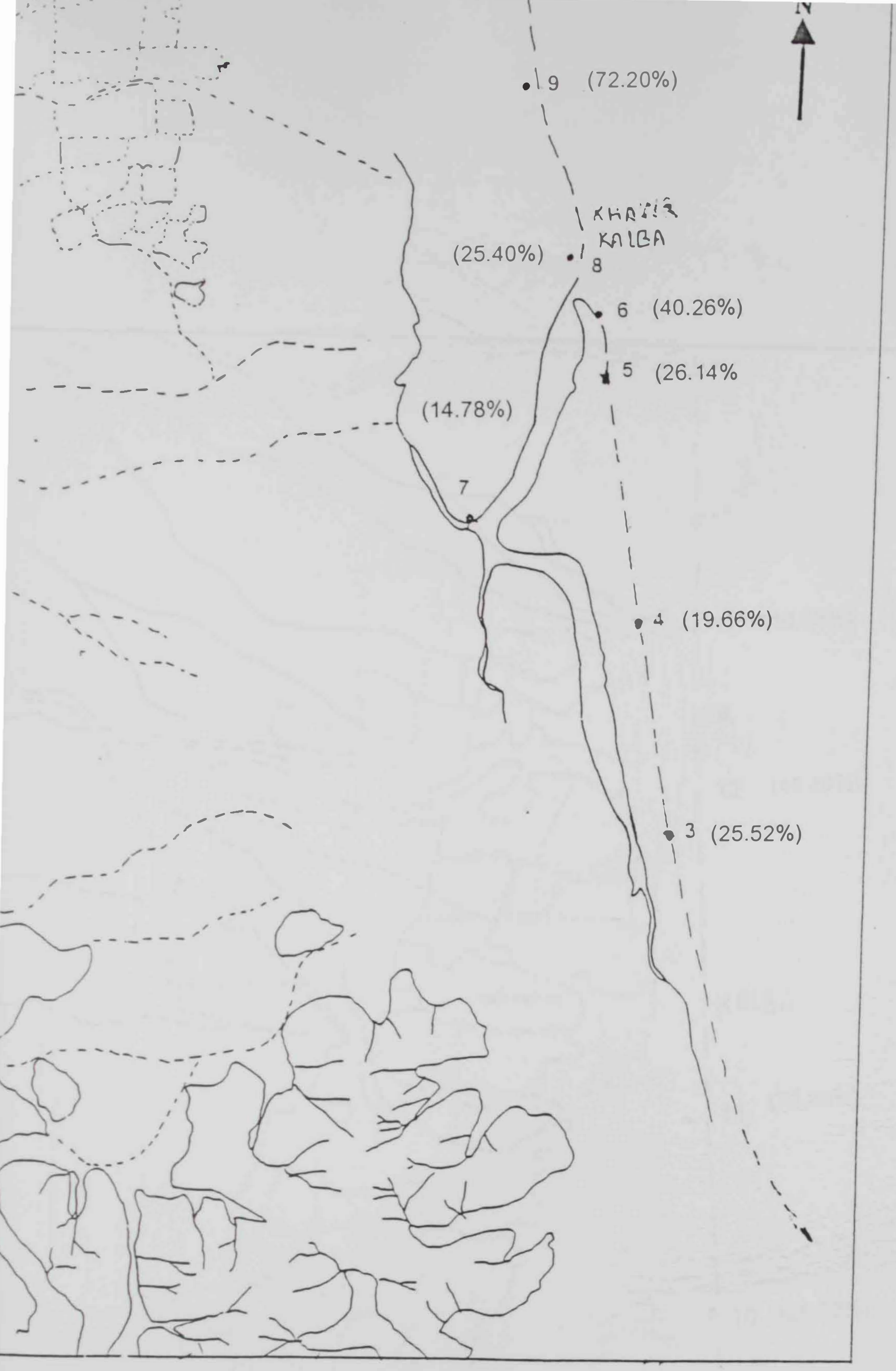


Fig. 28 A Map showing the drainage basin in the Northern Emirates Mountains (El-Hag, 1992).
* Location of areas with high heavy mineral concentrations.



g. 29a. Distribution of heavy minerals South Fujairah Town along Khawr-Kalba. Notice : The area is located to the north of a headland located within Oman territories..

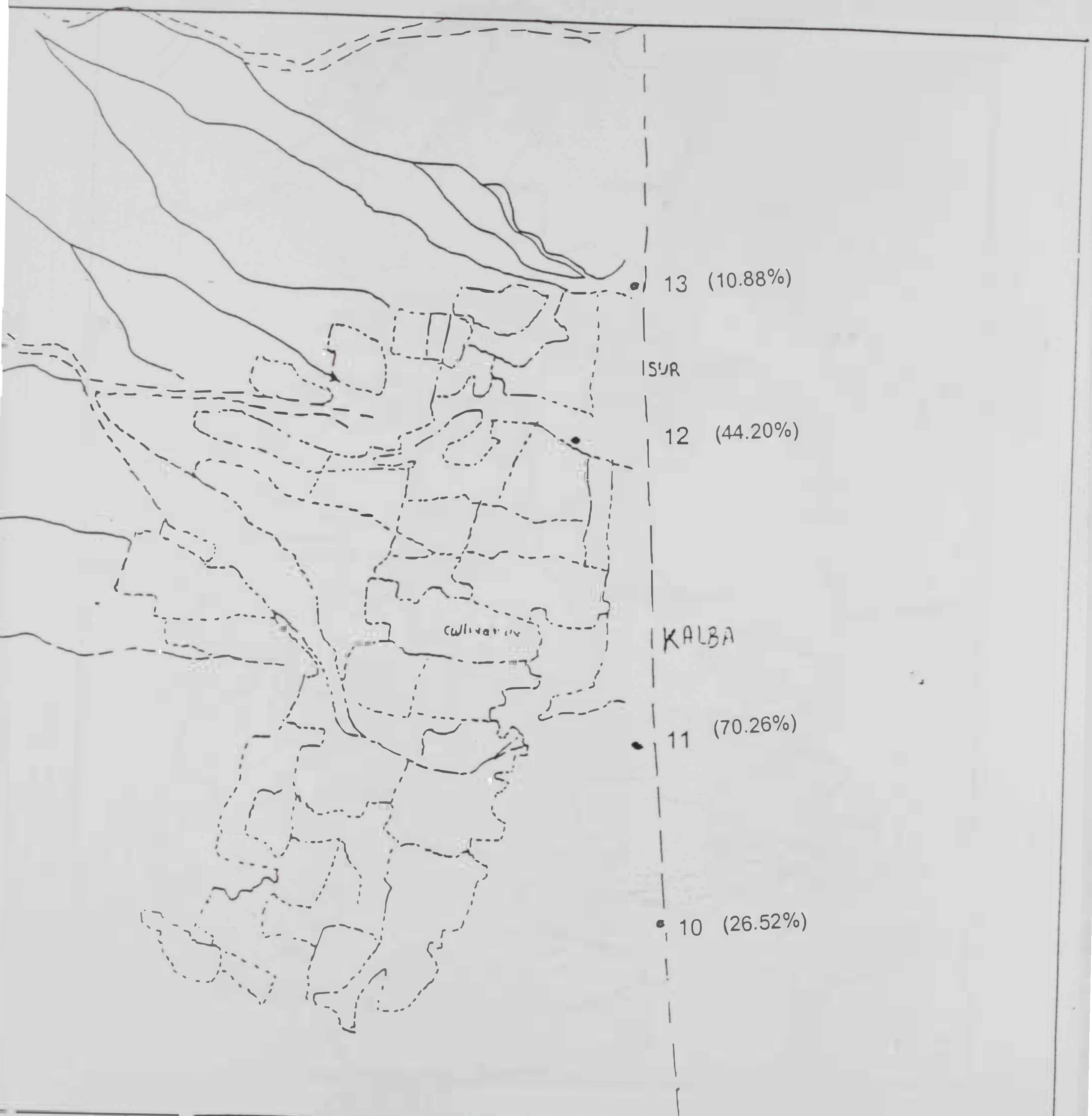


Fig. 29b. Distribution of heavy minerals South Fujairah Town.

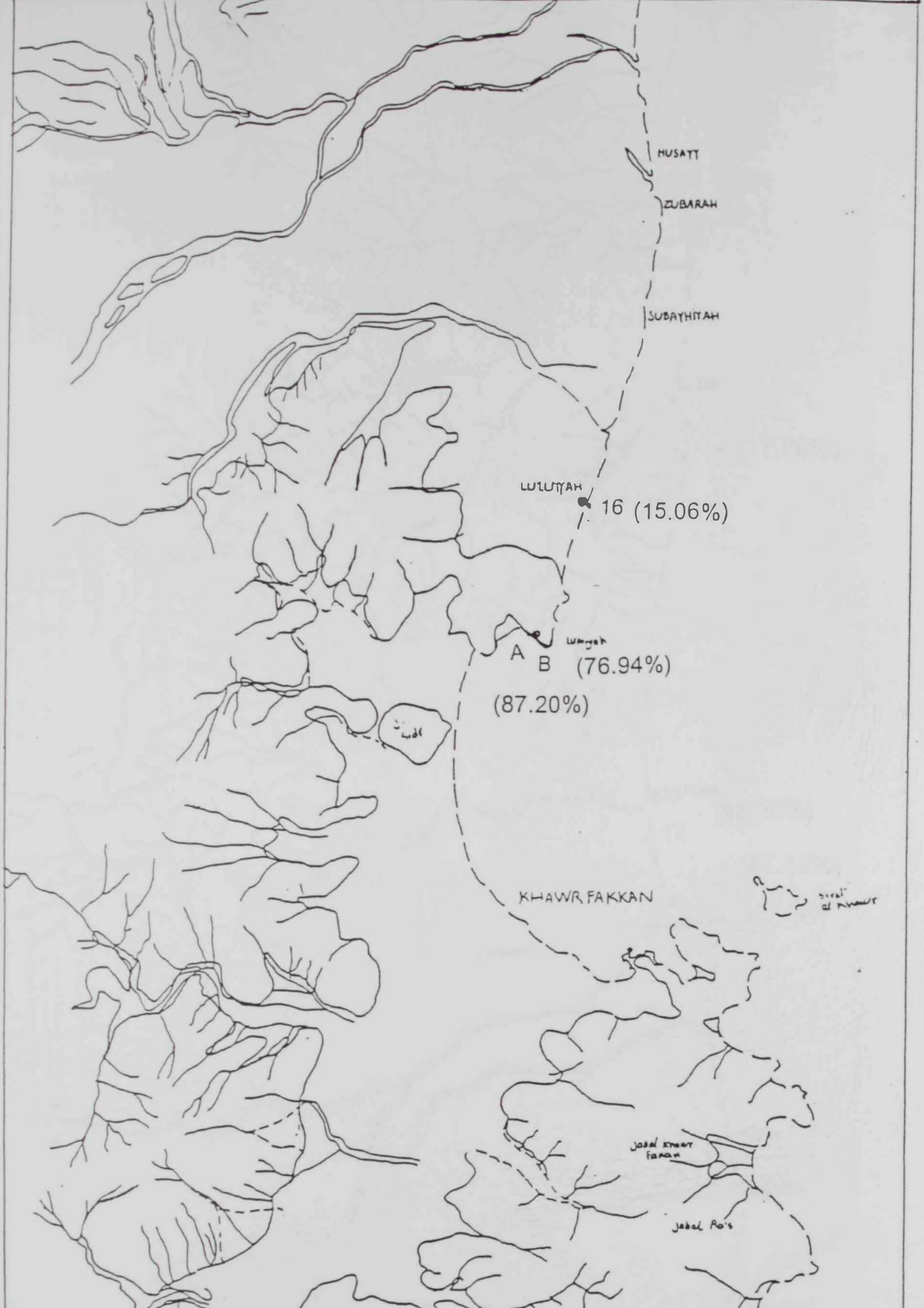


Fig. 30. Distribution of heavy minerals north of Oceanic hotel (Khor Fakkan).

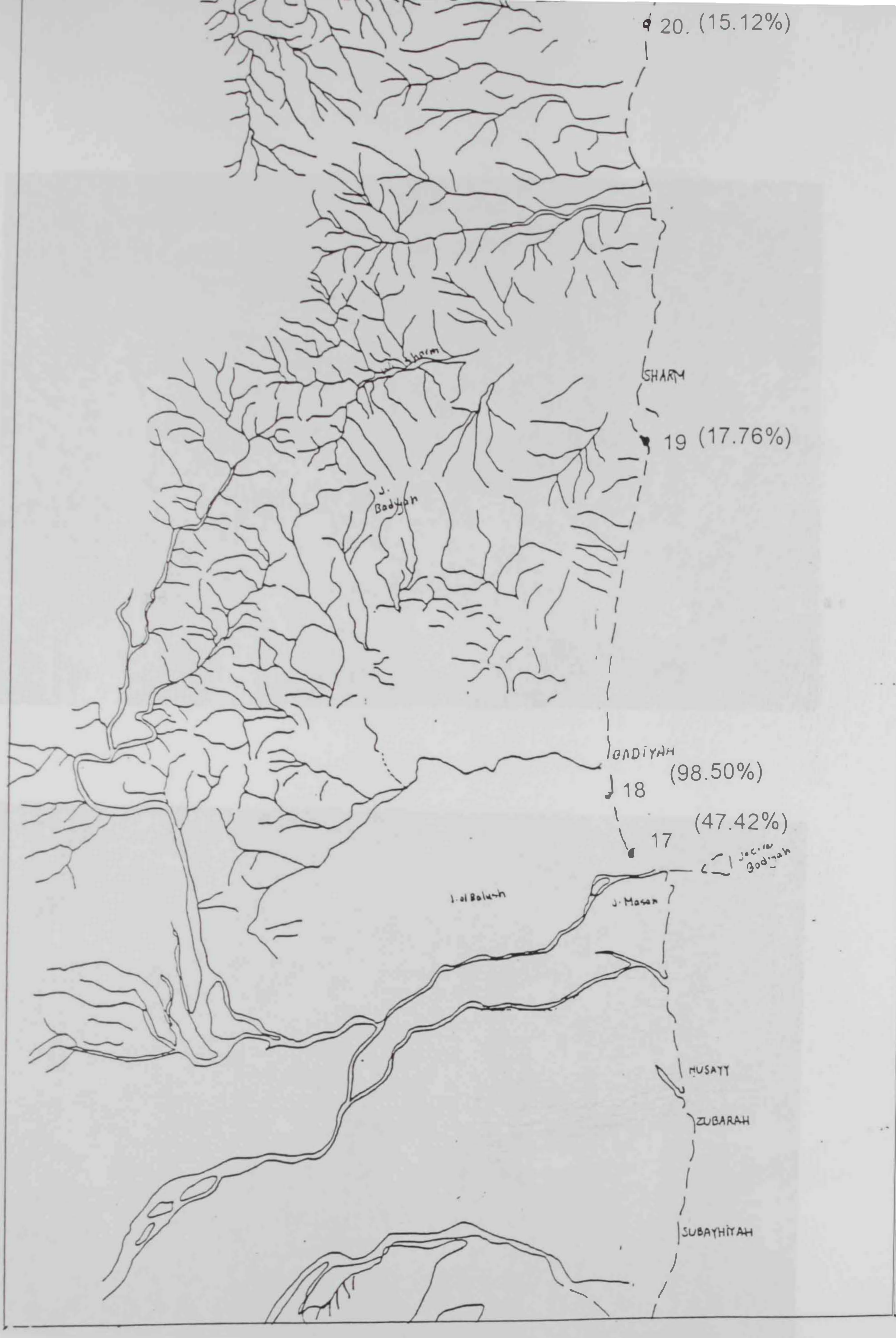


Fig. 31. Distribution of heavy minerals along the beach of Beida village.

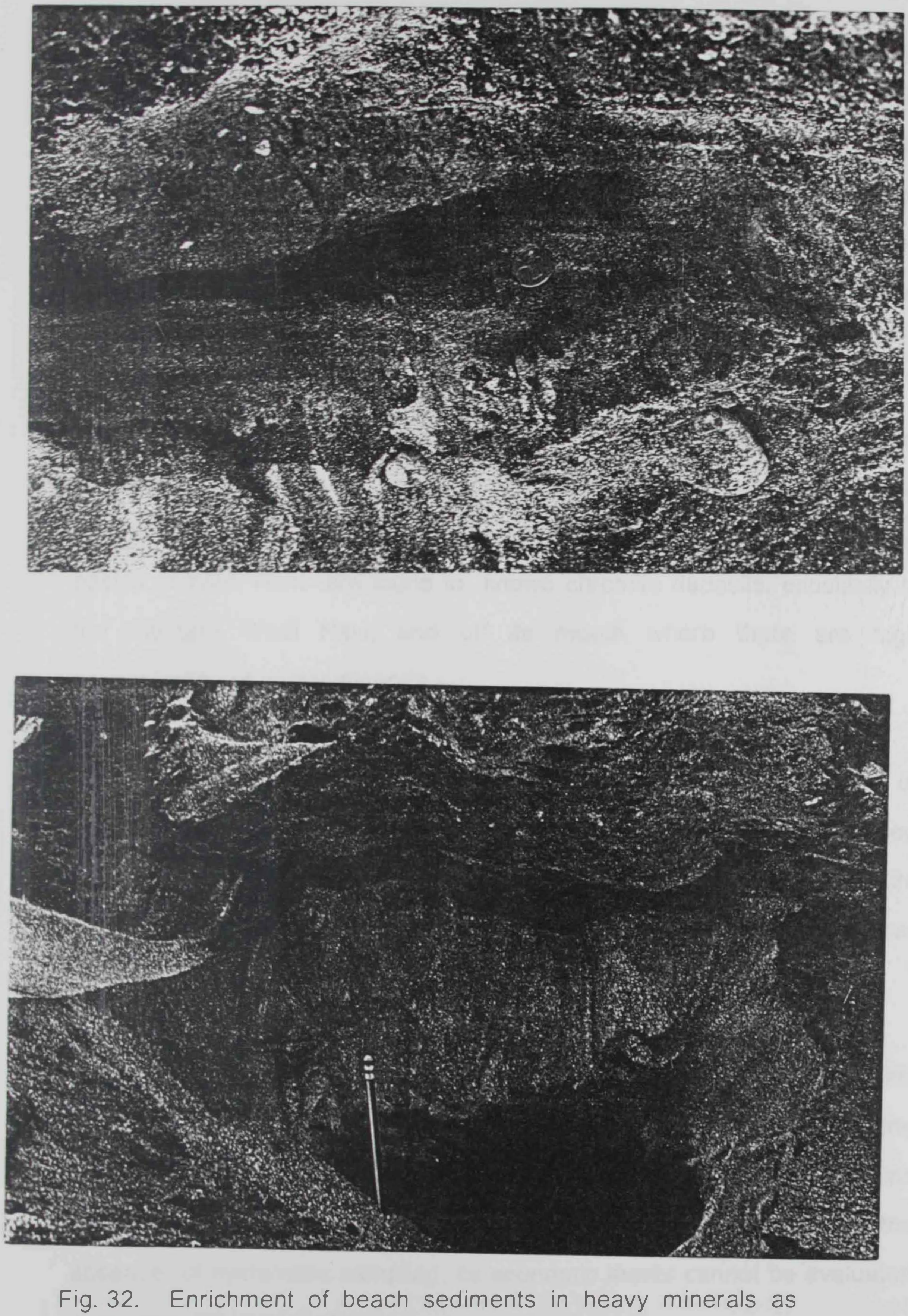


Fig. 32. Enrichment of beach sediments in heavy minerals as streaks.

