TERRAIN CLASSIFICATION AND SELECTED SOIL PROPERTIES OF PART OF al.ZUBAIR DESERT, SOUTHERN IRAQ

SAMI S. ABOOD

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This thesis contains clear overlays.

Overlays have been scanned as a complete image, then scanned separately.

To my parents

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ABSTRACT

Background information, including aerial photographs, and field sampling are used to produce a terrain classification for part of al.Zubair desert, southern Iraq. Published methodologies are found to be not entirely suitable and modifications of these are introduced for this study to take account of the nature of the study area and limitations imposed upon one field scientist working alone.

Fieldwork included more detailed soil sampling than would be normal in such a survey. These soil samples were analysed in the laboratory for particle size, shape and surface texture, organic matter content, pH, $CaCO_3$ content, clay minerals and soluble salt determinations. How far variations in these soil properties can be related to terrain facets is assessed. Available data were sufficient for only limited statistical analysis but it is determined that reliable predictions of soil texture, organic matter, pH, $CaCO_3$ and soluble salts, should be possible from the terrain type map whereas variations in clay mineral types are shown to be not significantly related to facets/systems. For the former group of soil properties maps of their distributionsare drawn.

Examination of similar terrain classificationscarried out in neighbouring countries identifies common problems and significant terrain properties (especially those of soil and slope) that are used to define terrain suitability classes for various land uses. Following the example of these studies, terrain suitability maps for agriculture and grazing are drawn

for the study area. Comparison with the existing government plan shows no great disparity.

Finally an assessment of the study is made and principal shortcomings are identified. Both the absence of suitable data to produce a geomorphological map and the limited depth of the soil sampling are indicated as major restrictions on the use of the study for engineering suitability assessment of the terrain types.

Acknowledgements

I am indebted to several people and establishments for the help given me during my study.

In Iraq, I would like to express my gratitude to:

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Oh for the black tent where thro' the winds blow:
  More home to me than this castle that towers so high
How 'twould gladden my eye, the sight of a wool cloak:
  Smoother to me than all rare garments and silks
Then grant me but a bread-crust in the tent corner:
  Sweeter to me than this honey-cake I now eat
Might I hear the breezes soughing down the gulleys:
  Rarer to me their music than the throbbing of drums.

A single poem written 1,200 years ago called "The desert is home", written by Maisun bint Bahdal el-Kalbiyeh (daughter of the desert) and translated by Iain MacPherson, of Oxford-England.

"A desert is a place where everything is different.
The desert frightens some men, but it charms others".

Aramco overseas company
1978

CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1 PREVIOUS WORK

Iraq has been studied by western scientists and scholars since the early nineteenth century. The first studies of this region were concerned mainly with geographical information. This information is both sparse and generalized. Research increased in both quantity and quality after the second World War. Many articles and reports that arose during this period were largely concerned with oil and water supply. However, despite these studies the physiographic regions have not been studied in detail. Physiographic information on Iraq has thus remained sparse, especially with respect to the Iraqi deserts.

Geological information has fared better than the geomorphological information because most of these studies were made in relation to oil and water resources.

Until 1970, the scientific research in Iraq had been hindered for many years by several factors: the most important of which was that of an unstable political climate and the lack of practical field experience on the part of many workers. After 1970, in order to enable greater progress to be made in land resources utilization and managements, the Government of Iraq (with the assistance of the United Nations special Fund and Unesco) created a national institute entitled The Institute for Applied Research on Natural Resources (IARNR). This institute, since its establishment has operated in cooperation with the other institutions such as the Directorate of the Development of the Western Desert of Iraq and permanent settlements for the travelling Bedouins and The State Organizations of Soil and Land Reclamation.

The information gathered during their researches is available in a series of reports, often concerned directly with water supply and grazing. These reports as well as the previous work of others are very useful for this study in providing preliminary information about geology, geomorphology, soil and vegetation in the study area.

1.2 THE SCOPE AND OBJECTIVE OF THE STUDY.

A detailed study similar in form to those of the C.S.I.R.O. or M.E.X.E. relating to Land/Terrain classification has not been attempted yet in Iraq. Thus the subject of this study has been chosen to claim such an aim, bearing in mind that the differences in experience of the above-mentioned organizations and the author are such that it will be unlikely that the methodology of a team survey will be found entirely appropriate for an individual worker. The study is mainly an attempt to fulfil both academic and practical or applied interests. Once the subject of the study had been decided upon, the problem of chosing a study area arose. Due to time and cost limitations and its proximity to Basra (the writer's home), al.Zubair desert was chosen.

The study area is located some 47km west of Basra (city) in southern Iraq (Fig.3.1). It forms the extreme southern part of the Western Desert of Iraq, and occupies an area of about 1593.15km^2. It is linked with Basra city by an asphalt road, and by another with UmQasr from the south east which runs some 2km north of Safwan town. The main road which connects the area with Basra city and continues to Kuwait gives accessibility for investigation of the eastern parts of the area. In addition, faraway from the main roads there are some unpaved roads and tracks which provide access for fourwheel-drive vehicles.

The scope of this thesis is to classify and map the terrain of the study area into landform types with the help of relevant climatic, geological, geomorphological etc. information and with the available maps and aerial photographs. Complementary physical, organic, mineralogical and chemical soil properties were then selected for more detailed study.

A presentation of the structure of this study is shown in figure 1.1.

The outline of this thesis is as follows. The regional conditions are first described. These conditions have a great effect on the climatic, geological and geomorphological nature of the study area. For instance, the rainfall, temperature and wind conditions of the study area are influenced by the regional climatic factors which control the whole climatic regime of Iraq. Moreover, the physiographic features of the study area are the product of the geology, geomorphology, soil, vegetation and land use of the region. This general background information is included in Chapter 2. A more detailed description of the physiographic background of the study area comprises Chapter 3.

Since there are wide variations in terrain classification terminology and methodology, Chapter 4 is a discussion of the various methods. It includes examples of the methodology of previous studies of terrain/land classification especially C.S.I.R.O. and M.E.X.E. methods. The terminology and methodology to be used in this study is explained and justified. The final part of Chapter 4 is the terrain classification of the study area.

A detailed examination of soil properties is described

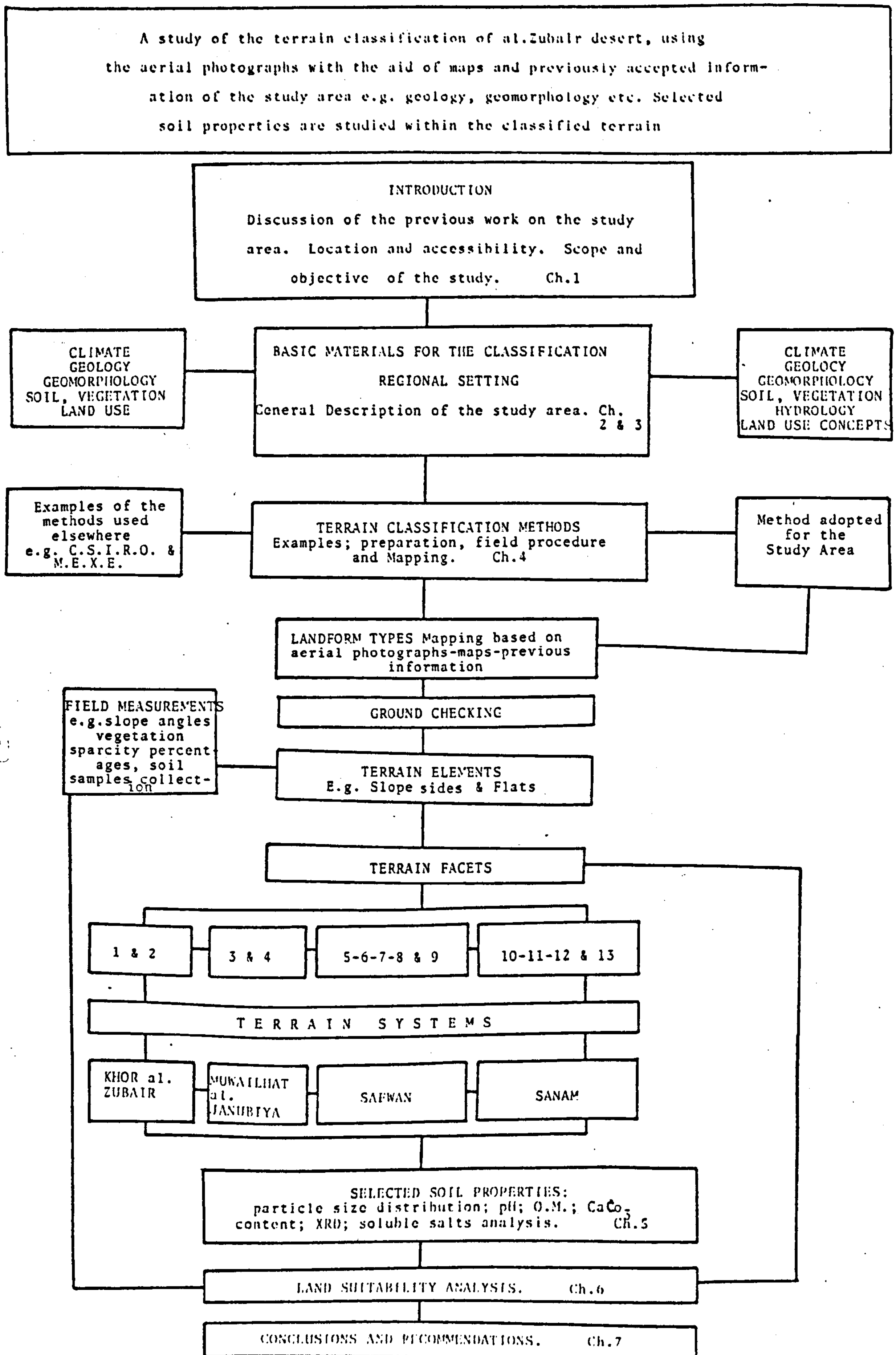

FIG.1.1: THE SCHEMATIC ORGANISATION OF THE STUDY.

in Chapter 5. Soils in general have many properties. It would only be reasonable therefore to study selected properties. The selected soil properties comprise particle size, shape and surface texture, pH, organic matter content, calcium carbonate content, clay minerals analysis and soluble salt determination. Descriptions of the soils and their relationship with the landscape are an essential component of most studies dealing with terrain classification. Therefore it is best to deal with these properties individually, using as much quantitative data as possible.

The mapping of the most significant of the results obtained from the analyses of the soil properties is the scope of Chapter 6. Examples of other survey work carried out elsewhere in the Middle East are given in this chapter. They have been used in their mapping objective factors, like slope angle and vegetation cover, to assess terrain suitability for specific purposes e.g. agriculture and grazing.

The conclusions of Chapter 7 centre on an assessment of the applicability of previous methods of terrain classification to the area studied here, in the light of recent thinking on the subject and the factual data accumulated from sampling and field verification carried out by the writer. Recommendations for further research work are also outlined in Chapter 7.

CHAPTER II

THE REGIONAL SETTING

THE REGIONAL SETTING

Iraq lies athwart the boundary between the alpine-Himalayan chain (metamorphic and strongly disturbed post-Hercynian sedimentary rocks of the Zagros mountains) and the flat-lying rocks overlying the Arabian Shield. The region is thus one of marked climatic, vegetational, hydrological and land use gradients.

It is important that the general distribution and range of variation of climate, geology, geomorphology, soils, vegetation and land use be recognised and these are set out in this chapter.

2.1 CLIMATE

Seventeen meteorological stations are maintained in Iraq, but only ten of these stations have long and continuous meteorological records.

Unfortunately, the present state of knowledge of the climate of Iraq has been, and still is, based upon data from only a few widely dispersed meteorological stations, of which those at Baghdad, Mosul and Basra are the only major ones.

In the vast Western Desert, the observation stations are poorly represented. The nearest stations to the study area are at Basra, Shuaiba and Nasiriya (Fig. 2.1).

2.1.1 Factors controlling the climate.

The climate of Iraq is characterised by dry warm and hot summers, and wet cold winters. These principal characteristics, however, vary from north to the south according to several factors. These factors are as follows:

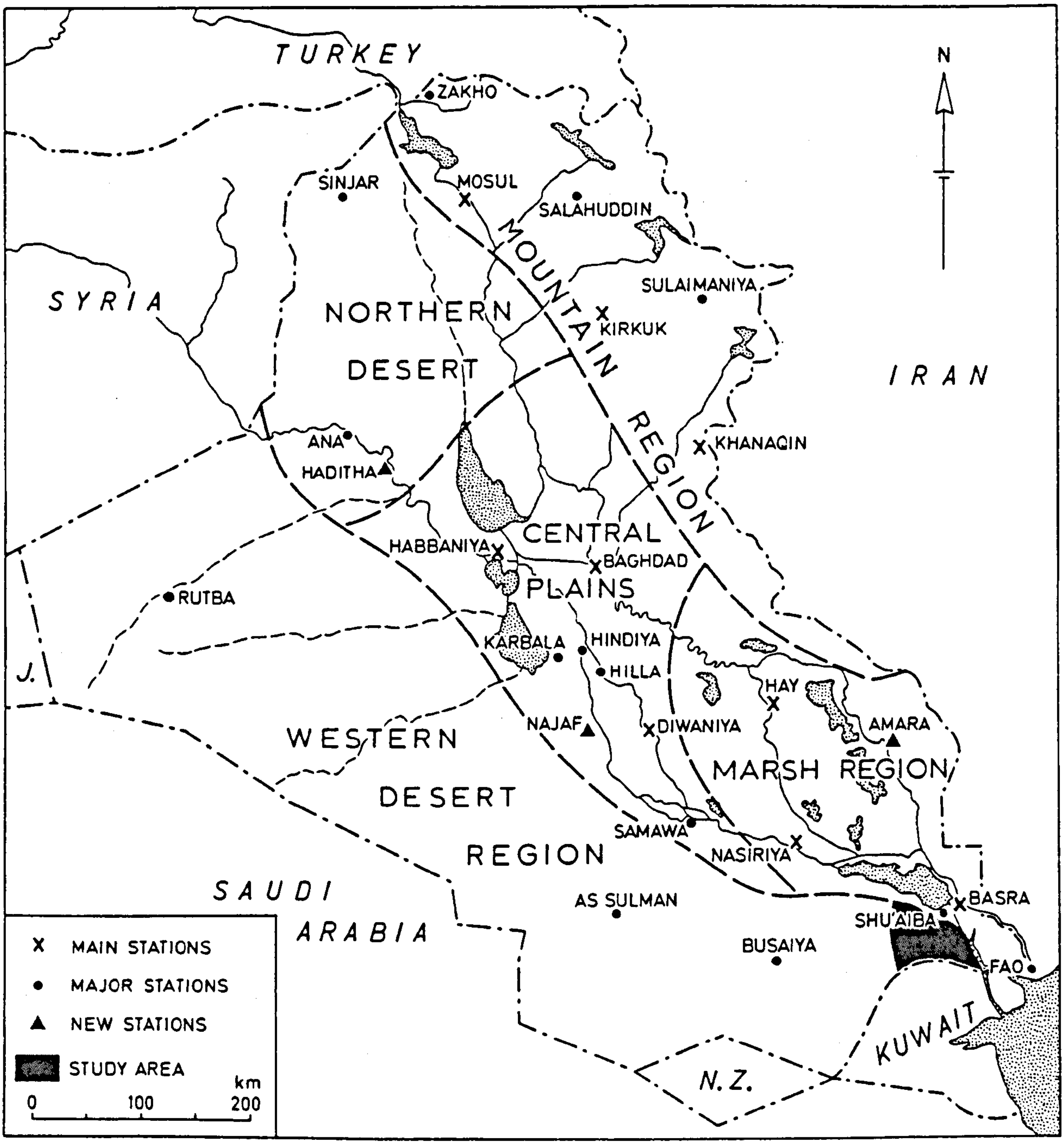

FIG. 2.1: METEOROLOGICAL STATIONS: LOCATION

i) Latitudinal Location.

Iraq extends from 29°5'20"N. to 37°33'50"N. As a result Iraq receives high sunshine totals. The annual temperature range in Iraq increases from the south to the north, a reflection of both latitude, distance from the ocean and increase in altitude.

ii) Location in relation to surrounding water bodies.

As can be seen from figure 2.2 Iraq is located between the Arabian Gulf and the Mediterranean sea. Moreover, to the north-east is the Caspian Sea, to the north is the Black Sea, and the Red Sea lies to the south-west.

According to Azeez (1968), the Mediterranean Sea is the major source of the precipitation in Iraq. The source of the precipitation is cyclonic systems, which cross the Lebanon and anti-Lebanon mountain ranges via the Syrian Plateau into Iraq during the winter months. In the summer, however, the Arabian Gulf is the major source of moisture, providing occasional hot and humid air masses which invade the southern part of Iraq and which may extend even beyond Baghdad.

The hot and humid weather which prevails in the study area during the summer results in hazy conditions both day and night.

iii) Topographic factor.

The main topographic features of Iraq as identified in figure 2.1 are the Western Desert, the Mesopotamian plains, and the mountains. These features are of major climatic significance. The correlation between the topography of Iraq and the precipitation pattern is

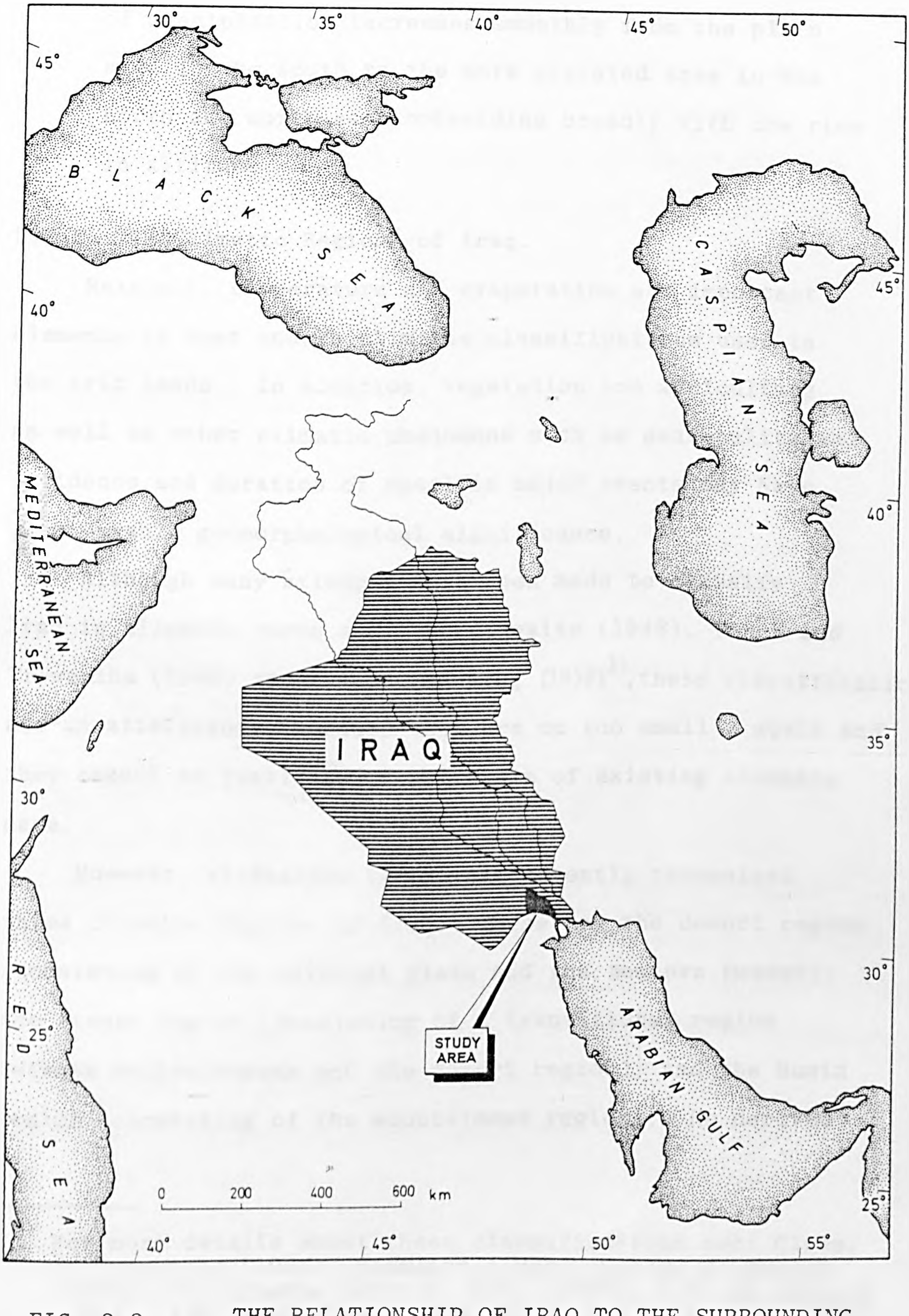

FIG. 2.2: THE RELATIONSHIP OF IRAQ TO THE SURROUNDING WATER BODIES

shown in figure 2.5. It can be seen that the amount of precipitation increases smoothly from the plain area in the south to the more elevated area in the north and north-east coinciding broadly with the rise in altitude.

2.1.2 The Climatic Regions of Iraq.

Rainfall, temperature and evaporation are important elements in most modern climatic classifications used in the arid lands. In addition, vegetation and agriculture as well as other climatic phenomena such as seasonality and incidence and duration of specific major events may have considerable geomorphological significance.

Although many attempts have been made to classify Iraq in climatic terms e.g. Thornthwaite (1948), Finch and Trewartha (1949) and Koeppe and Long (1958)[1], these classifications are unsatisfactory, because they are on too small a scale and they cannot be justified on the basis of existing climatic data.

However, al.Shalash (1972) has recently recognised three climatic regions of Iraq. These are the desert region (consisting of the alluvial plain and the Western Desert); the steppe region (consisting of a transitional region between Mediterranean and the desert region); and the humid region (consisting of the mountainous region). He derived

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1) For more details about these classifications see: Glenn, T. Trewartha (1968), K.Walton (1969), George R. Rumney (1968), C.E. Koeppe and G.C. Long (1958), A.H. al.Shalash (1972), J.M. al.Khalaf (1957), Finch and Trewartha (1949) and Thornthwaite (1948).

his classification by using a range of indices (which have been used to classify the world climatically e.g. simple index of aridity, precipitation effectiveness index and rain factor index) and applying them to Iraqi climatic data. This classification is broadly coincident with that of al.Khalaf (1957). Figure 2.3 shows the following three climatic regions.

1. Mediterranean: mountainous area in the north and north-eastern parts of Iraq, comprising approximately 12% of the country.
2. Low latitude steppe: A transitional region between the Mediterranean and the desert zone, located within the semi-mountainous area, and comprising approximately 18% of the country.
3. Low latitude desert: This consists of the alluvial plains and the Western Desert plateau, and comprises approximately 70% of the country.

According to this classification, the study area falls in the low latitude desert zone.

2.1.3 Climatic elements.

2.1.3.1 Temperature.

Throughout the country there are two dominant seasons. The hot season (summer) lasts for five months (May - October), whilst the cold season (winter) is longer and lasts from November to May. The two transitional seasons can be distinguished only in the north and north east of Iraq. Spring lasts one month (March - April), and the transition from winter to spring is very gradual. Autumn, consists of the months of October and November.

Kendrew (1949), pointed out that "the most important of the elements which combine to form climate are temperature, and rainfall". (p.1). However, the influence of wind, and

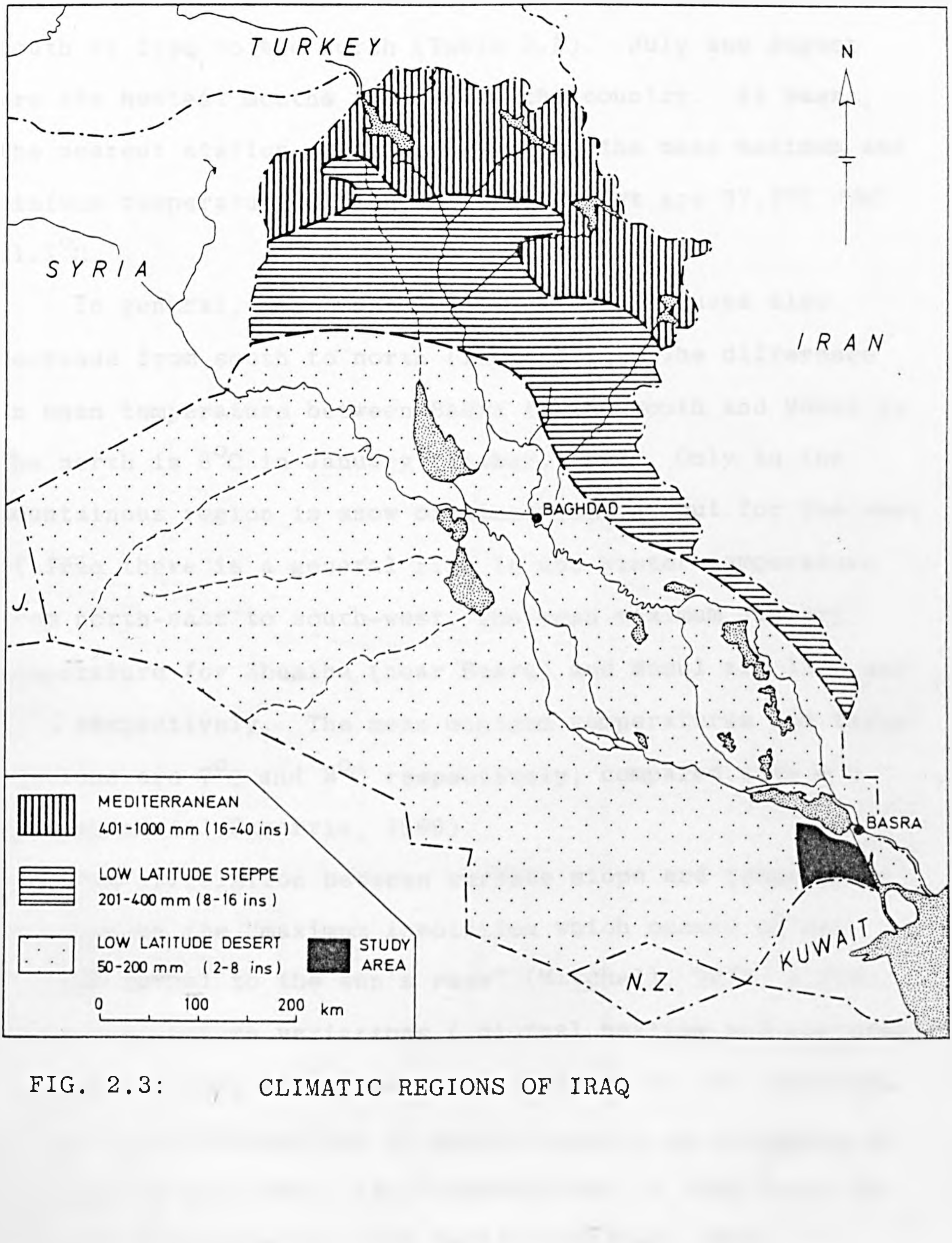

FIG. 2.3: CLIMATIC REGIONS OF IRAQ

duststorms should not be neglected.

Temperature varies according to several factors: latitude, topography and altitude and the influence of air masses. The statistics for mean air temperatures show that there is a general decrease in annual temperature from the south of Iraq to the north (Table 2.1). July and August are the hottest months throughout the country. At Basra, the nearest station to the study area, the mean maximum and minimum temperature during July and August are 37.7°C and 21.1°C.

In general, mean monthly winter temperatures also decrease from south to north (Table 2.1). The difference in mean temperature between Basra in the south and Mosul in the north is 6°C in January (Fisher, 1971). Only in the mountainous region is snow or sleet common, but for the rest of Iraq there is a general rise in the winter temperature from north-east to south-west. The mean maximum January temperature for Shuaiba (near Basra) and Mosul are 18°C and 12°C respectively. The mean minimum temperatures for these stations are 7°C and 2°C respectively, compared with 4°C at Baghdad (al.Samarrie, 1969).

The correlation between surface slope and temperature is shown by the "maximum insolation which occurs on any surface normal to the sun's rays" (Mitchell, 1973, p.102). Daily temperature variations (diurnal heating and nocturnal cooling) as well as the seasonal contrast in net radiation values in particular lead to thermal expansion and contraction of rocks which may result in disaggregation, a view which is gaining acceptance for arid regions (Ollier, 1969; Bultzer, 1964).

Stations	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Mosul	1941-70	7.0	8.7	12.3	17.4	24.1	30.5	34.0	33.0	27.7	20.5	13.5	8.3	19.3
Kirkuk	1941-70	8.6	10.1	13.8	19.2	26.2	32.2	35.2	34.8	30.4	24.0	16.5	10.6	21.8
Khanaqin	1941-70	10.0	12.5	15.3	21.1	28.3	33.6	36.4	35.7	30.2	25.2	17.6	11.9	23.2
Habbaniya	1941-70	9.5	12.0	16.1	21.7	28.1	32.7	34.8	34.2	30.0	24.1	16.8	11.0	22.6
Baghdad	1941-70	10.0	12.3	16.3	22.0	28.4	33.0	34.8	34.4	30.6	24.6	17.1	11.0	22.9
Rutba	1941-70	7.4	9.4	13.0	18.2	23.8	28.4	30.6	30.3	26.7	21.3	14.2	8.9	19.4
Nasiriya	1941-70	11.4	13.9	18.2	23.6	29.8	32.9	34.3	34.6	31.6	26.1	18.8	12.8	24.0
Basra	1941-70	12.4	14.6	18.7	24.1	29.7	32.7	34.0	33.6	30.6	25.9	19.3	13.6	24.1

Table 2-1: Normal/or Average monthly and annual mean air temperature (^{o}C) for Iraqi meteorological stations.

Source: Meteorological Department, Baghadad Airport, 1975.