4.6. Economic Considerations

The continental shelf areas, particularly, near the areas of high heavy minerals concentration should be surveyed for their heavy minerals potentials. Usually shelf areas at the mouth of main rivers (wadis) are considered areas of potential accumulation of heavy minerals as in for example on concentration of heavy mineral occur off the Rouge River reference or the less extensive but more highly concentrated of heavy minerals and metals off Cape Blanco and the Sixes River (Kulm, 1988).

The hinterland (drainage basins) of areas of high heavy mineral concentrations should be searched for possible occurrence of economic chromite deposits. In the Eastern mountain of the U.A.E. in the drainage basins of Wadi Ham are found to known chromite deposits, especially in the tributary Wadi Hayl, and off its mouth where there are high concentration of heavy minerals.

Similarly, the high concentrations at Bedia beach are a sign of potential chromite deposits in the hinterland. Recomaissance work carried out in the main wadis of Bedia area, indicates the presence of chromite float debris (with pebbles up to 10 cm in diameter), which encourage further detailed work (A. Eldougdoug; personal communication).

From the three locations characterized by high heavy minerals concentration, Bedia beach seems to be the only promising as the thickness of the sand sheet reaches up to 1 meter in thickness and contains heavy mineral as lenses and streaks up to 10 cm thick. However, in the absence of systematic sampling, its economic merits cannot be evaluated at the present level of study.

From the results of the present study it appears that the accumulation of large amounts opaque is controlled by the geomorphology of the shoreline. The areas of maximum curvature, north of the headlands, are potential areas of accumulation. Therefore, other areas should be studied, with some details and samples should be taken from deeper levels because of the possibility that heavy minerals concentration could be concealed by barren sand cover.

CHAPTER 5

CONCLUSIONS

5. CONCLUSIONS

The present investigation deals with the study of coastal sediments along the Eastern Coast, U.A.E., from three aspects: grain size analysis, trace metals content, and heavy minerals concentration.

The grain size analysis was carried out on the collected samples in order to identify the processes and environment of deposition of these sediments. Trace metal concentrations were determined in the fine sand fraction from two sets of samples before oil spill (October 1992), and after oil spill on (March, 1994). The concentrations represent trace metal fractions extracted by hydrochloric acid and usually used for the evaluation of the pollution level.

Based on mechanical analysis, the coastal sediments are classified mainly as sand (18 samples) slightly gravelly sand (13 samples) and gravelly sand (2 samples). Plotting of mean size vs. standard deviation and the standard deviation vs. skewness, show that the majority of the samples are occupying the river field. However, the plotting of skewness vs. mean size suggests a beach sediments. These textural parameters indicate that the sediment transported via streams and delivered to the beach and the residence time along the beach was not long enough for effective sorting, therefore, the sediments still bear the characteristics of river sediments.

With regard to the levels of trace metals in the samples collected before pollution, they display significant variations from one station to another. The differences can be explained in terms of composition of these sediments as a result of various types of rocks existing along the eastern coast of UAE. The levels of trace metals in the study area are in the order :

zinc > chromium > lead > copper > nickel > manganese > cadmium > cobalt. Cadmium, cobalt, chromium, copper, lead and zinc showed their peak concentrations at two different areas. The most prominent one is located at the southern part of the east coast. The high levels of trace metals reported in this area mainly due to a combination of factors, of which the most important are the geological nature of the area, the composition of sediments and the presence of mangrove forests. The other area of relatively high metal concentrations is located at the northern part of the eastern coast. In contrast to the southern zone, it is believed that the cause for relatively high levels of trace metals at the northern area particularly for cobalt, manganese, nickel, lead and zinc is natural and mainly associated with the geological formations but not with major anthropogenic sources, as evident from the significant correlations between metal pairs, (cobalt and copper), (nickel and chromium), (zinc and manganese) and (zinc and chromium) on one hand and the absence of such correlations with organic matter on the other hand. Generally speaking, the sediments collected from the northern part of the east coast contained less metal concentrations compared to the southern part.

The levels (μg/g dry weight) of cadmium, cobalt, chromium, copper, manganese, nickel, lead and zinc are fluctuating in the samples collected after March 1994 oil spill and the results indicate a considerable increase in the levels of some trace metals concentrations, particularly in heavily contaminated areas. The levels (μg/g dry weight) of cadmium (9.01 times), cobalt (193.23 times, chromium (38.87 times), copper (4.7 times), Mn (272.8 times), Ni (322.7 times), Pb (6.7 times) and Zn (5.6 times) were higher than their levels prior to the oil spill occurrence. The higher levels of some metals such as chromium, manganese and nickel after about three months from the accident were due to the solublization of metals from surfaces of clays and detrital particles by microbial degradation of petroleum compounds.

Comparing the data obtained here after three months from the spill time to other published data in sediments collected from Saudi Arabia (Fletkamp and Krupp, 1994) one year after the Gulf war oil spill (Table 11), one can safely conclude that the environmental impacts of the spilled oil on the east coast had minor effects in terms of trace metals levels and organic meterials and the marine environment of UAE is returning back to its normal condition.

Heavy minerals separation revealed the general enrichment of the eastern coastal sediments in heavy minerals. Their percentage were found to be as high as 78% and may reach 98% in some sites. Along the studied coastal area three locations showed pronounced concentrations of heavy minerals. These are : south of Fujairah town, north of the oceanic hotel (KhorFakkan) and the beach area of Bedia village (Fig. 16, 17, 28 and 29). These three areas were found to be characterized by the occurrence of heavy minerals in the form of lenses and streaks up to 10 cm thick. The areas characterized by heavy minerals enrichment render their situation in front of large drainage basins is a matter of self explanation. In general, the heavy mineral distribution along the coast was found to be increasing along with increasing proximity to areas suffered from major shoreline infection points (Fig. 28, 29 and 30). It is obvious that the source is the large basins drainage and the relative concentrations is attributed to the deceleration of the longshore currents at the inflection points.

Based on the findings of the present study, it is recommended that the areas on continental shelf adjacent to the beach areas with high heavy mineral concentrations should be systematically studied for possible occurrence of econmic placer deposits. In addition, the drainage basins of the areas of high heavy mineral contents are good target areas for chromite exploration program.

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APPENDICES

Appendix 1

Field Description of Samples' Locations

Site No.	Date	Description
1	04-10-1992	Khor Kalba behind Mangrove trees, black greyish sediments, black shore, lack pebble near Oman and U.A.E. boundaries, with some basalt. Width behind the trees is 6 m.
2		K. Kalba sediments, black covered with snails, some dead algae. Back shore: consolidated basaltic boulders (black). Width 15 m.
3		Kalba beach, grey-black fine sediments, gentle slope, covered partly with tar balls (low tide) ripple marks.
4		Similar to station 3 but to the north of station 3.
5		Similar to station 4, north of station 4. It is far away of station 4 for about 1.5 km.
6		Near the entrance of the Khor to the south. Black sediments.
7		West of the bridge. West of the university station. West branch of the Khor among mangrove trees. Black, muddy sediments.

Site No.	Date	Description
8		North of Khor Kalba entrance, in front of Khor Kalba fiber boat factory. Grey-greenish, polluted with oil (tar). Gentle slope.
9		Beach station (Kalba) in front of Kalba court. Fine sediments, grey sediments.
10		North of drainage mouth. Kalba beach near the bridge on the drainage mouth. Fine sediments mixed with small, medium and big pebbles and stony block for the constructions of the Corniche. Gentle slope. (Ultramafic stones, rocks, gabbroic blocks).
11A		500 m from the coast inside the Wadi and to the west of 1st drainage.
11B		1 km from the coast to the west.
12		South of second drainage mouth. Heavily polluted with oil (tar lumps). Medium slope, fine sediments.
12A		Inside the wadi 1.5 km from the beach and bridge. Mixed sand-gravel.s
13A,B		Kalba, south of the mouth of the Wadi (Wadi Sur). Low tide, gentle slope, greenish to grey sediments, polluted with oil tars, upper high tide

Site No.	Date	Description
		near fresh high tide. The sea is calm, waves 10–20 cm. Temperature is 37 °C of wet intertidal sand. The temperature of backshore and dry sand is 42° C. Disturbed Wadi (cannot be used for sampling).
14A		Fujairah-south of Furjairah port (Wadi beach). Wide beach. Very low tide, 12:10. Disturbed back beach.
14B		Close to the low tide mark, intertidal flat. Oil pollution (liquid) batches.
14C		Near the fresh high tide mark.
15		Wadi Hadha (Marbah village). Disturbed narrow back shore. The village houses occupy the wadi. Palm trees, gentle slope. Very low tide, rocky front intertidal beach, sandy middle intertidal zone with small pebbles and sands.
15A		Low intertidal zone, fine sand.
15B		Middle intertidal zone, coarse sand and shells and pebbles.

Site No.	Date	Description
15C		High intertidal zone, fine sand.
16		Rocky front intertidal zone covered by algaes. Middle intertidal zone. Consolidated sand. Rocky back shore.
16A		Near the lower rocky front. Intertidal zone. Covered with algae.
16B		Middle intertidal zone. Mixed coarse sand pebbles.
16C		Upper intertidal zone, white fine sand (top 8 cm). Coarse sand and shell fragments (8 cm). Lower sediments with black color.
17		In front of Badyah Island. South side of the beach is rocky, pebbles intertidal zone. Middle part of the beach is sandy, fine sand with palm farm on back shore. North beach is rocky front and sandy. Middle intertidal zone, low tide, some fishermen boats (20 m).
17A		Fine sand, lower intertidal zone.

Site No.	Date	Description
17B		Middle-coarse pebbles
17C		Highest backshore, upper with sand (2–3 cm). Middle section: black (4 cm), lower section: white sediments
18		Badyah. surface sample from black sediments
19		Rol Dadnah. Rocky front, intertidal zone, beach about 12 m. Then middle intertidal zone, white sand covering rocks at 10 cm. Back shore is rocky covered with sand and stone. Low tide, gentle slope, long beach.
19A		From middle sandy intertidal zone.
19B		Back shore fine white sand. Temperature is 38°C.
20		Rol Diba. Rocky-lower intertidal zone, sandy middle intertidal zone. Back shore sandy.
20A		Near lower intertidal zone.
20B		Middle intertidal zone.
20C		High intertidal zone. Batches of heavy minerals along the beach, fine-sand, white-grey with black batches. Gentle slope, narrow beach.

Site No	Date	Description
21		Diba Al Hasn. Near border of Oman. Intertidal zone, fine sand.
21 A		Lower intertidal zone, grey sediments, fine sand.
21B		Top sediments is fine grey sand (3–4 cm). Lower section, coarse sediments and shell fragments. Higher intertidal zone, fine sediments. back shore is concrete construction. Fishing activities.

Appendix 2

Results of Mechanical Analysis and Statistical Parameters Calculations

1

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	28.406	11.265	11.265
-1	17.688	7.014	18.279
0	39.128	15.517	33.796
1	48.819	19.361	53.157
2	62.432	24.760	77.917
3	38.162	15.134	93.051
4	11.400	4.521	97.570
5	6.111	2.423	99.995

ϕ 5	-3
ϕ16	-1.3
ϕ25	-0.5
ϕ50	0.9
ϕ75	1.9
ϕ84	2.3
ϕ95	3.2

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{-1.3+0.9+2.3}{3} = 1.83$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.3-(-1.3)}{4} + \dfrac{3.2-(-3)}{6.6} = 1.839$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{-1.3+2.3-2(0.9)}{2(2.3)-(-1.3)} + \dfrac{-3+3.2-2(0.9)}{2(3.2)-(-3)} = 0.240$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.2-(-3)}{2.44(1.9)-(-0.5)} = 1.058$

2

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	8.380	3.274	3.274
-1	8.024	3.135	6.409
0	16.453	6.428	12.837
1	20.311	7.936	20.773
2	46.54	18.177	38.450
3	89.818	35.095	74.045
4	54.46	21.156	95.201
5	12.274	4.795	99.996

ϕ5	-1
ϕ16	-0.4
ϕ25	1.3
ϕ50	2.4
ϕ75	3.1
ϕ84	3.4
ϕ95	4

$$\text{Graphic Mean } (M_z) = \frac{\phi16+\phi50+\phi84}{3}$$

$$= \frac{-0.4+2.4+3.4}{3} = 1.8$$

$$\text{Inclusive Graphic Standard Deviation } (\sigma_1) = \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$$

$$= \frac{3.4-(-0.4)}{4} + \frac{4-(-1)}{6.6} = 1.707$$

$$\text{Inclusive Graphic Skewness } (Sk) = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$$

$$= \frac{-0.4+3.4-2(2.4)}{2(3.4)-(-0.4)} + \frac{-1+4-2(2.4)}{2(4)-(-1)} = -0.416$$

$$\text{Inclusive Graphic Kurtosis } (KG) = \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{4-(-1)}{2.44(3.1-1.3)} = 1.138$$

4

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	---	---	---
-1	---	---	---
0	0.048	0.018	0.018
1	3.502	1.384	1.402
2	69.296	27.395	28.797
3	153.140	60.542	89.339
4	26.894	10.632	99.971
5	0.065	0.025	99.996

ϕ5	1.6
ϕ16	1.9
ϕ25	2.1
ϕ50	2.4
ϕ75	2.7
ϕ84	2.9
ϕ95	3.3

$$\text{Graphic Mean } (M_z) = \frac{\phi16+\phi50+\phi84}{3} = \frac{1.9+2.4+2.9}{3} = 2.4$$

$$\text{Inclusive Standard Deviation } (\sigma_1) = \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$$

$$= \frac{2.9-1.9}{4} + \frac{3.3-1.6}{6.6} = 0.51$$

$$\text{Inclusive Graphic Skewness } (Sk) = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$$

$$= \frac{1.9+2.9-2(2.4)}{2(2.9-1.9)} + \frac{1.6+3.3-2(2.4)}{2(3.3-1.6)} = 0.03$$

$$\text{Inclusive Graphic Kurtosis } (KG) = \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.3-1.6}{2.44(2.7-2.1)} = 1.16$$

5

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	---	---	---
-1	---	---	—
0	---	---	---
1	1.149	0.457	0.457
2	63.641	25.317	25.774
3	159.309	63.376	89.150
4	27.224	10.830	99.98
5	0.048	0.019	99.999

ϕ5	1.4
ϕ16	1.8
ϕ25	2
ϕ50	2.3
ϕ75	2.7
ϕ84	2.9
ϕ95	3.3

Graphic Mean (M_Z) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$$= \frac{1.8+2.3+2.9}{3} = 2.33$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$$= \frac{2.9-1.8}{4} + \frac{3.3-1.4}{6.6} = 0.562$$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$$= \frac{1.8+2.9-2(2.3)}{2(2.9-1.8)} + \frac{1.4+3.3-2(2.3)}{2(3.3-1.4)} = 0.071$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.3-1.4}{2.44(2.7-2)} = 1.112$

6

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	---	---	---
-1	---	---	---
0	---	---	---
1	0.126	0.0502	0.0502
2	34.532	13.773	13.823
3	181.248	72.292	86.115
4	34.666	13.826	99.941
5	0.144	0.057	99.998

ϕ5	1.8
ϕ16	2
ϕ25	2.1
ϕ50	2.4
ϕ75	2.8
ϕ84	2.9
ϕ95	3.4

Graphic Mean (M_Z) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{2+2.4+2.9}{3} = 2.433$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.9-2}{4} + \dfrac{3.4-1.8}{6.6} = 0.467$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{2+2.9-2(2.4)}{2(2.9-2)} + \dfrac{1.8+3.4-2(2.4)}{2(3.4-1.8)} = 0.18$

Inclusive Graphic Kurotosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.4-1.8}{2.44(2.8-2.1)} = 0.936$

7

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	---	---	---
-1	---	---	---
0	---	---	---
1	1.036	0.410	0.410
2	5.325	2.110	2.520
3	198.907	78.845	81.365
4	46.721	18.519	99.884
5	0.286	0.113	99.997

$\phi 5$	2.3
$\phi 16$	2.6
$\phi 25$	2.7
$\phi 50$	2.8
$\phi 75$	3
$\phi 84$	3.1
$\phi 95$	3.4

Graphic Mean (M_Z) $= \dfrac{\phi 16+\phi 50+\phi 84}{3}$

$$= \frac{2.6+2.8+3.1}{3} = 2.8$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi 84-\phi 16}{4} + \dfrac{\phi 95-\phi 5}{6.6}$

$$= \frac{3.1-2.6}{4} + \frac{3.4-2.3}{6.6} = 0.291$$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \dfrac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$$= \frac{2.6+3.1-2(2.8)}{2(3.1-2.6)} + \frac{2.3+3.4-2(2.8)}{2(3.4-2.3)} = 0.14$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \dfrac{3.4-2.3}{2.44(3-2.7)} = 1.502$

8

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	24.596	9.723	9.723
-1	10.640	4.206	13.929
0	15.721	6.214	20.143
1	15.944	6.303	26.446
2	47.504	18.779	45.225
3	76.395	30.201	75.426
4	44.752	17.691	93.117
5	17.401	6.879	99.996

$\phi 5$	-3
$\phi 16$	-0.6
$\phi 25$	-0.3
$\phi 50$	2.2
$\phi 75$	3
$\phi 84$	3.4
$\phi 95$	4.1

Graphic Mean (Mz) $= \dfrac{\phi 16+\phi 50+\phi 84}{3}$

$$= \frac{-0.6+2.2+3.4}{3} = 1.66$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi 84-\phi 16}{4} + \dfrac{\phi 95-\phi 5}{6.6}$

$$= \frac{3.4-(-0.6)}{4} + \frac{4.1-(-3)}{6.6} = 2.075$$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \dfrac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$$= \frac{-0.6+3.4-2(2.2)}{2(3.4)-(-0.6)} + \frac{-3+4.1-2(2.2)}{2(4.1)-(-3)} = -0.432$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \dfrac{4.1-(-3)}{2.44(3)-(-0.3)} = 0.88$

9

Class (φ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	--	--	----
-1	0.344	0.230	0.230
0	2.344	1.570	1.800
1	15.182	10.172	11.972
2	105.305	70.558	82.530
3	14.255	9.551	92.081
4	11.815	7.916	99.997
5	---	---	---

φ 5	0.6
φ16	1
φ25	1.1
φ50	1.3
φ75	1.8
φ84	2.1
φ95	3.1

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1+1.3+2.1}{3} = 1.46$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.1-1}{1.4} + \dfrac{3.1-0.6}{6.6} = 0.653$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1+2.1-2(1.3)}{2(2.1-1)} + \dfrac{0.6+3.1-2(1.3)}{2(3.1-0.6)} = 0.447$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.1-0.5}{2.44(1.8-1.1)} = 1.468$

10

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	--	---	--
-1	--	---	--
0	--	---	--
1	1.172	0.467	0.467
2	34.554	13.772	14.239
3	172.650	68.813	99.694
4	41.756	16.642	99.694
5	0.215	0.085	99.779

ϕ5	1.6
ϕ16	2.1
ϕ25	2.3
ϕ50	2.6
ϕ75	2.9
ϕ84	3
ϕ95	3.3

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$$= \frac{2.1+2.6+3}{3} = 2.566$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$$= \frac{3-2.1}{4} + \frac{3.3-1.6}{6.6} = 1.367$$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$$= \frac{2.1+3-2(2.6)}{2(3-2.1)} + \frac{1.6+3.3-2(2.6)}{2(3.3-1.6)} = -0.143$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.3-1.6}{2.44(2.9-2.3)} = 1.41$

11

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	---
-1	—	---	---
0	—	---	---
1	1.436	0.567	0.567
2	114.124	45.068	45.635
3	126.673	50.024	95.659
4	10.988	4.339	99.992
5	—	---	---

$\phi 5$	1.4
$\phi 16$	1.7
$\phi 25$	1.8
$\phi 50$	2.1
$\phi 75$	2.5
$\phi 84$	2.7
$\phi 95$	3

Graphic Mean (Mz) $= \dfrac{\phi 16+\phi 50+\phi 84}{3}$

$= \dfrac{1.7+2.1+2.7}{3} = 2.16$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi 84-\phi 16}{4} + \dfrac{\phi 95-\phi 5}{6.6}$

$= \dfrac{2.7-1.7}{4} + \dfrac{3-1.4}{6.6} = 0.492$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \dfrac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$= \dfrac{1.7+2.7-2(2.1)}{2(2.7-1.7)} + \dfrac{1.4+3-2(2.1)}{2(3-1.4)} = 0.2$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \dfrac{3-1.4}{2.44(2.5-1.8)} = 0.930$

12

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	---
-1	—	---	---
0	0.619	0.251	0.251
1	6.529	2.654	2.905
2	86.590	35.2006	38.105
3	138.098	56.139	94.244
4	14.112	5.736	99.980
5	0.042	0.0170	99.997

ϕ 5	1.2
ϕ16	1.6
ϕ25	1.7
ϕ50	2.1
ϕ75	2.4
ϕ84	2.6
ϕ95	3.1

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1.6+2.1+2.6}{3} = 2.1$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.6-1.6}{4} + \dfrac{3.1-1.2}{6.6} = 0.537$

Inclusive Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1.6+2.6-2(2.1)}{2(2.6-1.6)} + \dfrac{1.2+3.1-2(2.1)}{2(3.1-1.2)} = 0.026$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.1-1.2}{2.44(2.4-1.7)} = 1.112$

...ht (%)	Cumulative weight (%)
14	0.214
26	0.340
42	2.082
202	20.284
390	52.174
01	92.275
22	99.99
	--

$\phi 5$	-0.7
$\phi 16$	-0.1
$\phi 25$	1.3
$\phi 50$	2
$\phi 75$	2.5
$\phi 84$	2.7
$\phi 95$	3.2

$\phi 5$	0.4
$\phi 16$	0.8
$\phi 25$	1
$\phi 50$	1.6
$\phi 75$	2.2
$\phi 84$	2.5
$\phi 95$	3.2

$$\frac{\phi16+\phi50+\phi84}{3}$$

$$\frac{-0.1+2+2.7}{3} = 1.53$$

Deviation (∂_1) $= \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$ ... $\frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$

$$= \frac{2.7-(-0.1)}{4} + \frac{3.2-(-0.7)}{6.6} = 1.29 \quad \ldots \frac{2.5-0.2}{4} + \frac{3.2-0.6}{6.6} = 0.968$$

(Sk) $= \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$ ... $\frac{\ldots 50}{\ldots} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$$= \frac{-0.1+2.7-2(2)}{2(2.7)-(-0.1)} + \frac{-0.7+3.2-2(2)}{2(3.2)-(-0.7)} = -0.44 \quad \ldots \frac{\ldots .6)}{\ldots)} + \frac{0.6+3.2-2(1.6)}{2(3.2-0.6)} = 0.0137$$

...G) $= \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.2-(-0.7)}{2.44(2.5-1.3)} = 1.33$ ... $= \frac{3.2-0.4}{2.44(2.2-1)} = 0.956$

13-E

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	0.279	0.111	0.111
-1	0.583	0.232	0.343
0	4.186	1.668	2.011
1	56.185	22.406	24.417
2	89.013	35.497	59.914
3	80.459	32.086	92.000
4	20.009	7.979	99.979
5	0.042	0.016	99.99

ϕ 5	0.3
ϕ16	0.8
ϕ25	1.1
ϕ50	1.8
ϕ75	2.3
ϕ84	2.6
ϕ95	3.3

Graphic Mean (Mz) $= \dfrac{\phi 16+\phi 50+\phi 84}{3}$

$$= \frac{0.8+1.8+2.6}{3} = 1.53$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi 84-\phi 16}{4} + \dfrac{\phi 95-\phi 5}{6.6}$

$$= \frac{2.6-0.2}{4} + \frac{3.3-0.7}{6.6} = 0.99$$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \dfrac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$$= \frac{0.2+2.6-2(1.8)}{2(2.6-0.2)} + \frac{0.7+3.3-2(1.8)}{2(3.3-0.7)} = 0.096$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \dfrac{3.3-0.3}{2.44(2.3-1.1)} = 1.024$

14-C

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	--
-1	—	---	--
0	1.062	0.423	0.423
1	6.545	2.611	3.034
2	65.924	26.304	29.338
3	144.797	57.778	87.114
4	32.161	12.832	99.945
5	0.126	0.050	99.996

ϕ 5	1.2
ϕ16	1.7
ϕ25	1.9
ϕ50	2.3
ϕ75	2.7
ϕ84	2.9
ϕ95	3.5

Graphic Mean (Mz) $= \frac{\phi16+\phi50+\phi84}{3}$

$= \frac{1.7+2.3+2.9}{3} = 2.3$

Inclusive Graphic Standard Deviation (∂_1) $= \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$

$= \frac{2.9-1.7}{4} + \frac{3.5-1.2}{6.6} = 0.648$

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

$= \frac{1.7+2.9-2(2.3)}{2(2.9-1.7)} + \frac{1.2+3.5-2(2.3)}{2(3.5-1.2)} = 0.021$

Inclusive Graphic Kurtosis (KG) $= \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.5-1.2}{2.44(2.7-1.9)} = 1.178$

15-A

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	--	---	—
0	1.936	0.762	0.762
1	2.093	0.824	1.586
2	8.502	3.350	4.936
3	198.624	78.275	83.211
4	42.227	16.641	99.85
5	0.368	0.145	99.99

ϕ 5	2.1
ϕ16	2.2
ϕ25	2.3
ϕ50	2.6
ϕ75	2.9
ϕ84	3.1
ϕ95	3.4

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{2.2+2.6+3.1}{3} = 2.6$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{3.1-2.2}{4} + \dfrac{3.4-2.1}{6.6} = 0.421$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{2.2+3.1-2(2.6)}{2(3.1-2.2)} + \dfrac{2.1+3.4-2(2.6)}{2(3.4-2.1)} = 0.170$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.4-2.1}{2.44(2.9-2.3)} = 0.88$

15-B

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	33.311	13.125	13.125
-1	24.508	9.656	22.781
0	70.138	27.636	50.417
1	61.129	24.086	74.503
2	24.071	9.484	83.987
3	24.207	9.538	93.525
4	16.297	6.421	99.946
5	0.125	0.099	99.99

ϕ 5	-3
ϕ16	-1.5
ϕ25	-0.8
ϕ50	0
ϕ75	1.3
ϕ84	2.2
ϕ95	3.2

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{-1.5+0+2.2}{3} = 0.23$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.2-(-1.5)}{4} + \dfrac{3.2-(-3)}{6.6} = 1.864$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{-1.5+2.2-2(0)}{2(2.2)-(-1.5)} + \dfrac{-3+3.2-2(0)}{2(3.2)-(-3)} = 0.110$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.2-(-3)}{2.44(1.3)-(-0.8)} = 1.209$

15-C

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	0.430	0.178	0.178
-1	0.867	0.359	0.537
0	10.137	4.204	4.741
1	29.786	12.353	17.094
2	41.938	17.392	34.486
3	135.447	56.173	90.659
4	22.517	9.338	99.99
5	---	---	—

ϕ 5	0.1
ϕ16	0.9
ϕ25	1.6
ϕ50	2.4
ϕ75	2.7
ϕ84	2.9
ϕ95	3.2

Graphic Mean (Mz) $= \frac{\phi16+\phi50+\phi84}{3}$

$$= \frac{0.9+2.4+2.9}{3} = 2.06$$

Inclusive Graphic Standard Deviation (∂_1) $= \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$

$$= \frac{2.9-0.9}{4} + \frac{3.2-0.1}{6.6} = 0.969$$

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

$$= \frac{0.9+2.9-2(2.4)}{2(2.9-0.9)} + \frac{0.1+3.2-2(2.4)}{2(3.2-0.1)} = -0.49$$

Inclusive Graphic Kurtosis (KG) $= \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.2-0.1}{2.44(2.7-1.6)} = 1.409$

16-A

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	6.544	3.389	3.389
-1	22.442	11.622	15.011
0	65.197	33.765	48.776
1	77.820	40.303	89.079
2	20.706	10.723	99.802
3	0.357	0.184	99.986
4	0.019	0.009	99.99
5	---	---	—

ϕ 5	1.7
ϕ16	-0.9
ϕ25	-0.6
ϕ50	0
ϕ75	0.5
ϕ84	0.2
ϕ95	1.3

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$$= \frac{-0.9+0+0.2}{3} = -0.2$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$$= \frac{0.2-(-0.9)}{4} + \frac{1.3-(-1.7)}{6.6} = 0.731$$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$$= \frac{-0.9+0.2-2(0)}{2(0.2)-(-0.9)} + \frac{-1.7+1.3-2(0)}{2(1.3)-(-1.7)} = -0.38$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{1.3-(-1.7)}{2.44(0.5)-(-0.6)} = 1.117$

16-C

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	9.270	3.697	3.697
-1	7.970	3.178	6.875
0	10.392	4.144	11.019
1	10.758	4.290	15.309
2	87.599	34.938	50.247
3	120.263	47.966	98.213
4	4.469	1.782	99.99
5	---	---	---

ϕ 5	-1.3
ϕ16	1.1
ϕ25	1.5
ϕ50	2
ϕ75	2.2
ϕ84	2.5
ϕ95	2.9

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1.1+2+2.5}{3} = 1.866$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.5-1.1}{4} + \dfrac{2.9-(-1.3)}{6.6} = 0.986$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1.1+2.5-2(2)}{2(2.5-1.1)} + \dfrac{-1.3+2.9-2(2)}{2(2.9)-(-1.3)} = -0.427$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{2.9-(-1.3)}{2.44(2.2-1.5)} = 2.51$

17-A

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	1.716	0.679	0.679
-1	1.737	0.688	1.367
0	5.781	2.290	3.657
1	13.163	5.214	8.871
2	32.119	12.725	21.596
3	159.712	63.275	84.871
4	37.870	15.003	99.874
5	0.310	0.122	99.99

ϕ 5	0.5
ϕ16	1.8
ϕ25	2.1
ϕ50	2.6
ϕ75	2.8
ϕ84	3
ϕ95	3.2

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$$= \frac{1.8+2.6+3}{3} = 2.4$$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$$= \frac{3-1.8}{4} + \frac{3.2-0.5}{6.6} = 0.7$$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$$= \frac{1.8+3-2(2.6)}{2(3-1.8)} + \frac{0.5+3.2-2(2.6)}{2(3.2-0.5)} = -0.44$$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.2-0.5}{2.44(2.8-2.1)} = 1.58$

17-B

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	41.539	16.413	16.413
-1	26.692	10.547	26.960
0	56.629	22.376	49.33
1	53.116	20.988	70.324
2	15.426	6.095	76.419
3	29.106	11.501	87.79
4	30.055	11.876	99.79
5	0.509	0.201	99.99

$\phi 5$	-3.5
$\phi 16$	-2
$\phi 25$	-1.2
$\phi 50$	0.1
$\phi 75$	1.7
$\phi 84$	2.7
$\phi 95$	3.2

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{-2+0.1+2.7}{3} = 0.26$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.7-(-2)}{4} + \dfrac{3.2-(-3.5)}{6.6} = 2.190$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{-2+2.7-2(0.1)}{2(2.7)-(-2)} + \dfrac{-3.5+3.2-2(0.1)}{2(3.2)-(-3.5)} = 0.016$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{3.2-(-3.5)}{2.44(1.7)-(-1.2)} = 0.946$

17-C

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	—	---	—
0	1.576	0.628	0.628
1	6.500	2.593	3.221
2	34.523	13.774	16.995
3	161.484	64.430	81.425
4	46.324	18.482	99.90
5	0.227	0.090	99.99

ϕ 5	1.2
ϕ16	2
ϕ25	2.2
ϕ50	2.6
ϕ75	2.9
ϕ84	3.1
ϕ95	3.5

Graphic Mean (Mz) $= \frac{\phi16+\phi50+\phi84}{3}$

$$= \frac{2+2.6+3.1}{3} = 2.56$$

Inclusive Graphic Standard Deviation (∂_1) $= \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$

$$= \frac{3.1-2}{4} + \frac{3.5-1.2}{6.6} = 0.623$$

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

$$= \frac{2+3.1-2(2.6)}{2(3.1-2)} + \frac{1.2+3.5-2(2.6)}{2(3.5-1.2)} = -0.153$$

Inclusive Graphic Kurtosis (KG) $= \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.5-1.2}{2.44(2.9-2.2)} = 1.346$

17-D

Class (φ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	0.330	0.131	0.131
-1	0.605	0.241	0.372
0	9.734	3.887	4.259
1	90.167	36.00	40.259
2	132.882	53.067	93.326
3	16.615	6.636	99.96
4	0.069	0.027	99.989
5	---	---	---

φ 5	0.1
φ16	0.5
φ25	0.7
φ50	1.1
φ75	1.5
φ84	1.7
φ95	2

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{0.5+1.1+1.7}{3} = 1.1$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{1.7-0.5}{4} + \dfrac{2-0.1}{6.6} = 0.58$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{0.5+1.7-2(1.1)}{2(1.7-0.5)} + \dfrac{0.1+2-2(1.1)}{2(2-0.1)} =-0.026$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{2-0.1}{2.44(1.5-0.7)} = 0.973$

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	--	---	—
0	--	---	—
1	0.308	0.127	0.127
2	28.455	11.755	11.882
3	192.907	79.697	91.579
4	20.379	8.419	99.99
5	--	---	--

ϕ 5	1.7
ϕ16	2.1
ϕ25	2.2
ϕ50	2.6
ϕ75	2.8
ϕ84	2.9
ϕ95	3.2

$$\text{Graphic Mean (Mz)} = \frac{\phi16+\phi50+\phi84}{3}$$

$$= \frac{2.1+2.6+2.9}{3} = 2.5$$

$$\text{Inclusive Graphic Standard Deviation } (\partial_1) = \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$$

$$= \frac{2.9-2.1}{4} + \frac{3.2-1.7}{6.6} = 0.427$$

$$\text{Inclusie Graphic Skewness (Sk)} = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$$

$$= \frac{2.1+2.9-2(2.6)}{2(2.9-2.1)} + \frac{1.7+3.2-2(2.6)}{2(3.2-1.7)} = -0.225$$

$$\text{Inclusive Graphic Kurtosis (KG)} = \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{3.2-1.7}{2.44(2.8-2.2)} = 1.02$$

19-B

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	—	---	—
0	0.698	0.278	0.278
1	35.800	14.288	14.566
2	167.287	66.766	81.336
3	45.654	18.221	99.55
4	1.118	0.446	99.999
5	---	---	—

ϕ5	0.7
ϕ16	1
ϕ25	1.2
ϕ50	1.7
ϕ75	2
ϕ84	2.1
ϕ95	2.4

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1+1.7+2.1}{3} = 1.6$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.1-1}{4} + \dfrac{2.4-0.7}{6.6} = 0.532$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1+2.1-2(1.7)}{2(2.1-1)} + \dfrac{0.7+2.4-2(1.7)}{2(2.4-0.7)} = -0.224$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{2.4-0.7}{2.44(2-1.2)} = 0.870$

20-B

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	7.373	2.943	2.943
-1	4.008	1.600	4.543
0	16.393	6.544	11.087
1	42.637	17.021	28.108
2	100.491	40.117	68.225
3	76.225	30.430	98.655
4	3.363	1.342	99.99
5	—	---	—

ϕ 5	-0.8
ϕ16	0.4
ϕ25	0.9
ϕ50	1.6
ϕ75	2.1
ϕ84	2.2
ϕ95	2.7

Graphic Mean (Mz) $= \dfrac{\phi 16+\phi 50+\phi 84}{3}$

$= \dfrac{0.4+1.6+2.2}{3} = 1.4$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi 84-\phi 16}{4} + \dfrac{\phi 95-\phi 5}{6.6}$

$= \dfrac{2.2-0.4}{4} + \dfrac{2.7-(-0.8)}{6.6} = 0.980$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \dfrac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$= \dfrac{0.4+2.2-2(1.6)}{2(2.2-0.4)} + \dfrac{-0.8+2.7-2(1.6)}{2(2.7)-(-0.8)} = -0.357$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \dfrac{2.7-(-0.8)}{2.44(2.1-0.9)} = 1.195$

21-A

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	6.332	2.707	2.707
-1	5.065	2.165	4.872
0	14.164	6.056	10.928
1	12.870	5.503	16.431
2	70.549	30.168	46.599
3	119.875	51.261	97.860
4	4.997	2.136	99.99
5	—	---	--

ϕ 5	-0.8
ϕ16	1
ϕ25	1.4
ϕ50	2.1
ϕ75	2.4
ϕ84	2.6
ϕ95	2.8

Graphic Mean (Mz) $= \frac{\phi16+\phi50+\phi84}{3}$

$$= \frac{1+2.1+2.6}{3} = 1.9$$

Inclusive Graphic Standard Deviation (∂_1) $= \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$

$$= \frac{2.6-1}{4} + \frac{2.8-(-0.8)}{6.6} = 0.945$$

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

$$= \frac{1+2.6-2(2.1)}{2(2.6-1)} + \frac{-0.8+2.8-2(2.1)}{2(2.8)-(-0.8)} = -0.493$$

Inclusive Graphic Kurtosis (KG) $= \frac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \frac{2.8-(-0.8)}{2.44(2.4-1.4)} = 1.475$

21-C

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	—	---	—
0	1.175	0.471	0.471
1	2.698	1.081	1.552
2	11.108	4.452	6.004
3	159.867	61.682	67.686
4	79.257	31.772	99.458
5	1.347	0.539	99.99

ϕ5	1.9
ϕ16	2.3
ϕ25	2.5
ϕ50	2.8
ϕ75	3.1
ϕ84	3.3
ϕ95	3.6

Graphic Mean (Mz) $= \frac{\phi 16+\phi 50+\phi 84}{3}$

$= \frac{2.3+2.8+3.3}{3} = 2.8$

Inclusive Graphic Standard Deviation (∂_1) $= \frac{\phi 84-\phi 16}{4} + \frac{\phi 95-\phi 5}{6.6}$

$= \frac{3.3-2.3}{4} + \frac{3.6-1.9}{6.6} = 0.507$

Inclusie Graphic Skewness (Sk) $= \frac{\phi 16+\phi 84-2\phi 50}{2(\phi 84-\phi 16)} + \frac{\phi 5+\phi 95-2\phi 50}{2(\phi 95-\phi 5)}$

$= \frac{2.3+3.3-2(2.8)}{2(3.3-2.3)} + \frac{1.9+3.6-2(2.8)}{2(3.6-1.9)} = -0.029$

Inclusive Graphic Kurtosis (KG) $= \frac{\phi 95-\phi 5}{2.44(\phi 75-\phi 25)} = \frac{3.6-1.9}{2.44(3.1-2.5)} = 1.161$

A

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	0.729	0.290	0.290
0	3.202	1.277	1.567
1	20.405	8.137	9.704
2	138.119	55.084	64.788
3	85.504	34.100	98.888
4	2.779	1.108	99.99
5	—	---	—

ϕ 5	0.8
ϕ16	1.2
ϕ25	1.4
ϕ50	1.8
ϕ75	2.2
ϕ84	2.4
ϕ95	2.7

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1.2+1.8+2.4}{3} = 1.8$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