It has been said that the latitudinal location of Iraq and its largely land-locked situation are responsible for the continental-type temperature characteristics of the country, particularly its large annual, seasonal, and daily temperature ranges. al.Shalash (1966) stated that "the continentality of Iraq shows itself in the large annual and daily ranges of temperature, the annual range varies from 4.3°C to 15.6°C". (p.42)

Basra due to its location near the Arabian Gulf has the highest index of oceanicity[2)] in the country. It has the smallest difference between summer and winter diurnal temperatures, 5.1°C and 6.7°C respectively of all stations in Iraq.

2.1.3.2 Rainfall

Iraq receives the majority of its rainfall in the winter season (October-May). The rain is associated with the depressions which track through Iraq during the winter (Table 2.2).

These depressions originate in the Atlantic, pass through the Mediterranean Sea, and move towards Iraq. The majority take a south-easterly track through Iraq (towards the Arabian Gulf), the remainder following a route to the north-east.

Southern Iraq and the Western Desert have a low rainfall, the amount increasing towards the north, broadly matching the

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2) The method of obtaining oceanicity indices was devised by Kerner and applied to Iraq by al.Shalash (1966, p.56).

Months	30°–32° N	32°–34° N	34°–36° N	36°–38° N	Total per.mo.
Jan.	2	4	9	1	16
Feb.	1	8	12	1	22
March	0	5	7	0	12
April	2	10	5	0	17
May	3	4	1	0	8
Oct.	1	1	5	0	7
Nov.	5	2	2	2	11
Dec.	1	4	6	0	11
Total	15	38	47	4	104

Table 2-2: Number of depressions per month which entered Iraq in various Latitudes during the period 1938-40. The study area is located in latitudes 30°-30° 27′N.

Source: al-Shalash, A.H. (1966, p.70).

increase in altitude (Fig. 2.4).

Those meteorological stations located near the main water bodies (the Gulf and swamps) have high rainfall amounts compared with other stations as shown in table 2.3.

Glancing at table 2.4 and figure 2.5 the differences in rainfall amounts between the north and south of Iraq are evident. Rain especially in spring is very important for the dry farming agriculture in the northern parts of Iraq. Total rainfall amount is the critical factor in success or failure of the crops.

In other regions where rainfall is low, agriculture depends on either river water or the presence of aquifers. Some parts of the desert may be green in the early summer, whilst the rest may be parched and dry. However, the small amount of rainfall that the south-west of Iraq receives in winter falls as showers and the combination of raindrop impact and the low strength of exposed surface sand, and surficial debris results in widespread rilling and gulling of the surface (Gerson, 1977).

It is important, from the agricultural point of view that not only the amount of rainfall should be calculated, but also the time when it occurs.

Because of the dearth of annual rainfall records in many parts of Iraq, the calculation of rainfall variability is impossible in most places. Basra is one of three stations (Baghdad, Basra and Mosul) which have relatively complete data. The year-to-year fluctuation in rainfall at Basra is shown in figure 2.6.

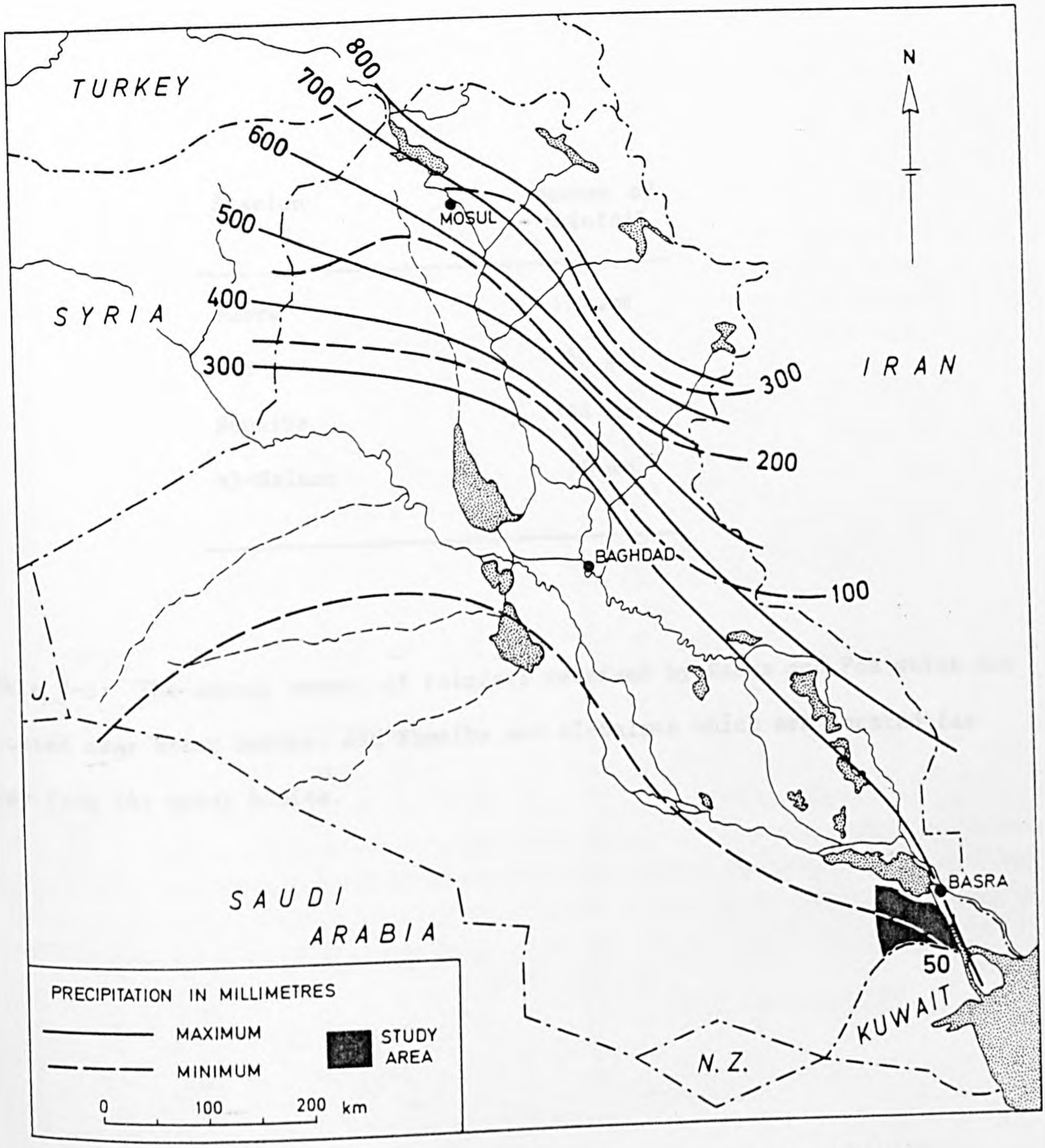

FIG. 2.4: MAXIMUM AND MINIMUM SEASONAL AMOUNT OF PRECIPITATION, 1950-1970

Station	Amount of rainfall
Basra	170 mm
Fao	186 mm
Shuaiba	144 mm
al-Salman	78 mm

Table 2-3: The annual amount of rainfall received by Basra and Foa which are located near water bodies, and Shuaiba and al-Salman which are located far away from the water bodies.

Station	MONTHS								SEASONS				Annual	Number of years, data used
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Oct-Feb Autumn	Dec-Feb Winter	Mar-May Spring	Jun-Sept Summer		
Mosul	10.2	36.5	65.6	67.7	64.6	69.6	50.8	24.9	46.7	197.9	145.3	practically nil	390.2	30
Kirkuk	4.3	40.8	58.6	60.7	61.8	75.5	51.0	21.0	45.1	181.1	147.5		374.1	30
Khanaqin	4.3	30.6	47.8	62.0	53.7	66.7	37.3	18.2	34.9	143.5	122.2		321.2	26
Rutba	5.4	13.3	16.3	62.0	13.6	15.4	17.6	15.0	18.7	43.5	48.0		110.0	29
Baghdad	3.7	17.2	22.9	25.3	24.4	22.7	22.3	8.1	20.9	72.6	53.1		146.9	30
Nasiriya	2.2	16.8	20.4	19.2	13.4	15.8	16.6	7.1	19.0	53.0	39.5		111.5	30
Diwaniya	3.9	15.5	20.2	21.2	15.0	16.9	17.8	8.4	19.4	56.4	43.1		119.0	30
Basra	1.0	22.8	30.2	22.8	13.8	20.2	20.4	7.8	23.8	66.8	48.4		139.5	30

Table 2-4 Mean Monthly, Seasonal and Annual Rainfall (mm)

Source: United Nations Development Programme - Iraq; Contributions on natural resources research, paris, 1975.

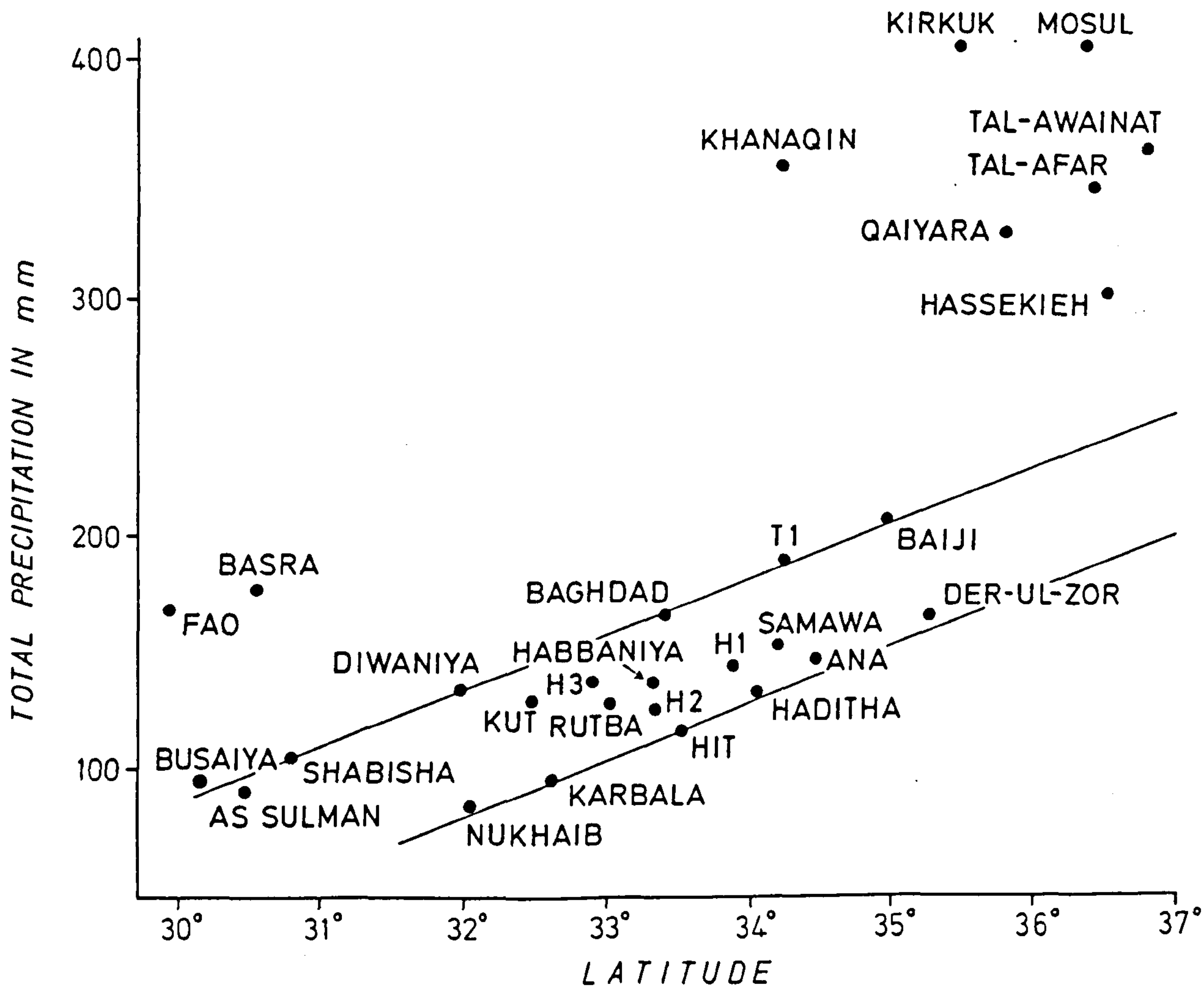

FIG. 2.5: CORRELATION BETWEEN TOTAL SEASONAL PRECIPITATION AND LATITUDE

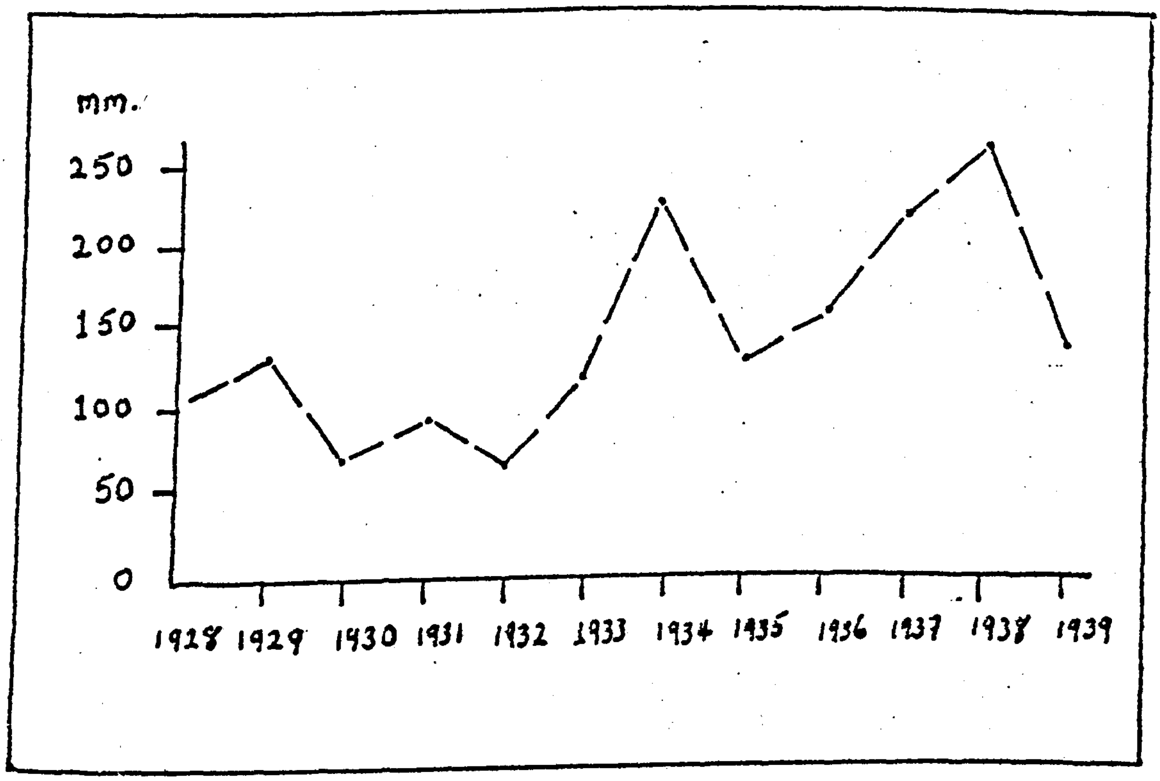

FIG.2.6: *SHOWS THE FLUCTUATIONS IN TOTAL AMOUNT OF* RAINFALL FOR 12 YEARS 1929-1939 AT BASRA STATION.

Source: selected and adopted from al.Shlash (1966).

2.1.3.3 Pressure, wind and duststorms.

In winter when the Asian high pressure centre extends south and south-west into Persia, Iraq and parts of Arabia, the pressure gradient is very high adjacent to the Arabian Gulf and winds are thus directed down to the Mesopotamian trough. The result is a cold north-westerly wind which affects most of Iraq. In this season there also develops a local high pressure system over western Arabia which results in a cold and predominantly westerly wind over the desert south-west of the Euphrates.

The fact that none of these winds are uniform or constant (because of the frequent interruption by depressions moving eastwards from the Mediterranean) causes changes in wind direction and rainfall, particularly in December, January and February (Naval Intelligence division, 1944). al.Shargi[3] is the warm south-easterly wind in front of the depressions, and it breaks up the normal winter circulation (al.Shalash, 1957; McGinnies et al,1968).

In average summer conditions, a low pressure system is centred over north-west India and the Arabian Gulf. As a result north-westerly winds blow over the whole of Iraq and are known as al.Shamal.[4] al.Shamal normally begins in June. It brings a considerable cooling during summer. The atmospheric conditions throughout June, July and August are usually uniform, but local differences may occur through-

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3) al.Shargi: is an Arabic (local) word for the south wind.

4) al.Shamal: is the Arabic word for 'north'. It increases the rate of evaporation from the skin.

out the country. For instance, at Baghdad the al.Shamal blows on nine out of every ten days, whereas at Mosul there is a higher proportion of calm days throughout the year. In the Western Desert the winds are westerly rather than north-westerly. In the Basra area the situation is different. The prevailing west or north-west winds of the early morning regularly veer to a more northerly wind in the afternoon. This phenomenon occurs throughout the year (al.Samarrie, 1966).

Duststorms develop throughout most of Iraq's desert areas, the nature of the surface material making it susceptible to blowing. Such duststorms may occur at any time of the year, and their occurance is common in south and central Iraq. In winter (November-May) duststorms are generally associated with depressions and with thunderstorms. When the ground is dry dust may rise over a wide area in front of the oncoming depression. The winter rainfall and spring vegetation are two factors which help to reduce the frequency of duststorms. This is more noticeable in the north of Iraq.

In the summer the severest storms occur in northern Iraq in October, in central Iraq in March, and in southern Iraq in June and July (as well as being common in the south from February to June). Summer dust storms are caused by small variations in the pressure gradient, particularly during the onset of al.Shamal (Naval Intelligence division, 1944). The hard stoney desert surface of the Western Desert (northern part) is more difficult to break up into fine particles of dust and so dust storms are less frequent in this area.

2.1.4 Past climatic changes and recent climate of Iraq.

During the Pleistocene, considerable changes in climate have occured in desert areas (Goudie, 1977 a & b). Much more humid climates alternated with much drier periods and these have been called respectively pluvials and interpluvials. In Iraq during the pluvial periods, the highest parts of the Zagros mountains were covered by ice, while central and southern Iraq experienced a wetter climate.

This climatic sequence of pluvials followed by inter-pluvials has had a profound influence on the landscape of Iraq. For instance, the vegetation in the pluvial periods was denser than it is today while in the dry periods aeolian erosion prevailed (Buringh, 1956). In the pluvials fluvial erosion and sheetwash removal became important. A substantial amount of erosion occurred in the mountains and upland areas, while in the valleys and broad plains, widespread deposition took place.

In the Western Desert of Iraq, the higher rainfall and lower temperatures of the pluvials enlarged the interior lakes and extended the surface drainage. Subsequently, dry conditions returned and the dried up vegetation became sparser, and the area of dune sand became more extensive.

Perhaps the most significant features related to the climatic changes of the Pleistocene are the formation of the various terraces which formed along the Tigris and Euphrates rivers and their tributaries in central and northern Iraq (Buringh, 1960; Wright, 1952), the deep incision of some desert areas (readily seen in al.Wadian part of the Western Desert), the formation of gypsum and limestone crusts, and abundant sedimentation in the lower Mesopotamian plain.

al.Feel (1960) believes that the present climate is similar to that of the inter-pluvial periods, while Huntington (quoted by al.Feel) stated that the last major change to have occurred in the climate of Iraq was in the thirteenth century. Buringh (1960) has indicated that the climate has not changed significantly during the last 6,000 years; possibly it is tending to become somewhat drier and al.Hessani (1978) has recently agreed with this. A period of dessiccation is known to have occurred in Neolithic times.

It seems certain that the Holocene, which started at the end of the last pluvial period some 8,000-10,000 years ago, includes some important climatic deviations, e.g. arid climate in central and southern parts of the country and more continental climate in the northern part. Some particular characteristics of the Holocene include severe water and wind erosion, cultivation practices related to the floods and irrigation, several changes in the courses of the rivers, and the salinization particularly in central and southern Iraq. The influence of Holocene climate changes upon the morphology of the country has been discussed by Voute and Wedman (1963).

2.2 GEOLOGY

Two features have been of major significance in the form and evolution of the geology of Iraq. These are the stable Arabian shield to the south-west of the sub-continent and the Tethys Sea. The Arabian shield has provided a barrier to plate movements to the north and has caused the repeated initiation of mountain building phases as northern plates have been forced against the shield. During the Permian age, the area of Iraq was included within an extension of the Tethys geosynclinal basin. The basin has been infilled and uplifted on numerous occasions and has acted as a significant control on both structure and stratigraphy in Iraq.

Iraq may be divided geologically into four units (Dudek and Ronner, 1967) as follows:

UNIT A: The folded mountain belts in the north and north-east which are the result of Alpine tectonics.

UNIT B: The equally folded foreland of these mountain belts.

UNIT C: The Holocene deposits of the Euphrates and Tigris basins (Mesopotamia) between the mountain and the Arabian shield, the prehistoric head of the Persian (Arabian) Gulf.

UNIT D: The sedimentary cover of the ancient Arabian shield in the south-west.

These units, however, have been affected in different ways throughout geological time. Their histories are long and complicated, but may be summarised as follows. The folded mountain belts and the equally folded foreland are the result of the pressure exerted from both sides when the African-Arabian mass in the south and the Eurasian continent in the north moved towards each other. They were for long periods of time covered by the Tethys Sea. Subsequently, a thick accumulation of sediment was deposited and folded later into mountains. Unit C occupies a large area of Iraq and is considered the youngest one of the four units.

The Arabian shield is a part of the ancient continent ending west of the Euphrates river. It has formed a resistant foundation covered by continental sedimentary layers, thin in the west, but thickening as the river is approached. A detailed appreciation of the geology of Iraq may be found in the following publications: Lees (1938); Dunnington (1960, 1967); Bellen et al (1959); Lees and Richardson (1940); Gregory (1929); Dudek and Ronner (1967); Shor (1958) and Mitchell (1957b).

2.3 PHYSIOGRAPHY AND GEOMORPHOLOGY OF IRAQ

Iraq can be divided into three major physiographic divisions (Fig.2.7) which in part illustrate the main geomorphological features.

i) The Alluvial Plain

This extends from the Arabian Gulf in the south to Samara in the north, occupying 93,000 km^2 and oriented south-east - north-west. It is an almost flat plain which rises gradually to the north and north-east. It reaches a maximum elevation of about 65m in the north, 50m near Ramadi in the north-west and about 100m in the east. It is believed that this plain was formed as a result of the accumulation of deposits brought in by the Tigris and Euphrates rivers. No precise estimation has been made of the amount of these deposits, but it is believed that they are very thick, having accumulated between the steeply sloping mountain front to the north-east and the geosynclinal trough to the south-west. An additional factor was the higher rainfall during pluvial periods of the Pleistocene.

This part of Iraq has been troubled by annual floods

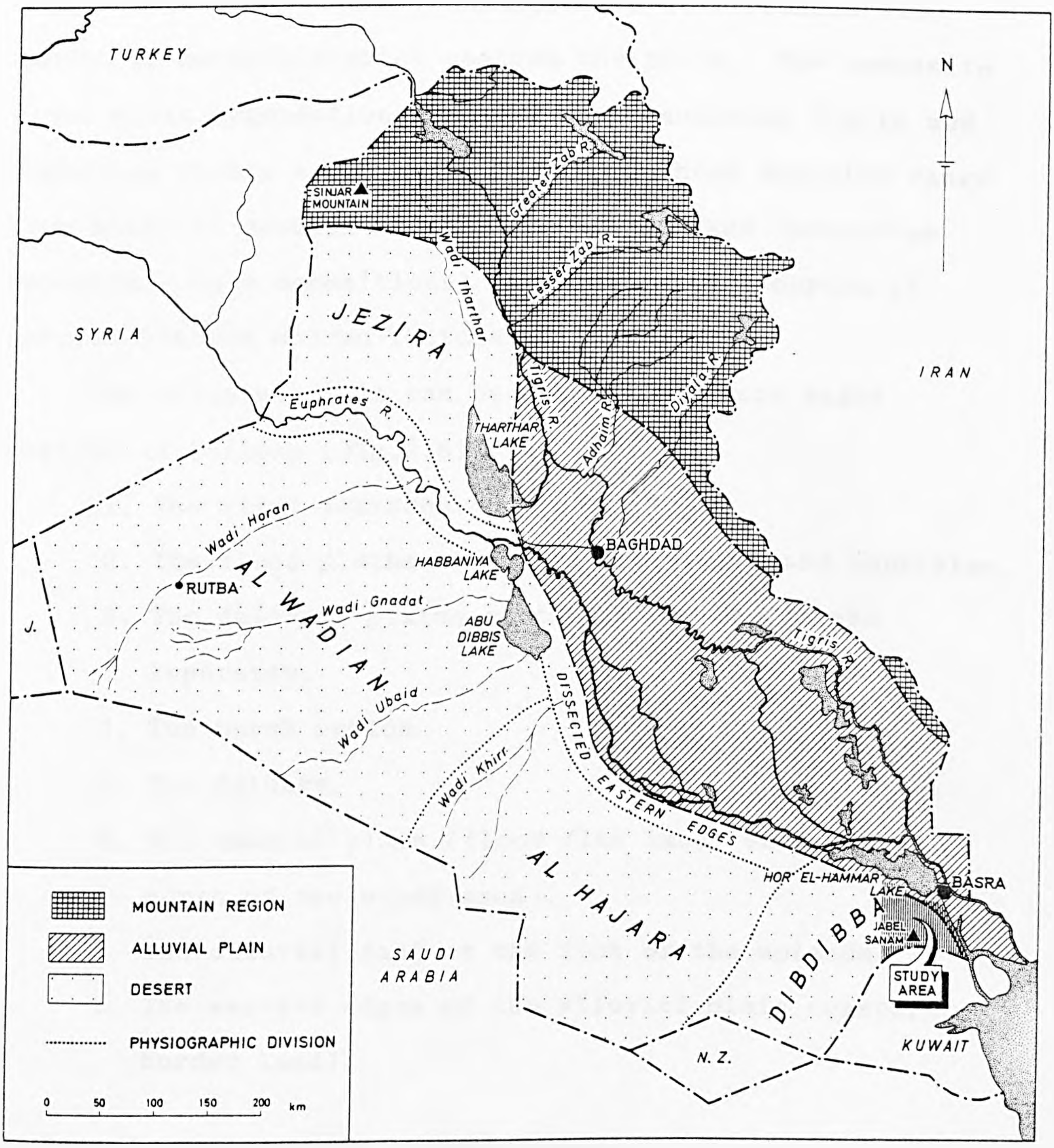

FIG. 2.7: THE PHYSIOGRAPHIC REGIONS OF IRAQ

since the country was settled. In recent years these annual floods have caused the Government to construct many dams across the turbulent mountain tributaries such as the Tharthar reservoir in the vicinity of the Tharthar depression. These dams and reservoirs have reduced the amount of materials which reaches the plain. The composite flood plain/aggradation plain of the meandering Tigris and Euphrates rivers are a major feature. These deposits range from silts to pebbles and include aeolian and lacustrine deposits. Such depositional material reaches depths of several hundred metres (Mitchell, 1957a).

The alluvial plain can be sub-divided into eight regions as follows (Fig.2.8):

1. The river terraces.
2. The flood plains of the rivers Tigris and Euphrates.
3. The deltatic plains of the rivers Tigris and Euphrates.
4. The marsh region.
5. The Estuary.
6. The coastal plain (flood flat land; east and north of the study area).
7. The alluvial fans at the foot of the uplands.
8. The eastern edges of the alluvial plain (eastern border land).

ii) The Western Desert Plateau Region

This is located in the west of Iraq and is considered to be a part of the Arabian shield (see section 2.2) Its altitude varies from 100m to 1,000m , although most of the region is between 300m and 500m above sea level. The

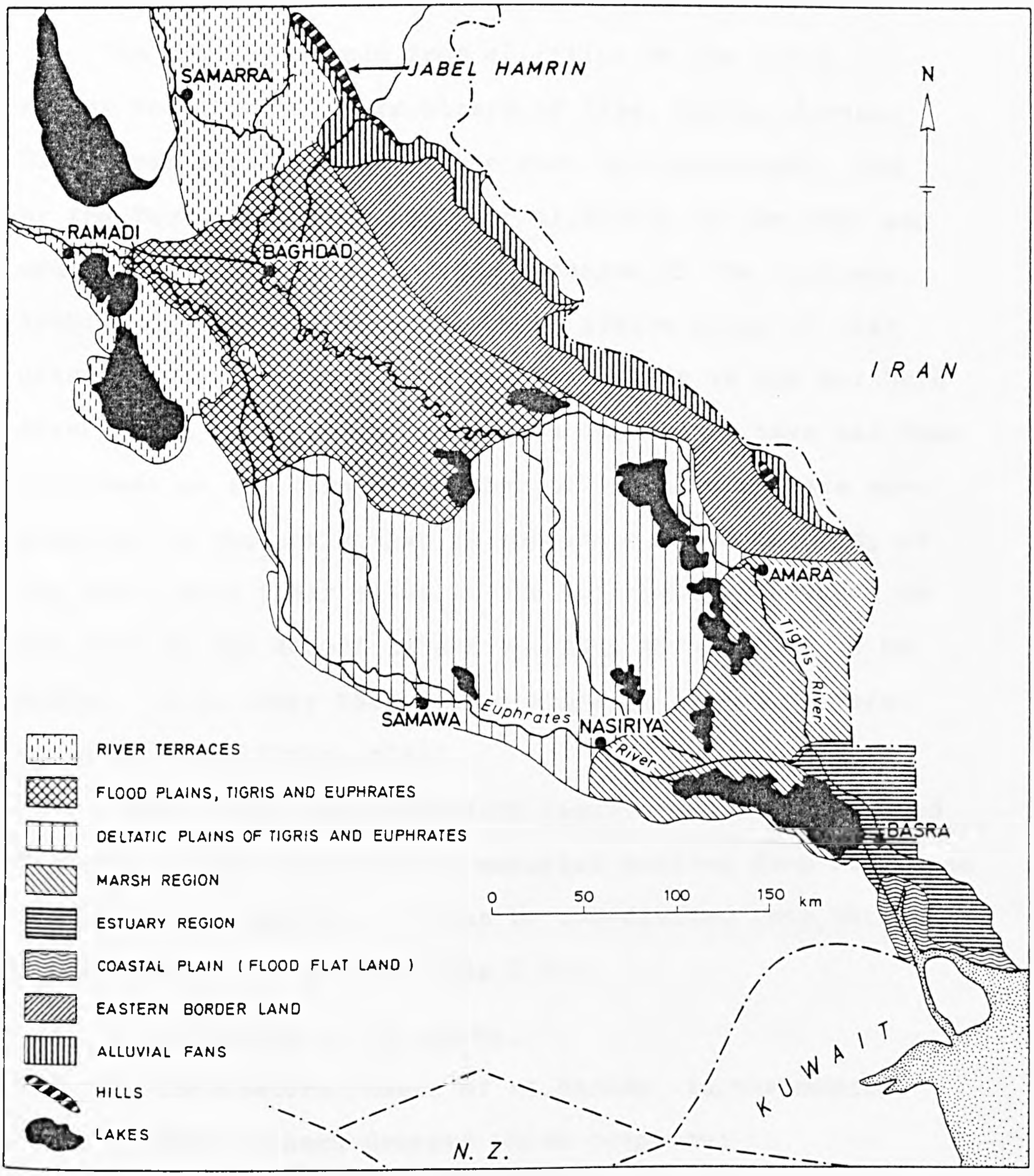

FIG. 2.8: THE PHYSIOGRAPHIC REGIONS OF THE ALLUVIAL PLAIN

land surface is gently undulating with most of the country's depressions being located in this area, as well as the wadis, river terraces, sandy and sandy gravel surfaces of the western desert.