$= \dfrac{2.4-1.2}{4} + \dfrac{2.7-0.8}{6.6} = 0.587$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1.2+2.4-2(1.8)}{2(2.4-1.2)} + \dfrac{0.8+2.7-2(1.8)}{2(2.7-0.8)} = -0.026$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{2.7-0.8}{2.44(2.2-1.4)} = 0.973$

B

Class (ϕ)	Weight (g)	Weight (%)	Cumulative weight (%)
-2	—	---	—
-1	—	---	—
0	2.564	1.029	1.029
1	14.051	5.639	6.668
2	85.365	34.260	40.928
3	140.354	56.329	97.27
4	6.831	2.741	99.99
5	—	---	--

ϕ 5	0.9
ϕ16	1.4
ϕ25	1.7
ϕ50	2.1
ϕ75	2.4
ϕ84	2.5
ϕ95	2.9

Graphic Mean (Mz) $= \dfrac{\phi16+\phi50+\phi84}{3}$

$= \dfrac{1.4+2.1+2.5}{3} = 2$

Inclusive Graphic Standard Deviation (∂_1) $= \dfrac{\phi84-\phi16}{4} + \dfrac{\phi95-\phi5}{6.6}$

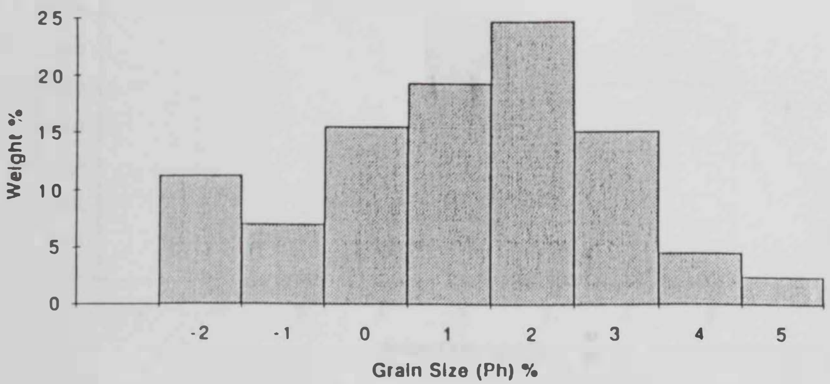
$= \dfrac{2.5-1.4}{4} + \dfrac{2.9-0.9}{6.6} =$

Inclusie Graphic Skewness (Sk) $= \dfrac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \dfrac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$

$= \dfrac{1.4+2.5-2(2.1)}{2(2.5-1.4)} + \dfrac{0.9+2.9-2(2.1)}{2(2.9-0.9)} =$

Inclusive Graphic Kurtosis (KG) $= \dfrac{\phi95-\phi5}{2.44(\phi75-\phi25)} = \dfrac{2.9-0.9}{2.44(2.4-1.7)} = 1.17$

1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5
Grain Size (Ph) %

2


Weight (%)
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35
30
25
20
15
10
5
0
-2
-1
0
1
2
3
4
5
Grain Size (ph) %

3


Weight %
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20
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10
5

4


Weight %
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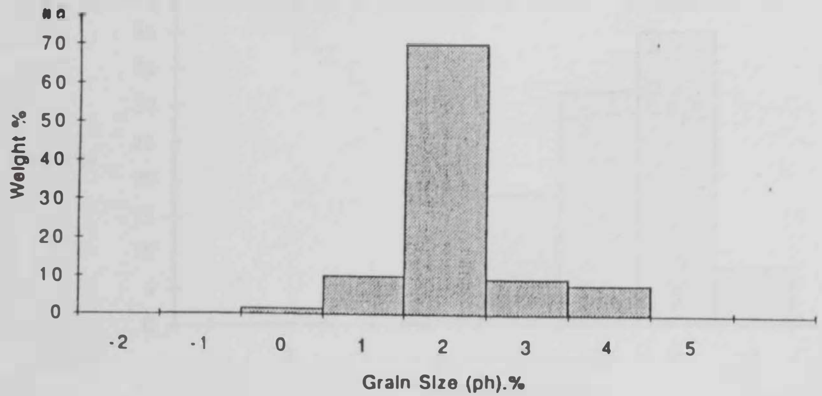
10

9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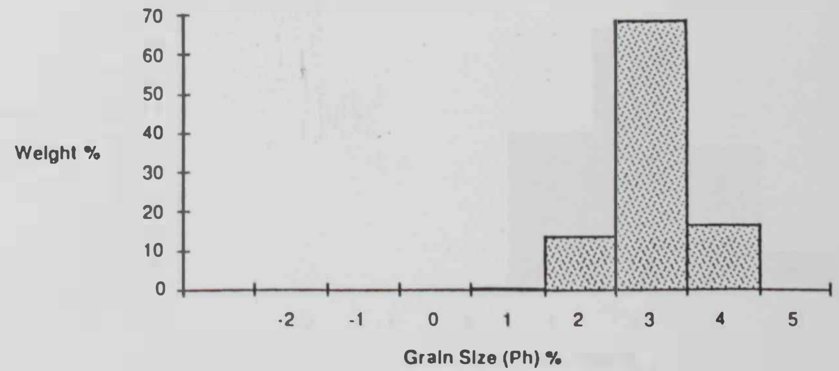
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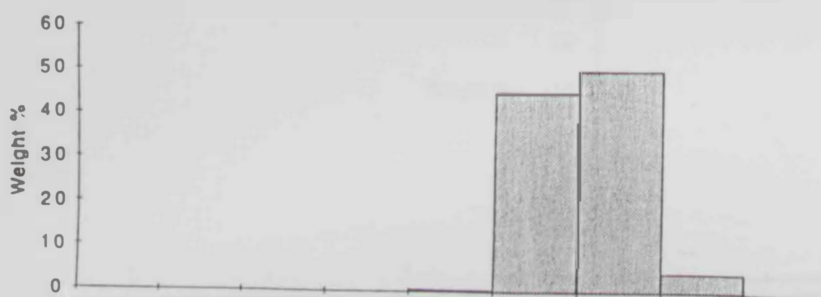
5
Grain Size (Ph) %

11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30
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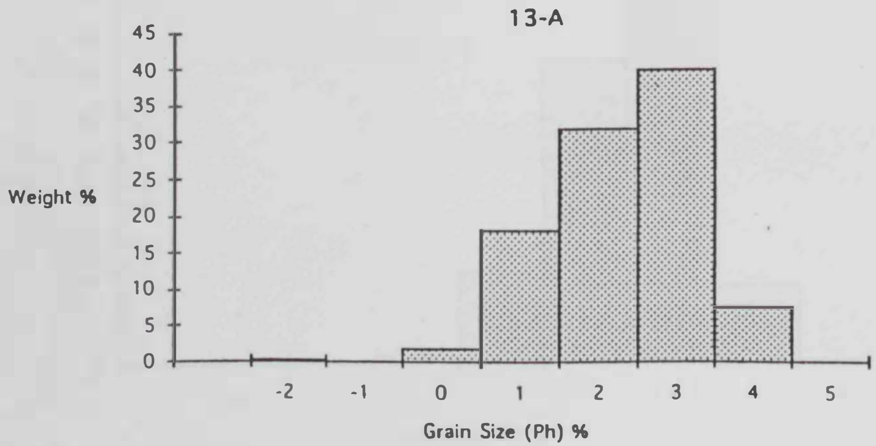
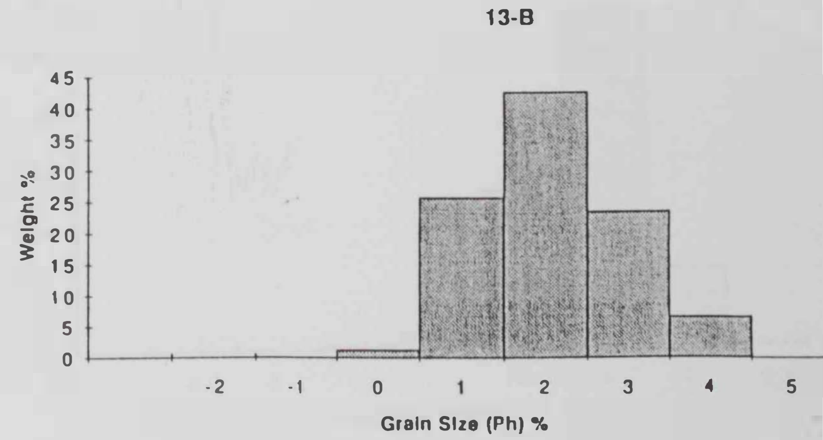
10
Weight %


13-A
45
40
35
30
25
20
15
10
5
0
Weight %
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %


13-B
45
40
35
30
25
20
15
10
5
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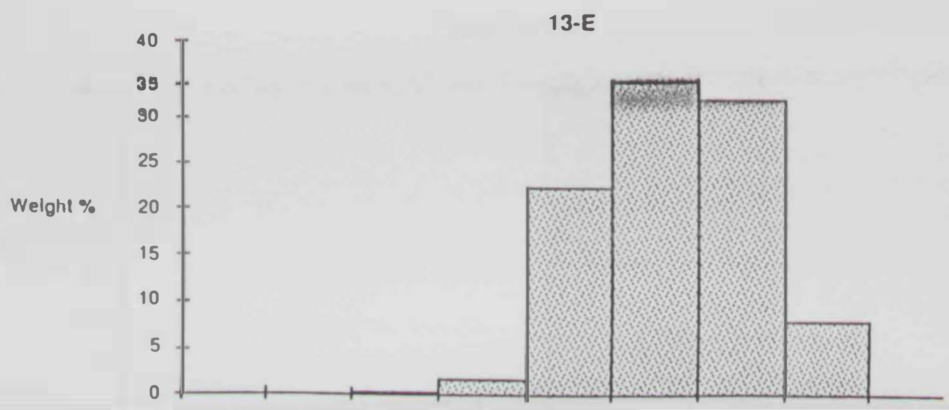
Weight %
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %


13-E
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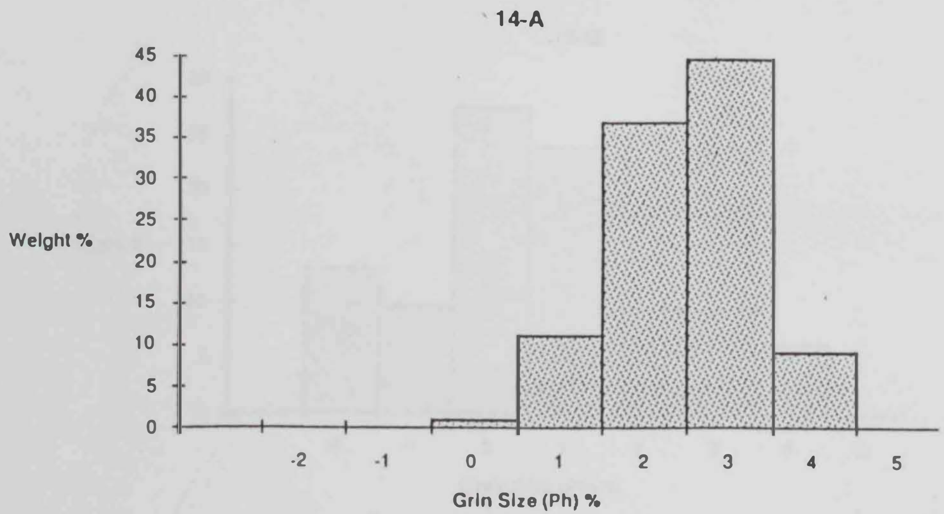
Weight %


14-A
Weight %
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20
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10
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-1
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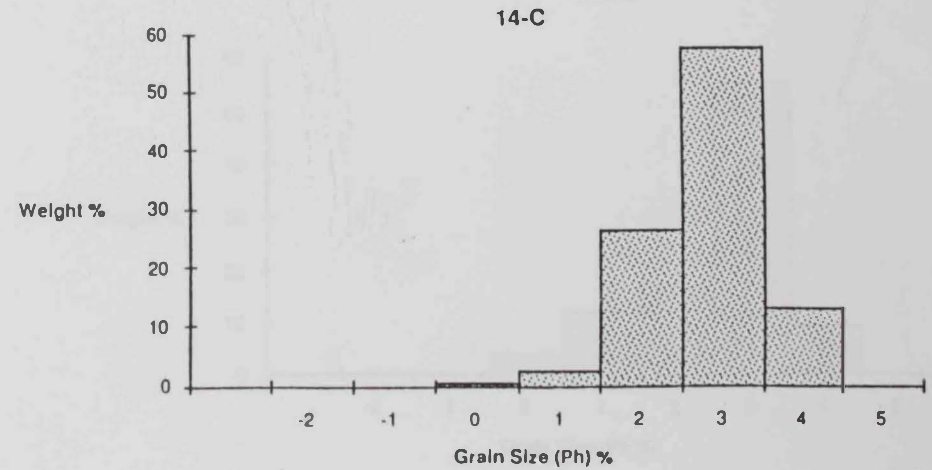
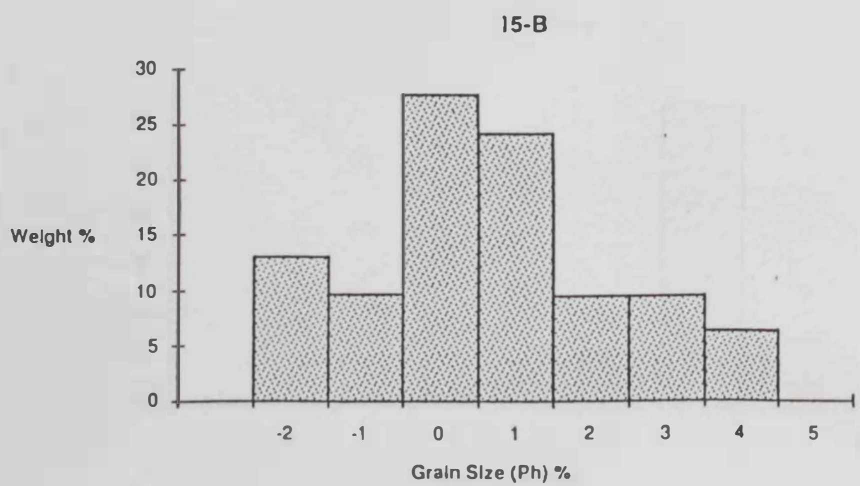
1
2
3
4
5
Grin Size (Ph) %


14-C
Weight %
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %


15-A
Weight %
80
70
60
50
40
30
20
10
0


15-B
Weight %
30
25
20
15
10
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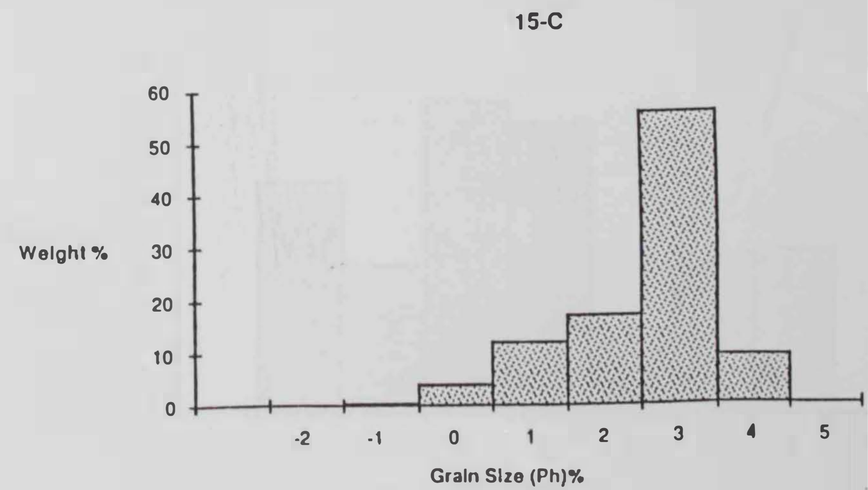
0
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %


15-C
Weight %
60
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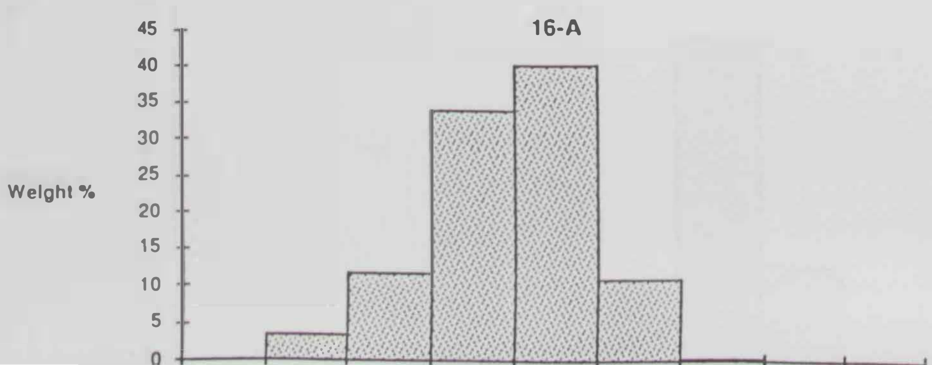
40
30
20
10
0
-2
-1
0
1
2
3
4
5
Grain Size (Ph)%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Weight %
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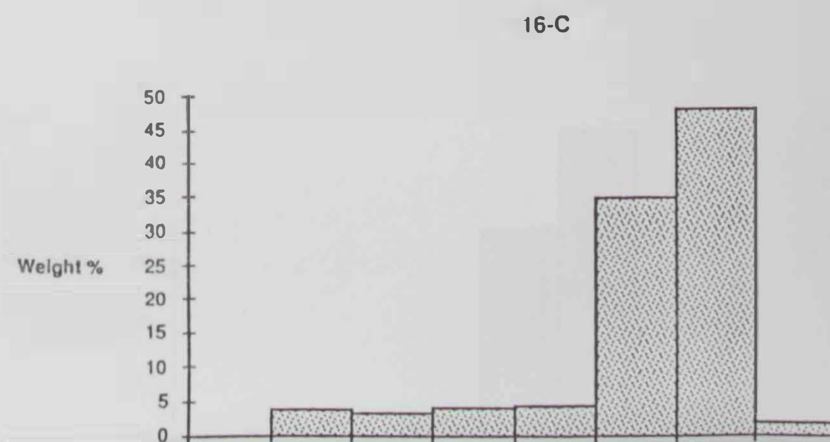
16-C
Weight %
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25
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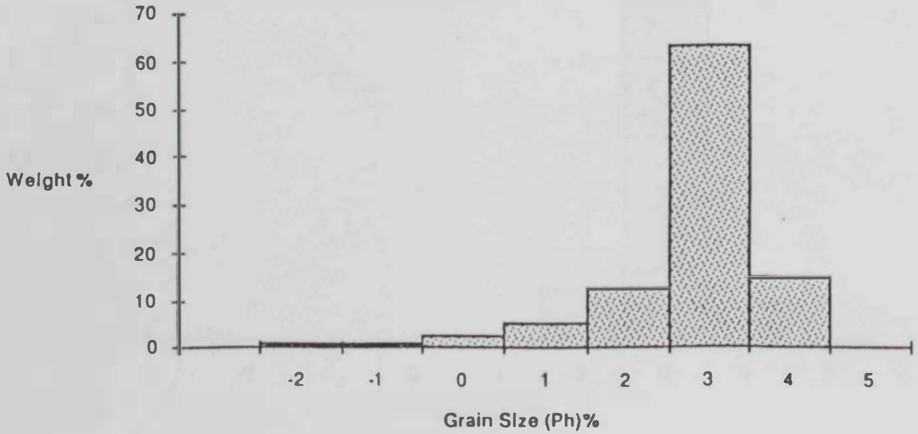
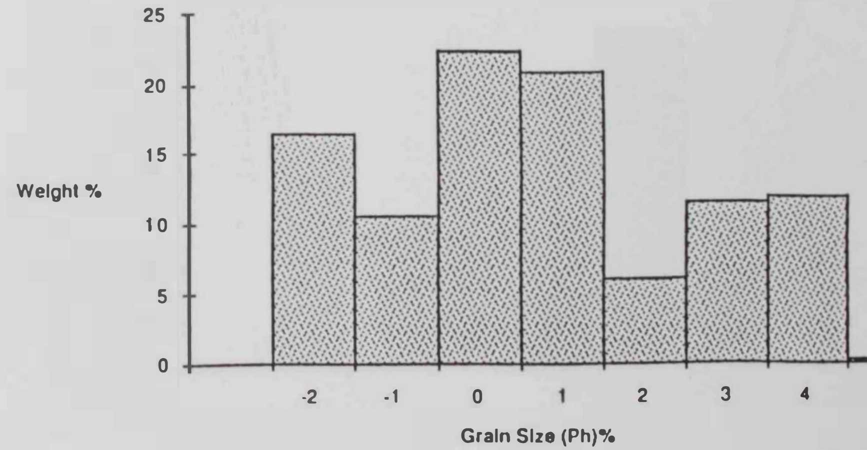
10
5
0