The region extends from al.Jezira in the north and is bounded by the frontiers of Iraq, Syria, Jordan, Saudi Arabia and Kuwait in the west and south-west, and by the Euphrates river and khor al.Zubair in the east and south-east. It is an eastern extension of the northern Arabian desert formed on the lower gentle slope of that desert. Annual rainfall totals are higher in the northern desert than in the southern. This appears to have had some influence on the form and number of wadis, which are more numerous in the north than in the south. The majority of the wadis have their heads in the neighbouring uplands to the west of the desert, where rainfall totals tend to be higher. From there they flow north-east to the western edges of the alluvial plain.

A great part of the Western Desert region is composed of rocky steppe developed on material derived from sandstone and limestone bedrock. It can be sub-divided into three major regions, as follows (Fig.2.7):

1. al.Jezira in the north.
2. The Western Desert of al.Wadian, in the middle.
3. The southern deserts which comprise:
    a) al.Dibdibba - the greater part of the study area,
    b) al.Hajara,
    c) The Euphrates sand-belt (not included in the figure because it has not been indicated on the original map!)

al.Jezira region has a gentle slope towards the south, down into the Tharthar depression. The general characteristics of this region are the interior drainage, the presence of small playas and marshes, numerous small depressions, buttes and mesas, extensive development of massive gypsum beds, and general flats. The presence of saline deposits in the playas indicate the importance of active chemical processes. Much of the region is covered with recent sediments of aeolian, lacustrine and fluvatile origin. Surface conditions show strong folding, but sub-surface data indicate numerous low, shallow folds of general E-W strike (Mitchell, 1957a).

In the south east of al.Jezira region is the largest depression in Iraq. It has the form of a long wadi, with which several small wadis originating in the hilly region of Sinjar and vicinity (north) are co-extensive. The depression is about 300 km long and averages 45 km in width (al.Khalaf, 1959).

The surface of the Western Desert of al.Wadian is somewhat similar to that of the Hajara region of the southern desert. The first one has a characteristically stony and hard surface. The wadis in this desert are long and some of them reach the Euphrates river. Although, numerous wadis appear in this desert, three wadis are more important than the rest: wadi Hauran, wadi Ghadaf and wadi Ubaiyidh. Also the Gaara depression is considered to be the most important geomorphic feature in the region. This depression is some 80 km north of Rutba town.

The southern desert has been divided into three districts. The Dibdibba is a gently undulating desert with a slightly sandy surface. The most remarkable feature in this desert is wadi Batin 10 miles south-west of Basra. This part of the southern desert is considered to be an important part of the study area and it will be discussed in detail in the following chapter. The Euphrates sand belt is a belt of sand lying parallel to the Euphrates river. It begins south of Najaf town and extends for a distance of 270 km west of the Euphrates, south-eastwards almost to the Batin in al. Dibdibba district. al.Hajara, the western part of the southern desert, is a stony flat with shallow depressions and an abundance of low-stone ridges and numerous short rocky-sided wadis. The general trend of the wadis is south-west to north-east.

Occasionally, these wadis fill with water after heavy rain, but never reach the Euphrates river because they are prevented from doing so by a belt of sand.

It has been mentioned earlier in this chapter that the Pleistocene climatic variations have left their mark on the land surface of Iraq. The Western Desert which makes up part of the Arabo-Syrian shield was affected by the Pleistocene climatic variations. The depressions which appeared are now incorporated in the desert landscape which during the Pleistocene was flooded by rivers waters (Voute et al 1963). Subsequently, a rise in sea level and a return of a hot, arid climate slowed down the rate of wadi cutting (Fookes,1976). However the correlation of climate and sedimentation is very complicated, and precise correlations are still to be determined.

Some climatic elements, notably precipitation, affect the landscape directly by the medium of runoff, whereas others have indirect effects or are important only locally (Ollier, 1969). Walton (1969) stated that modern research has, however, clearly demonstrated that, as in the more humid periods of the past, the contemporary desert landscape is the work of running water and that the wind plays only a relatively less important part. Although the Western Desert, including the study area was strongly influenced by running water in past pluvial phases, there is no doubt that, under the present climate, wind is a major factor in forming the land surface features of al.Zubair desert. Basically, wind performs two kinds of erosional work: deflation and abrasion and wind in the desert area seems to be selective in its deflation action.

The first material to be moved by deflation is of silt grade but clay-size particles may also be blown if they are aggregated in silt-sized clusters. Sand-size grains are removed only by moderately strong winds and tend to travel close to the ground. Gravel-size fragments and rounded pebbles up to 2 to 3 ins (5 to 8 cms) in diameter may be rolled over flat ground by strong winds but do not travel far (Strahler, 1969).

Wind action may have served to reduce the width of the wadis by transfer of material, so decreasing the side slopes.

iii) The Mountainous Region (Fig.2.7)

The northern mountain region of Iraq occupies 20% of the country's total area (90,000 km^2). Its height increases from south to north and from west to east. This means that it reaches its highest elevations near the Iraqi-Turkish and the Iraqi-Iranian borders. These mountains have a great influence upon the form of the alluvial plain (see section 2.2) in supplying it with the materials transported by the Tigris river and its tributaries.

This region consists of high mountain ranges orientated north-west to south-east, whose sub-parallel nature is tectonically controlled. Snows persist on the highest mountains for most of the year. These ranges are cut through by aligned river gorges which link the intra-mountain undulating valleys and plains. The mountains are the source of the tributaries of the Tigris (Greater Zab, Lesser Zab, Adhaim and Diyala).

This region can be divided into two sectors as follows:

1. The high mountains;
2. The low mountains.

The first sector occupies only about one quarter of the mountainous region. It has been divided into two units on the basis of rock type and elevation. The elevation is approximately 1,000-2,100m whereas the northern unit is folded in a complex manner and its elevation is about 2,100-3,600m. Between these two, there are important agricultural plains e.g. Rania, Syndi and Shahrazor.

The low mountain sector consists of a transitional area between the lowest plain in the south and the high mountainous area in the north and north-east of Iraq. This area is characterised by its long and low mountain ranges, numerous hills, and wadi plains which extend between the mountains and the hills (al.Khalaf, 1959).

2.4 SOIL

The factors of climate and physiography play a major role in controlling the distribution and type of soil. Accordingly, soil type varies from one part of Iraq to another. Prolonged human influence (extending over thousands of years) has further changed the soil conditions.

Studies of the soils of Iraq have been carried out for different purposes e.g. soil classification, soil reclamation, soil productivity etc. (State Organisation for Soil and Land Reclamation reports, Nos: 1, 5, 8, 9, 56, 1975; Yahya, 1968; al.Taie, 1968).

Generally, the soils of Iraq fall into five broad associations, as set out below:

a) Reddish chestnut, Brown forest, Red Mediterranean and associated lithosols.
b) Reddish brown, Brown and associated lithosols.
c) Desert and associated soils.
d) Alluvial soils.
e) Wet alluvial soils.

The climatic factor is clearly important. In southern Iraq, for instance, approximately 25% of winter rainfall may infiltrate the soil, most of the remainder evaporating. As only a relatively small amount of infiltration occurs, the existence of ground water is doubly important in soil formation. Ground water is slowly brought to the surface by capill ary action. In the upper part of the soil evaporation causes the deposition of mineral salts from the soil water. Calcium carbonate, the commonest of these deposits tends to form a whitish crust in the soil known as calcrete (Strahler, 1969; Goudie, 1977a).

A good deal of research on soil erosion has made it clear that water erosion involves two processes, namely the detachment of particles due to rainsplash, and the transportation of detached soil material by runoff (Cooke and Doornkamp, 1974). However, soil erosion is a complex process. It is influenced by the amount, intensity and duration of rainfall, by the amount and velocity of surface flow, by the nature of the soil, by the ground cover and by the slope of the land surface. (Stallings, 1957).

In dry lands, wind erosion is greater when the surface is smooth and weaker when it is ridged. Wind is a major agent of soil removal. Subsequently, this may hinder plant growth by decreasing the organic matter content and nutrient status of the soil.

2.5 LAND USE AND VEGETATION

The influence of climatic elements, morphology and human activity upon soil type and soil condition, extends to vegetation and land use. Zohary (1950) has briefly discussed the effect of climate on the vegetation of Iraq.

Careful study of plant communities and their interaction with it is neccesary to determine functional boundaries between grass-steppe and desert in Iraq. The boundary follows the lines of 200mm of rainfall for the desert, and 300 to 400mm in the main steppe area (Boesch, 1939), but these criteria are relatively crude.

In winter, when the rain arrives, temperatures generally become too low for plant growth so that little benefit is derived from it. By April, the rainy season is over and the short spring season begins, giving desert plants the opportunity to grow.[5] During the long hot summer months the water which has been stored in the upper 20-30cm of soil is soon exhausted and the grass and herbs wither (Hessani, 1978).

Some plants in the desert can use the water quickly before it evaporates (Money, 1972), and of course, the vegetation which survives plays quite an important role in soil protection.

In the northern part of Iraq, extensive grazing lands and forests exist.

In many areas, however, in both south and north, the natural vegetation has been destroyed either by grazing or by direct human interference.

This problem has led the Government to take steps to protect this resource, by restricting forest cutting and establishing grazing stations all over the Western Desert. Studies by Guest (1932, 1933, 1953, and 1966), Zohary (1950) and Springfield (1954) have indicated the need for further studies of impact on vegetation in Iraq.

Kaul (1970) has classified the vegetation into three major groups, thus:

a) Desert and semi-Desert;

b) Dry Steppe;

c) Moist Steppe.

In the water balance equation, water loss is limited by the rate of the potential evapotranspiration. A study

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5) Plant communities in the detailed (sampled) study area are discussed in detail in Chapter 3.

of evapotranspiration is therefore an important matter in any agriculture programme. Van Dan (1970) noted that evapotranspiration greatly affects the yield and irrigation requirements of crops in Iraq (Kettaneh et al, 1974).

In arid lands crops cannot be grown economically without irrigation (Cressey, 1957). This is true in the Iraqi arid lands.

Temperature is the second climatic element important to agriculture. Of course, crops vary widely, but broadly an average temperature of 15°C is ideal for agricultural crops during their greatest growth period (U.N.D.P.,1975). From the monthly temperature data given in section 2.1.3.1, it is evident that April and May are the months most conducive to optimal plant growth all over Iraq.

In addition to increasing the rates of evapotranspiration, high wind velocities contribute to a reduction in the fertility of the soil. Wind is a particular problem for the farmers in al.Zubair area. Storms of tornado violence, though very rare, do occur.

2.6 SUMMARY

Iraq is generally poorly provided with meteorological stations especially in the vast Western Desert including the study area.

The climate of Iraq is controlled by latitude, topography and location in relation to surrounding water bodies. Generally only two seasons, summer (May-October) and winter (November-May), can be recognised.

Throughout the country July and August are the hottest months whilst January is the coldest. The mean annual temperature decreases from south to north. The annual rainfall shows the opposite trend, broadly matching the increase in altitude. Iraq receives the majority of its rainfall in winter. Southern Iraq and the Western Desert including the study area have a low rainfall.

In winter, the extension of the Asian high pressure centre results in cold north-westerly winds over most of Iraq. This is often reinforced by the development of a more local high pressure system.

al.Sharqi is the local name given to the warm south-easterly wind which blows in this season as a result of the interruption by depressions moving eastwards from the Mediterranean. In average summer conditions a low pressure system is central over north-west India and the Arabian Gulf. As a result north-westerly winds blow over the whole of Iraq and are known locally as al.Shamal. While there is still argument about whether or not the present climate of Iraq is similar to the so-called inter-pluvial periods there can be little doubt that the alternation of pluvials and interpluvials has had a profound influence on the landscape of Iraq.

The two major geological components are the stable Arabian shield and the rocks occupying an extension of the Tethys geosynclined basin. These may be subdivided further as follows: the folded mountain belts in the north and north-east which are the result of Alpine tectonics; the equally folded foreland of the mountain belts; the Holocene deposits of the Euphrates and Tigris basins (Mesopotamia) between the mountain and the Arabian shield; and the sedimentary cover of the ancient Arabian shield in the south-west.

The alluvial plain, the Western Desert and the mountain region are the main physiographic divisions of Iraq. The alluvial plain produced by deposition by the Tigris and Euphrates rivers is oriented south-east - north-west and rises gradually to the north and north-east. It is sub-divided into the river terraces, the flood plains, the deltaic plains, the marsh region, the estuary, the coastal plain, the piedmont alluvial fans and the eastern edges of the alluvial plain.

The Western Desert is gently undulating with depressions, wadis, river terraces, and sandy gravel surfaces.

The mountainous region occupies 20% of the country's total area. It consists of two sectors: high mountain ranges and the low mountains. Snow persists on the highest mountains for most of the year, the plains within these mountains being the most important agricultural area in northern Iraq.

Five broad soil associations are recognised: (i)reddish chestnut, brown forest, red Mediterranean and associated lithosols; (ii) reddish brown, brown and associated lithosols; (iii) desert and associated soils; (iv) alluvial soils; (v) wet alluvial soils.

Three major vegetation groups are recognised in Iraq: desert and semi-desert, dry steppe, and moist steppe. The natural vegetation in many parts of Iraq has been destroyed either by over-grazing or by direct interference, and this constitutes a serious problem.

CHAPTER III

GENERAL DESCRIPTION OF THE STUDY AREA

GENERAL DESCRIPTION OF THE STUDY AREA

3.1 INTRODUCTION

The study area has an extent of about 1593.15 km^2. It is situated in the eastern portion of the Arabian desert plateau, and extends to the alluvial flood plain of the Euphrates and khor al.Zubair. The vast shallow lake (Howr al.Hammar)[1] borders the study area to the north, and a small river flows from this lake to join the shatt[2] al. Arab known as "Garmat Ali" in the north-east.

The new shatt al.Basra (canal) links Garmat-Ali in the north with the khor al.Zubair in the south. This project area together with khor al.Zubair and khor Abdullah form the eastern border of the study area. The Iraqi-Kuwaiti border forms the southern boundary and the western limit runs through a series of wadis.(Fig.3.1)

3.2 CLIMATE

The climatic information of the study area is based on recordings from three meteorological stations, one located within the study area (at Shuaiba), and the others lying outside the area, at Basra (Airport station) in the north-east, and at Nasiriya in the north-west.

al.Zubair area is clearly arid (AC 24)[3] according to the world climate classification of Meigs (1953). Meigs'

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1) Howr or Haur: a lake or marsh.

2) shatt: a river.

3) A - arid C - winter precipitation
2 = 10° to 20°C 4 = more than 30°C.
First digit indicates mean temperature of coldest month.
Second digit indicates mean temperature of warmest month.

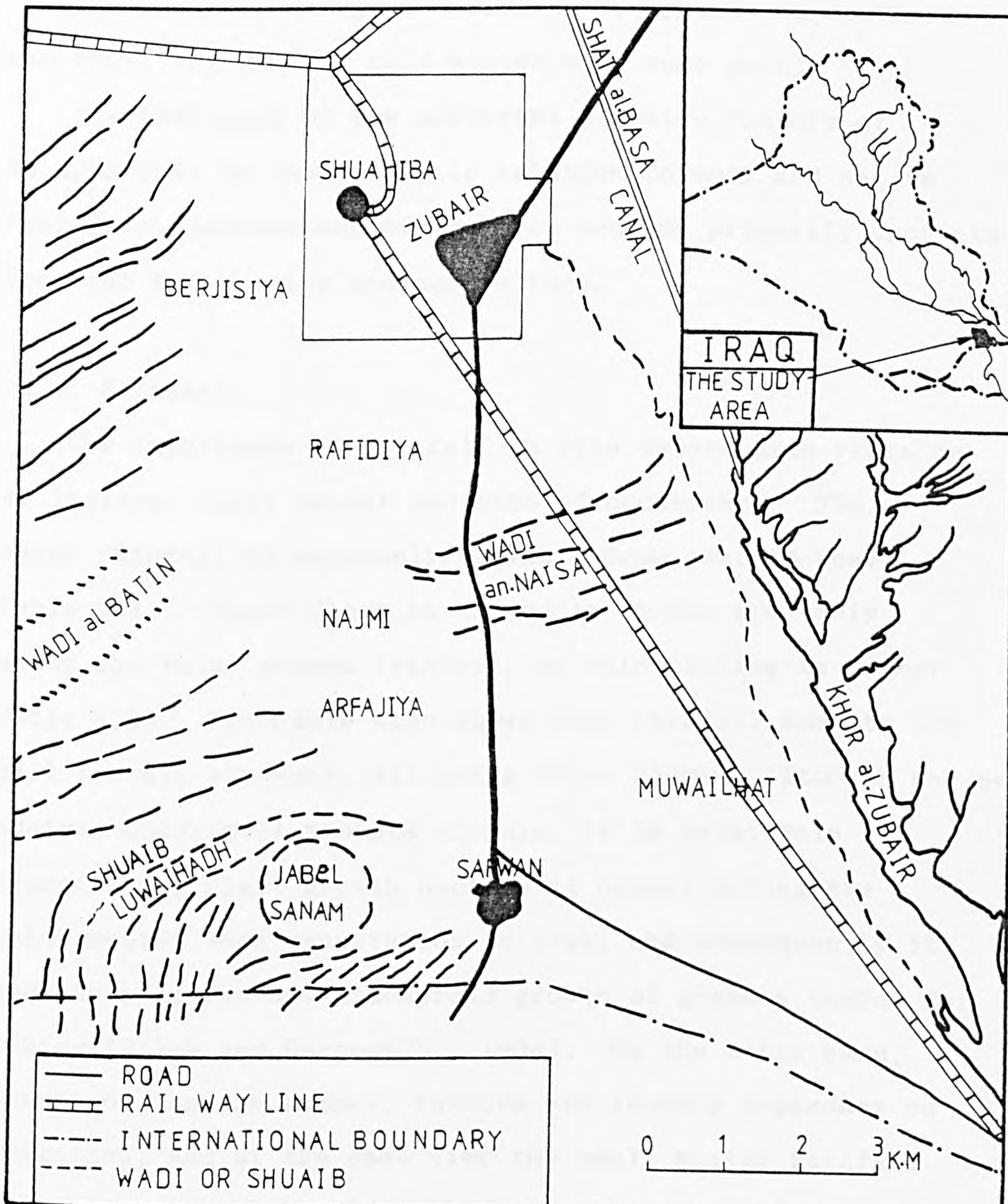


FIG. 3.1: MAJOR LOCATIONS AND SURFACE FEATURES OF THE STUDY AREA

definition of an arid region is one in which rainfall is not adequate for the regular production of crops without supplementary water sources.

Generally speaking, the climate is typical of Southern Iraq (hot, dry summer, cold winter with some rain).

The influence of the different climatic factors of the area must be considered in relation to soil and native vegetation, because use of the area depends primarily upon its potential for grazing and agriculture.

3.2.1 Rainfall.

The importance of rainfall in this desert area rests on two factors: total amount and time of occurrence. The annual rainfall is extremely variable from year to year (Table 3.1). Water flows in the wadis of the area only during the rainy season (winter), no rain falling in summer (Table 3.2). The table also shows that rainfall amounts are small for all stations, all being below 254mm. Although the area receives only small amounts of rain, it is relatively effective for plant growth because it occurs during the cooler months when evaporation is less, and consequently it supports a sparse but widespread growth of grasses useful for grazing (Ralph and ParsonsCo., 1955). On the other hand, because of the dry summer, farmers are largely dependent on irrigation, and at the same time the small winter rainfall totals discourage them from relying on it for their crops.

3.2.2 Temperature

Temperatures fluctuate widely on both a seasonal and a diurnal basis. The maximum daily temperature for December at

Year	Annual Mean Temp. ^{o}C Max.	Min.	Rainfall MM.	Mean Relative Humidity %
1964	30.9	17.3	31.9	52
1965	31.8	18.1	85.0	55
1966	32.5	18.4	98.8	60
1967	30.4	17.1	156.5	62
1968	31.3	18.3	98.8	64
1969	31.0	19.5	175.9	65
1970	32.1	17.7	148.4	56
1971	31.3	17.1	106.5	55
1972	30.2	17.1	181.8	60
1973	32.6	16.8	51.7	55

Table 3-1: The annual mean temperature, rainfall and relative humidity of the study area for the period 1965-1975.

Source: Gulf Consult (1975), p.31.

Station	MONTHS								SEASONS				Annual	Number of years data used
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Oct-Nov Autumn	Dec-Feb Winter	Mar-May Spring	Jun-Sept Summer		
Nasiriya	2.2	16.8	20.4	19.2	13.4	15.8	16.6	7.1	19.0	53.0	39.5	NIL	111.5	30
Basra	1.0	22.8	30.2	22.8	13.8	20.2	20.4	7.8	23.8	66.8	48.4		139.5	30

Table 3-2: Mean monthly, seasonal and annual rainfall (mm) for Nasiriya and Basra Stations.

Source: Unesco, (1975). p.20.

Shuaiba is 19.6°C, 18.0°C in January and 20.5°C in February. The mean monthly temperature at Shuaiba in July is above 26.6°C. The difference between the mean monthly maximum and minimum in Shuaiba varies between 5°C and 11°C. Temperature also affects the life style of local inhabitants e.g. people in al.Zubair city on the eastern margin of the desert use a 'Sirdab' (cellar) during the hottest part of the summer days, whilst the flat roofs of their dwellings are used for sleeping during the summer nights. Farmers (Fallaheen) in this area guard against the effects of low temperatures on their crops by covering them with plastic sheets (Plate 3.1).

3.2.3 Wind and Duststorms

Although the dominant winds over the area follow the north-westerly wind system which prevails over most of the country, westerly winds are also persistent due to the local high pressure system over western Arabia (see Chapter 2).

Winds occur most frequently from the west during the early hours of the morning and from the north-west in the afternoon. The mean wind velocities for each month are listed in Table 3.3 below:

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
kilo-metres per hour	14.5	13.3	15.3	15.3	16.1	20.8	21.2	18.7	15.3	14.8	12.7	12.5	15.9

Table 3.3: Mean wind velocities at Shuaiba station for the period 1943-57

The characteristics of al.Zubair desert (dry, sandy soil, lacking a continuous vegetation cover) encourage the transport of superficial material by wind. This, combined with the

PLATE 3.1

Plastic sheets are in general use to guard the crops from the effects of low temperature.

diurnal increase of wind speed, is responsible for dust storms which are common during the summer months, and occur occasionally in winter, although the summer dust storms are the more severe. They can damage crops as well as accelerate soil erosion. The Safwan area (south-east margin) is famous for its duststorms. It is probably due to this phenomenon that the area acquired its name (al.Rawi, 1972). In winter, rainfall tends to dampen the ground and encourage natural vegetation growth, thereby reducing the availability of loose material for transport.

3.2.4 Relative Humidity

The high humidities of al.Zubair area are usually associated with the south-easterly wind called the "Sharqi". These are accompanied by relatively high temperatures, making conditions very uncomfortable in summer.

Records of relative humidity at the Nasiriya, Basra and Shuaiba meterological stations (Table 3.4), show that values are higher at Basra than at the other two desert stations. This may be due to the proximity of the Basra station to the shatt al.Arab and to the increased vegetation cover in this irrigated area. The relative humidity at Shuaiba is about the same as at Nasiriya.

The monthly and annual averages for Shuaiba are shown in table 3.4 below.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Shuaiba 1923-52	73	68	57	46	36	29	24	26	29	37	58	73	46
Nasiriya 1941-70	79	74	67	61	51	43	40	38	39	49	66	79	57
Basra 1941-70	89	85	79	74	66	60	60	59	62	70	81	85	80

Table 3.4: Monthly and annual average relative humidity at Shuaiba, Nasiriya and Basra meteorological stations.

3.2.5 Potential Evaporation

This area is characterised by its high evaporation rates resulting from the prevalent high temperatures and dry winds. The annual average potential evaporation reaches approximately 3679 mm (Tippetts-Abbett-McCarthy-Stratton Engineers, 1957) which is 25 times the annual average of rainfall.

Evaporation rates, however, vary from season to season according to the temperature and wind characteristics. In the summer, it reaches its maximum (688 mm in July), but it decreases in winter 60 mm in December). Although the evaporation is much less in winter, it still exceeds the normal amount of rainfall in this area.

3.3 GEOLOGY OF THE STUDY AREA

3.3.1 Introduction

The study area has shared the sedimentary history of the Western Desert of Iraq. Moreover, the structural history has been reflected in the mode of sedimentation.

al.Naqib (1970) pointed out that the various unconformities in the geological sequence, taken together with the type of sedimentation, point to several epeirogenic movements which resulted in marine transgression and retrogression in this area. The duration and extent of these movements has varied widely.

However, during late Miocene and Pliocene times al. Dibdibba clastics were deposited, the material being derived possibly from a rapidly rising component of the Arabian shield. The aeolian sand and alluvial materials are of Quaternary age. The outline geology of the area is shown in figure 3.2.

The rock types occurring in the study area are described below in their stratigraphic order, their significance to terrain classification being emphasised. The economic geology of the area is considered in the discussion of the land use (Section 3.8.3).

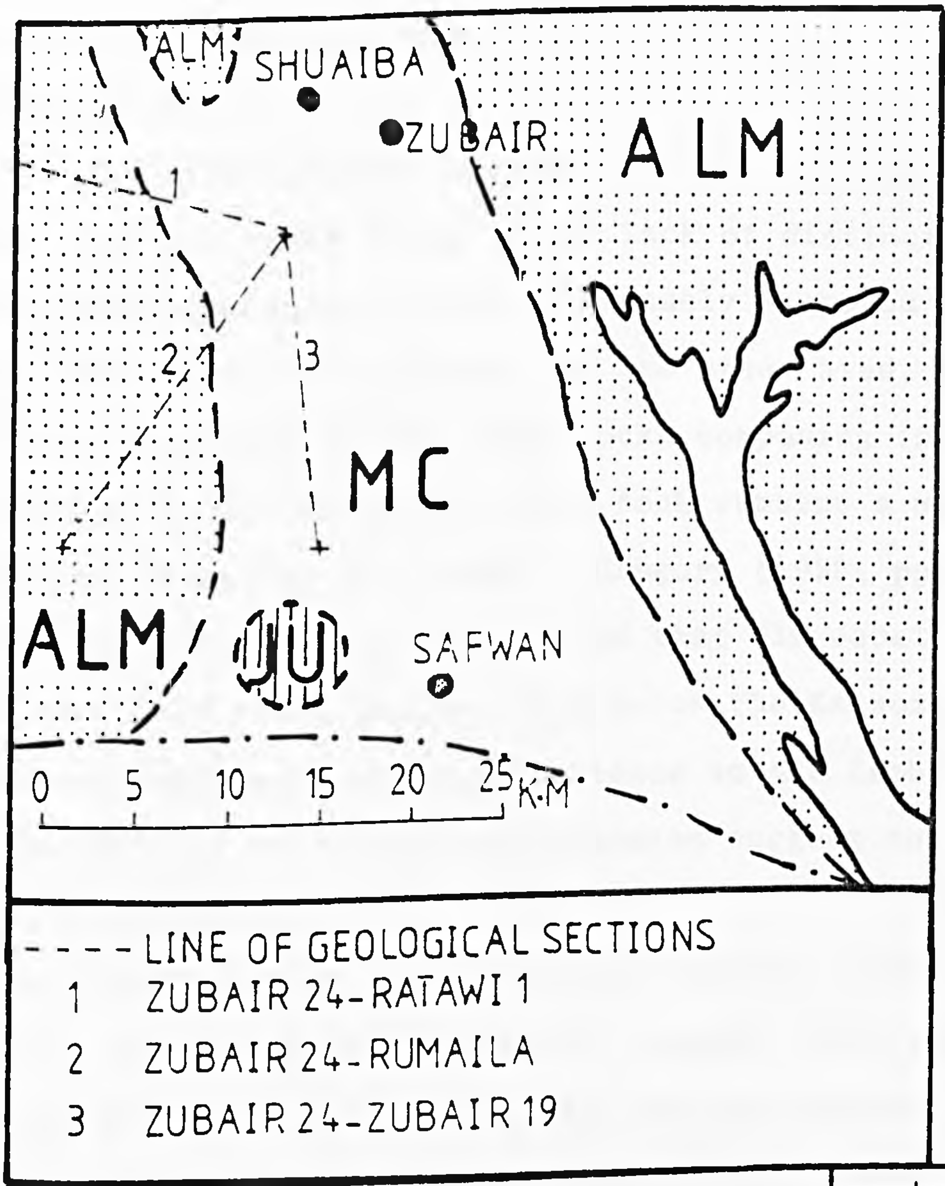
3.3.2 Stratigraphy

Geologically the eastern and northern parts of the area are occupied by alluvial deposits, while Dibdibba deposits cover the remaining area.