17-A

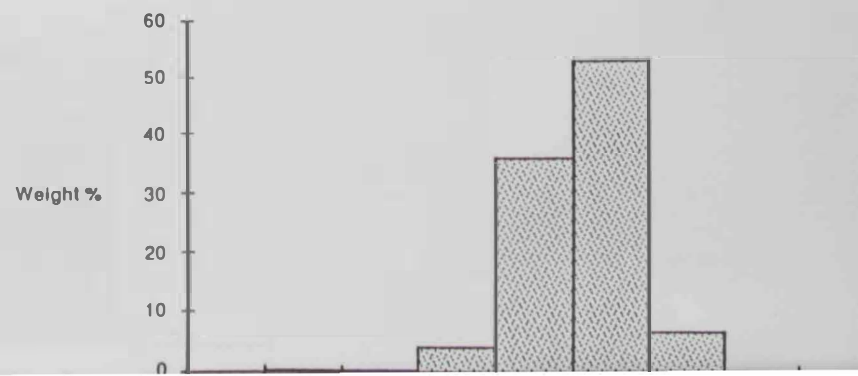


17-B

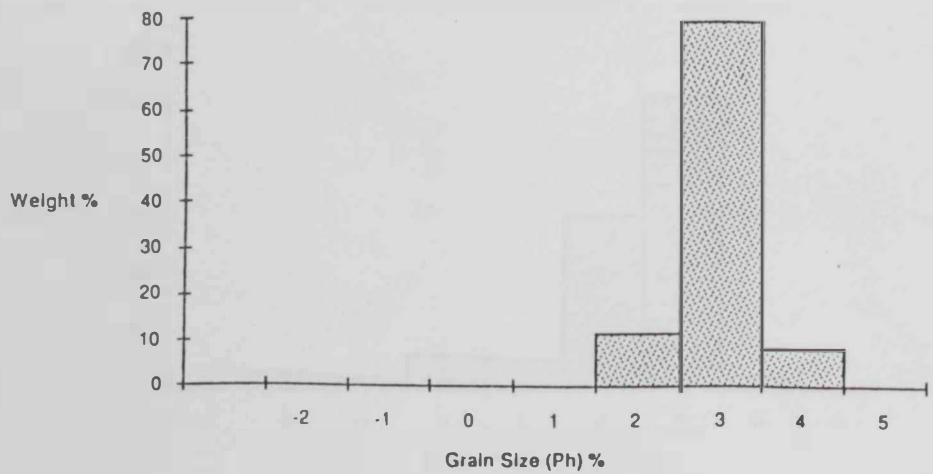


17-C

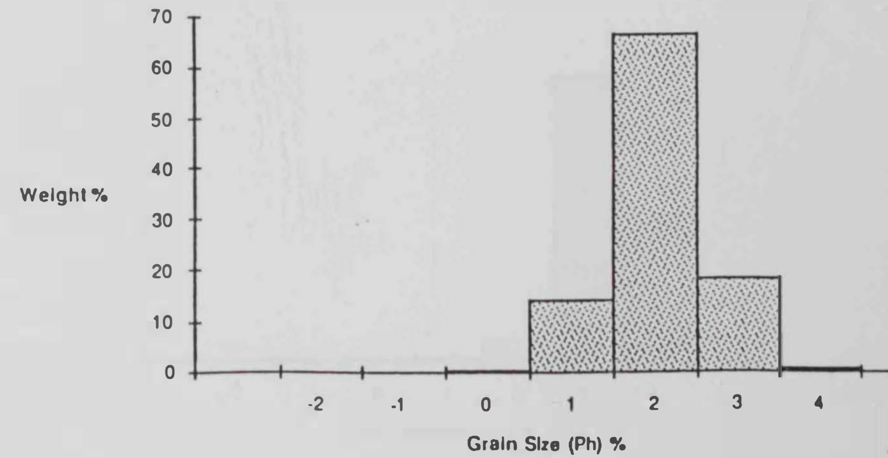
17-D



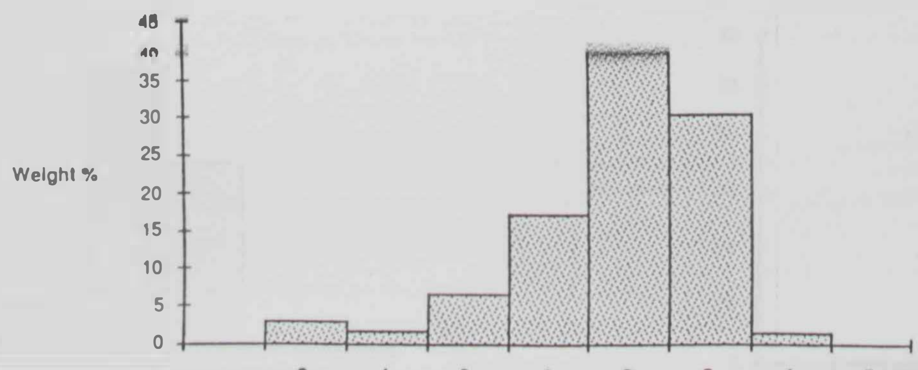
18


80
70
60
50
40
30
20
10
0
Weight %
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %

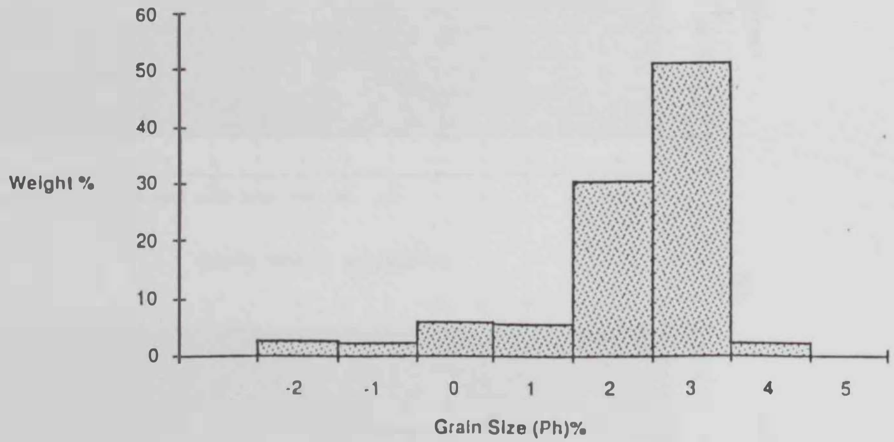
19-B


70
60
50
40
30
20
10
0
Weight %
-2
-1
0
1
2
3
4
Grain Size (Ph) %

20-B


45
40
35
30
25
20
15
10
5
0
Weight %

21-A


Weight %
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20
10
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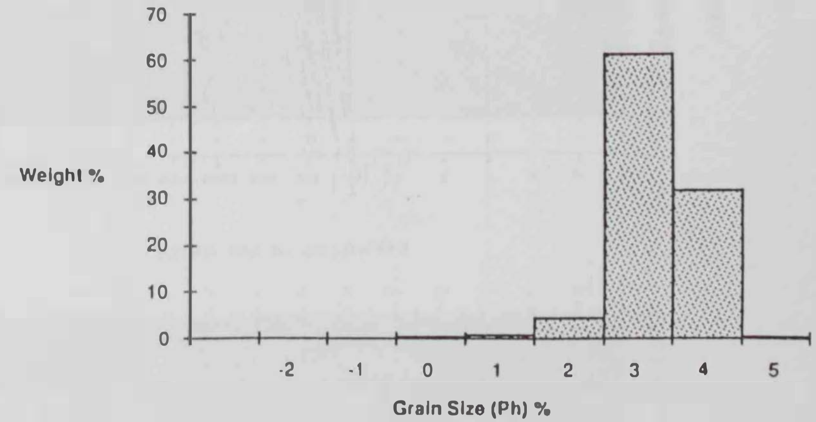
-2
-1
0
1
2
3
4
5
Grain Size (Ph)%

21-C


Weight %
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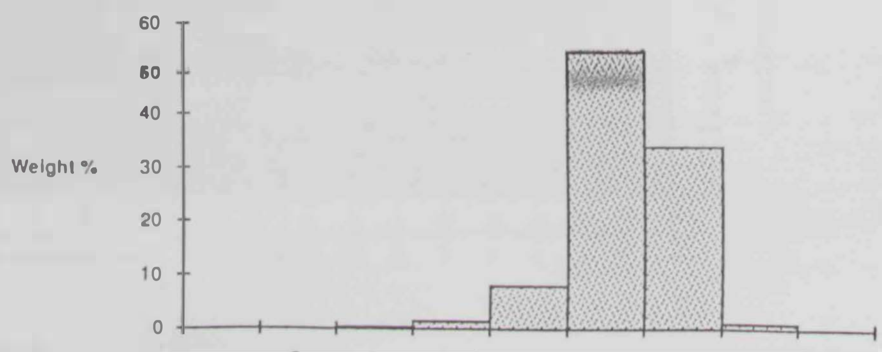
30
20
10
0
-2
-1
0
1
2
3
4
5
Grain Size (Ph) %

A


Weight %
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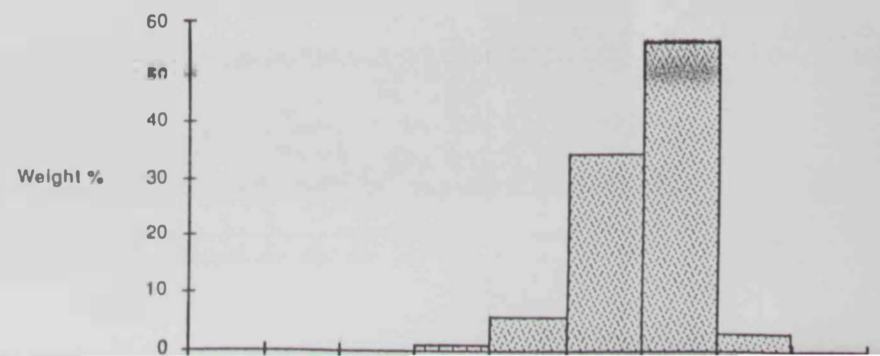
30
20
10
0

B


Weight %
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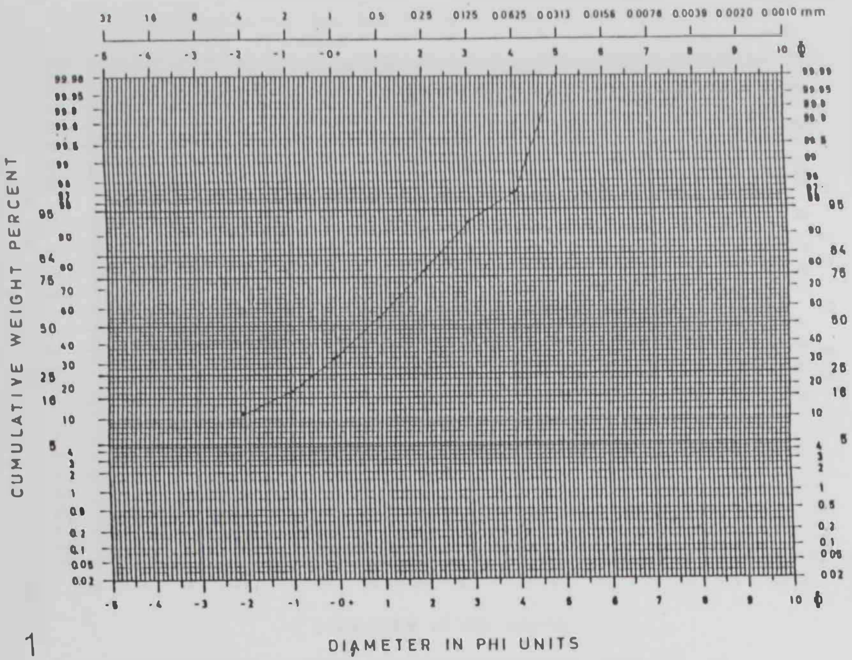
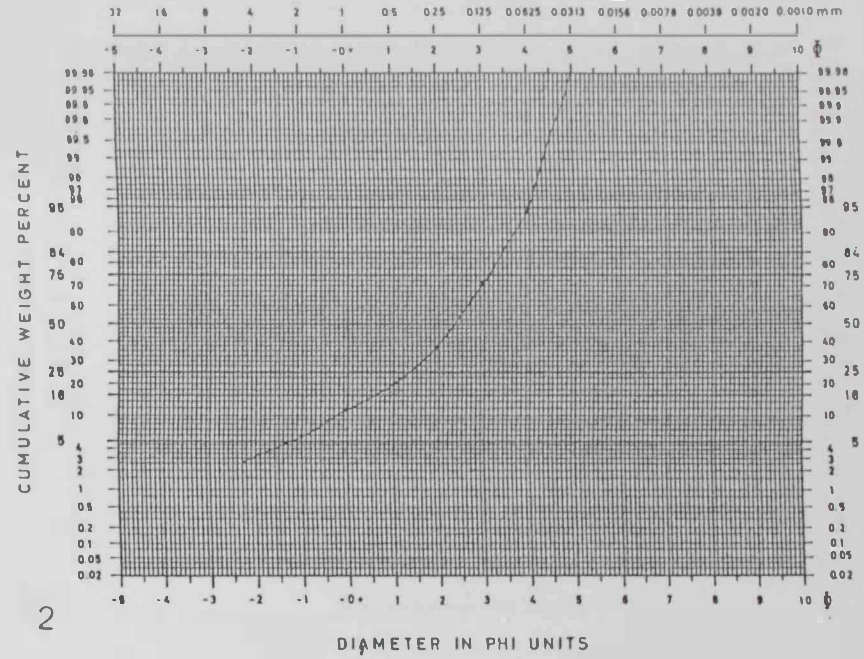
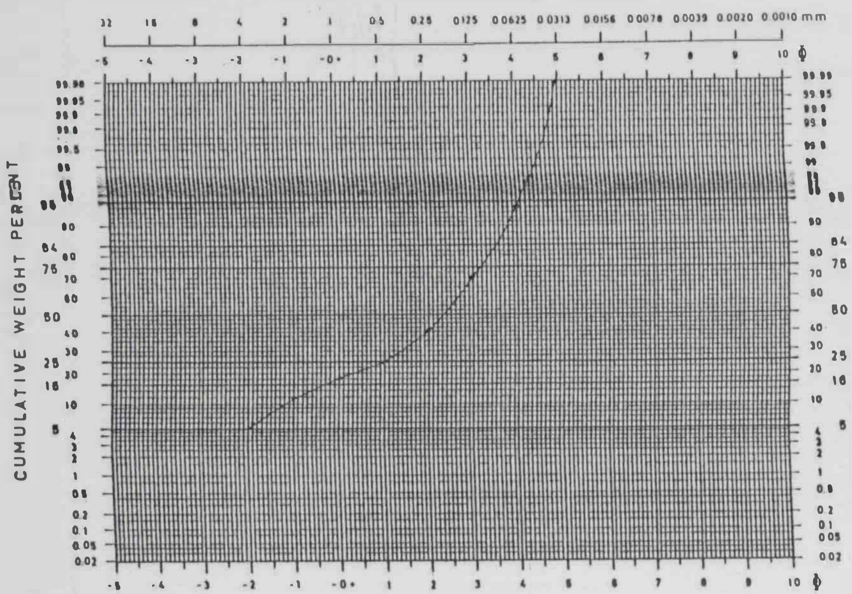
30
20
10
0