According to the literature the age of the rocks of the area (Williamson and Rogers, 1939; Lees and Falcon, 1952; Macfadyen, 1955; Bellen et al, 1959; al.Baghdadi, 1960; Masin et al, 1965; al.Naqib, 1967 and 1970 and Larsen, 1975) vary from Cretaceous to Quaternary.

The available geological sections included in this study are few, due to the restricted nature of their distribution and poor availability.[4] Those geological sections shown in

4) Such geological sections are available only within Government offices, but they are unpublished and unavailable to the general public.



era	period	formation	symbols
CAINOZOIC	RECENT & PLEISTO.	ALLUVIUM	ALM
	MIOCENE	UPPER FARS FORMATION (including L.F of Dibdibba For.)	MC
MESO.	CRET.	NOT EXPOSED	
	JURASSIC?	JABEL SANAM BEDS	JU

FIG. 3.2: GEOLOGICAL FORMATIONS IN THE STUDY AREA.

figures 3.3 and 3.4 and table 3.5, are summarised in the following stratigraphic account.

Jurassic and older

A detailed stratigraphic sequence has not yet been determined at Jabel Sanam owing to the lack of distinct and continuous bedding coupled with the intensely fractured and dislocated character of the rocks. On the other hand, no fossils have been found in the older rocks composing the core of the Jabel, so the age of these rocks remains a matter of speculation (Masin *et al*, 1965). Gregory (1929, pp.62-63) quoted by Macfadyen, 1955, p.118, stated that "In Jabel Sanam, south of Basra, old rocks project from below the Kainozoic cover. These rocks show a great resemblance to the Cambrian rocks of the Persian Gulf, and the tectonics suggest the presence of a salt plug."

Despite the fractured and dislocated nature of the rocks of the Jabel, the geological literature suggests that there are two types present. The older rocks form the core of Jabel. They are broken and fractured and perhaps slightly metamorphosed silty and dolomitic limestones. These old rocks are surrounded by younger beds of gravel, sand and silt and they belong to the Dibdibba formation. al.Naqib (1970) has recognised four lithological units of Jabel Sanam. These are shown in figure 3.5, and their distribution and relative position are shown in figure 3.6.

Cretaceous

The Cretaceous is divided into upper, middle and lower stratigraphic units. The Shuaiba limestone formation (90m thick) and the Zubair formation (200m thick) are the principal

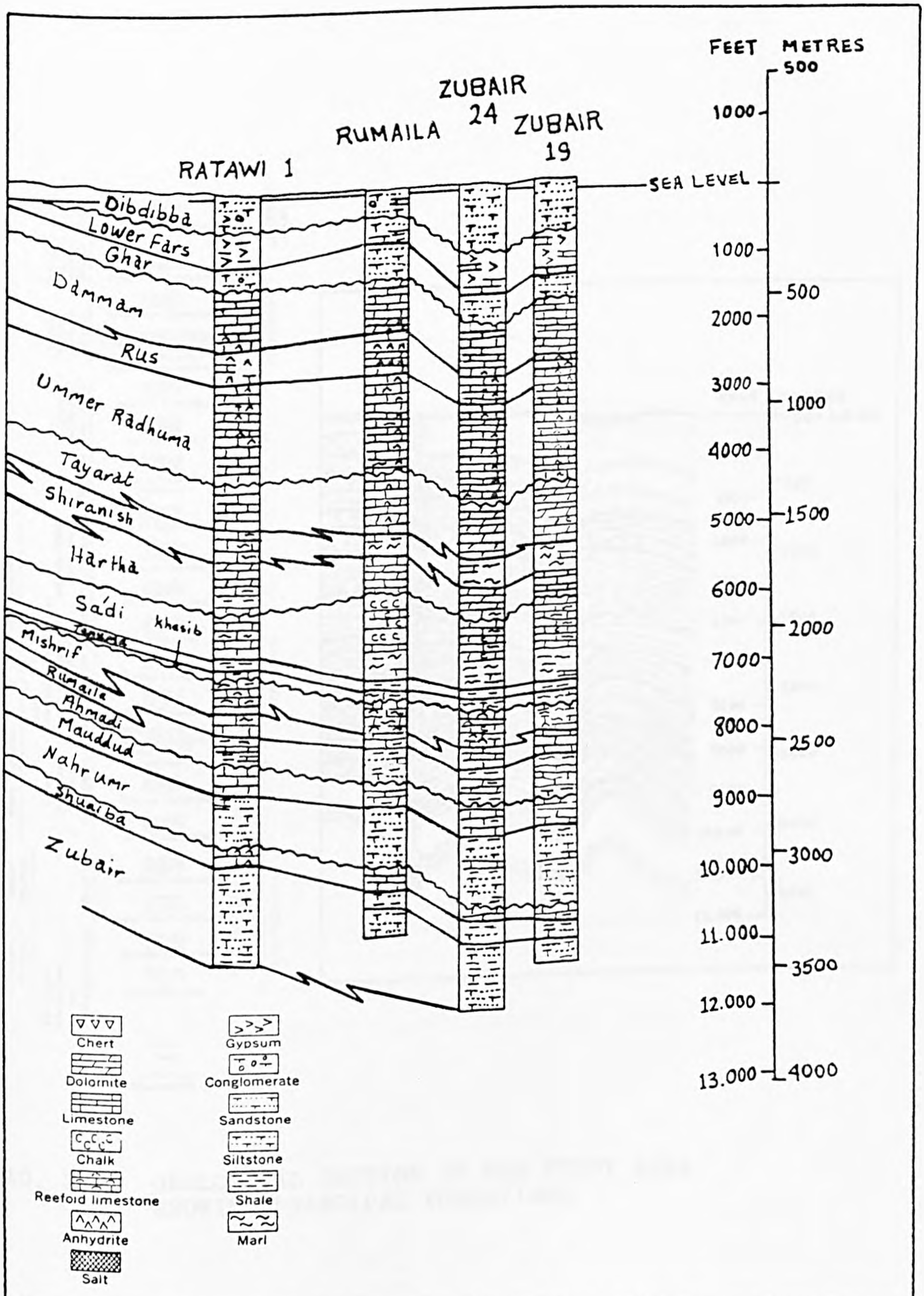


FIG. 3.3: GENERALISED GEOLOGICAL SECTIONS OF THE STUDY AREA SHOWING LITHOLOGICAL SUCCESSION

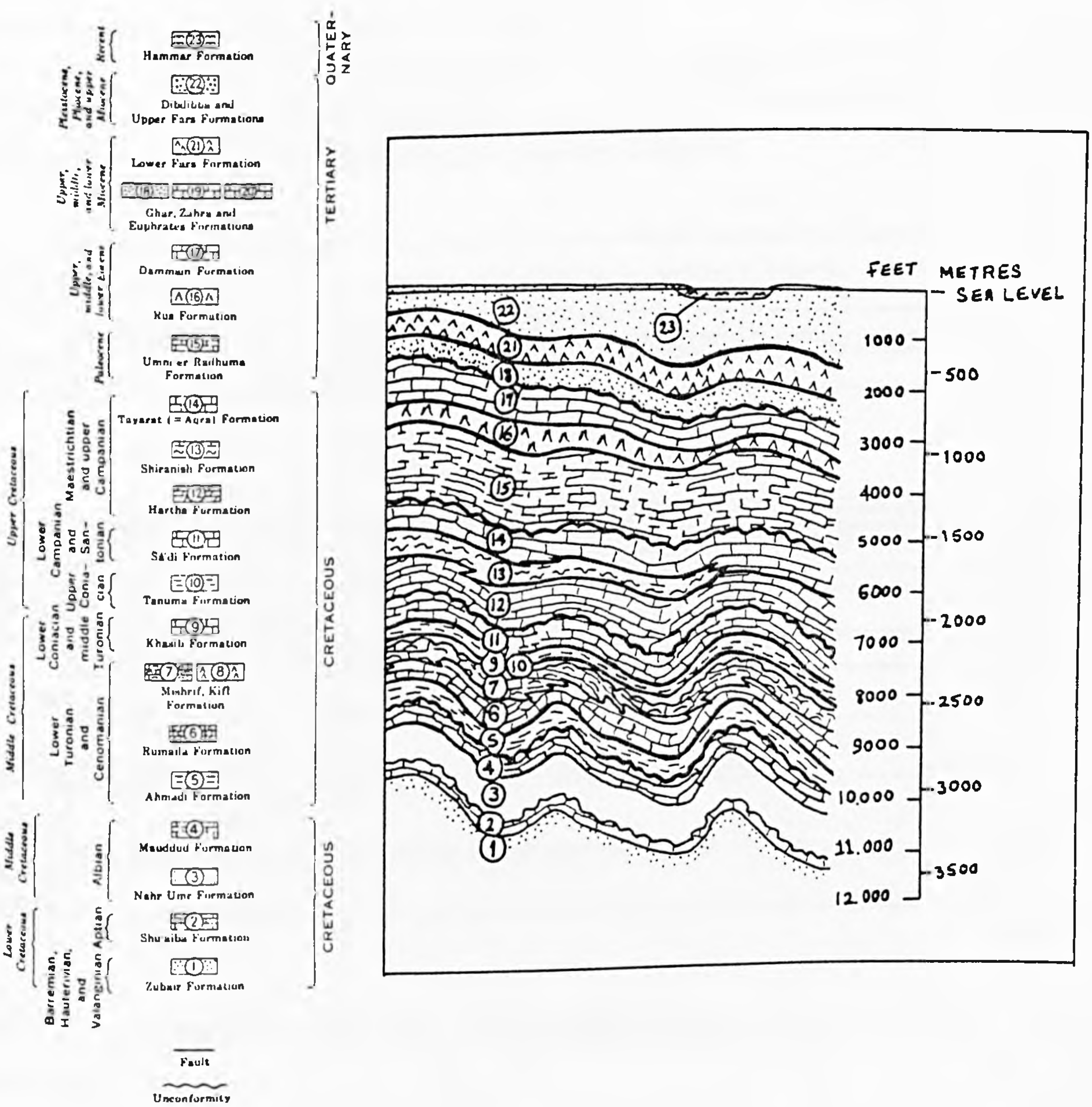


FIG. 3.4: GEOLOGICAL SECTION OF THE STUDY AREA SHOWING PRINCIPAL FORMATIONS

	AGE	FORMATION	LITHOLOGY	DESCRIPTION
QUAT.	RECENT	AlluVIUM		Recent alluvium, The Reworked gravel of Dibdibba formation, blown sands.
	PLIOCENE/ U.MIOCENE	DIBDIBBA		Sands and gravels of igneous rock, Subordinate marls.
	M.MIOCENE	LOWER FARS		Marls, gypsum, anhydrite, shallow water limestone.
	M/L.MIOCENE	GHAR		Sands and gravels, rare clay.
	M.EOCENE	DAMMAM		Porous dolomitized limestone.
	L.EOCENE	RUS		Bedded anhydrite. subsidiary limestone and marls.
	L.EOCENE / PALEOCENE	UMM ER-RADHUMA		Cherty Anhydritic and dolomitic limestone.
UPPER CRETACEOUS	MAASTRICHTIAN / U.CAMPANIAN	TAYARAT		Limestone, fossiliferous, dolomitic, marly.
		SHIRANISH		Globigerinal marl.
		HARTHA		Organic, detrital, glauconitic dolomitized limestone subordinate shale.
	SENONIAN.	SA'DI		White, chalky, marly, globegerinal limestone, and well developed marl.bed.
		TANUMA		[illegible]
		KHASIB		Marly limestone and shale
MIDDLE CRETACEOUS	CENOMANIAN	MISHRIF		Limestone, limonitic fresh water, organic & detrital, algal banks of rudist. marly downwards.
		RUMAILA		Limestone. fine-grained. marly, and chalky in parts.
	CENOMANIAN ALBIAN	AHMADI		Black silty shale and limestone.
	ALBIAN	MAUDDUD		Limestone. organic, occasionally detrital. [illegible]
		NAHR UMR		Interbedded shales and sandstones.
	APTIAN	SHUAIBA		Limestone, partly chalky and argillaceous.
L. CRETACE.	APTIAN / HAUTERIVIAN.	ZUBAIR		Interbedded shales and sandstones.

Table 3.5: Generalised Composite Stratigraphic Sub-surface section, Basra area.

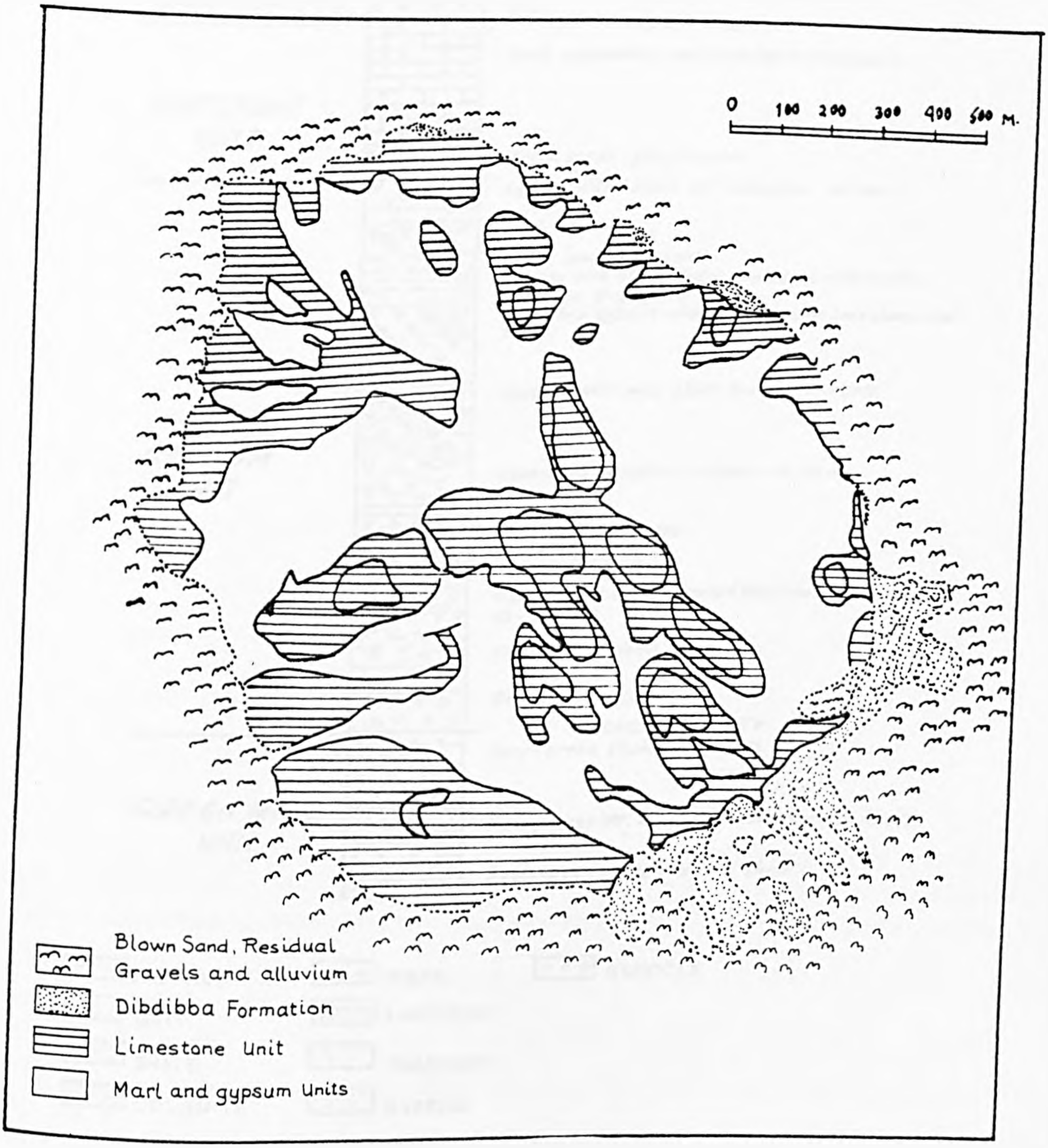


FIG. 3.5: LITHOLOGICAL UNITS OF JABEL SANAH (after al.Nagib, 1970)

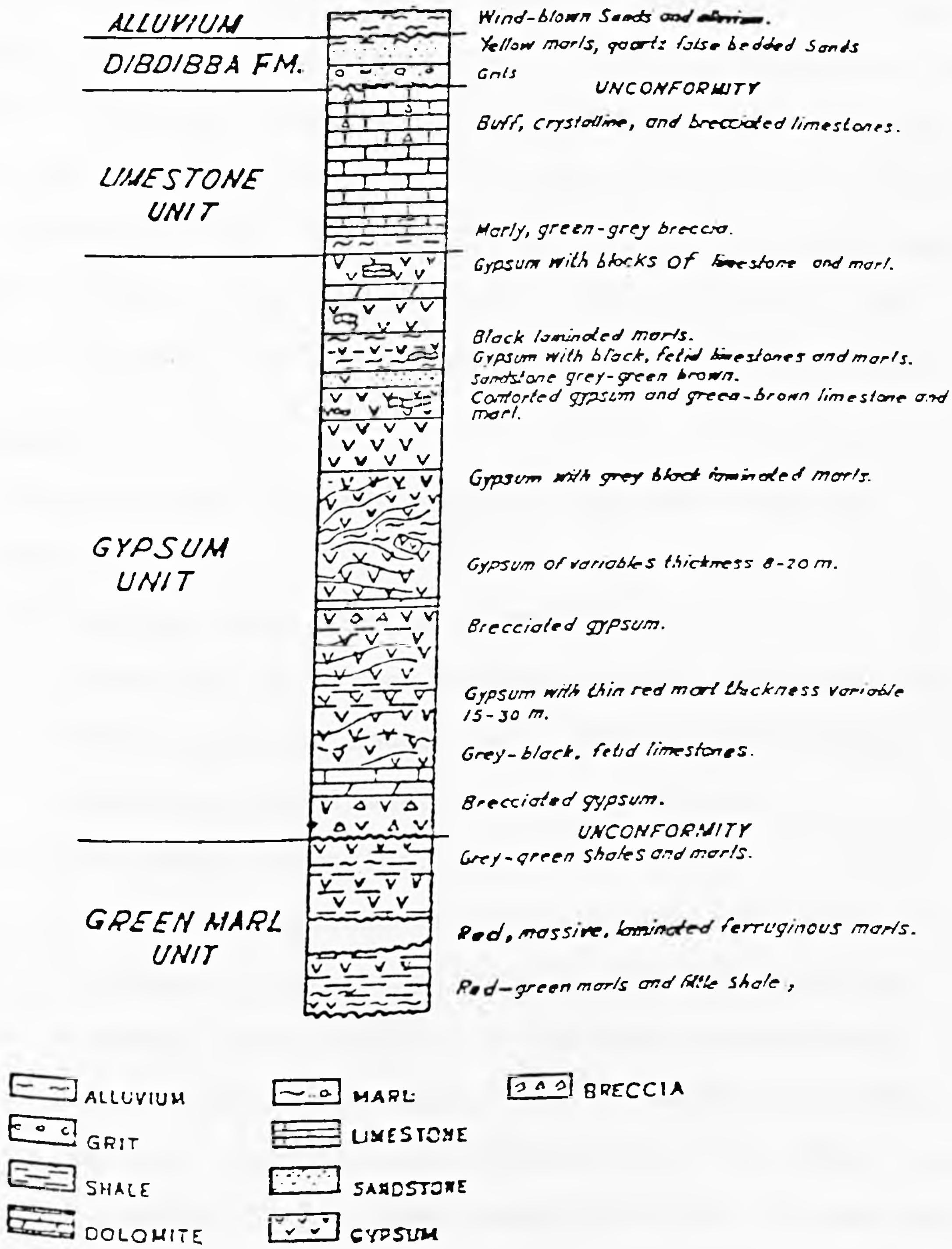


FIG. 3.6: GEOLOGICAL SECTION OF JABEL SANAM
SCALE 1:1000

(after al.Nagib, 1970)

lithological formation in the Lower Cretaceous. In the Middle Cretaceous sequence, five units (formations) have been identified. They are as shown in table 3.5 and figure 3.3: Mishrif limestone formation (140m); Rumaila formation (70m); Ahmadi formation (140m); Mauddud formation (110m); and Nahr Umr formation (250m). The Upper Cretaceous includes six formations (see Table 3.5). The sequence is as follows: Tayarat (250m); Shriranish (90m); Hartha (170m); Sadi (360m); Tanuma (45m) and Khasib formation (45m thick).

Tertiary

The Tertiary deposits range in age from Eocene to Pliocene.

i) Rus and Ummer Radhuma formations.

These are the oldest Tertiary formations being of Middle to Lower Eocene age. They consist mainly of anhydrites and limestones.

ii) The Dammam formation.

This is a limestone of Middle Eocene age. Its thickness is slightly variable from one place to another. For instance, at the British Petroleum Company Zubair No.3 bore hole, a thickness of 223m is reported, whilst in the Safwan area it is 235m thick (al.Naqib, 1970). The Dammam formation is characterised by whitish-grey to pink, porous, dolomitic limestone. The limestones are locally chalky (al.Jawad et al, 1970).

iii) Ghar formation.

The age of the Ghar formation is unknown, but it has been suggested that it belongs to the Middle or Lower Miocene.

This formation which is composed of sandstones with subordinate gravels and occasional clays attains a thickness of 150m.

iv) The Lower Fars formation.

According to Van Bellen (1959) the Lower Fars formation decreases in thickness towards the south so that in northern Kuwait it has dwindled to a thin dark shale between the Dibdibba and the Ghar formations. al.Naqib (1967) pointed out that this formation has been found in the sections of the Basra oil fields at Nahr Umr, Zubair and Rumaila. The formation is of Middle Miocene age. Its thickness shows great local variations, e.g. 305m at Nahr Umr, 182m at Zubair and 91m at Rumaila (Owen and Nasr, 1958; Meltric, 1963). It is composed of anhydrites, gypsum, marls and shallow water limestones.

v) The Dibdibba formation.

This formation covers a large portion of the southern desert including the study area, with the exception of the Jabel Sanam. It is found extensively in southern Iraq between Howr al.Hammar and the river Euphrates in the north, as far as the Neutral Zone in the west and into Saudi Arabia and Kuwait in the South (Milton, 1967; Powers, et al, 1966). Direct evidence of the age of the Dibdibba formation is not available. However, comparison with other areas in the Middle East suggests that the formation is of late Miocene (upper Miocene) or Mio-Pliocene age. (Hudson et al , 1957). The area covered by this formation is known locally as al.Dibdibba.

The thickness of the formation varies considerably. In al. Zubair area it reaches a thickness of between 300 and 390m (Meltric, 1963), and in the Safwan area it is 140m thick (al.Naqib, 1970).

Darmoian (1971) examined samples of the formation from the Zubair and Rumaila oil fields. He found the formation to consist generally of grits, gravels of igneous origin, sand, sandstone, marls, slates of different colours, pebbles and gypsum. These are also found in other parts of the Dibdibba formation e.g. Safwan area.

Quaternary

The Quaternary deposits comprise the marine unit of Hammar formation (Recent or Holocene), recent alluvium, the reworked gravel of the Dibdibba formation and blown sands. The thickness of these deposits varies from place to place according to the underlying structurally-controlled morphology (al.Naqib, 1970).

3.3.3 Structure.

The general geological structure of the study area appears relatively simple. The strata are almost flat-bedded over wide areas, with a gentle dip towards the east or north-east. In this it contrasts with the northern and southern deserts both of which have more pronounced structural features (e.g. Gaara north of Rutba, northern desert (Phillip *et al*, 1968), and al.Salman basin in the southern desert). According to al.Naqib (1967), the area is included within the non-folded zone which includes an extensive area of central, southern and western Iraq, the Jabel Singar, Makhul and Hamrin making the northern and eastern limits. He also states that "the non-folded area considered falls within the interior homocline of the Arabian tectonic framework defined by Aramco geologists". Jabel Sanam, situated about 45km southwest of Basra, is a geological inlier forming a unique physiographic phenomenon in the area (Solecki, 1955). It rises to a height of 150m above sea-level, and is about 1 x 1.5km in area (Lorimer, 1969). The surrounding plain nowhere exceeds 50m in altitude. The hill is important in the area as a source of roadstone and building material, for it forms the only outcrop of hard Jurassic (?) rock in the Basra district.

Apart from Jabel Sanam, and the gentle,elongated folds of Zubair and Rumaila, the area does not show significant structural features. Both topographically and structurally there is general rise towards the west.

The origin of this Jabel Sanam is uncertain, but it is believed that the degree of shattering and dislocation of the rocks of the core suggest that they have been subjected to stress and movement in excess of that to be expected in a simple fold created by lateral compression. This uplift has a different nature from that evident in the surrounding rocks. It has been suggested that Jabel Sanam overlies a salt dome or plug (Macfadyen, 1955) but this is contentious and difficult to assess. According to al.Naqib (1970) the Jabel resembles in its size and shape some of the salt plugs that are so common in the Arabian Gulf and south-western Iran. (Details of these salt plugs may be found in Lees, 1931; Harrison, 1931). Jabel Sanam, however, attained its present condition during the late Tertiary.

The younger Dibdibba beds are relatively flat-lying in the surrounding region, but on the flank of Jabel Sanam they dip towards the surrounding lowland at angles up to 10°. These beds were deposited prior to the uplift of Jabel Sanam; their present altitude is the result of mobility in the rocks of the core, presumably igneous or salt. (Masin et al, 1965);

Lees and Falcon (1952) stated that "Recent geophysical work and bore-holes by the Iraq Petroleum Company in the Basra area have proved an axis of uplift trending north-north-west a little to the west of Zubair. In this and neighbouring areas the underground structure is to some extent related to the present topography". They added that "... it is a quite normal geological occurrence for the axes of earth movement to move spasmodically throughout long periods of time and geologists are accustomed to studying the drainage and topography of flat areas for clues to the underlying structure." (pp.35-36). Such knowledge of the fold structure of al.Zubair confirms that the Khor Zubair tidal embayment (east of the study area) is likely to be a subsidence feature, because the area coincides with a structural depression to the north-east of the Zubair axis of uplift.

3.4 GEOMORPHOLOGY

3.4.1 General Morphological Characteristics.

Desert surface conditions have been studied by many geomorphologists, their motives being as varied as the types of conditions which exist from one arid area to another. A wealth of published information pertaining to surface conditions and features of arid lands is available.

Several authors have recognised "desert flats" as a recurrent morphological component of deserts. Clements <u>et al</u> (1957), for instance, have estimated the extent of desert flats in four areas (south-western U.S.A., Sahara, Libyan desert and Arabia. Similar classifications have been suggested by Mabbutt (1969, 1971) who confined his studies to the Australian deserts; Glennie (1970) in the Gulf States and Libya; and Seligman, Tadmor and Raz (1962) in the Neger desert.

Cooke and Warren (1973) criticize these classifications when they point out "... that the categories are not always mutually exclusive or collectively comprehensive, nor are the distinctions between them clear. For example, 'desert flats' so grouped by Clements, could presumably include 'playas'" (p.53).

Wind may be the most important factor in the creation of the particular desert features of the flat area. The processes of sand transport and deposition are related to wind regime. Dune types, e.g. sand ridges, sand ripples, longitudinal dunes, have been studied by Brookfield (1970), Bagnold (1941), Mabbutt (1977), Allen (1970), Glennie (1970) and related to wind action in different desert conditions.

Sand dunes exhibit a variety of shapes (Pettijohn, Potter and Siever, 1972), and occupy a considerable area of the desert surface. Sand sheets, formed by deflation of the desert surface, constitute another characteristic aeolian form and cover vast areas. Conybeare (1976), after Reineck and Singh (1973), pointed out that "sand sheets are usually very large areas of desert country, more or less flat in nature. Slight undulating or small dune-like features may be present."

Desert pavements are also a feature of deflation, formed by fine materials removed by wind. Hammadas, sometimes known as lag deposits, (Bultzer, 1964) are a product of selective aeolian removal of sand and silt.

Beheiry (1972) described the desert as "the kingdom of sand and wind". There is no doubt that comparison of desert features between one area and another can be illuminating. Buringh (1960) stated that the "...aeolian sands are widespread in the south-west of Iraq. Similar soils in the Sahara Desert are called 'erg'". (p.203). However, according to Buringh the aeolian sand in south-west Iraq originated as an erosional product of sandstone areas in Saudi Arabia. The latter are derived from disintegrated Palaeozoic and Mesozoic sandstones (Brown, 1960). Stocek and Saadalah (1972) reject Buringh's suggestion however. Their studies reveal that the aeolian sand in this desert is quite different from that of Saudi Arabia. They stated that: "... the heavy minerals, together with a high carbonate content and wind directions, give evidence that the erosional products of the sandstone exposed in Saudi Arabia cannot be the only or the main source of detrital material." (p.43) Finally, they conclude, from their study of heavy minerals, carbonate content, and wind direction, that sediments of the Mesopotamian plain[6)] are the main source of air-transported material. They also conclude that both the alluvial sediments and the desert dust soils contain polycyclic material of mixed origins.

Their studies, however, are confined to aeolian sand

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6) The clastic material is delivered to the lower Mesopotamian plain mainly from igneous and metamorphic rocks cropping out in north-eastern Iraq and adjacent areas (Phillip,1968; Kukal and Saadallah, 1970).

accumulations. They refer to the narrow belt of dunes extending parallel to the Euphrates River from south Najaf and ending in this area, as elongated accumulative sands.

The small sand dunes and 'al.Nabik'[7] sand found near Safwan (in the farms area) are not related to that belt. Such sand cover can also be found in the north-east of Kuwait, and is clearly visible on aerial photographs. (Funch et al, 1968).