mm
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

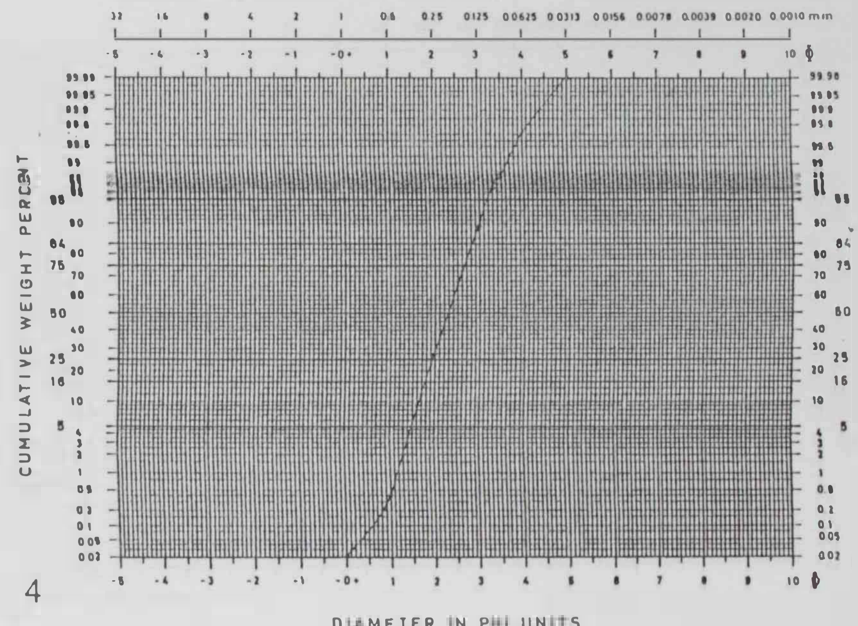
1


mm
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

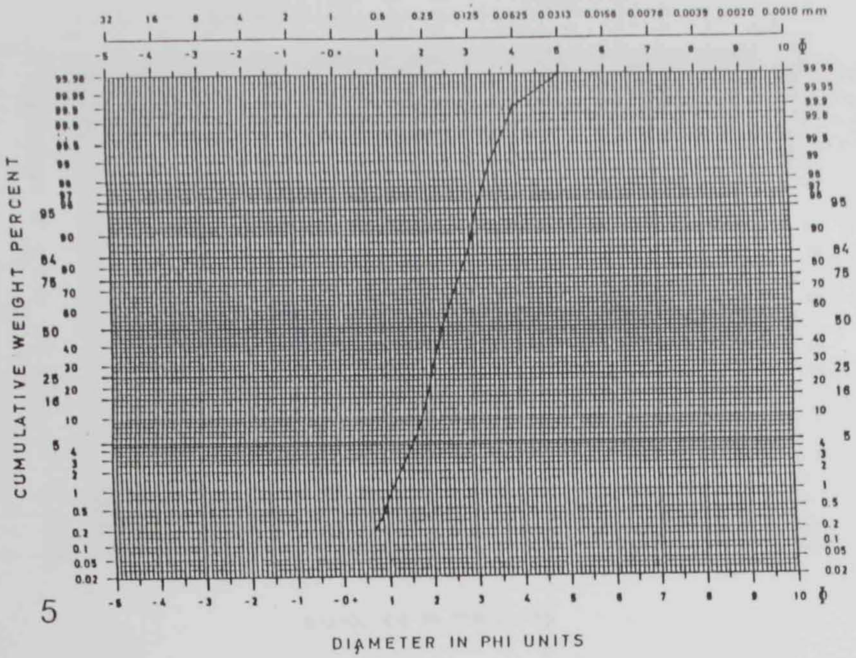
2


mm
CUMULATIVE WEIGHT PERCENT

3

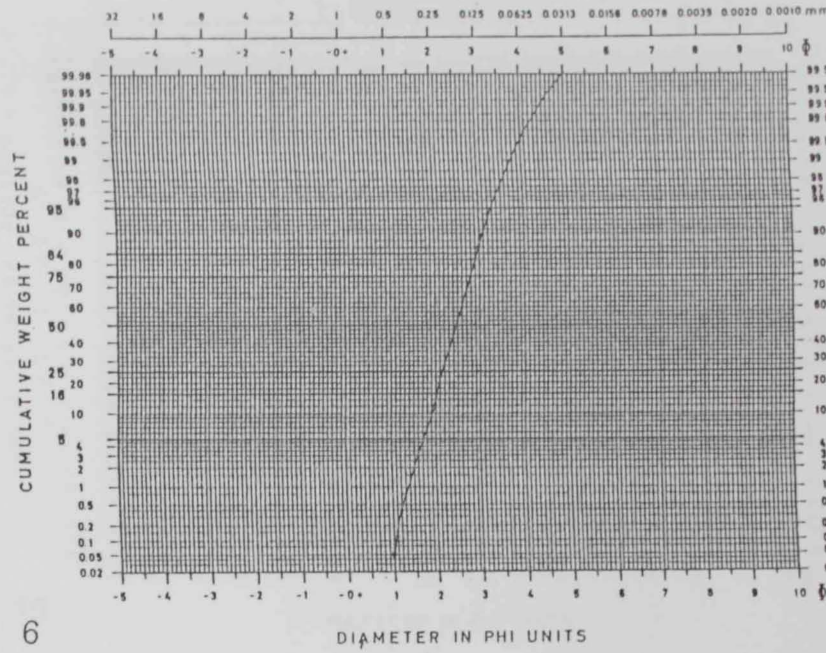

mm
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

4



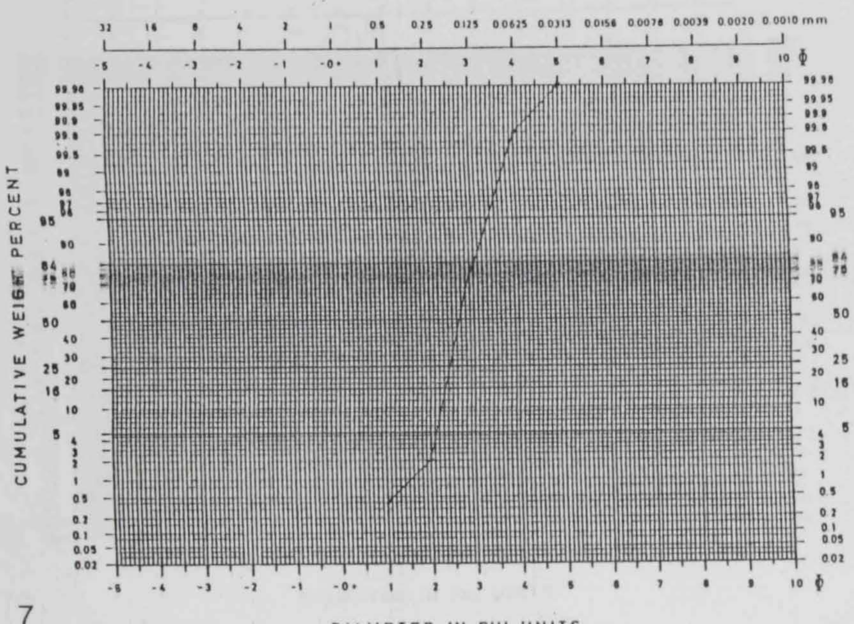
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

5



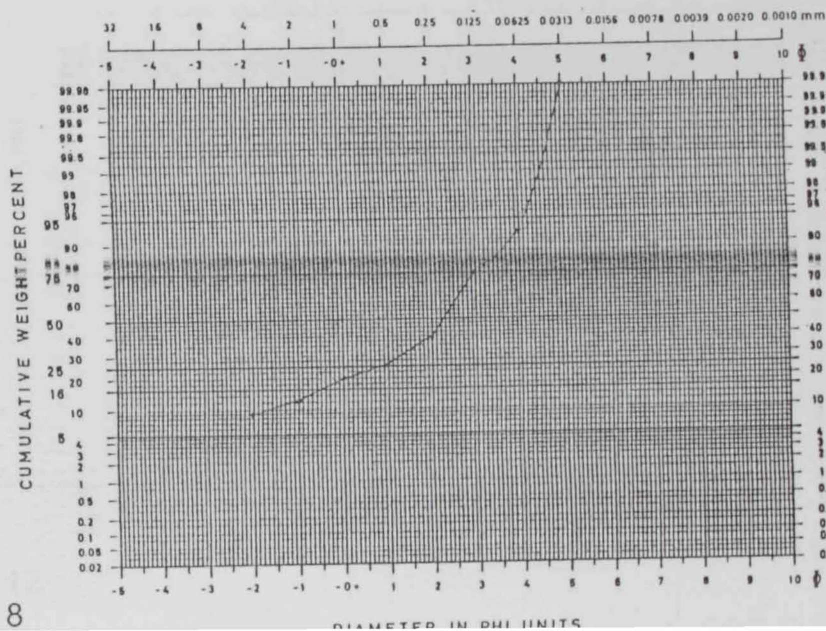
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

6



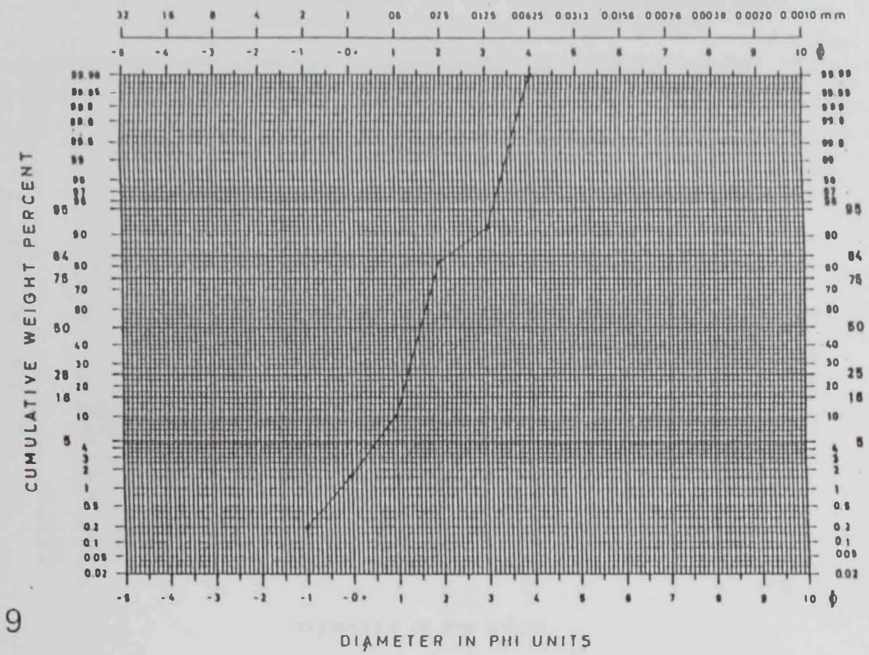
CUMULATIVE WEIGHT PERCENT

7

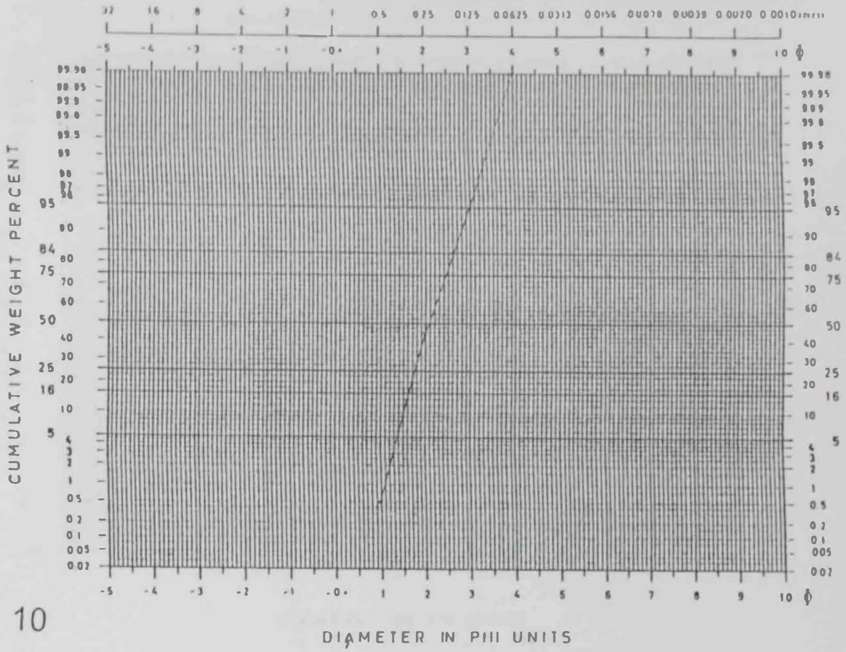


CUMULATIVE WEIGHT PERCENT

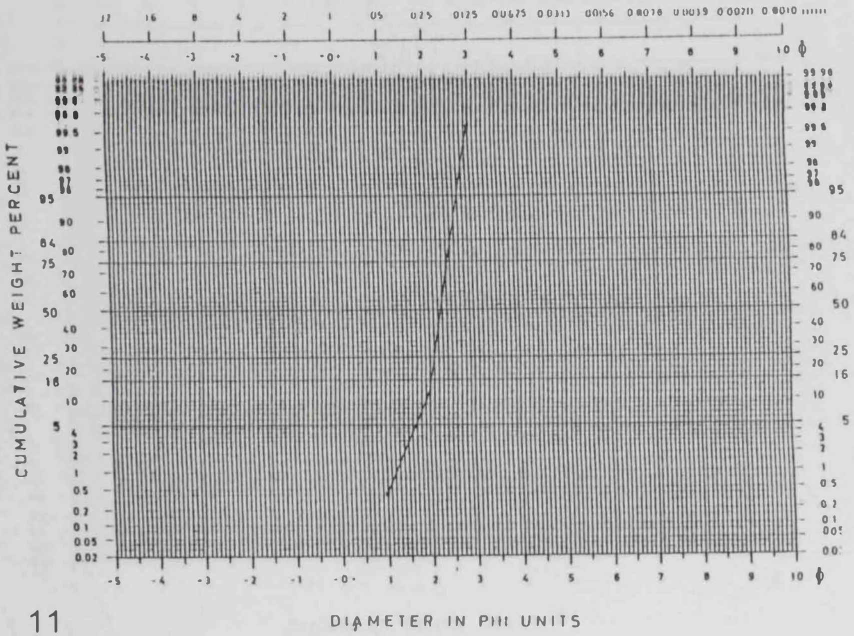
8


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

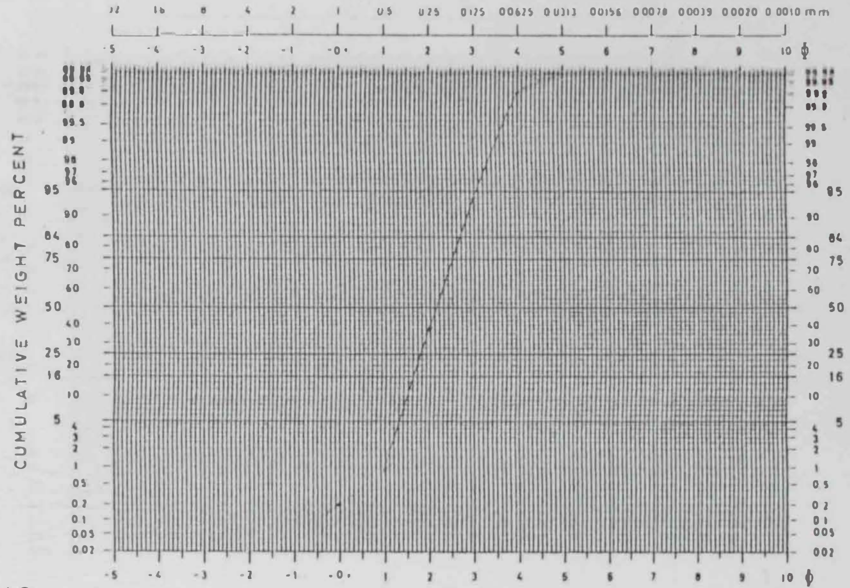
9


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

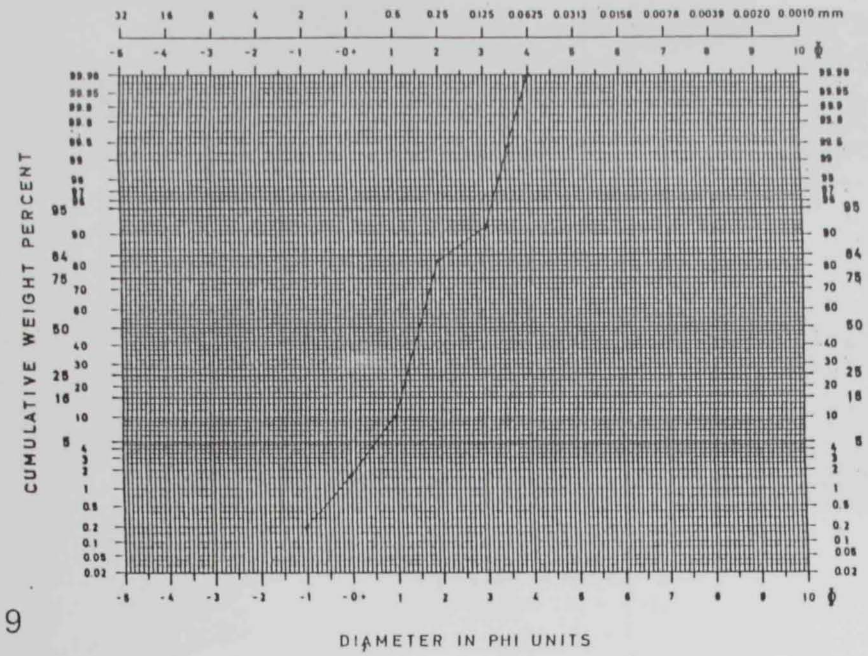
10


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

11

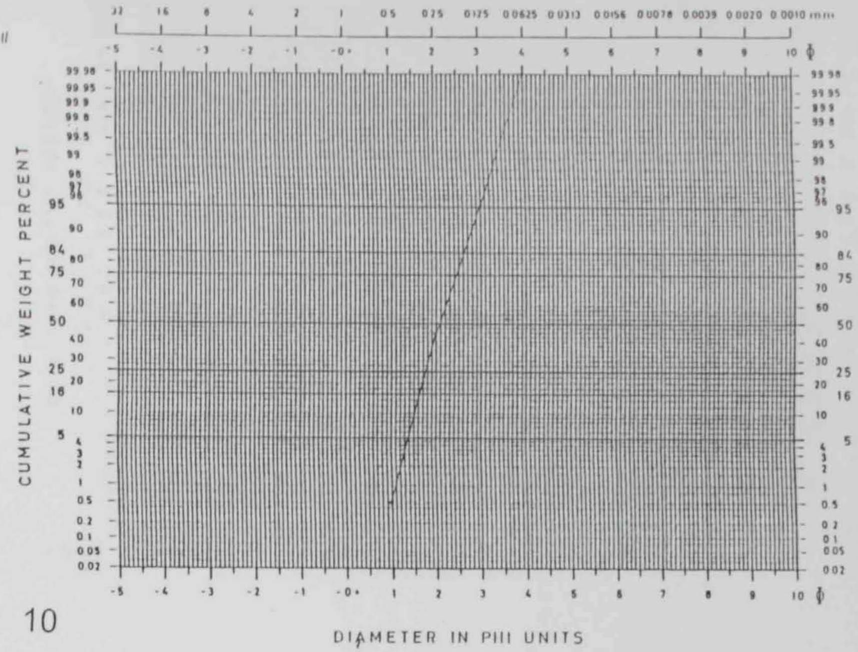

CUMULATIVE WEIGHT PERCENT

12



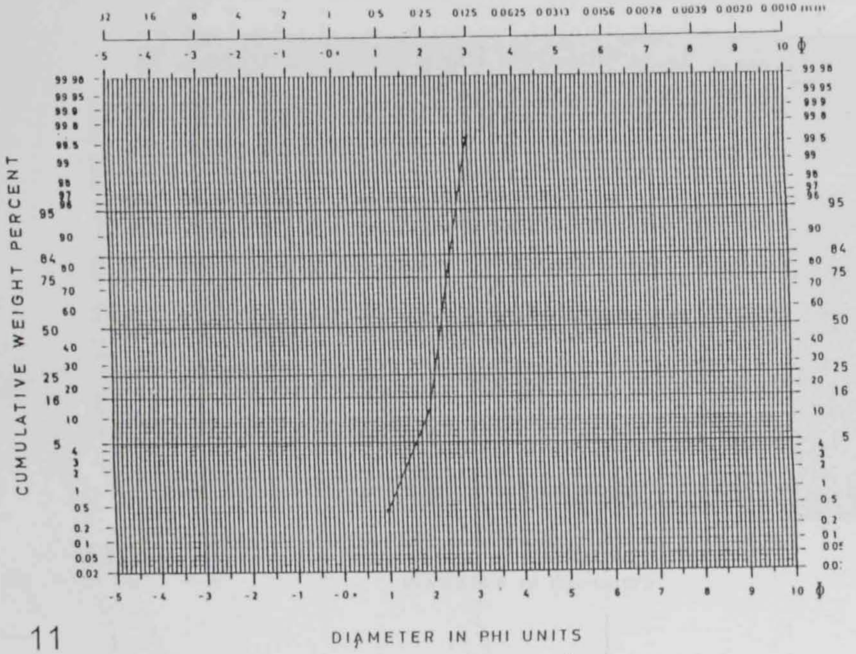
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

9



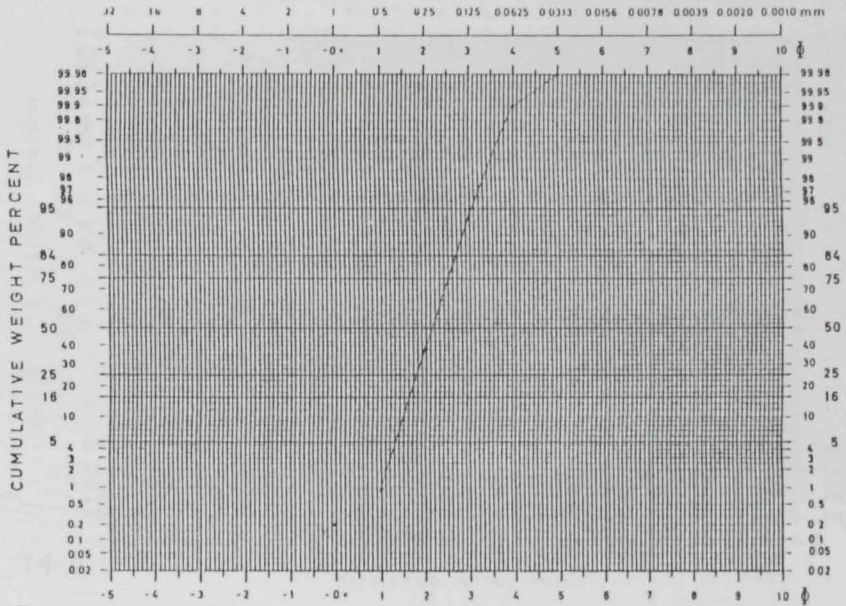
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

10



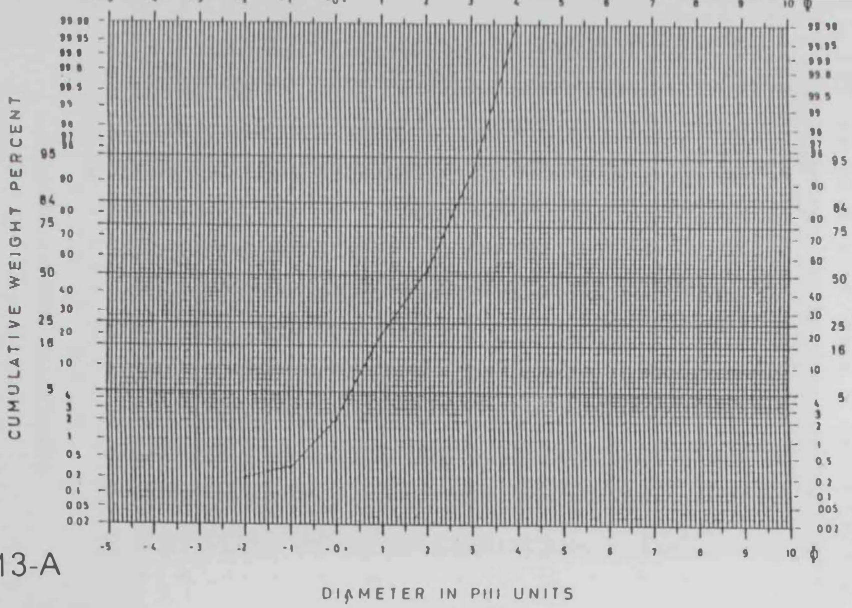
CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