3.4.2 Physiographic Regions.

The area may be divided into two distinct physiographic regions. These coincide closely with the geological structure. They include the alluvial flood plain which occupies the eastern and northern portion of the Desert, with the remainder being what is known as al.Dibdibba area, including Jabel Sanam on its south-western margin.

i) The alluvial flood plain is part of the vast alluvial plain of Iraq. The Khor al.Zubair is only a conjunctive channel between the Euphrates River and the Arabian Gulf, located in the west of the plain, and forming the eastern boundary of the study area.

A flood plain is defined as "... a strip of alluvial land which borders a stream channel and is periodically inundated by flood water emanating from the channel." (Allen, 1970, p.136).

The flood plain of al.Zubair area is a part of what is known historically as 'the Mesopotamian plain'. In Chapter II, it was noted that the plain is part of the geosyncline which

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7) al.Nabik: a small sand or dust accumulation. Such sand accumulations (al.Nabik) are widespread in the Arabian Bawadi (deserts). (Beheiry, 1972).

in historical times was covered by the sea and filled with deposits over thousands of years, the accumulation rate of which has been estimated as 10^{10} tons per annum. (Mitchell, 1957b; Lloyd, 1961). Sedimentation is variable according to the river's regime (Moor, 1966; Collinson, 1976).

There is some controversy concerning the alluvial sediments of the Mesopotamian plain. This controversy centres around the deltaic advance and retreat of the head of the Gulf. Beke (1835) envisaged the head of the Arabian Gulf originally lying near Samarra (north Baghdad), its position gradually shifting to its present one as a consequence of alluvial infilling by the rivers. This theory was supported by Ainsworth (1838). De Morgan (1900) published a map portraying the coast at the time of Sennacherib (B.C.696). The shoreline of the delta is shown to be as far inland as the Howr al.Hammar. Similar interpretations were suggested until in 1952 Lees and Falcon presented a new and widely accepted interpretation of the delta geology, based primarily on modern physical evidence and specifically on recent tectonic activity. They claimed that changes in the delta have been far more complex than had previously been assumed, and suggested that the concept of a simple delta advance from Samarra to the present shoreline is untenable. (Larsen, 1975). They reached the conclusion that "The Tigris, Euphrates and Kuran rivers are not building forward a normal delta; they are discharging their load of sediment into a tectonic basin which is the successor to a geosyncline in which may be thousands of feet of sediment accumulated in the past, over a period to be measured in hundreds of millions of years.[8] The balance between subsidence and sedimentation in the recent past seems to have been finely poised; subsidence was episodic and in the intervals the depressions tended to fill up with sediment. But in general, subsidence has been dominant, with the exception of some minor local uplifts.representing a late movement of anticlinal structures" (Lees and Falcon, 1952, p.38). Mitchell (1957a) expressed the view that this theory appears to be geologically sound.

Lees and Falcon made several points in defence of their theory. Some of these points have significance with relation to the form of the floodplain of the study area. For instance, in February 1946 during a flight from Basra to Kuwait, one of the G.M.L. team observed irrigation from old canals leaking out into the tidal embayment area of Khor Zubair. They point out that there are two old canals, one running south-east from the Howr al.Hammar and passing al.Zubair on the east, the other running south-east from the Shatt al.Arab. The two canals join 25km south-east of Zubair and continue south-east as one canal to disappear below the alluvium east of the Khor al.Zubair. The tidal drainage of the Khor Zubair cuts right across these old canals. The old irrigation pattern shows clearest in the west along the Shatt al.Arab, whilst to the south it gradually disappears beneath the alluvium. The

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8) However, Ionides (1954, 394-395) indicated that in his view, they were "... mistaken in their assumption that the whole silt load of the Euphrates and Tigris ends up in the 1500 square miles of marsh area ... the area over which the river silt load has been deposited is more like ten times that on which the authors (Lees and Falcon, 1952) have based their calculations."

existence of the present alluvium with respect to the flood and tidal current action of the river has led Lees and Falcon and other researchers to infer that the head of the Gulf was not very far away from its present position.

In addition, fossil evidence within the alluvium gives credence to their theory. They indicated (p.36) that the recent boreholes by the Iraq Petroleum Company in the Nahr Umr, 33km west-north-west of Basra have provided 30m of alluvial clay and sands, with fresh water shells at the base, resting on bedrock of Miocene age.

Generally speaking, this region is almost flat in its features with a gentle gradient towards the Gulf. This flatness also results in very low river gradients, the maximum being 6.9cm per km for the Tigris and 10.5cm per km for the Euphrates, (al.Khalaf, 1959).

The alluvial tract is also influenced by the Shatt al.Arab river and the tides of the Arabian Gulf affect the Khor al.Zubair. Shores of Khor al.Zubair are swampy, with sandy desert on each side (Naval Intelligence Division, 1944). The whole of the alluvial floodplain is characterised by seasonal flooding. In the flood season, the water reaches the minor road to the west of Khor al.Zubair. Observers have noted that, during the high flood season, the Khor Abdulla (which is fed by the Khor Zubair) and the Howr al.Hammar occasionally form a single sheet of water. Nevertheless, the marshes are gradually being infilled with fine graded deposits brought in by the Euphrates and Shatt al.Arab rivers. On the whole, the alluvium forms a featureless plain with only the occasional occurrence of small coastal dunes to break the monotony of the landscape. (AART, 1972). It has been argued that, because of the very low gradients, a rise of only 0.70 - 2m in the level of the Howr al.Hammar can result in an overbank flood extending over an area of this plain estimated to be 500,000 meshara.[9)] (Ministry of Irrigation, 1971, Blanckenhorn, 1914).

The alluvial floodplain consists of three components (Fig. 2.8):

i) The coastal plain, which is located in the extreme south of the lower Mesopotamian plain, close to the Arabian Gulf. It is distinguished by the tidal inlets of Khor al.Zubair. (Brice, 1966), and by the marine deposits from the adjacent Arabian Gulf.

ii) The estuarine region which, in the study area, extends north of the coastal plain but is affected by the tidal regime of the Arabian Gulf.

iii) The marsh region which lies to the south of Hammar lake. In the wet season the waters of the lake extend southwards to flood the whole of the marsh area.[10)]

The thickness of the alluvial deposits is not well known but generally varies from some tens of metres in the northern part to thousand metres or more near Basra. The alluvial deposits overlie older formation including Bakhtiari and Lower-Fars formation which contain saline layer rings (AART, 1972).

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9) Meshara or Donem = 2,500m^2.

10) Recently the National Petroleum Company has established many barriers on the southern margin of the Howr al.Hammar to ease its investigation and production processes. These barriers prevent the floods extending south of Howr al. Hammar.

ii) al.Dibdibba area comprises the south-eastern quadrant of the southern Desert of Iraq. Only its northernmost part lies in Iraq, the remaining and much the largest part extending southward into Kuwait and Saudi Arabia (Ralph Parsons Co., 1955). It forms a large part of the study area. It is distinct in its relatively large altitudinal range, 6 - 76m above sea level.

Within the study area, al.Dibdibba begins at the Tuba Railway Station in the north-west and stretches to the south-east until it crosses to the eastern side of Shuaiba Junction. Thereafter, it turns southwards and passes east of al.Zubair city and parallel to Khor al.Zubair until it joins the Khor in its extreme southern part.

Large portions of the surface of al.Dibdibba range between slightly undulating and flat. It is a sandy and pebbly desert. The gravels of quartzite and various igneous rocks, together with the coarse sands are in places cemented into hard grit. The desert grades into gently sloping ranges of hills (Mitchell, 1957a; al.Jawad et al 1970 a&b). The whole area possesses a regional slope to the north-east. The area is also covered by deposits of windblown sand which form hummocks and small accumulated sand dunes.

On the flank of the Zubair axis, there is a relatively elevated tract separating the alluvial area from al. Dibdibba area. This elevated land is, in fact, only the ruins of the old site of Basra[11)] which occupies an extensive area between Shuaiba and the present town of al. Zubair. These ruins now "... form mounds of brick rubble at the edge of the flat plain and on the first slope of the marginal terrace towards Shuaiba, and an examination of the terrace, which at its edge is about 12 feet high, shows that it is composed of gypseous sand, silt, and pebble beds containing occasional fresh water shells."[12)] (Lees and Falcon, 1952, p.36). al.Dibdibba area can be divided into three major landform zones as follows: (a) depressions, (b) wadis and (c) sand accumulations and Jabel Sanam.

a) Depressions: It has been made clear in the geological section that these are two major sub-surface folds, the Zubair and Rumaila anticlines, separated by synclinal structures. From north-west to south-east they are the Berjisiyah depression, the Rafidiyah depression, and the Arfajiyah depression (see Fig. 3.1).

Sugden (1964) points out that there is no integrated effluent surface drainage from this area, and that any runoff becomes ponded temporarily in local broad but very shallow depressions. He assumed these depressions to have been formed by wind erosion, as no other genetic agency seems to be available. However, more recent work by Haddad

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11) This city has been described by Lees and Falcon, 1952. It was a flourishing urban centre between 800 and 1200 A.D. and has been described in considerable detail by Arab geographers. They added that it is often referred to as a sea port, but while it had connecting canals with the sea via the Shatt al.Arab, the course of the latter was then approximately in its present position.

12) Because this area is now considered as an excavated area it is a prohibited area for other types of research.

(Personal Communication, 1979) suggests that the depression east and north-east of Jabel Sanam, for instance, is possibly linked to the formation of Jabel Sanam and includes the location of Safwan town and extends to its north and north-west for more than 5km with a depth of about 3 to 4m. Slopes are generally inclined towards that depression. Moreover, the Berjisiya depression, as mentioned above, is certainly closely coincident with certain surface structures and may be a product of subsidence including movements related to the formation of the Zubair oilfield east of this depression. It may be that the depressions referred to by Sugden are the widespread small rain pools, in which over a metre of storm water sometimes accumulates and may take several weeks to soak away into the sandy subsoil. These rain pools may be found anywhere in the study area e.g. at Berjisiya, near Zubair. The accumulated water in these ponds is very important for Bedouin animal husbandry, especially with regard to camels. On the other hand, the existence of underground water in the major depressions has also encouraged people to settle in the area.

b) Wadis: The Western Desert of Iraq is dissected by numerous wadis. These are better defined in the northern part of the desert than in the south, including the study area. (Sousa, 1965). In the northern part, the wadis descening from the high plateau towards the Tigris-Euphrates trough and most of them are 30.48 - 45.72m deep. (al.Khashab, 1958; see plate 3.2). In contrast, the aerial photographs of the study area reveal that the area in the southern part of Western Desert is only weakly incised by intermittent wadis. These are shallow and poorly defined courses of temporary surface streams and may carry water after sporadic rain-storms in winter. They generally slope to the east and north-east, following the

PLATE 3.2

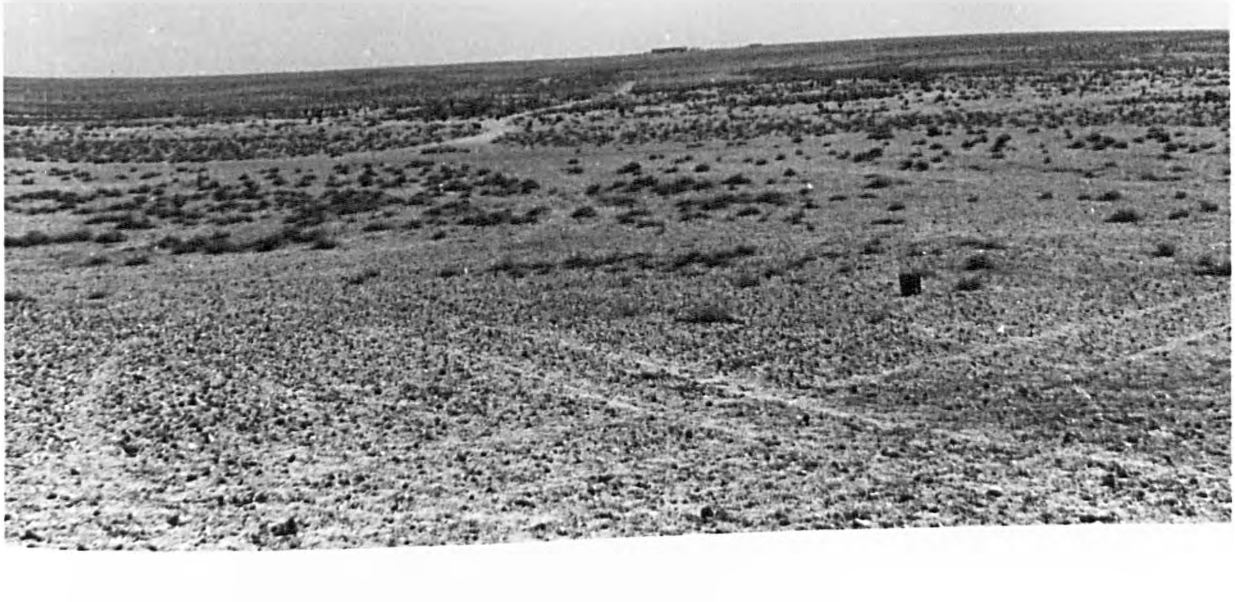

PLATE 3.2

Wadis of the western desert of Iraq. The wadis of northern part of western desert (top) are deep in comparison with those of southern part (bottom).

overall topographic trend of the region.

These wadis are Shuaib Muwailhat which ends in the east side of the study area, Shuaib al.Shich which ends in the Berjisiya depression, and Shuaib al.Luwaihadh which ends in the Arfajiyia depression. Shuaib al.Jorfan originates in Kuwait, whereas Shuaib al.Shuaib runs north-eastward and to the west of Jabel Sanam area (Fig.3.1). Besides these wadis, there are another two wadis in the study area. The first is Shuaib al.Batin which runs eastwards through the town of Zubair. In the past, and today at times, when the Shuaib carries a considerable amount of water after heavy rain, flooding occurs in villages adjacent to it. This Shuaib is now built over and paved, and it has become known as al.Batin Street. (al.Rubayi, 1978). The second wadi, known as Wadi al.Batin forms the boundary between Iraq and Kuwait a few kilometres to the west of Jabel Sanam. This wadi can be traced over a considerable distance through Saudi Arabia to Kuwait and into Iraq. Funch et al,(1968)points out that in central Kuwait, the wadi is incised by some 50m below the level of al. Dibdibba area but near the Iraqi border it becomes more subdued.[13)]

These Shuaibs and wadis are important for animal grazing, especially in springtime.

c) Sand accumulation and Jabel Sanam:Sand accumulations are widespread in the study area. They are small and usually found in the depressions. The vegetation forms focal points for sand accumulation (Plate 3.3).

To the south-west of the study area, the relatively small

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13) For more details about this wadi see Dickson, 1956, pp.53-54; Lorimer, J., 1969, pp.404-5; Naval Intelligence Division, 1944, pp.115-7 and Williams, 1952, pp.217-8.

PLATE 3.3

Plants form focal points for sand accumulation but prominent hill of Jabel Sanam rises from al.Dibdibba plain. Its essential characteristics have already been outlined (Section 3.3).

3.5 SOILS

Little published work is available on the soils of Iraq generally and the study area specifically. Recently, the National Soil Survey and Land Reclamation Organization has begun to investigate the soils of the Iraqi deserts. Such investigations have been conducted with a view to practical applications. Naturally the problem of the effects of saline irrigation water on soil characteristics has been high on the list of their priorities. (al.Nakhabandi et al, 1967, Russel et al, 1965, Farhan, 1973 and Hardan et al, 1969).

3.5.1 Soil Groups of the Study Area

Soil formation and soil conditions are usually different from one place to another according to several controlling factors outlined in Chapter II.

Buringh (1960) recognised eighteen soil groups in Iraq, of which four can be found in the study area (Fig.3.7). Generally, these soils are characterised by their low moisture content, their low organic matter content, their poor vegetation cover and by the fact that they are developed on recent cover materials. According to Buringh these soils are those of the northern marsh region, the tidal and coastal flats to the east and north-east, the sand dunes area and the pebbly and sandy desert regions.

The marsh tracts of the study area comprise part of the extensive marsh region of Iraq which occupies an area of more

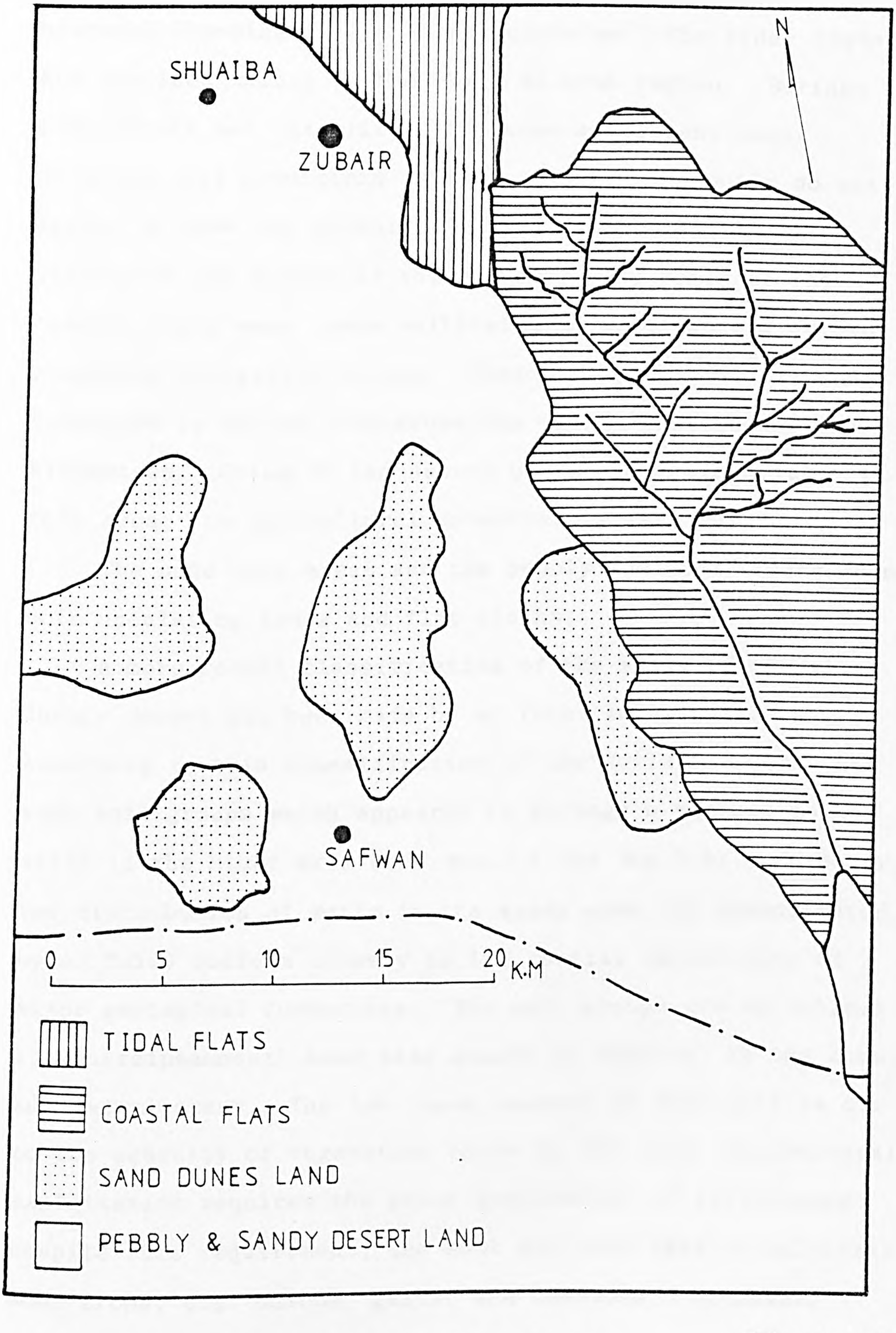

FIG. 3.7: SOIL GROUPS IN al ZUBAIR AREA (after Buringh 1960

than 35,000km^2. The whole region is affected by the seasonal flooding of the River Euphrates. The tidal flats are confined mainly to the Shatt al.Arab region. Buringh also points out that little is known at present about detailed soil conditions of this region. The soils do not appear to have any potential value, except for the date gardens on the levees of the estuary. The soils of the coastal flats were once cultivated as is evidenced by old abandoned irrigation canals. These irrigation canals were submerged by marine transgressions over a distance of many kilometres. Owing to the nature of marine sedimentation in this area, its agricultural potential is very low.

The sand dune areas and the pebbly and sandy lands form both undulating areas and flat plains.

A more recent classification of the soils of the al. Zubair desert has been made by al.Taie (1970) (Fig.3.8). According to this classification of the soils it seems that some soil groups which appeared in Buringh's account do not exist in the study area (cf. Fig.3.7 and Fig.3.8). Moreover, the distribution of soils in the study area (as demonstrated by al.Taie) conform closely to the spatial variability of major geological formations. The soil groups are as follows:
i) Quartzipsamment: sand size quartz is dominant in the Zubair and Safwan areas. The low humus content of this soil is due to the scarcity of vegetation cover in the area. Agricultural exploitation requires the prior application of fertilisers. Despite this requirement, the soil has been used to cultivate some crops, e.g. onions, garlic and tomatoes. Moreover, it is considered as the main source for sand and gravel for construction purposes.

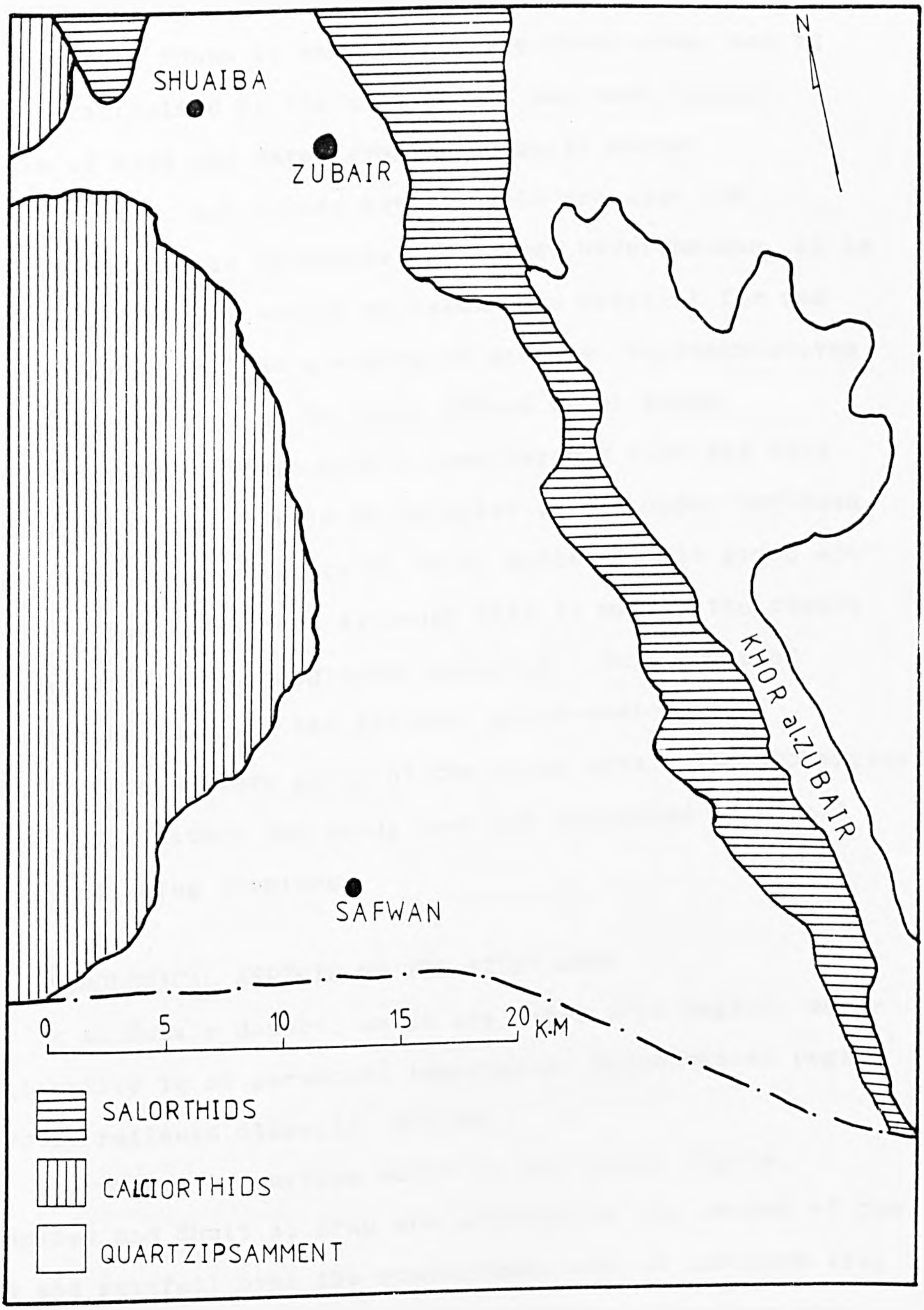

FIG. 3.8: SOIL GROUPS IN al.ZUBAIR AREA (after al Taie) 1970

ii) Calciorthids: The soils of this group are characterised by accumulations of calcium carbonate and calcium sulphate. This group is found in the west of the study area, and is also characterised by its high pebble and sand content. Because of wind and water erosion, organic matter content is low, and ground water levels are also low. Crop agriculture is therefore precluded. Nevertheless. it is considered a useful source of calcareous material for use in building as well as a source of gravels. Representatives of this group also can be found around Jabel Sanam.

iii) Salorthids: These have a considerable clay and sand content, with high levels of salinity in the upper horizons of the soil. According to al.Taie, soils of this group are generally badly drained, although this is mainly the result of their low-lying topographic position. This group of soils can be found in the eastern, north-eastern and extreme north-western parts of the study area. The properties of the soils within the study area are discussed in detail in the following chapters.

3.6 HYDROLOGICAL ASPECTS OF THE STUDY AREA

In al.Zubair desert, as in any other arid region, water availability is of paramount importance. Hydrological regime directly reflects climatic regime.

The volume of surface water in the rivers Tigris, Euphrates and Shatt al.Arab are affected by the amount of the snow and rainfall over the mountainous area of northern Iraq (Tigris and its tributaries) and in Turkey (affecting the Euphrates) (al.Khalaf, 1951; Ionides, 1937).

The rivers Tigris and Euphrates[14)] flood regularly. According to al.Khatab (1972) the lands located east of the margins of al.Dibdibba plain have "... a complicated water drainage system. During the flood period from May to June, the water rises in Howr al.Hammar from 0.7 metres to 2.0 metres above sea level." (p.53) Owing to the flatness of these two segments of the study area, they are often covered with water during the flood season. Meanwhile, tides and southerly winds during the low water season cause the water to penetrate from Khor Abdulla and Khor al.Zubair and flood over neighbouring areas.

Although the rainfall is low over the study area it can form significant runoff. A small amount of surface runoff may occasionally reach the Howr al.Hammar floodplain at the northern edge of the area. This, however, depends on the rainfall amount, the terrain types and the characteristic of the surface material.

The surface materials of the southern and central parts of the study area (sand and gravel) are very permeable. The alluvial flood plains have a higher silt and clay content and thus their permeability is lower (Tibbett-Abbett-McCarthy-Station, 1957). Most of the water courses are very shallow and broad, and terminate in the Safwan and Berjesiyah depressions (Fig.3.1). These two depressions are the richest areas for underground water supplies.

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14) The normal difference between low (September) and high (May) water level in the river Euphrates is as much as 2m (Naval Intelligence Division, 1944, p.38).

Underground water is very important in the study area at the present time, since rainfall is unreliable and there are no permanent rivers (Mahmood, 1971). Many reports relating to the underground water supply of the southern desert (including the study area) have been made by different researchers. For instance, reports have been completed by a hydrological survey team from the Institute of Applied Research of Natural Resources in Baghdad, whilst others have been carried out by private companies e.g. Ralph and Parsons Co.,; Tippett-Abbett-McCarthy Stratton Co., and specialist individuals e.g. Haddad (1978).

Digging wells in order to tap underground water in the study area is the only reliable method of access. Water here serves different purposes. Although Bedouins obtain water from scattered temporary rain-pools, they also obtain some from wells drilled by Government agencies. In the past, wells formed an important and major source of drinking water, supplying all the people of the study area. More recently, although wells are still an important source, especially for Bedouins and farmers (see also Table 3.6), their importance has declined following Government provision of piped water from Shuaiba to dwellings in Zubair, UmQasr and Berjisiya, for example.

Several factors serve to restrict the sinking of new wells. These are cost, quality of water, and thickness and depth below surface of the aquifer. Several new wells have been sunk in this area in the past few years and now support farms. Nearly everywhere in the study area, however, the ground-water is saline. As there is often a layer of fresh

Location of the well	wells depth "in meters"	production gallon/h.	dissolved salt per p.m.
Safwan No.1	16	2737	1350
Safwan No.2	19	4000	1320
Zubair-Safwan Road No.2	28	2800	4200
Zubair-Safwan Road No.1	28	2800	4200
Safwan No.3	19	3990	1000
Rafaiya No.1	38	1200	5000
Rumaila No.1	18	2760	10000
Safwan No.4	21	2800	4500
Ramâila No.7	26	2160	-

Table 3-6: Some recent wells sunk by the Government of Iraq.

Source: al-Khateeb, 1973.

water on top of the saline water, wells are dug down to the fresh water layer. Ground-water removal now exceeds re-charge values often causing these wells to become brackish after a period of some years.

3.7 VEGETATION

Climate, soil and landforms clearly influence the native vegetation of the study area. Vegetation in this area is characterised by its resistance to the drought, high temperatures, and high wind speeds. On the other hand, under-ground water also influences the distribution of the vegetation. Thus, the most intensive vegetation can be found in the depressions where water tends to accumulate from time to time.

3.7.1 Types of Vegetation

There are two main types of vegetation. The first grows only during the wet season providing reasonably good grazing at that time. It diminishes with the onset of summer. The second type can resist the high temperatures and drought conditions and is able to flourish for most of the year.

The vegetation that covers the study area can be classified as follows: annual and perennial shrubs, perennial grasses and herbs, and annual grasses and herbs. This account is based on various sources, mainly al.Khateeb (1973), Guest (1933, 1966), al.Rawi (1968), and Zohary (1941,1950); Long (1955, 1957), al.Ani et al (1974a & b).

I. Annual and Perennial Shrubs

Most of these shrubs belong to the "goose family". It has great value for grazing especially during summer when the herbs disappear. This group consists of a variety of different shrubs, as follows:

1) Rhanterium eppaposum oliv - scientific name
   Arfaj (plate 3.4) - local name

This is a perennial shrub, and belongs to Compositeae family. It reaches a height of about 75cm and growth begins 6 weeks after the onset of the rainy season. It is generally found on sandy and sandy pebbly soils. Its grazing value is high, making good fodder for camel and sheep. It is also used as a fuel by the Bedouins. (Plate 3.5).

This kind of shrub is widespread and especially dominant in al.Zubair desert. It is especially evident to the west of Zubair, on both sides of Zubair-Safwan road, on the Safwan to UmQasr road, the Zubair-Busiya road and in the Jabel Sanam area.

2) Calligonum comosum - scientific name
   Ardah - local name

This perennial shrub belongs to the Polognaceae family. Its height is between 1 and 1.5m. It starts flourishing towards the end of February and is usually found on the sandy soils near Jabel Sanam.

3) Seidizia rosmarinus - scientific name
   Shenan - local name

A perennial shrub belonging to the Chenopodiceae family. Its height is between 30 and 80cm. It flourishes during October and November.and is found in the subakh and saline soils, and also in scattered areas between Zubair and UmQasr.

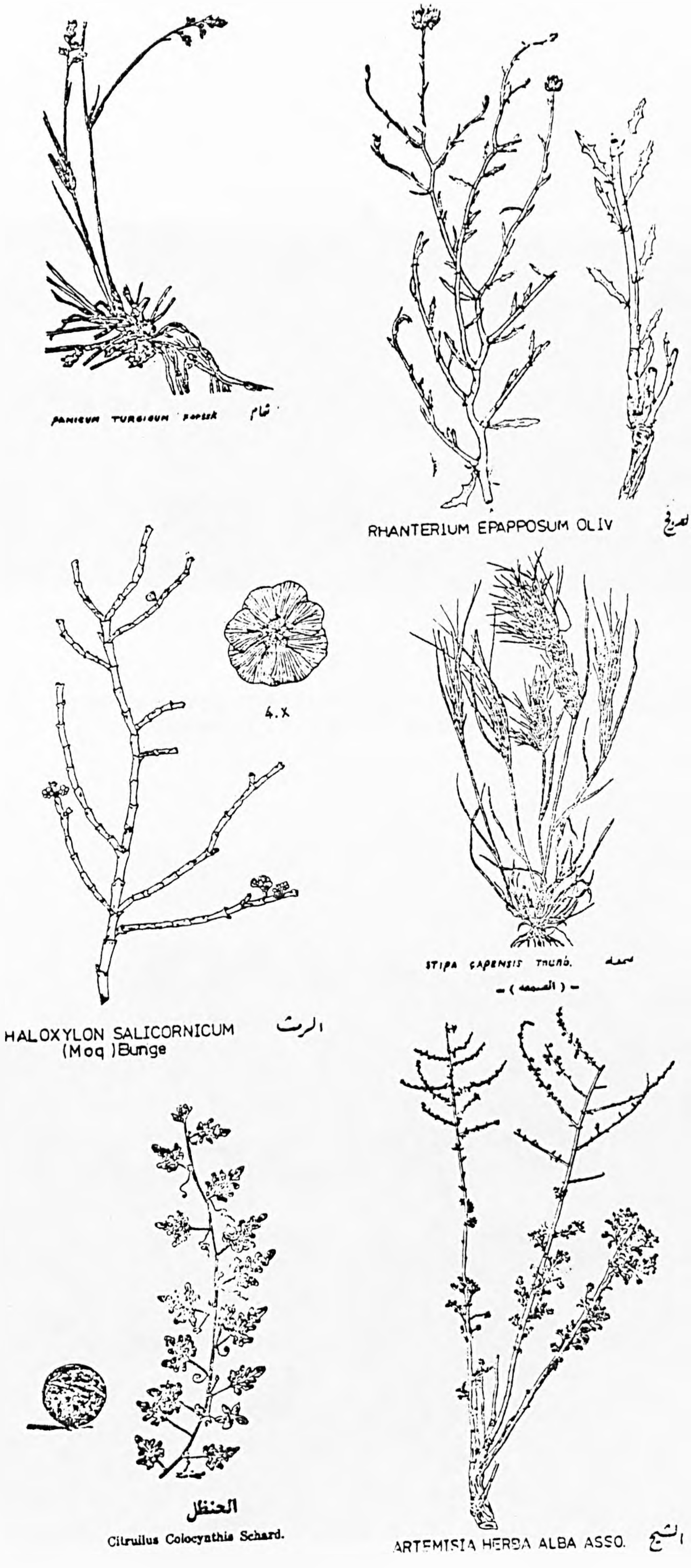

PLATE 3.4: EXAMPLES OF DIFFERENT TYPES OF VEGETATION OF AL.ZUBAIR AREA

Source: al.Khateeb M., Baghdad, 1973.

PLATE 3.5

'Arfaj' type of vegetation which has good grazing value for camel and sheep

PLATE 3.6

Belts of Athel trees are used as windbreaks to protect farms and towns of the study area from sand and sand storms.

4) Astragalus L. - scientific name
Chidad - local name

This is a member of Papilionaceae or pea family, occurring as a thorny perennial shrub and which flourishes at the beginning of March. It can be found in all areas of sandy and sandy pebbly soils. This kind of shrub may be either annual or perennial.

The perennial shrubs are listed as follows:

a) Astragalus bomby cinus boiss incl - Apalmyrensis post.
Found in 20-30km west of Zubair; 92km south-west of Basra; and in the Rumaila-Jabel Sanam area.

b) Astragalus Zubairensis
Small shrub with a height of between 15 and 20cm , found in areas 76km west of Basra, 60km west of Zubair and in the Jabel Sanam area.

c) Astragalus spinosis .
Height 5-50cm. Locations: 6-7km south-west of Zubair.

The annual shrubs are listed as follows:

a) Astragalus tribuloides (Kheshan)
This shrub is 30-100cm in height and favours sandy soils. Locations: 147km west of Basra, Rumaila area; 38km west of Basra; 90km south-west of Basra and UmQasir; and 40km south-east of Zubair and the Jabel Sanam area.

b) Astragalus Schimperi Boiss
Height: 5-20cm. Locations: 90km south-west of Basra, west of Zubair; 18km south-east of Zubair; 20km south-west of Safwan and the Sanam area.

c) Astragalus Corrugatus

Height: 30-40cm. Locations: 105km south-west of Basra, west of Zubair, and 40km south-east of Zubair.

d) Astragalus Gyzensis

Height: 50-100cm. Locations: 90-105km south-west of Basra; 18km south-east of Zubair, 20km south-west of Safwan and the Sanam area.

e) Astragalus annularis

Height: 10-30cm. Locations: 125km south-west of Basra, the Sanam area; 18km south of Zubair and 40km south-east of Zubair.

5. There are also perennial shrubs of minor importance found intermixed with the above shrubs. These are: (see plate 3.4):

a) Haloxylon Salicornicum, known locally as al.Rimth;

b) Artemisia Herba Alba Asso, known locally as al.Sheih;

and c) Citrullus colocynthis schrad or Hanthil.

II. Perennial (Ephemeroides) grasses and herbs

Such vegetation covers large areas of the Iraqi deserts. The most important shrubs of this group are as follows:

1. Stripaagrostus plumosa - scientific name
'Nesi' - local name

This is an important spring grass. It reaches 40cm in height, growth starting during March-May. It can resist high temperatures and drought and constitutes a good grazing resource for sheep and camel especially during the summer. It is usually found on sandy soils in the area between Busiya and Zubair and between Jabel Sanam and UmQasr.

2. Stripagrostis - scientific name
   Salaian - local name

This is an important spring perennial grass which reaches 30cm in height and flourishes between March-April. It is valued as sheep and camel fodder. It is found in the area between Zubair and Busiya in the west of the study area, and in the Jabel Sanam area.

3. Panicum turgidum - scientific name
   Thamam (plate 3.4 - local name

This is a spring perennial grass which flourishes in March. It is found on sandy and gravelly soils, and is drought resistant. It is considered a good food for camel and horses. It is found in an area about 15km south-west of Zubair near Jabel Sanam.

4. Cymbopogon parkeri stapf - scientific name
   Askhber - local name

This perennial grass can reach one metre in height. It has a pleasant smell resembling that of roses. It is usually found in sandy soils. Within the study area, it occurs 6km south-east of Safwan, 8km west of Safwan (near Jabel Sanam) and on the road between Zubair and Safwan.

III. Annual (Ephemeral) grass and herbs

Generally this vegetation accounts for 60% of the total vegetation of the Iraqi deserts.

Among the different grasses and herbs, of this type only five are recognised in the study area.

1. Stipa capensis - scientific name
   Samaah (plate 3.4) - local name

The samaah in fact can be either an annual or a perennial grass, but only the annual kind is found in the study area. The height of stipa capensis is about 40cm. It is found on calcareous soils but only during the early stages of growth is it suitable for fodder.

2. Hordeum glaucum steud - scientific name
   Khafor - local name

This grass reaches 10-40cm in height, flourishing in April, and can be found around Shuaiba and Zubair.

3. Lolium rigidum Gaud - scientific name
   Reweta - local name

This grass reaches 80cm in height, flourishes in April, and provides good grazing during early growth. It is found in the Zubair area.

4. Lophochloa phleoides - scientific name
   Heneta - local name

This reaches 40cm in height during March and is also found in the Zubair area.

5. Malva l., Malow - scientific name
   Khabaz - local name

This annual grass provides good grazing. It consists two kinds:

a) malva parviflora L.: 10-20cm in height and found in the Zubair area.

b) malva rotundifolia L.: 30-60 cm in height and found in the Sanam area.

Besides these three main types of vegetation the prosopis stephaniana (wild)spreng "shouk"and Tamarix articulata "Athel" are also found. The first is 30-100cm in height, thorny and with some grazing value especially in the summer when other forms have disappeared. It is widely distributed.

Tamarix is a perennial tree. It reaches 2-7 metres in height. Its ability to resist saline soil waters and drought is an important characteristic. When Tamarix is cultivated for the first time south of Zubair on the sandy soils it isirrigated for three years and then left without water. It managed to survive and now this area is called al.Athel forest which means the Tamarix forest. These trees can extend their roots to a depth of 10-12m and therefore can obtain moisture from deeper soil levels. They have been used as windbreaks to protect the farms and towns from sand and sandstorms (plate 3.6). They are also regarded as a decorative tree in arid areas such as the study area.

Table 3.7 lists the various vegetation types found in the area and the use for animal husbandry.

3.7.2 Vegetation Communities (or associations)

Dickson (1956) pointed out that the characteristic vegetation association changes little from Kuwait in the south to Syria in the north and north-west. Within this belt, Guest (1966) has recognised six main physiognomic types of vegetation: shrubs, shrublets, succulents, geophytes, ephemerals and switch plants. Only two major plant associations can be recognised in the study area (Fig.3.9):

1) Rhanterium epapposum, known to the Bedouins as Arfaj.
2) A Halophytic association, occurring in the east and north of the study area where dry saline flats are a characteristic feature of the terrain. (Zohary, 1950, al.Ani et al, 1971, 1974a & b and Thalen and al. Mufti, 1973).

Scientific Name	Local Name	Sheep	Goats	Camel
Rhanterium eppaposum oliv.	Arfaj	+	+	+++
Calligonum Commosum L Herit	Ardah	•	+	++
Astragalus spp.	Chidad	-	+	++
Aristida spp. (Stipagrostis)	Nesi	++	+	++
Panicum turgidum	Thamam	+	++	+++
Cymbopogon parkeri stap.	Askhber	+	++	++
Stipa spp.	Samaah	+	+	-
Lolium rigidum	Reweta	++	+	-
Lophochloaphleoides	Heneta	++	+	-
Malva L.Mallow	Khabaz	++	++	++
Prosopis stephaniana (wild) spreng	Shouk	+	++	++
Tamarix articulata	Athel	+	++	++
Lycium barbarum L.	Sereem	-	+	+

LEGEND:

(+++) suitability for grazing - very good

(++) " " " - good

(+) " " " - only in the early stages of growth

(-) not suitable for grazing

(•) " " " poor

Table 3-7: Availability and suitability of native vegetation of al-Zubair desert for Bedouin animal husbandry.

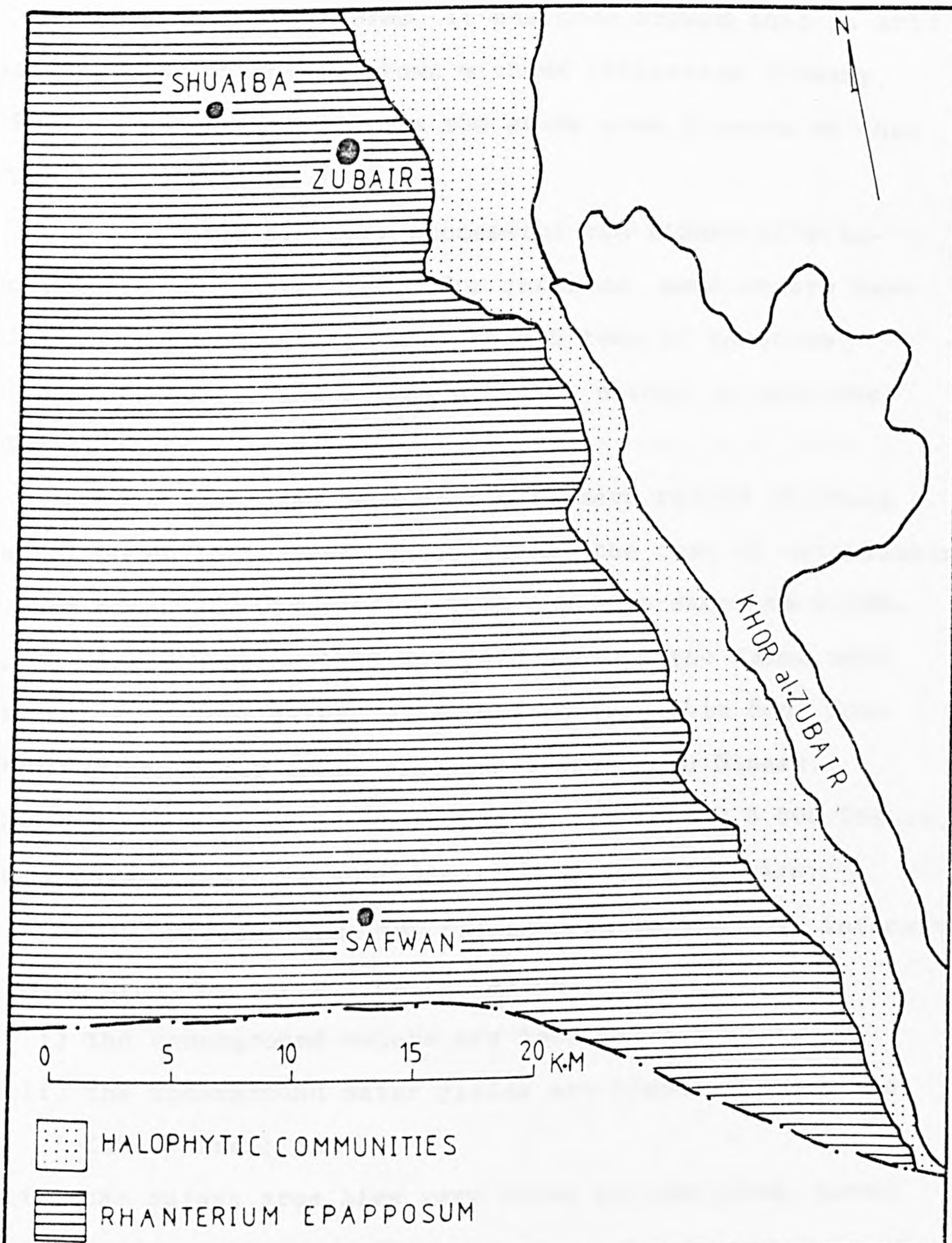

FIG. 3.9:

RECONNAISSANCE MAP OF THE VEGETION COVER OF THE ZUBAIR AREA

(after al-Ani et al., 1970)

3.8 AGRICULTURAL ASPECTS

In agricultural terms, it has been argued that in arid areas, crops cannot be grown without irrigation (Cressy, 1957). Irrigation water in the study area depends on that from local wells.

These farms are very successful and financially important to the Basra area. For instance, some owners have claimed to have produced more than 5 tons of tomatoes, 2 tons of garlic, and 3 tons of white onions in only one winter season.

Before 1958, and because the farmers relied on cheap animal power to irrigate their farms, the cost of establishing a farm was 60-10 Dinars[15)]. This cost increased to 1,000-1,200 Dinars between 1958 and 1970 because the farms used mechanical pumps instead of animal power. This cost rose even further after 1972, reaching 1,800-2,000 Dinars. Although the cost of establishing a farm is now 3,000 Dinars, the interest yield is approximately 30-40,000 Dinars.

At the present time the Safwan area is the most intensive farming area for the following reasons:

i) the underground waters are less saline;

ii) the underground water yields are higher than in the Zubair area; and

iii) the Safwan area lies very close to some good, paved roads.

The produce of both areas in winter includes tomatoes, beans, onions and garlic, while in summer the main products are watermelon, cantelupe, cucumbers and squash. The farms

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15) Dinar = £1.20 (1980)

are usually surrounded by Athel trees used as wind-breaks. The effective life of a farm depends primarily on the quality and yield of underground water.

Although farmers in this area use some fertilisers, they prefer to use manure on their land because it is cheaper. There are various types of irrigation. The first type is known locally as "Siaama". This demands continuous (24 hours) irrigation for a period of 10 days. It is used in the early stages of growth and stimulates rapid growth. The second method, known as "Adwar", is the more common. It consists of watering the crop 2-3 times a day for a longer period.

It is interesting to note that Egyptian agricultural experts have criticised the way Iraqi farms in this area are designed as shown in figure 3.10. They pointed out that 30% of the water is lost between the well and the farm in what is called the "qaium". However, the farmers continue to believe that their method is the most appropriate because if the farm is near the well, some of the water is likely to seep back to the well either at the surface or at depth owing to the soil permeability with the probable result that salinities in the well would rise and the life of the well be greatly shortened.

3.9 OTHER ASPECTS OF LAND USE

Some mention must be made of other aspect of land use as they have a bearing on the analysis presented in Chapter IV.

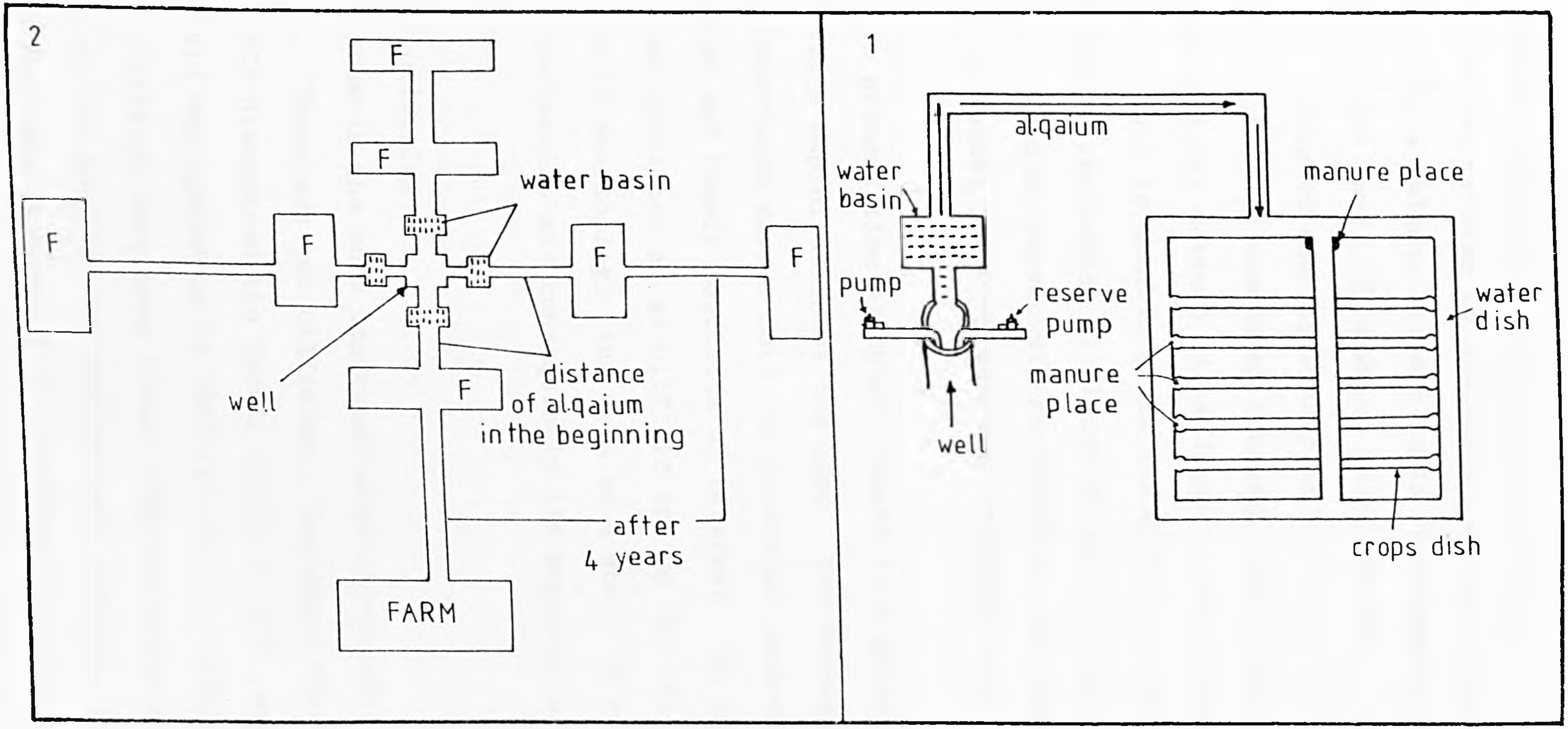

FIG. 3.10: DESIGN OF FARMS IN THE STUDY AREA

3.9.1 General Influence of Man on the Land

The central problem of sustained land-use in arid areas is to maintain a balance between human requirements and the potential of the land. Throughout the centuries, man has consistently reduced the capability of arid areas by the over-exploitation of their resources (Thomas, 1977) Historically, man has changed his methods of land-use to suit changing conditions. This is achieved, for instance, by sinking new wells to add to the number of places at which livestock can secure water, whilst previously he relied on the "haffirs" (superficial ponds) in which seasonal rainwater can be stored.

At the present time al.Zubair desert is a potential area for man's exploitation of the land. Two developments of economic importance reveal both its potential land-use capabilities and likely conflicts of interest. On the one hand, it has developed as an oilfield and on the other agriculture is developing. The area as a whole is responding to industrialisation and consequently its population is increasing.

3.9.2 The Oilfields:

Petroleum is the most important mineral resource of the study area. There are two oilfields. The Basra Petroleum Company (BPC) discovered the Zubair field in 1949, and the Rumaila field was opened up in 1953 (al.Khalaf, 1959). These two oilfields have been linked with the ports of Fao and UmQasr at the head of the Arabian Gulf (Taylor, 1969). Oil and natural gas extraction in this area has changed the land use. The oil company for instance, has built some artificial levees on the southern banks of the Howr al.Hammar to protect the area from floods. Because of the existence of oil in this area, many roads have been extended between Zubair town and Rumaila village. Oil and gas are used as a fuel for electric power stations in Basra city which, in turn, supplies all of southern Iraq with electricity. The iron works located on the eastern side of the study area is dependent on oil and gas for its fuel.

Most towns in the area have grown as a result of the increased wealth from oil and its products and the influence of people from neighbouring areas.

3.9.3 Gypsum, Sand and Gravel

According to Buringh's map (1960) showing the distribution of gypsum in Iraq, the study area has a secondary occurrence of gypsum in al.Dibdibba area. It appears as a gypsiferous alluvium in the flood plain area.

It is not of primary origin. Gypsum is one of the materials used in sculpture (alabaster). It is also used as a building material. In the past, people of Zubair town used to make plaster (Juz) in the following manner. First of all, they located the gypsum (which appears as a yellow-whitish sand). It can be found either in the surface layer of the soil or deeper (down to 2m). After extraction, it was spread out on the ground and a fire was lit on it for 24 hours or until it reached a white colour. Afterwards they refined it from the sand and gravel rendering it suitable for use (al.Rubayi, 1978) At the present time, due to technical progress, gypsum is used to make plaster in large quantities, "... often juz pits are dug in secondary gypsum deposits where at least 40% of gypsum is present. The material is burnt at 128^oC; $CaSO_4.2H_2O$ is transformed into 2 $CaSO_4.H_2O$. The quality of the plaster depends on the salt and clay content of the material." (Buringh, 1960, p.108)

The gravelly and sandy material of al.Dibdibba area is used in the making of concrete, and any occurrence of gypsum may decrease the quality of the material. The presence of gypsum in the alluvial soils of the study area affects the quality of concrete buildings and other construction works. At the same time, Buringh (1960) stated that "some soils of the lower Mesopotamian plain, however, contain gypsum in the subsoil or substratum only; it often occurs as crystals. Those gypsum crystals, however, may be covered with a thin layer of $CaCO_3$ making the gypsum ineffective." (p.109) Within the study area in the vicinity of Zubair town, there are 15 small factories devoted to the manufacture of juz.

At the present time, following increasing demand, the number of sand quarries in al.Dibdibba area is increasing. Quarries are found around Zubair town, between Zubair and Shuaiba village,in the area between Zubair and Safwan town and north of Sanam. Some of these reach 1-20m in depth, the size of the quarry and its depth depending on the quality of the sand and gravel. (plate 3.7) The rate of sand excavation is usually greater in the dry season for obvious reasons. Sand from quarries in the study area supplies Basra city and Amara city.

Gravel occurs either on the surface or mixed with sand in the sub-surface layers (plate 3.8). These superficial gravels are collected by people known as "Hasaia", the gravel collectors. They accumulate the gravel in heaps, and

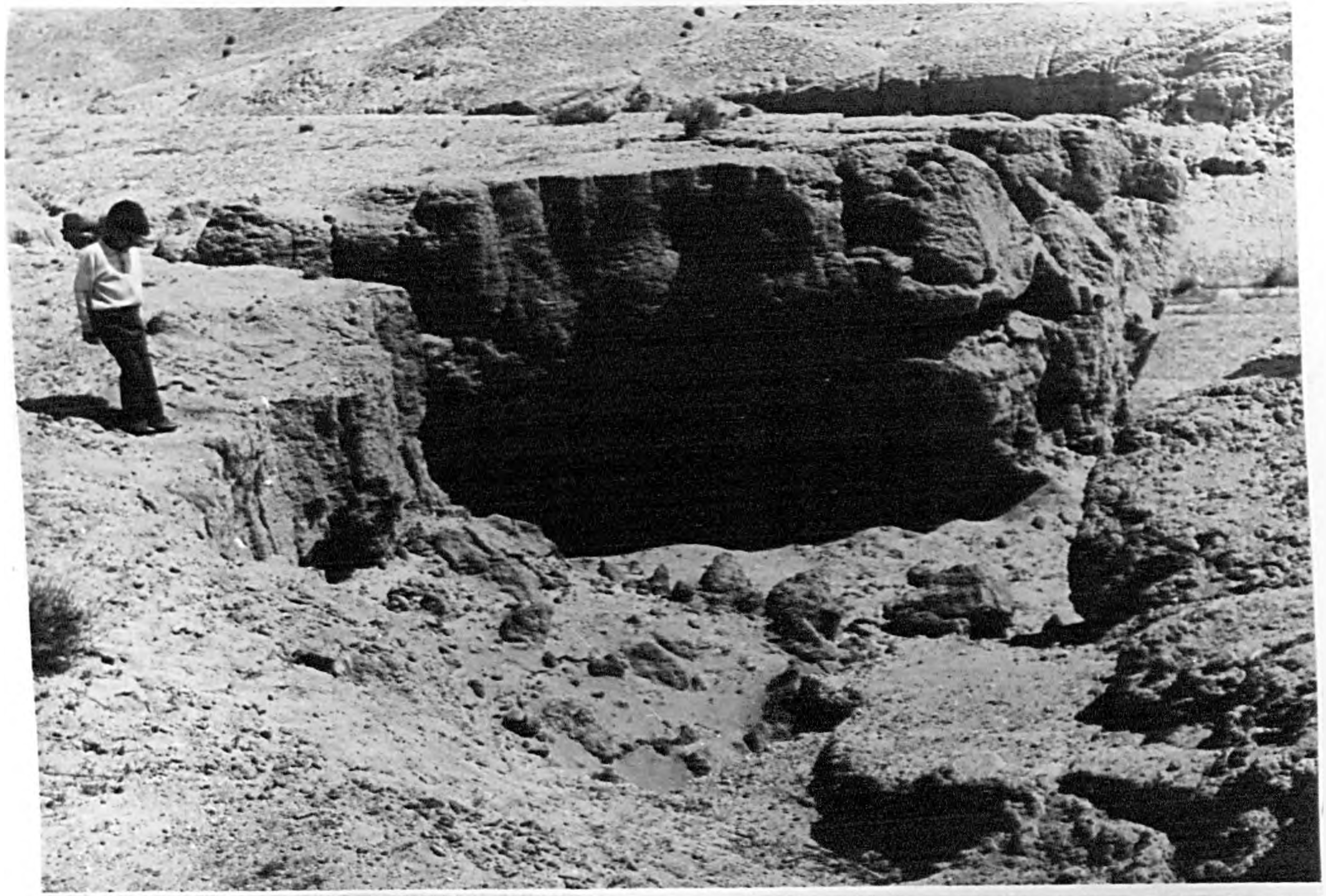

PLATE 3.7

One of the several sand quarries in the study area

PLATE 3.8

Mixture of sand and gravel in the subsurface layers they sell it to interested contractors. The contractor often lends them money and provides them with drinking water.