11

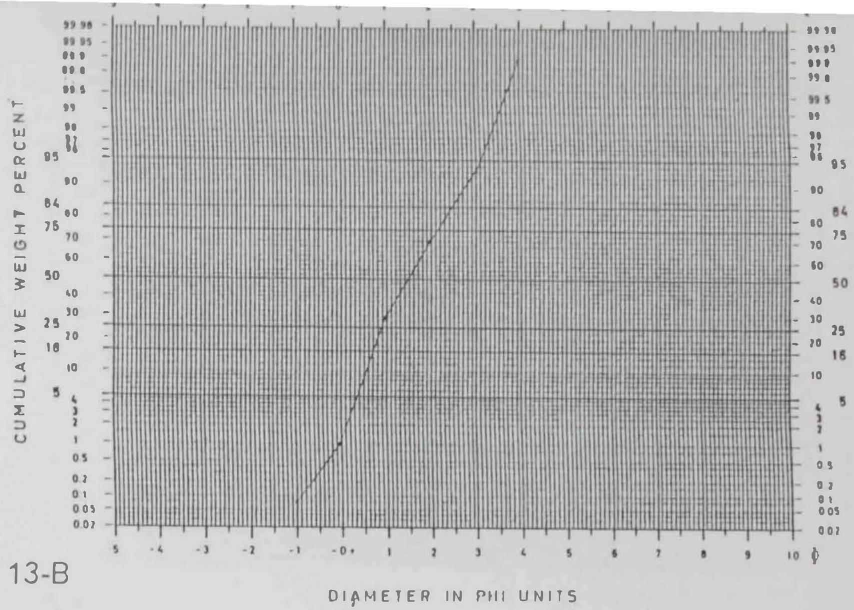


CUMULATIVE WEIGHT PERCENT

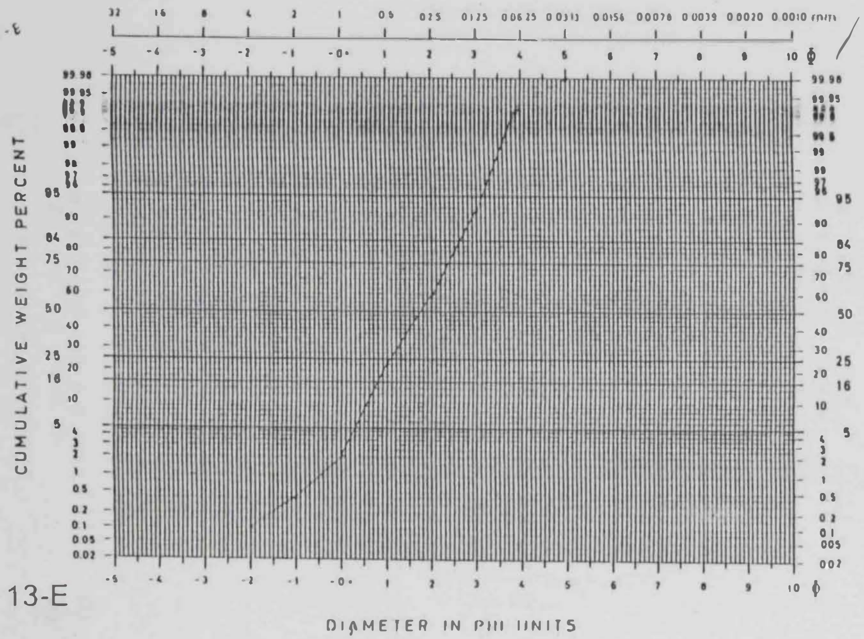
12



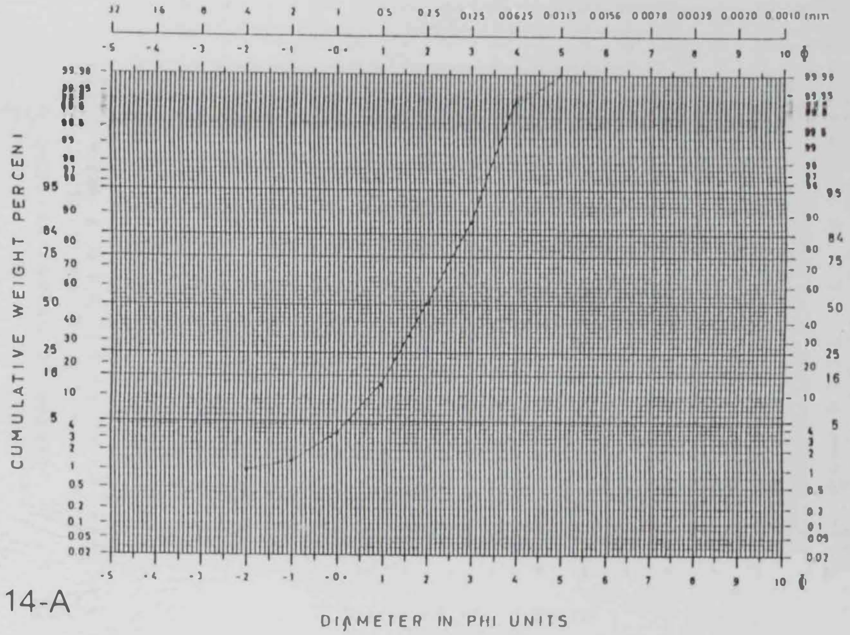
13-A



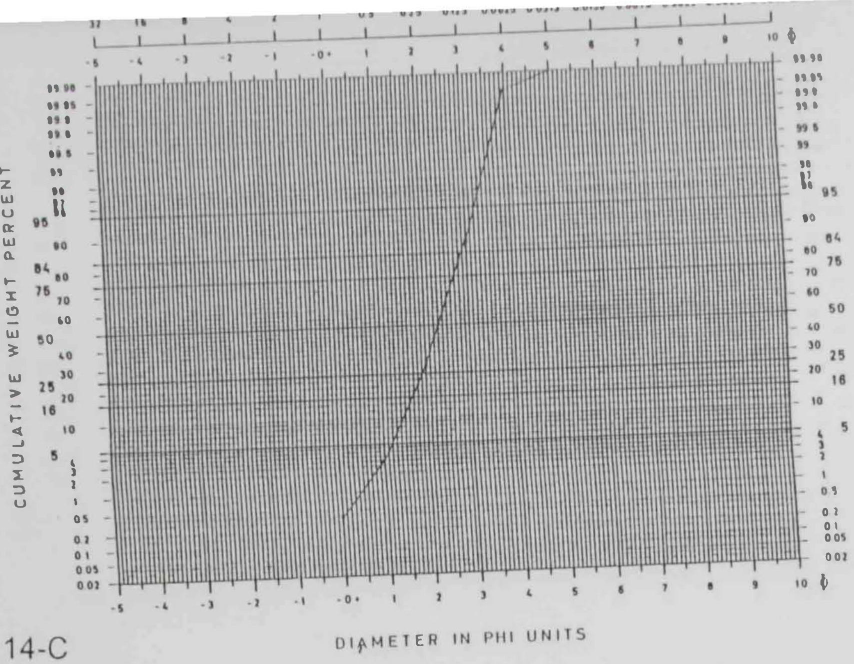
13-B



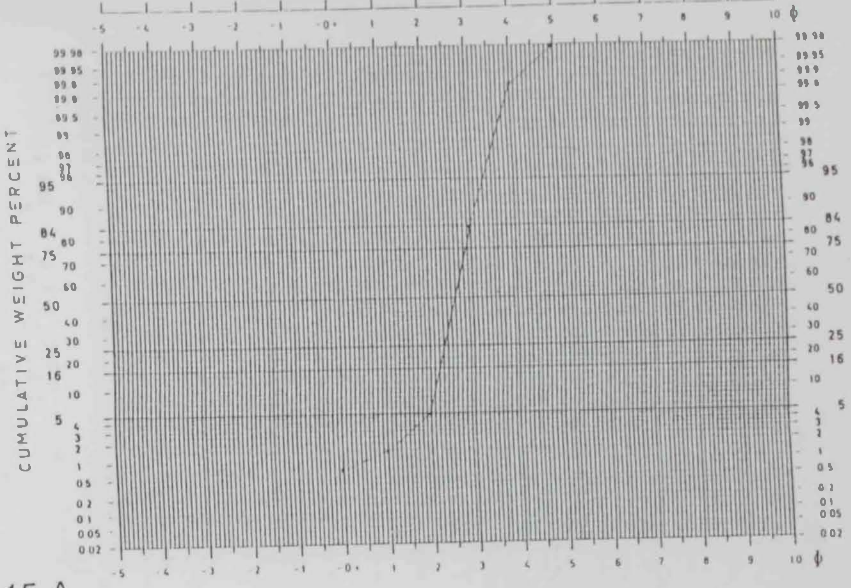
13-E



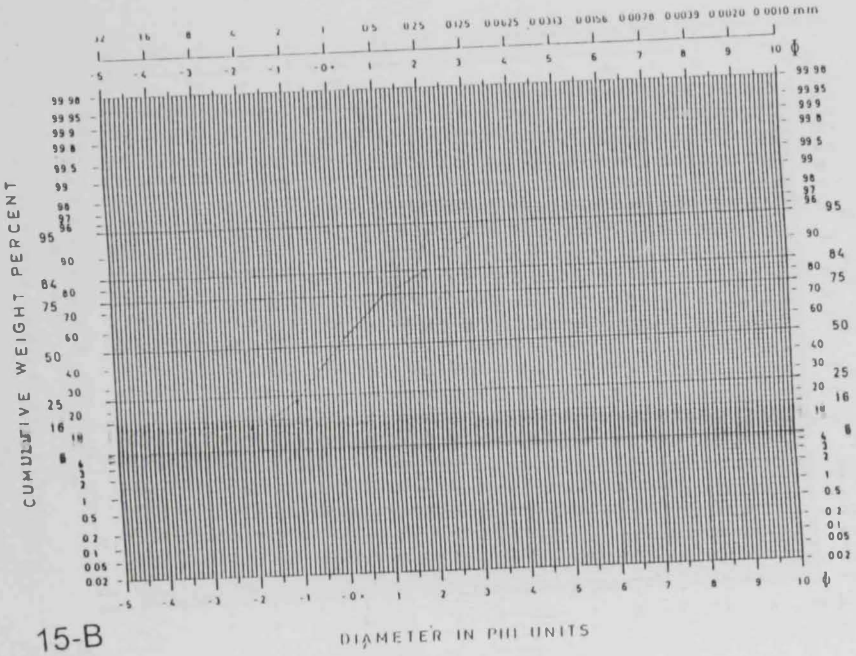
14-A



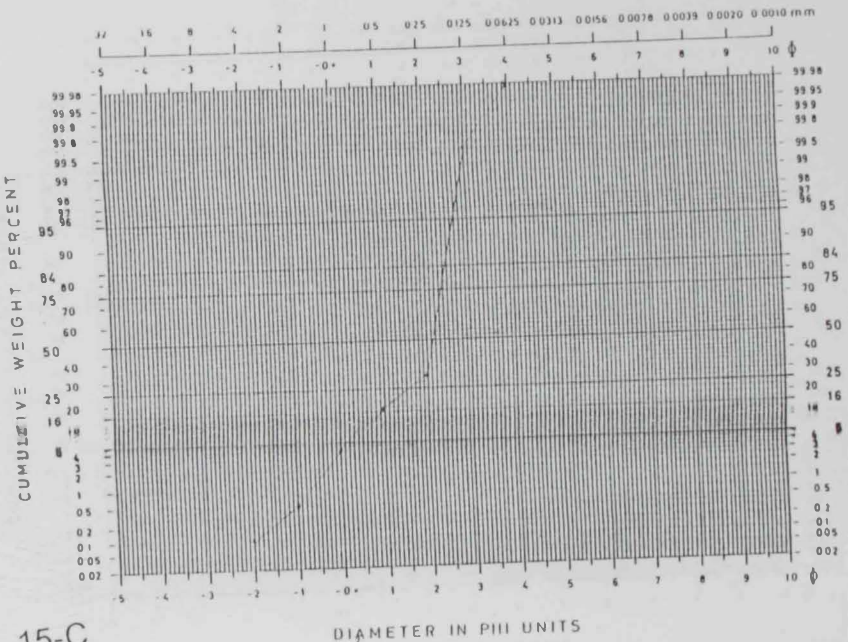
14-C



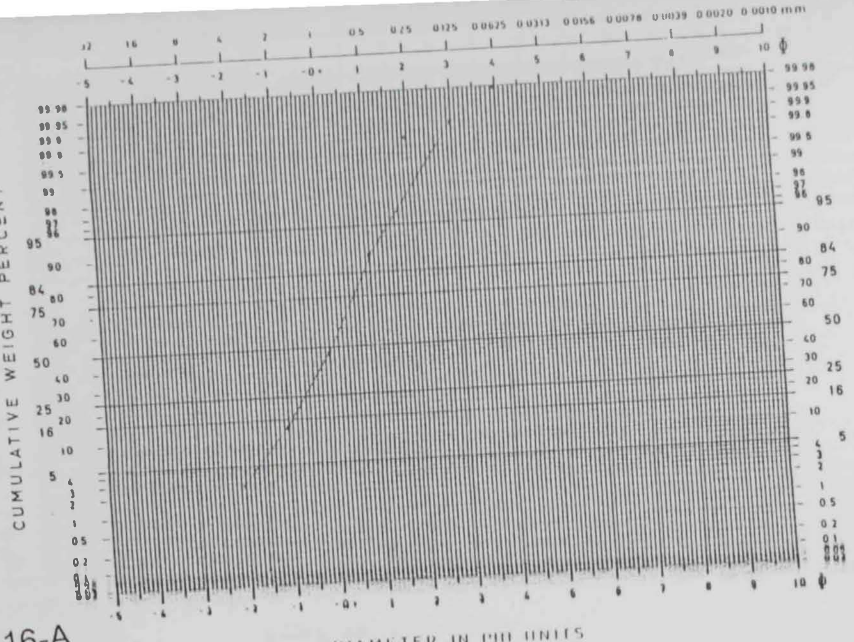
15-A



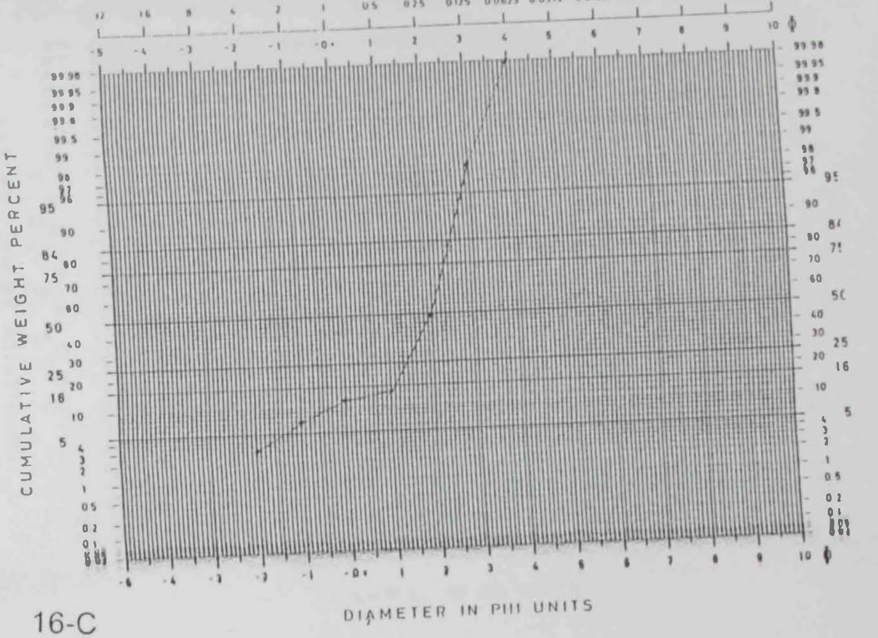
15-B



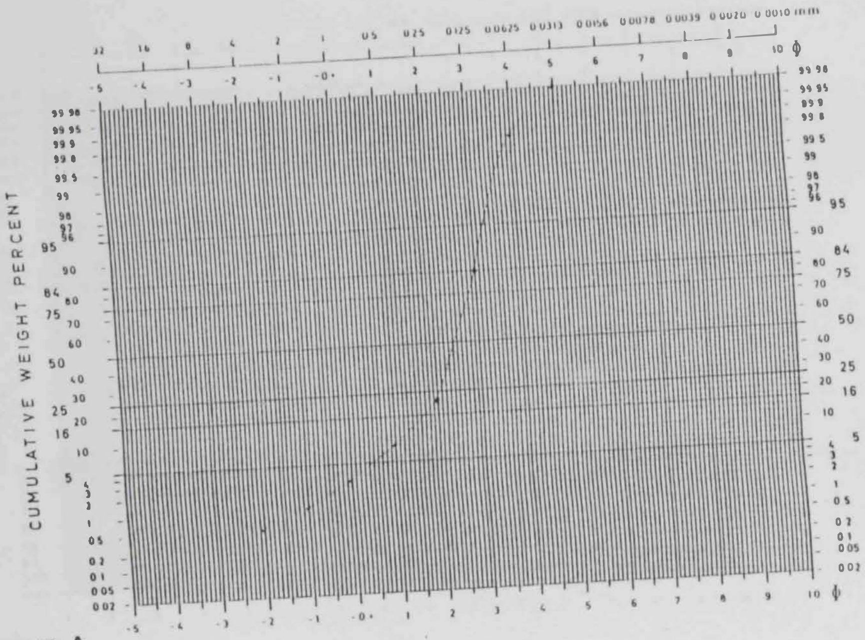
15-C



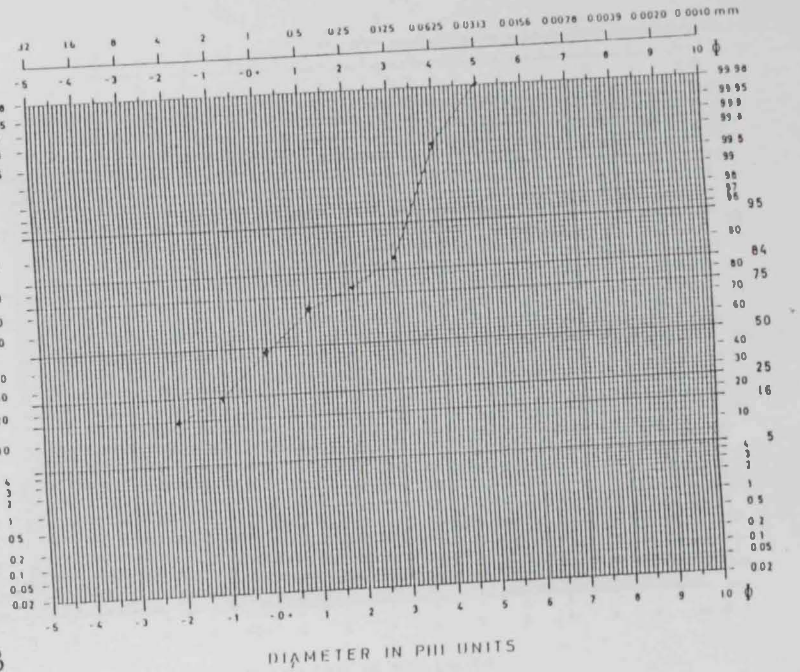
16-A



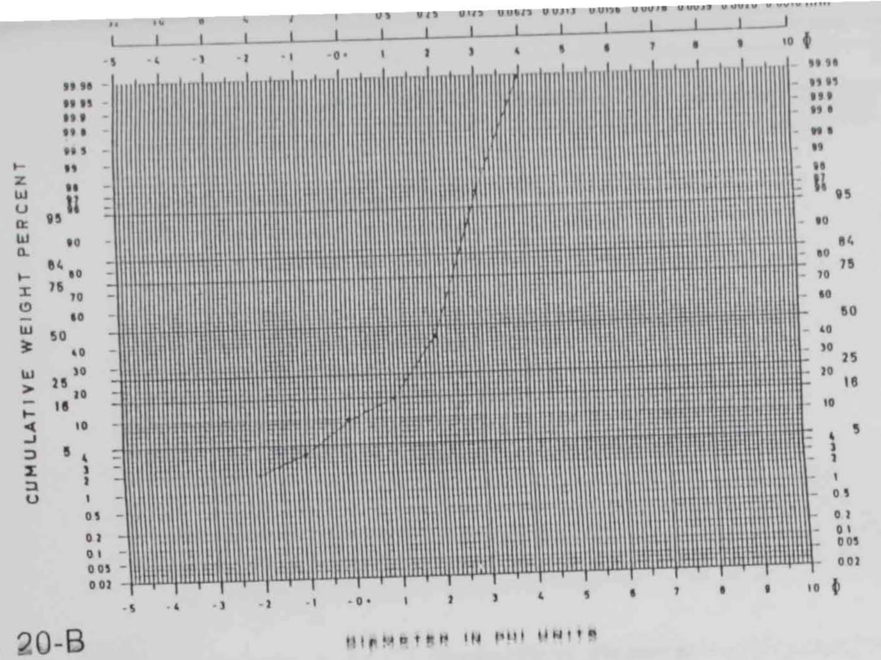
16-C



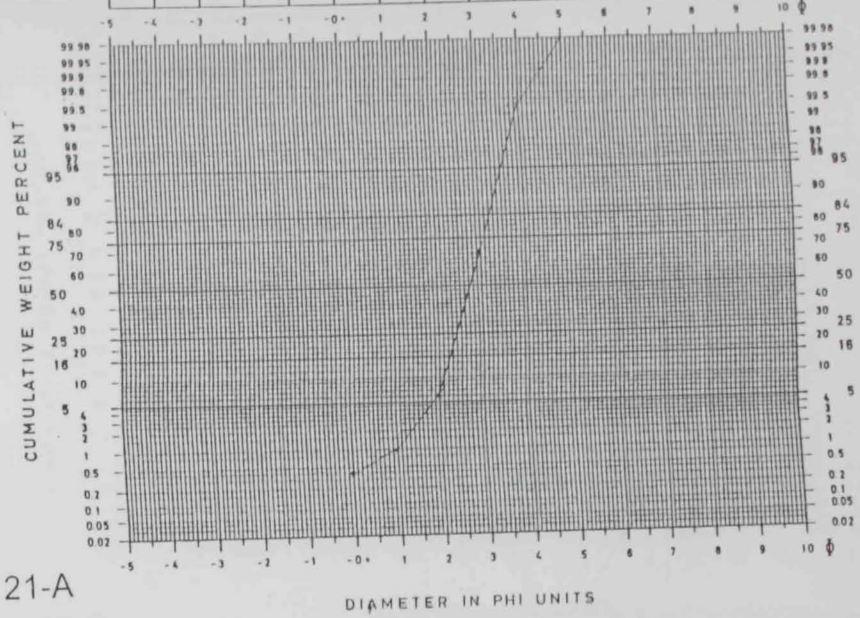
17-A



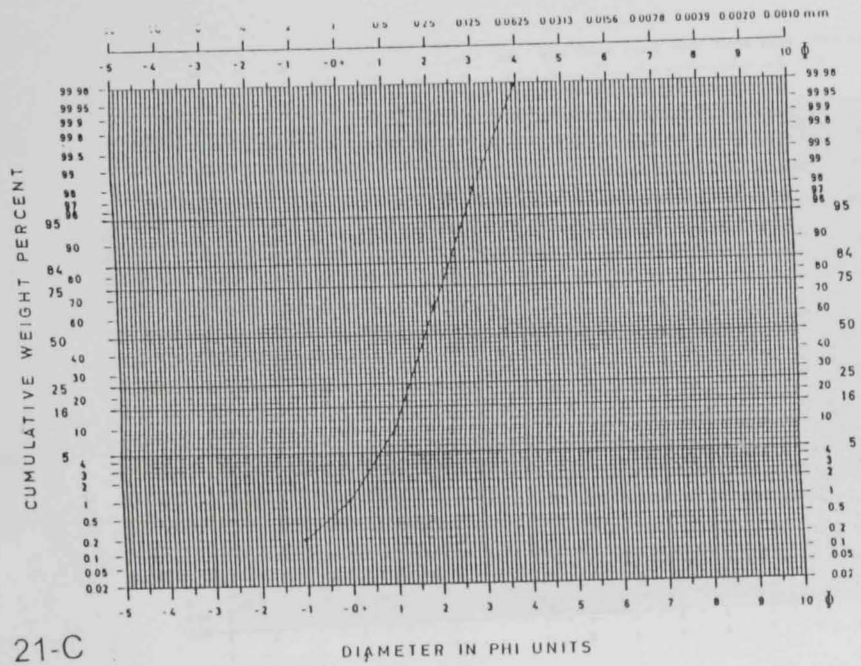
17-B


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

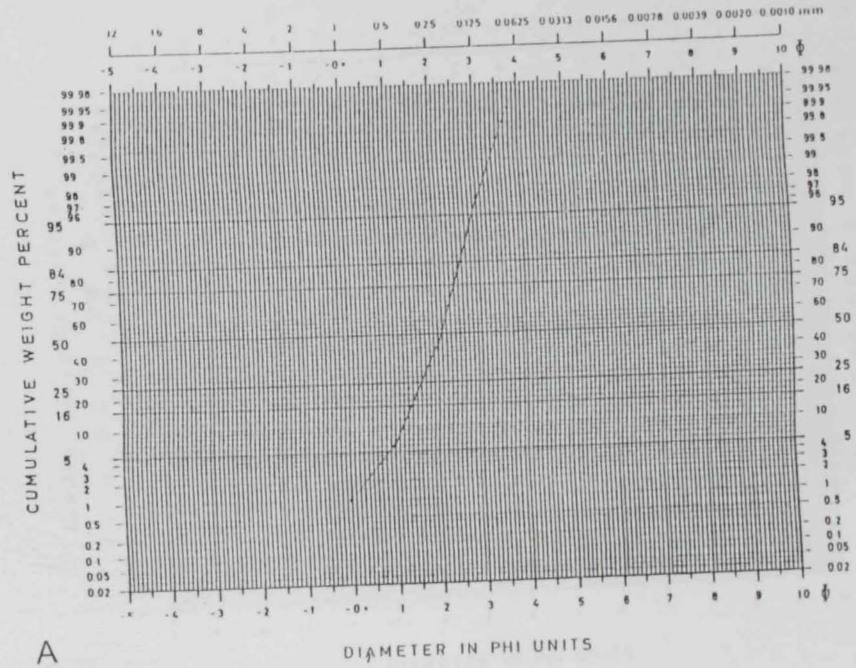
20-B


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

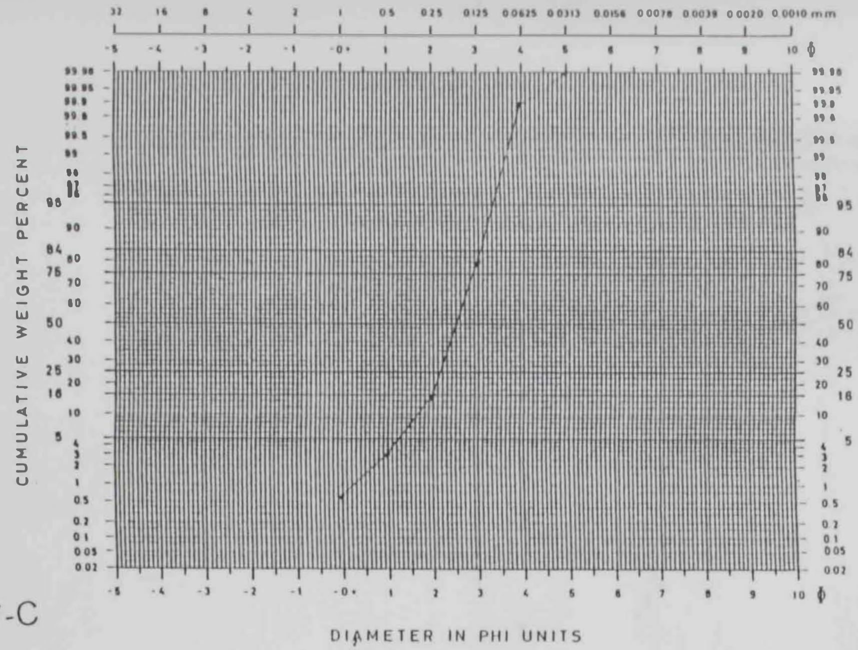
21-A


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

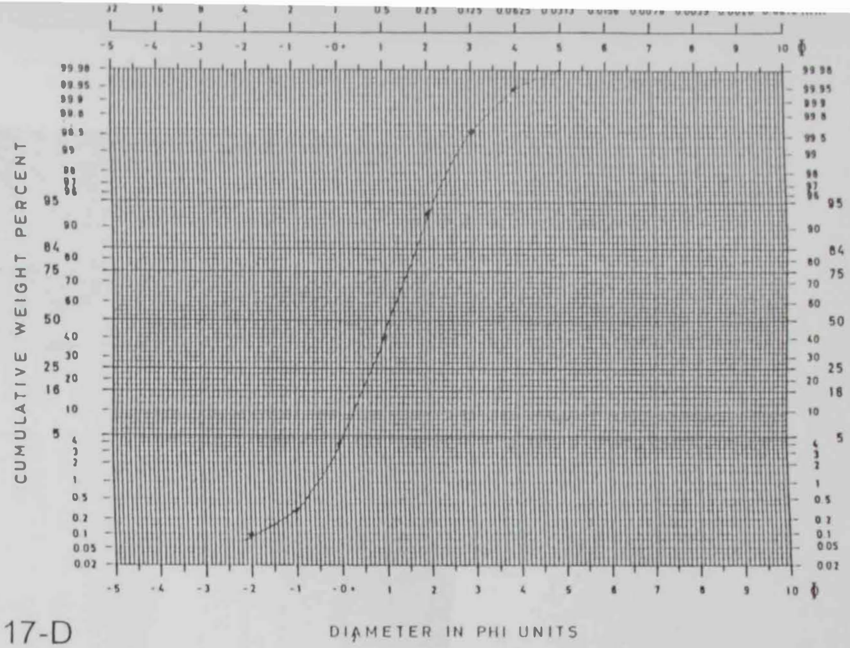
21-C


CUMULATIVE WEIGHT PERCENT
DIAMETER IN PHI UNITS

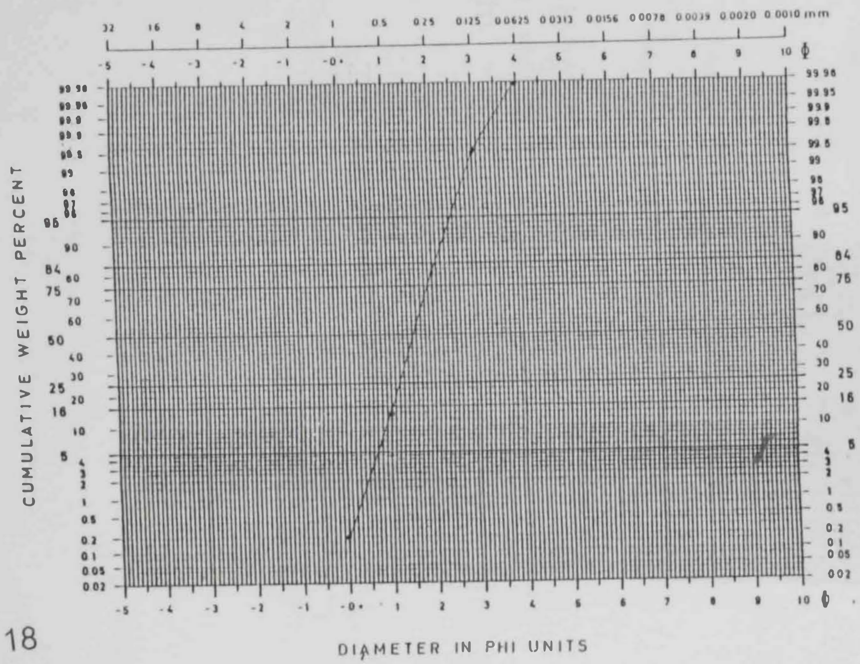
A



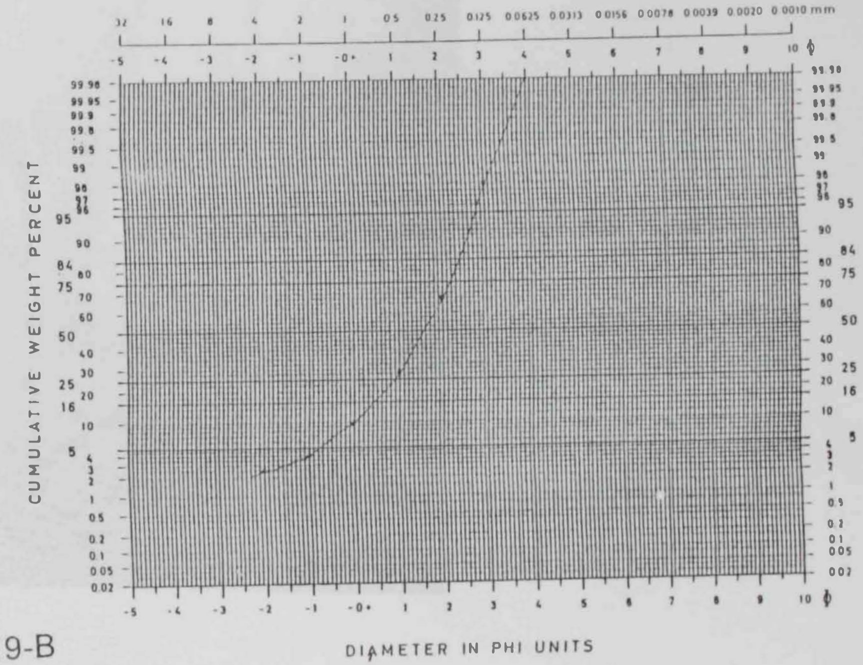
17-C



17-D



18



19-B

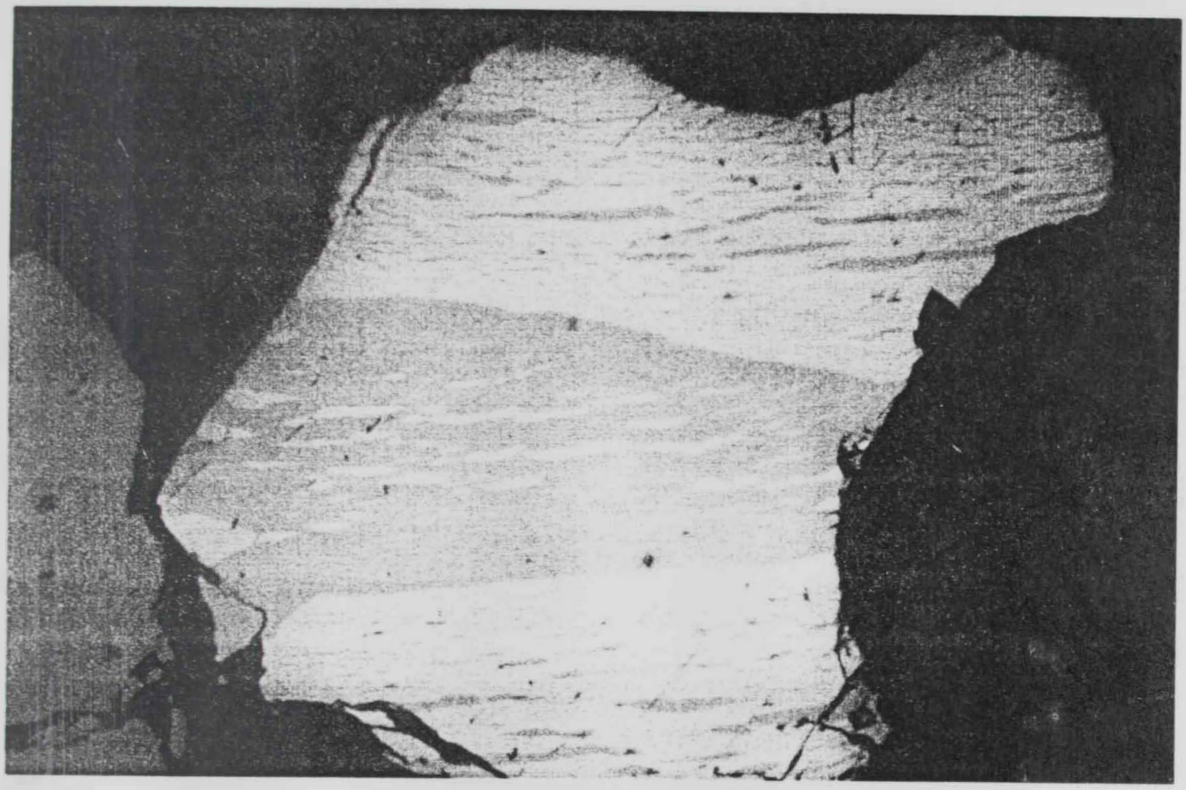


Fig. 23. Ilmenite (I) - Hematite (H) exsolution texture : Notice : hematite contains ilmenite lamallea (i) and ilmenite contains hematite lamallea (h).