3.9.4 The People and Settlements

In the past, this area had no sedentary population, and it was considered as a home for the Bedouins who move, with their livestock, from place to place (Warriner, 1957; Lebon, 1953). Cressey (1960) was right to say that "... without the camel the desert would scarcely be habitable." (p.171). After the discovery of oil and the resultant industrial progress in the area, lifestyles have begun to change. Such progress has attracted people from outside the study area and even from outside the Basra district itself. The population of the study area can be divided into five groups, as follows:

1) The Hasaia people who collect gravels;
2) The Bedouins, a nomadic people who live by animal husbandry;
3) The Falaheen, or farmers;
4) The Aomal people who work in the oilfields and factories, and
5) The settlers in the towns and villages.

Towns and villages are all found in the central and eastern sectors, the west being relatively sparsely populated (by Bedouins). Zubair town is the oldest town in the area. It is located 14km south-west of Basra city and is the main commercial town of the area. Safwan[16)] town is located in the south of the study area. It is the customs

16) Its name may be due to the dust storms which are so frequent in the Safwan area. (See also Chapter 3 section 3.2.3).

post for controlling traffic between Iraq and Kuwait and the Gulf states. It is also an agricultural and business centre for the area and serves the surrounding farms. UmQasr is a town on an inlet of the Gulf located in the extreme south-east of the study area. It was set up as a small military port during the second world war. (Naval Intelligence Division, 1944; Brice, 1966). It is now the second largest port in the country. Shuaiba village, Berjisiya village and other small villages are scattered in the north and centre of the study area. They are important in that they provide amenities and services to people working in the oilfield.

CHAPTER IV

CLASSIFICATION AND MAPPING

CLASSIFICATION AND MAPPING

4.1 INTRODUCTION

This chapter presents the results of landform type analysis of al.Zubair region in the light of earlier studies of this kind.

Several operations were involved in the recognition of the several landform types and these are set out below.

1. The major landform types (features) of al.Zubair desert were initially recognised on the basis of aerial photographic interpretation and additional map-derived data.
2. The landform types so identified were checked against traverse lines (Fig. 4.2) representing means of access to the relevant areas.
3. All field appraisal involves some field measurement (within any selected area of study). In this case, this involved measurement of slope angles, vegetation percentages measurements and soil samples. For such field measurements at least two representative sites have been selected within each landform type.
4. Facets defined in section 4.2 were identified and confirmed in the field on the basis of photograph and map study.
5. Homogenous groups of small units (facets) were combined to make up a number of large units (systems).
6. The operationally important characteristics of these systems and facets are described, analysed and mapped.
7. Recurring associations of similar facets and systems have

been identified throughout the study area and a map of the homogenous terrain systems is presented.

8. Finally, a terrain classification was synthesised and then evaluated in the light of methods used elsewhere by, for example, C.S.I.R.O. and MEXE (or MVEE).

4.2 TERMINOLOGY

Some consideration of definitions of terms is necessary here because of the wide variation evident in the terminology of terrain classification studies.

i) <u>Terrain classification</u>

'Terrain' is defined as "... a general term to describe any piece of ground" and "... it implies that the ground is being assessed for some purpose." (Lawrance, 1972 , p.3). This term has already been used in the publications of the MEXE establishment (Beckett and Webster, 1976). The New English Dictionary's definition of terrain is "a tract of country considered with regard to its natural features and configuration". (quoted by Mitchell, 1973, p.4). Lawrance (1972) defined the term 'land' as "... an area of any size and may refer either to its surface form, or to the distribution of its rocks and soils, or both." (p.3). The term terrain, however, seems to be used at least according to Mitchell (1973) when the description is more strictly confined to the surface of the earth.

The term 'classification' means to describe, name and record the various terrain types of the study area, as well as to analyse their properties and their relationships to each other. 'Classification' is defined as "...the process of dividing ground into a number of classes having certain characteristics in common. A classification can be based on any attribute possessed by the ground whether superficial or at depth." (Lawrance, 1972, p.3). It is defined by Wright (1972) as "... the arrangement of things in groups, or classes, according to their common properties. Data relating to these properties determines the position of the things in the classification and thereafter are reflected by that position." (p.352).

Lawrance (1972) pointed out that terrain classification suggests that the classification has been made specifically for some kind of land use.

ii) Landform Types

Way (1973) pointed out that there is no accepted standard definition of this term. The definition of a landform varies in relation to terrain classification. It depends on whether the user is for instance, a geologist, an engineer, or a planner. (Belcher, 1948; Lueder, 1959).

The accepted definition for landforms in this work is "... landforms are terrain features formed by natural processes, which have a definable composition and range of physical and visual characteristics that occur wherever that landform is found." (Way, 1972, p.2). Landform types which have similar characteristics or features can be identified from aerial photographs with the aid of other sources of information such as maps within the study area. The boundaries of landform types as identified from aerial photographs are considered preliminary to the analysis of the terrain in the study area.

iii) Terrain Elements

A terrain/land element is defined by Perrin and Mitchell (1969) as the simplest part of the landscape for practical purposes, uniform in lithology, form, soil and vegetation. It is too small to be mapped but it "... is normally significant in preliminary and perhaps detailed surveys. For example, a hill slope may consist of two land elements, a steep upper slope and a gentle lower slope. To an engineer each slope element is important when considering slope stability and amounts of cut and fill. Other examples of land elements are very small river terraces, gully slopes and small rock outcrops." (Lawrance, 1972, p.6)

Such terrain elements are found in the study area, where for example, the wadi slope and wadi floor are considered as elements within one facet. Another example is provided by the gullies of Jábel Sanam.

iv) Terrain Facets

The definition of terrain facet/unit varies from one terrain classification group to another. Grant (1968), for example, defined a terrain unit as being "... the area covered by a single physiographic feature of geomorphic significance having a characteristic soil and vegetation association." (p.10). Beckett (1971) on the other hand, defined it as "... a reasonably uniform part of the landscape of an area that is conveniently mapped at scales of 1:20,000 to 1:50,000.

The terrain facet, however, is regarded as a composite made up of a limited number of terrain elements which always recurr in the same ratio within the terrain facet.

The variation in terrain elements is the major factor in determining the degree of simplicity and complexity of the terrain facet. The terrain facet is the basis of the terrain classification system of al.Zubair area. It is mapped at the scale of 1:35,000. All detailed information on terrain (which is obtained from selected sites) is indexed in terms of the terrain facet to which it refers.

v) Variants and Included Facets

'Variant' is a term used for features identifiable only by a knowledge of the physiography from direct field observation, and cannot usually be mapped and predicted. 'Variant' may be defined on the basis of surface differences which are unrecognisable and unpredictable from the position or form of the facet or from a knowledge of its physiography. (Lawrance 1972,Beckett and Webster 1976). An example of a variant is found in the alluvial flood plain system (of al.Zubair desert) where the occasional occurrence of small coastal dunes (or sand accumulations) break the monotony of the landscape (see also chapter 2).

However, although 'variants' are significant to engineers and agriculturalists, these variants should not be confused with the term 'elements'. Thus care should be taken to distinguish between these terms, where "elements are different parts of a facet which are definable and predictable; variants are different manifestations of a facet which, though definable, are not predictable." (Brink *et al*, 1966, p.10).

The best definition of the 'included facet' has been given by Lawrance (1972). He stated that "The facets of a land system are normally genetically linked, and therefore occur in a specific relationship to each other. Occasionally, a facet appears whose origin is not connected with the geomorphic evolution of the landscape around it. Such a facet is called an included facet because its occurrence and location are not influenced by the surrounding facets." (p.7) Within the study area, for instance, Jabel Sanam is regarded as an 'included facet' because its origin, occurrence and location are not influenced by the surrounding facets. It is a part of the dissected terrain system.

vi) Terrain system

A group of terrain facets which always occurs in the same pattern is known as a 'Terrain system'. Wright (1972) stated that "No precise definition of a land[1)] system has been framed." (p.362) However, the terrain facet/unit is the subdivision of the terrain system (Coklin, 1961). Terrain system in Christian and Stewart's (1953) opinion is an area, or group of areas, throughout which there is a recurring pattern of topography, soil and vegetation. (see also Christian 1958 and Christian and Stewart, 1968). It was agreed (as a result of a conference held at Oxford in summer 1965 (Brink *et al*, 1966), and included C.S.I.R.O., N.I.R.R. and MEXE), that the C.S.I.R.O. term land system should be used for the larger units and the MEXE term facet should apply to the smaller units (Perrin and Mitchell, 1969). Nevertheless, the term 'terrain' is used here in the manner

1) In Wright's usage, the term "land" is synonymous with "terrain

defined earlier in this chapter.

vii) Higher Units

The terrain region, terrain province, terrain division and terrain zone, are considered as higher terrain units. They are defined by Lawrance (1972) and Perrin and Mitchell (1969). As far as the study area is concerned, terrain zone is the only term applicable from this series. Terrain zone refers to a major climatic region of the world, and, as has been shown, the study are lies within arid lands (Meigs, 1953) in general and the hot deserts in particular (Mitchell, 1973).

4.3 METHODOLOGY OF PREVIOUS STUDIES: SOME EXAMPLES

There are numerous and varied methods available for terrain systems analysis. Differences between one method and another arise from various factors, the more important of which are briefly considered below.

i) Geographical location:

To some degree, geographical location has affected the methodology used by various practitioners, e.g. Webster and Beckett, 1970; Ray, 1956; Rutter, 1977; Webster 1967 in cold areas; Young, 1968; Lawrance, 1972; Ollier et al 1967; Paijmans, 1970; Haantjens, 1965; and Astle et al, 1969 in tropical areas; Kadomura, 1970 in tropical semi-arid conditions; and C.S.I.R.O. reports; Thomas Clements, 1957; Unesco reports for arid regions. In each case the needs of the specific environment have led to particular methodological solutions. For instance, in cold areas such as Canada, Rutter (1977) pointed out that the method used to define the terrain system for the Mackenzie area was initially based on surficial geological mapping which also served as a basis for determining the relationship between landform, materials, vegetation and soils. It was also possible to merge the findings on the geology, engineering geology, geomorphology, vegetation cover and pedology in order to produce a synthesis. Young (1968) also pointed out that it is probably appropriate for countries such as Britain to take numerous soil (i.e. regolith) samples for a project area, although this procedure may be inefficient and expensive in underdeveloped countries. He emphasised that "work in South Africa showed that it was possible to produce soil engineering maps by dividing the land surface into units on the basis of landform and vegetation features visible on air photographs, and then taking samples from each of the mapped units." (p.233). The desert environment has its own type of terrain classification methodology. It can be explained by recognition of two distinct types of classification. It has been pointed out by Mitchell et al (1979) that "terrain can be grouped into one class because it is all of the same kind, i.e. it is similar in several important properties. Examples are dunes, dune fields mountains, and out-wash fans. In each case the class has characteristics that enable us to recognise it wherever it occurs. Alternatively a class usually having some unifying character, may be circumscribed on the ground and be 'location specific', to use the current jargon. Examples include particular dunes, dune fields, mountains and fans, and regions such as Wadi Marsit, the Karoo and Socotra." (p.73).

ii) The purpose of the study and classification:

Every group or organization claims a particular purpose for its classification. These vary widely from planning to engineering, soil investigation or simply academic purposes. (Penning-Rowsell, 1973 & 1975; Penning-Rowsell, et al , 1977; Gullett, 1973; Barrie 1968; Brink et al, 1967; Brink, 1968; Aitchison, 1968; Uppal and Nanda, 1968; Fookes and Knill, 1969; Brink et al, 1968; Grant and Lodwick, 1968; Aitchison and Grant, 1961 and MEXE report No.1053, 1967).

iii) The size of the area to be classified:

Because the size of the land chosen for classification varies, the methods adopted differ accordingly. This is explained by the fact that a more intensive study can be achieved by choosing a smaller area (namely in sampling, measuring etc.) and thus a more precise prediction is obtained. In reverse, the larger the area, the more generalised the study becomes in classifying and evaluating the terrain of that chosen area. Size also influences the time and cost involved as well as the particular method adopted. Beckett and Webster (1972) for instance, pointed out that economy of time and money could be made by simple measurement procedures producing limited but useful information or describing wide areas by means of a small number of observations. Usually it is necessary to do both. (See also Peltier, 1962).

iv) The accessibility of the area:

Accessibility is an important concern for workers in this field. Christian (1952), for example, realised through his research in Australia that the process of exploration are relatively easy in the inhabited and accordingly more accessible parts of the country. Beckett and Webster (1972) stated that "The military problem of finding out about terrain in hostile or inaccessible territory is formally the same as the civil problem of finding out about the whole extent of an underdeveloped territory from field observations only in the easily accessible parts of it." (p.243).

Three approaches have been outlined. These are as follows: the genetic approach; the landscape approach; and the parametric approach. (See, for example , Mitchell, 1973; Mabbutt, 1968 and Wright, 1972).

An explanation of landscape and parametric approaches was made by Cooke (1977) who stated that "Landscape approaches to terrain classification are highly subjective and generally qualitative and place much emphasis on the interpretative skill of the aerial photograph analyst", while the parametric method "... is to analyse the distribution of selected (and preferably quantified) relevant variables and to combine the resulting patterns into composite generalisations". (p.197). In viewing the advantages as well as the disadvantages of the parametric approach given by Mitchell (1973) together with the advantages and disadvantages of the landscape approach used by Beckett and Webster (1976), it could be stated that the landscape approach to classification is the more acceptable from the geomorphological point of view. This may be because the parametric approach attempts to achieve a classification based purely upon quantitative measures of physical properties of the terrain surface in contrast to the landscape approach which incorporates not only measures of physical properties but attempts at understanding processes acting on the surface and genetic links between landscape surface.

As Cooke (1977) points out, the methods applied in desert terrain "... fall into one of two groups: geomorphological surveys with potential value in applied work, and resource surveys for specific purposes that include a geomorphological component." (p.189)

Making a choice between these two groups for the investigation and sampling of the terrain surface so as to elicit the required information is not easy. Both of them require aerial photographs and field checking and sampling, and both of them employ landform and sediment data as tools for their classification and inventory.

However, according to the work which has been done by interested groups and organisations, e.g. C.S.I.R.O., D.O.S.; MEXE and the joint group called MEXE-Oxford group,[2] and the individual workers in desert environments, it has been found that landform and landscape always plays an important part in terrain classification and evaluation. Thus, the importance of the landform types in any classification cannot be underrated. Their significance has been shown by many geomorphological researchers (e.g. Nakano et al, 1962; Worrall, 1974; Warnke, 1969; and Paterson, 1977). These methodologies are applied in terrain classification work concerned with land improvement. (Nakano, 1967; Linton, 1951; Wright, 1972; Goosen, 1962; Beckett and Webster, 1976 and Cooke, 1977).

Although, landform types are considered to be an important factor in the recognition of terrain facets, they are inseparable in practice from other terrain factors, e.g. climate and geology. For instance, the

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2) C.S.I.R.O.: The Division of Land and Regional Survey of the Commonwealth, Scientific and Industrial Research Organisation of Australia.

D.O.S.: The Land Sources Division of the Directorate of Overseas Surveys

M.E.X.E.: The Military Engineering Experimental Establishment, now changed to:

M.V.E.E.: The Military Vehicle Experimental Establishment.

impact of past and present climates of the desert can be discerned in the variability of its geology and geomorphology and one can distinguish, for example, between the mountainous deserts, the desert plains of the past, and the sandy or stony deserts of the younger sedimentary basins. Any such features in the study area must be identified and mapped and incorporated in the landform types. Verstappen (1967) stated that such maps should receive ample consideration, because the method affords a wide knowledge of landforms and the processes active at present and in the past, which, in turn, provides a more comprehensive classification of the terrain and also reveals the economic potentialities of the various distinguishable units.

Although "... description of the land-surface of an area and an explanation of the processes which have operated to produce it or which could change it ..." (Christian and Jennings, 1957, p.52) comprise the formal aspects of the geomorphology of deserts (see also, Clements, 1957); Western, 1972; Bofinger, 1974; Kobori Iwao, 1970; Sen 1966; Cooke and Warren, 1973) there are many other aspects concerned with interpretation of geomorphological features of an area in relation to the terrain factors, e.g. landforms, soils, vegetation and the use to which the land is put.

The latter aspect has been developed in many arid areas (Webster, 1963; Mitchell & Perrain, 1966). Arid areas in Australia and New Guinea, for instance, the

Alice Springs area of the Northern territory; the Georgina Poison area of the Northern territory and Queensland; and the Wiluna-Meekatharra area of Western Australia have been surveyed by C.S.I.R.O., (Perry et al, 1962; Mabbutt et al, 1963).

The method used for land classification by C.S.I.R.O. is summarised as follows:

i) Areas with distinctive patterns on aerial photographs are delineated. In the light of available information from other sources on the geology and topography, these areas form the bases of mapping units.

ii) A team of specialists spend several weeks or months in the field examining the landforms, soil, vegetation and land use associations at selected sites along traverses based on the preliminary mapping.

iii) The last stage consists of correcting the maps and data and amending them where necessary, followed by grouping the patterns into land systems.

The distribution of land systems are often shown on maps at a scale of 1:250,000 (and sometimes smaller scales to 1:1,000,000), and each land system is described in a conventional style in an accompanying memoir.

The land system description should include:

i) the title or the name of the land system;

ii) the area covered, and, written in one sentence, a description of the landscape;

iii) a short statement on the geology, geomorphology and the range of altitude of the area selected; and

iv) a block diagram showing (a) the form of the land,

(b) the underlying geology, (c) the location of the land units, indicated by small numbers within circles, and (d) a table describing the landforms, soils and vegetation in each unit.

The method employed by the joint group of MEXE (MEXE-Oxford Study or the Cambridge Study) has been tested to cover the whole climatic zone of the world's hot deserts. The regions considered in this study are the Sahara, the Kalahari, and the U.S., Australian and Middle East deserts. (Perrin and Mitchell, 1969)

This method defines a limited number of units and recurrent landscape patterns which finally record both detailed and general terrain information.

This method is summarised as follows (Hughes et al, 1965):

i) Information is given for the area selected which is physically inaccessible but covered by aerial photographs.

ii) Data provided on the climate, relief, geology, vegetation and land use of the area obtained either directly from aerial photographs or from other sources (maps, survey publications, scientific investigation, miscellaneous reports).

iii) Select analogous areas at accessible points are studied and a limited number of 'recurrent landscape patterns' made up of small units (or facets) recognised.

iv) Description and analysis of the operationally important characteristics of these patterns and facets follows as the next stage.

v) The findings about 'facets and patterns' is then extrapolated to the inaccessible area and operationally important characteristics can then be predicted.

4.4 METHODS USED IN THE PRESENT STUDY

The terrain classification of this study of al. Zubair desert and especially the field procedures shown later on in this section do not match for several reasons the land classification and the field procedures adopted by specialist organisations and establishments e.g. C.S.I.R.O. and MEXE..

Four major differences between the terrain classification adopted for the study area and those of the organisations and groups mentioned above are given below.

i) The surveys made by C.S.I.R.O. and MEXE were usually completed by a varied team of experienced specialists, whilst this work has been carried out by one geomorphologist.

ii) The necessary cooperation between the mapping team and other sources of information including government offices is often better developed and easier than it is for the individual operator. It is usually easier, for example, for the government mapping team to obtain additional information and access to restricted land areas than it is for the lone researcher.

iii) The equipment used in the field by government-sponsored teams tends to be more sophisticated than in the case of an individual studying on a more restricted budget.

iv) The facilities which these organisations and groups possess e.g. money spent on obtaining and analysing data, transport etc., are far greater than those available to the individual student.3)

Because of the foregoing restrictions some problems were encountered. Some essential information was found to be lacking e.g. the available aerial photographs are not up to date (1961), and some of them are of very poor quality. The only maps available are old.

The area of study itself is poorly accessible and this had repercussions on the sampling sites, many of which are near the main roads or tracks. Nevertheless particular care was taken to ensure than they were as representative as possible. The time available for the collection of data in the field was less than optimal. Obtaining a vehicle during field work was troublesome and very expensive, although some transport was kindly provided by the Directorate of agriculture in Basra city and University of Basra. However, use of this vehicle was limited to working hours (approximately from 8 a.m. to 3 p.m.) and it was not available for us on consecutive days.

Finally, soil samples for laboratory analysis had to be rigorously selected because of the cost and effort of transporting them from Iraq to Keele.

4.4.1 Sources of Information

Data from different sources concerning the climate,

3) The author has personally funded some stages of this research.

geology, geomorphology, soil, vegetation and land use, of the study area was collected as essential background information (see chapters 2 and 3).

Aerial photographs and their interpretation are an important part of any terrain classification exercise. These were the initial source for al.Zubair desert study and played an important part in the preliminary reconnaissance of the study area (1975-1976). During the first fieldwork period (1975-1976), two weeks were spent obtaining aerial photographs from the General Survey Directorate in Baghdad and the Iraqi Ministry of Higher Education and Scientific Research.[4)]

To facilitate the categorisations of the aerial survey of Iraq the Directorate have indexed the Iraqi map. The study area is located within what is called 'Iraq B'. One hundred and ten black and white aerial photographs were obtained from the General Survey of Baghdad for this area. They are of standard vertical (9" x 9") type, at a scale of 1:35,000. Owing to the relatively low cost, other black and white photo mosaics of the study area have been obtained from other sources (Table 4.1). These are at a scale of 1:1,000,000 and 7"x7" in size. Recently, a colour print at the scale of 1:1,000,000 has become available for study. Three wavelength bands of the Landsat images (5, 6 and 7) were also obtained for the purposes of comparison with other aerial photographic sources with a view to identification of the terrain features in the study area. (see also, Table 4.1).

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4) The cost of the aerial photographs was borne by the Ministry, to whom the photographs must be returned on completion of this work. Only those aerial photographs covering the southern part of the study area (the detailed study area) were reprinted.

Source	'Company Country'	Number Obtained	Scale	Date	Type	Price	Quality	Date Obtained
1. General Survey Directorate 'Baghdad'	KLM Netherlands	110	1:35,000	1961	Black & White	£582.40	Poor-Fair	1975
2. Fairey Survey Ltd.	U.K.	2	1:1,000,000	1963	Black & White	£9.74	Good	1976
3. ERTS 'Earth Resources Technology Satellite' (Landsat) MSS Band 7	U.S.A.	2	1:1,000,000	1973	Black & White	£5.00	Good	1976
4. Same Source ERTS (Landsat) Bands 5, 6 & 7	U.S.A.	1	1:1,000,000	1973	Black & White	£3.00	Good	1977
		1	1:1,000,000	1973	Black & White	£3.00	Good	1977
		1	1:250,000	1973	Black & White	£7.00	Poor	1977

TABLE 4.1: SOURCES OF AERIAL PHOTOGRAPHS

Although Iraq is covered by maps at a scale of 1:500,000, these are not available to the public (see appendix I) Two physiographic maps were obtained from the Map Library in the Department of Geography at the University of Keele at the scales of 1:500,000 (1936) and 1:1,000,000 (1945). Ground photographs were taken to aid the identification of terrain features in the study area. The size of these photographs is 15 x 10 cm. Similar photography can be found together with available aerial photographs and maps in reports published by C.S.I.R.O. and MEXE.

Ground photographs included here are used to help identify and thus illustrate terrain features initially gleaned from the aerial photographs and other sources.

4.4.2 Preparation

It has been suggested that in the early stages of any terrain classification exercise all available maps; aerial photographs and bibliographic sources should be consulted to obtain a broad picture of the natural features of the area in question before commencing any field work. (See, for example, Christian and Stewart, 1953 and Beckett, 1971, Stage 1, p.1) The available aerial photographs are examined using a stereoscope and mosaics made up (see, for example, Brink et al, 1966, p.4).

The available aerial photographs are arranged according to the scheme depicted below (Fig.4.1):

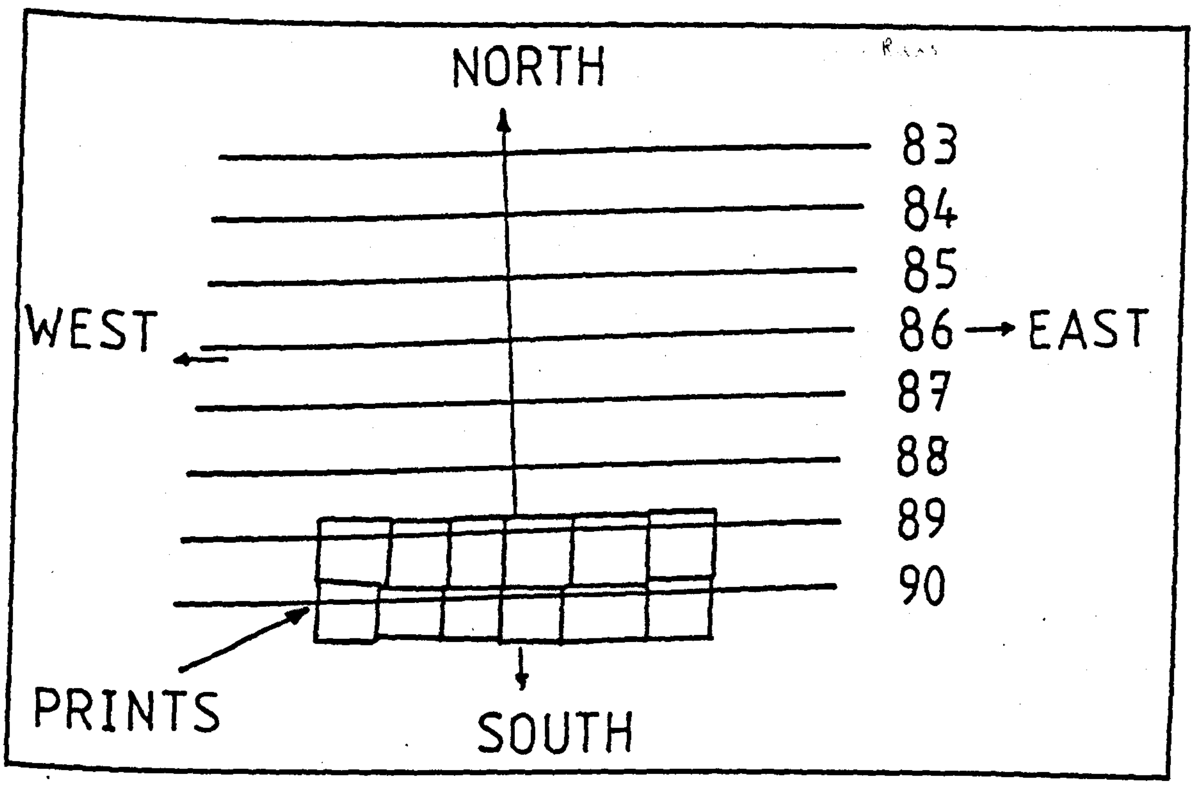

Fig.4.1: Schematic organisation of the available aerial photographs of the study area.

Many of these aerial photographs (prints) were omitted due to overlapping. (This process has been explained in the aerial photographic literature; see, for example, Carrol et al., 1977, pp.5-6)

Once the mosaic has been produced, the process of delineating landform types begins utilising all other sources of data at the same time. The amount of detail that can be recognised on aerial photographs depends largely upon the scale and quality of the photographic prints and the skill of the interpreter.

Boundaries were drawn on the mosaics delineating the landform types as recognised by tonal differences. Details of vegetation are not recognisable on these photographs because of the sparsity of vegetation and the scale of the analysis.

However, these visual landform types (features) are not sufficient to define either the terrain systems or the terrain facets; nor do they necessarily coincide with the extent of the terrain systems that are finally delineated (see, for example, stage 2 of Annex 'E', Beckett, 1971). According to Webster and Beckett (1969) "They are simply units between which tentative boundaries can be drawn, and from which sampling areas can be chosen in the next stage." (p.64) (see also stage 3, Annex 'E', Beckett, 1971). At this stage of the classification process the tentative landform features are distinguished on the basis of their surface form and by tonal changes on the photographs. It has been pointed out by Perrin and Mitchell (1969) that in order to confirm that they really exist and are capable of being recognised on the ground, it was necessary to carry out a final check by making field measurements in areas defined on the photographs as representing certain facets. It has to be accepted that a detailed study of the whole of al.Zubair desert is impossible. The alternatives are to choose accessible areas containing several contrasting landform types or features. Potential areas are located in a strip extending from the wadis west of Jabel Sanam in the west to the Khor.al.Zubair in the east.[5)] (see Figs. 4.2 and 4.28).

Lines of traverse for the purpose of field verification and checking were chosen from aerial photographs and coincided with roads and tracks which offer efficient and obvious means of access (Fig.4.2). Map data is considered subordinate to the more up-to-date photographic record.

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5) This area totals 419.25 km^2, the whole area being about 1593.15 km^2, i.e. the area of detailed study represents 26% of the total area.

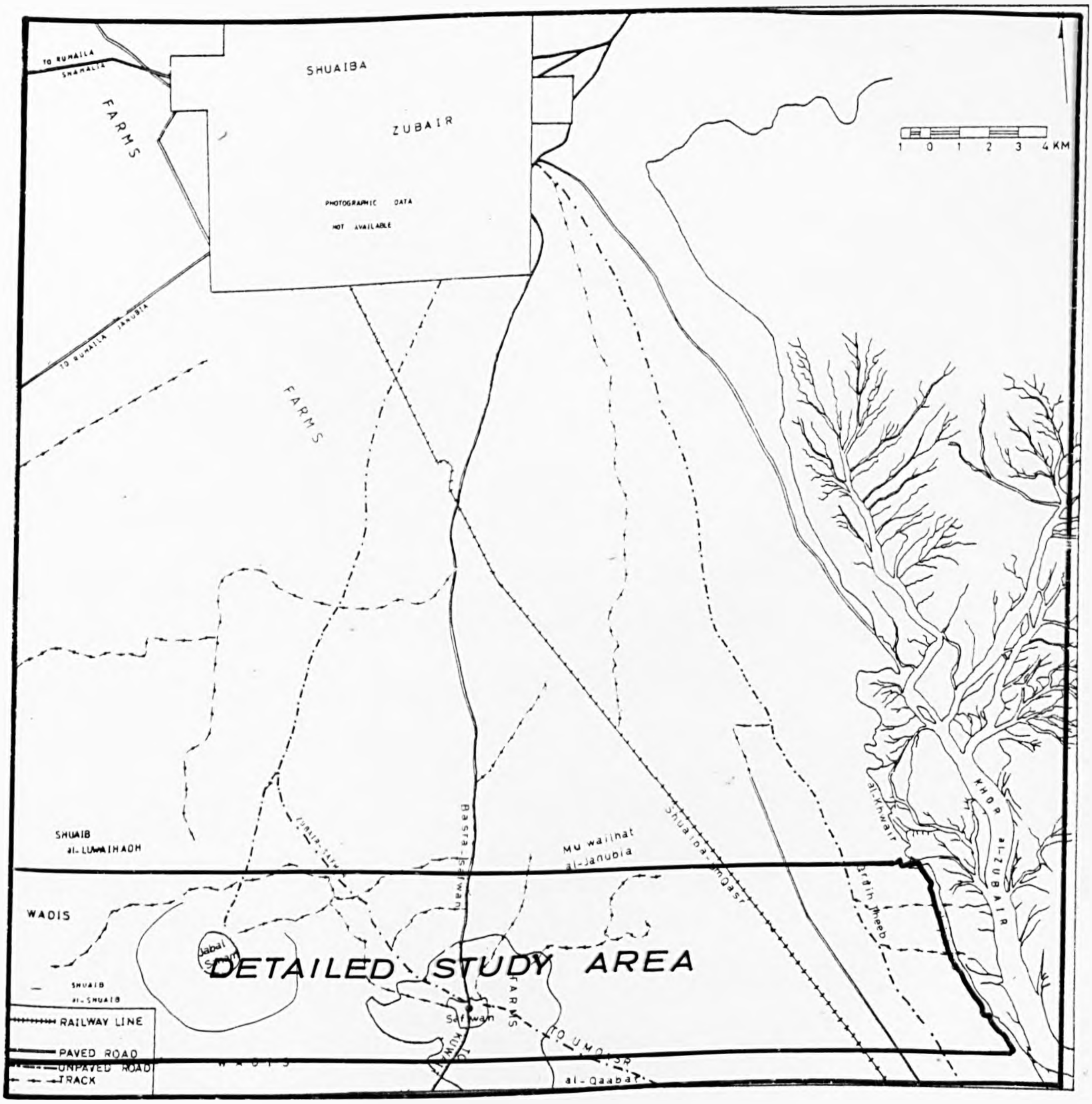
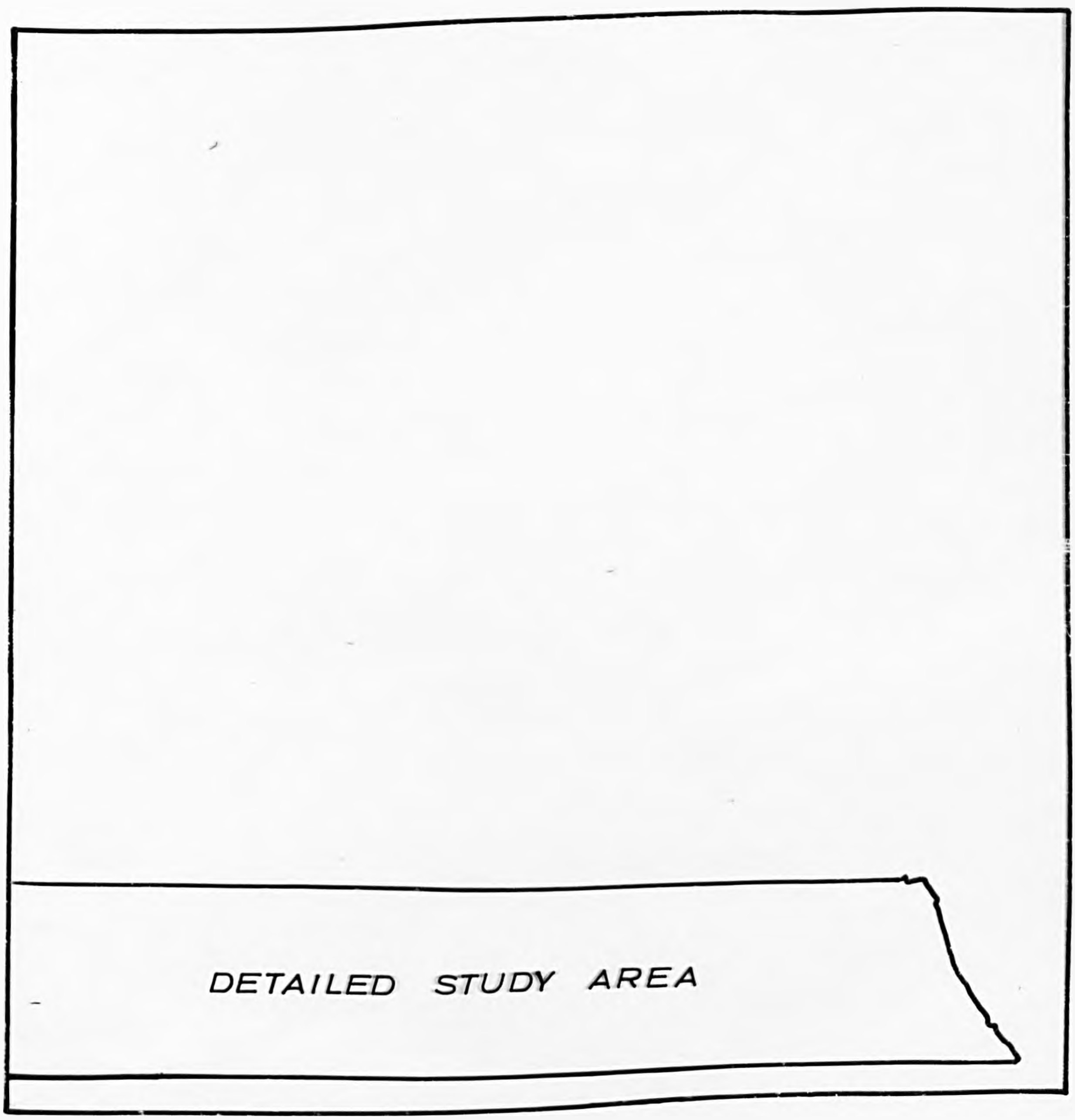


FIG. 4.2: ACCESS ROUTES FOR FIELD TRAVERSING AND SAMPLING.


DETAILED STUDY AREA

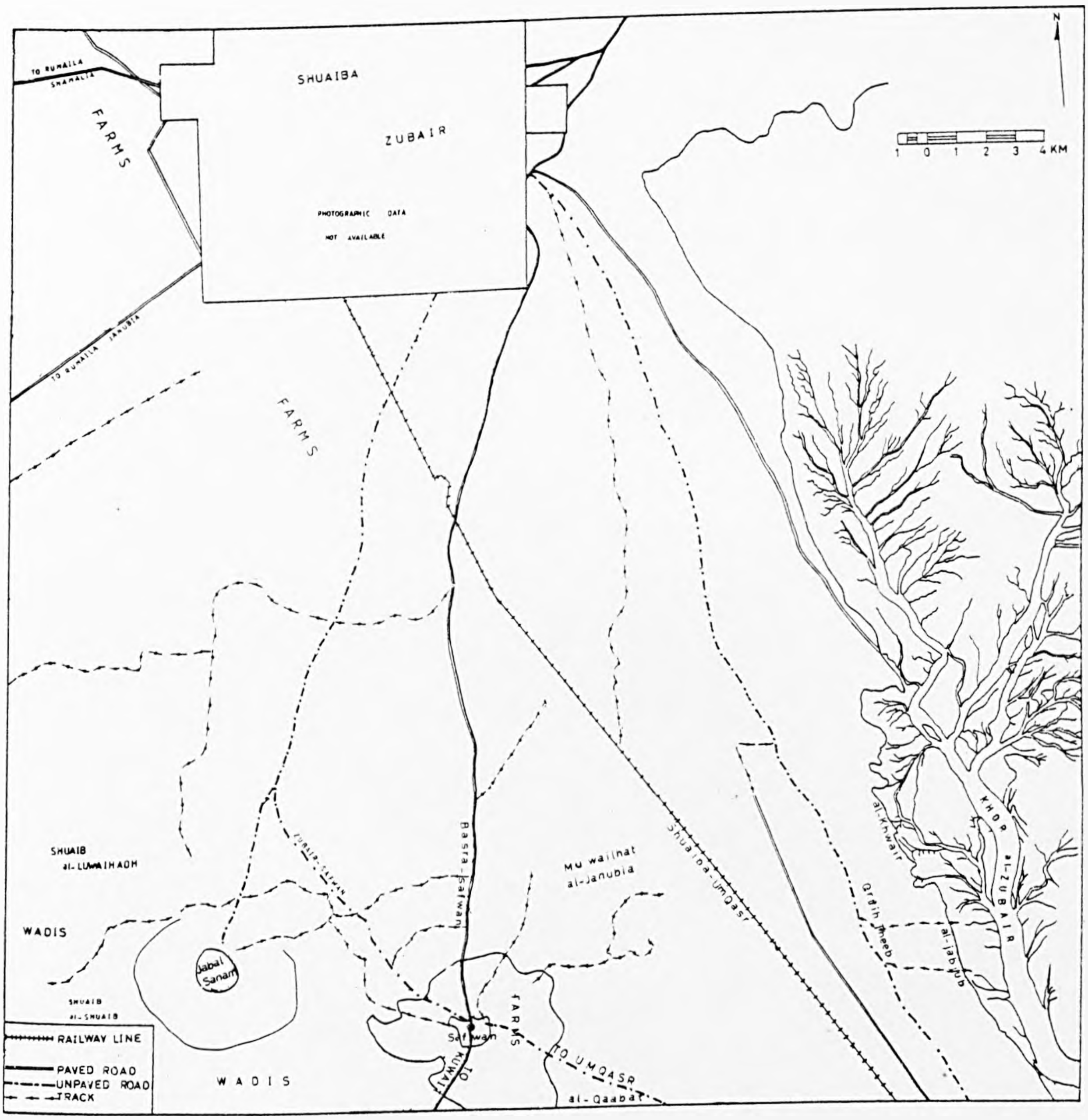


FIG. 4.2: ACCESS ROUTES FOR FIELD TRAVERSING AND SAMPLING.

Traverses were chosen so as to intersect the tentative landform type boundaries for the purpose of field appraisal.

4.4.3 Field procedure

In order to check the existence of the proposed land types and to make the field measurements, it was decided that at least two representative sites would be chosen within each landform type.

Certain limitations had to be accepted from the start. First, collection of extensive information for each site was found to be unduly time-consuming, e.g. vegetation measurements were restricted only to percentage cover, vegetation type and associations being based only upon the available literature. Second, the time restrictions of the field programme limited the number of observations to only 1-2 sites per day. Third, since the analysis had to be completed in the U.K., the equipment had to be as simple as possible, and easy to carry in the field under the hot conditions. Similar restrictions and limitations were encountered by Perrin and Mitchell (1969) during their expedition in Libya.

Measurements taken were of three types: slope profiling, soil sampling and vegetation cover sampling.

i) Slope profiles

It has been mentioned earlier in this chapter that the principal source of information was aerial photographs. The quantitative delimitation of slope classes on aerial photographs is impracticable for routine facet mapping in arid areas (see, for example, Perrin and Mitchell, 1969) such as the study area. The alternative is to go directly into the field. (Beckett, 1971).

The equipment used for slope measurements was simple and portable and yielded reasonably accurate results. It included the hand Abney level, 3 ranging rods, one measuring tape and 20 steel pins.

The area under study can be regarded as flat or slightly undulating. Tippetts (1957) for instance, stated that it is "... slightly undulating, and the overall slope throughout is less than one-half percent. The land will generally require only light levelling". (p.V.8) It is difficult to make a precise distinction between the terms 'flat' and 'slope' and because of this, recognition of slope angle classes varies. Parsons (1973), for instance, argued that "where slope angles have been recognised on the basis of significance with respect to some other variable, for example soil properties or land use, approximately seven classes have been recognised. Macgregor (1957), in a classification that relates slope angle to land use, recognised seven classes. Curtis et al (1965) recognised seven classes in a classification based upon previous work, mainly in soil survey and land classification. The FAO soil survey system used six slope angle classes. Young (1972) proposed seven classes but allowed for subdivision of the two end classes." (p.95) However, according to Wooldridge (1932), for practical purposes 'flat' relates to the more gently inclined surfaces, while 'slope' is the more steeply inclined. He left the precise distinction between 'flat' and 'slope' dependent upon the nature of the area concerned and the purpose for which the distinction is made.

Savigear (1965) stated that "A flat is a surface area which is horizontal or is inclined at an angle of less than two degrees", whereas, the "... surface area which is inclined at two or more, and less than forty degrees or more", is called 'a slope' (p.517). According to Savigear's distinction, the slope measurements of the study area have been taken where confirmation is needed of flatness or undulation. In addition, slope profiles have been taken at locations in order to prove the existence of the tentative landform types/elements of the study area. Numerous publications have mentioned slope profile terminology, e.g. Young (1963, 1964 a & b; 1971), Young and Young (1974), Savigear (1956 and 1967) and Parsons (1973).

The number of the slope profiles measured in the study area was determined by the time available and the significance of the slope characteristics. As recommended by Pitty (1967), Young et al (1974), Gerrard & Robinson (1971) and Young (1972), all measured lengths were taken between a minimum of 3m and a maximum of 15m. The unpaved road in the east of the study area has been taken as 'station A' in the profiles of the alluvial flat plain.[6] In the undulating area, the unpaved road was taken as the base point for some profiles, whilst for

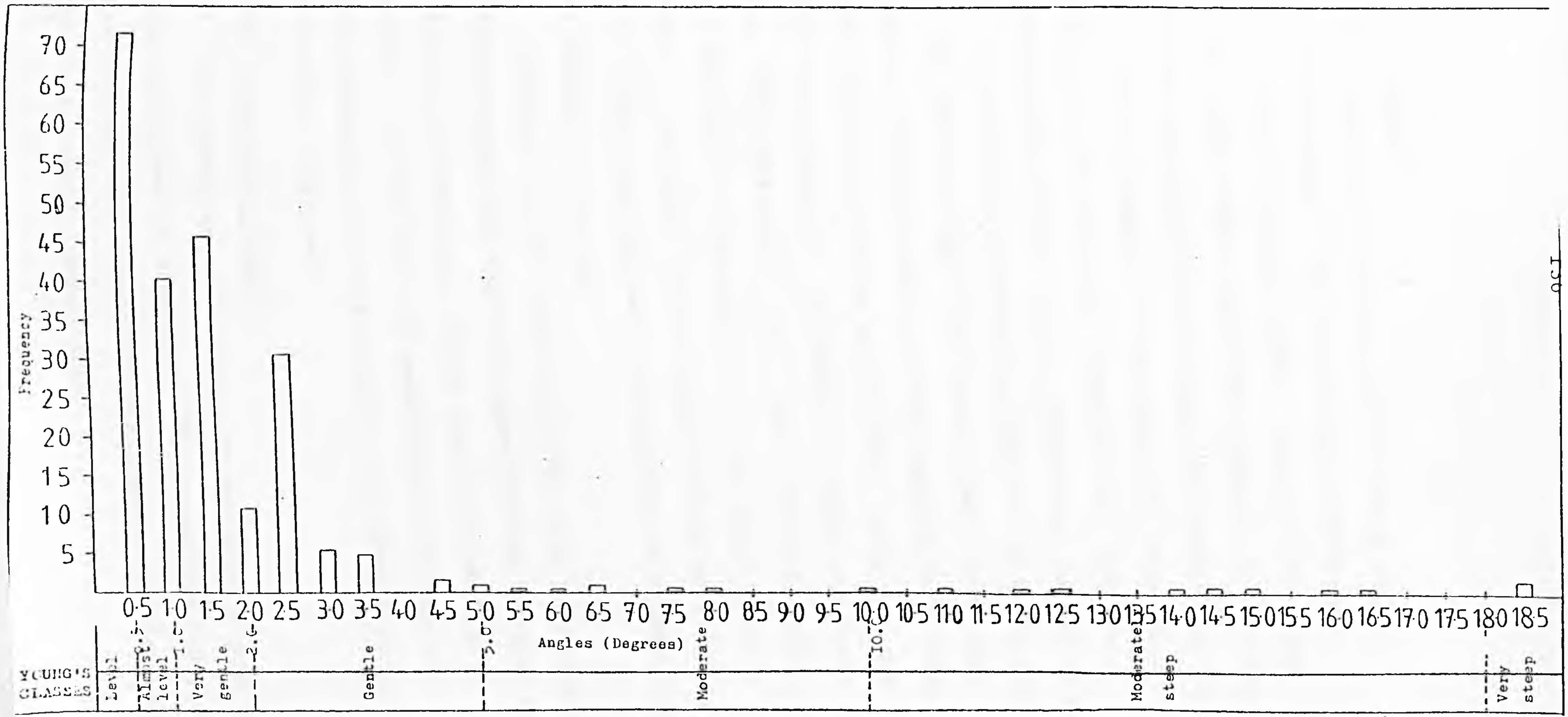
6) The term alluvial flat plain is used as an equivalent to the alluvial flood plain.

the remaining profiles there were no such features outstanding enough to use as the base point. In this case the adjoining area /exclusively flat/ was designated as the base point.

In all, 39 slope profiles were measured in the selected area (the detailed study area) (Appendix 2). Thirteen slope profiles represent the alluvial flat type (Appendix 2), whilst nine slope profiles represent the undulating landform type (Appendix 2). The variations in these slope angles are not significantly great. The majority of profiles have slope angles of less than 2 degrees. Profiles 25-30 represent the flat landform type of al.Dibdibba area (Appendix 2). They have been taken to confirm the flatness of this type. On this flat area there are some man-made features (near the farms). Slope profile sites of these features were measured and called ' man-made or altered slope profiles'. Profiles 31-42 of the dissected area are representative of the landform types/elements of Sanam Plateau; wadis and gully side slopes (Appendix 2).

Slope analysis and frequency distributions were investigated as explained by Strahler (1950; 1956) and the frequency distribution of angles is also shown in the form of histograms (Chorley, 1966). The slope profiles of each landform type/element were sampled to form a frequency distribution of angles. The frequency and classes of slope angles for the detailed study area is shown in figure 4.3.

FIG. 4.3: Frequencies and classes of slope angles for the detailed study area.



ii) Soil samples

Soil sampling was carried out according to soil sampling procedures to be found in the literature. (see, for example, Cornwall, 1966). Samples were taken along the access road and tracks shown in figure 4.2. It is to be expected that the task of identifying and classifying the terrain facets/elements is facilitated by information derived from soil analysis. Despite time, cost and transport difficulties, 9 - 12 samples were collected from each of the tentative terrain systems of the study area.

The depths at which soil samples were taken vary. During the second fieldwork season, samples were taken at depths of 0-15cm, 15-30cm and 30-45cm. Later on, and after consultation, it was decided to extend the depth to 60cm. Thus samples of 0-15 , 15-30, 30-45 and 45-60 cms were collected for each profile in the final field season.. The weight of each sample had to be small (½ to 1 kilogram) because of the problem of transporting the samples to the U.K.

Pebbles were also sampled in the field to determine dominant shapes and degree of edge rounding, samples being taken on a random basis within each landform type or element. A total of 1,475 pebbles were selected for axial measurements using calipers, the results being presented in Chapter 5.

iii) Vegetation cover

The common vegetation species and associations have been summarised in Chapter 3. The search for individual species and their identification presents difficulties when using aerial photographs. Satyanarayan and

Dhruvanarayan (1968) state that only the broad vegetation cover can be thus distinguished. Thus in order to check accurately one must subsequently return to the field to carry out spot-checks on vegetation. (Ward et al,1971).

There is, unfortunately, no literature which gives the precise percentage coverage of the plant communities of the study area. Botanists have provided only general descriptions and distributions of the plant communities of the whole of the Iraqi desert. As a consequence, our knowledge of vegetation species and its percentage cover remains scanty and limited.

It was not possible to calculate the percentage cover of each plant species separately. There are several reasons for this, namely inaccessibility, the scattered nature of most species, shortage of time and limited botanical experience. The enormity of the problem is perhaps expressed for instance by Hanwell and Newson (1973), when they say that "... it would take a lifetime to plot the various grasses and herbs established on the average lawn!" (p.99). However, an attempt has been made to calculate the percentage cover of all species within selected sites in the study area. The percentage cover measurements have been designed to prove the relationship between the vegetation and terrain features of the study area, and at the same time to show the existence of the landform types and elements determined from aerial photographs.

The method used to measure the percentage cover of a randomly selected sample of vegetation is called quadrat recording and is illustrated in the work of such authors as Kershaw (1964), Brown (1954) and Gregory and Walling (1973).

This method involves taking suitable quadrat frames ($25m^2$ in this study), and dividing each side into 5 parts making a total of 25 squares as shown in figure 4.4. The percentage cover of vegetation occurring in each square is then estimated, the total percentage of the sample being:

$$T\% = \frac{\text{Total percentage}}{\text{Number of Squares}}$$

A total of 120 samples were measured within the detailed study area (Appendix 3). The results of the percentage cover measurements are listed in tables in Appendix 3, and the percentage cover frequency distribution is shown in the form of a histogram (Fig.4.5). According to these results, and due to sparsity of plant cover, five classes have been derived. These are as follows:

0-20 percent	very sparse vegetation
20-40 percent	sparse vegetation
40-60 percent	moderate vegetation
60-80 percent	dense vegetation
80-100 percent	very dense vegetation

Taking the tables separately, it can be seen that the sparsity of the vegetation cover varies quite distinctly from one landform type or element to another.

Generally, the sparsity of cover increases from those sites which represent the alluvial flood plain landform types to those representing the undulating landform types. Vegetation cover is also increasingly sparse from those in the Safwan sites to those in the undulating area. In dissected areas more vegetation cover exists on the wadi

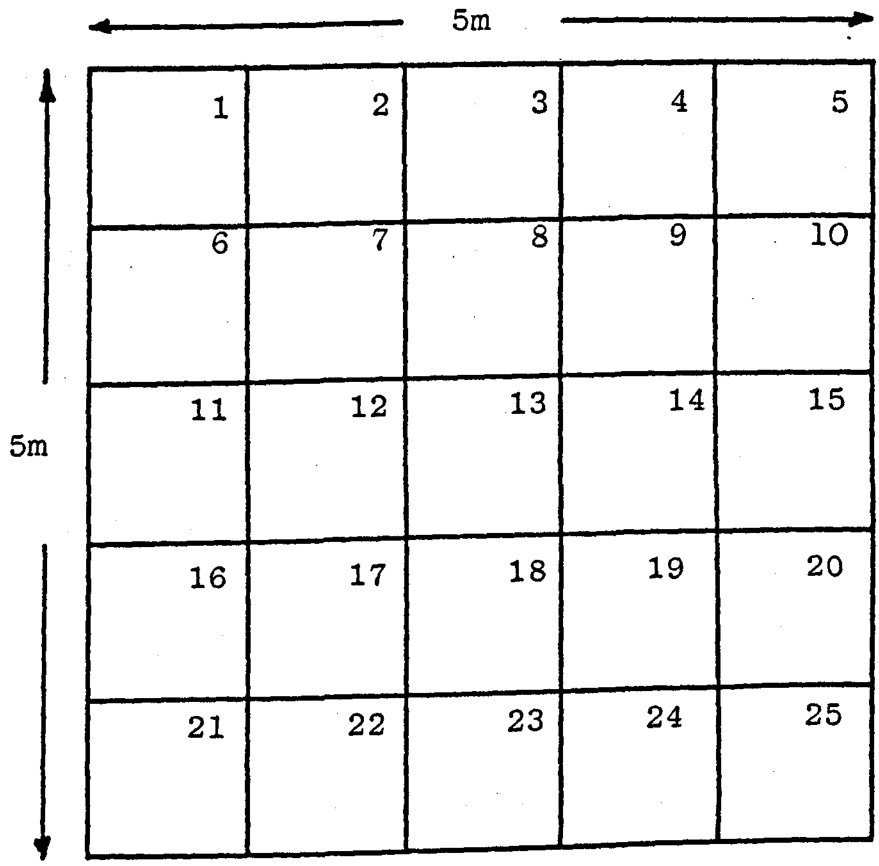


FIG. 4.4: QUADRAT SIZE AND SUBDIVISION

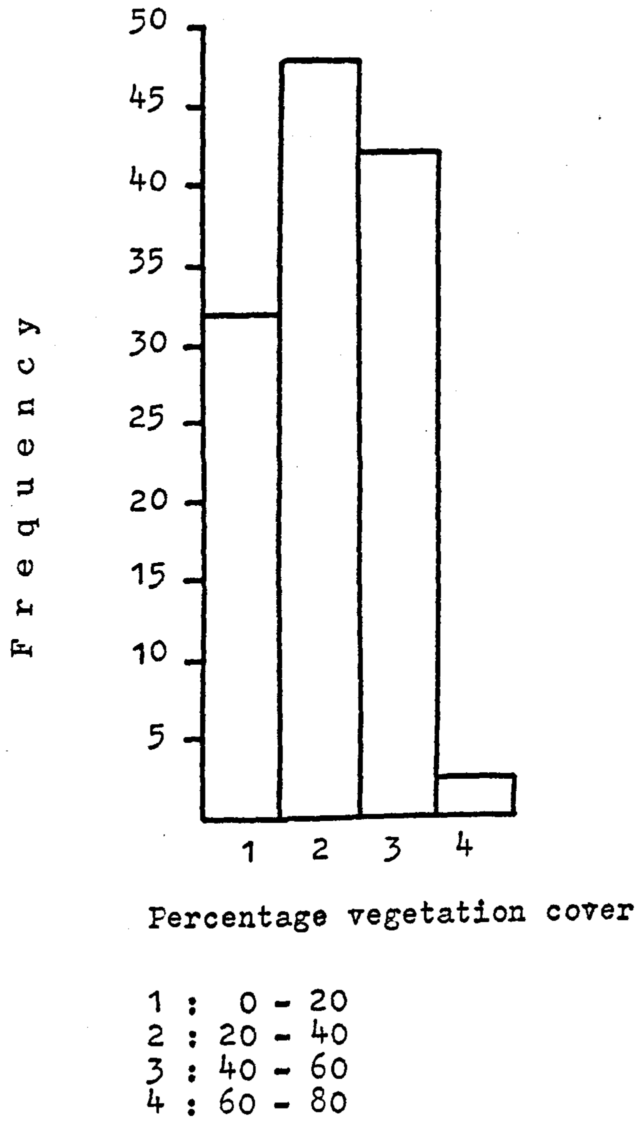


FIG. 4.5: FREQUENCY OF PERCENTAGE VEGETATION COVER OF THE STUDY AREA

slopes than on the wadi floors.

The analysis of the variation of percentage cover for those selected sites shows the existence of landform facets as reviewed and explained in the following section.

4.5 DELIMITATION OF THE TERRAIN SYSTEMS AND FACETS

The means of recognising the facets or units may vary from place to place. We may define a terrain facet by its water regime; for instance, when the water table is usually high, and the terrain is liable to annual floods. We may also recognise it by noting the ecological and cultural responses to the water regime (Beckett & Webster, 1976). However, such definitive characteristics must either themselves be easily recognised or be closely related to features of relief, land use or vegetation, which can be fairly easily recognised. This type of terrain facet recognition is regarded as qualitative recognition. Traditionally, recognising the terrain facets qualitatively is not satisfactory, so, terrain units and facets must be defined on the basis of their intrinsic properties (quantitatively).

Quantitative determination of these facets is based on field measurements. Such identification needs extensive sampling which is often expensive and optimal intensities of sampling are rarely attained.

The simplest compromise assumes that if the facets are recognised from aerial photographs (with the aid of other data, e.g. maps), recognition then requires information from only a few sites (see, for example, Beckett, 1971) The facets of the study area have been determined by using this simple procedure explained above. The landform types and features were established using aerial photographs and then subjected to ground checking before they could be considered as a basis for field measurements. These measurements effectively delimit the terrain facet system characteristics of the sample area.

At this stage, it is important to answer the following question: What is the distribution of the facets in the detailed study area and how are they related to each other?

Generally speaking there are two main terrain units. The larger unit is the 'terrain system' and the smaller is the 'terrain facet'.

The occurrence of such a hierarchy in the classification of the study area may be explained as follows. It is evident from the geological background information that there are two geological formations underlying the study area. These are the alluvium formation (Recent and Pleistocene) and Dibdibba formation (Miocene: Fig.3.2, Chapter 3). The largest units 'terrain systems', could be recognised according to these formations, but since the purpose of the classification is related to the land use of the study area, it is preferable to sub-divide the Dibdibba formation into three geomorphological areas. Thus proposed, the terrain systems of the study area are as follows: Khor al.Zubair; Muwailhat al.Janubiya system; Safwam system and Sanam system.

Each system is made up of a group of facets, each of these, in turn, containing elements. The facets were recognised from the landform types identified on the aerial photographs. In the field the landform types, i.e. hills, wadis, gullies etc., were divided into elements e.g. hill slope surface and base of hill slope; wadi slope surface and wadi floor ... etc. The systems and facets of the study area are listed in table 4.2.

To answer the question posed above, field checking and some field measurement (see section 4.4.3) was completed within the facet sub-divisions in the selected area (known as the detailed study area, Figs.4.2 & 4.28). Field checking included viewing the configuration of the terrain, estimating vegetation cover, recording soil colour and assessing water regime. It is clear that the elevation increases from the Khor al.Zubair area where facet 1 is nearly level, towards facet 2 (in the same area; Appendix 2 and Fig.4.3) which in turn forms a transition facet between the Khor al.Zubair system and the Muwailhat system (Fig.4.20). The vegetation percentage cover coincides with this transition (Figs. 4.6 and 4.7). There is no doubt that the existence of facet 1 near Khor al.Zubair makes this facet more liable to flooding and explains its higher water-table in comparison to the other facet which is near to al.Dibdibba area. The higher water-table and occasional flooding maintain a denser vegetation cover. At the same time, the high water-table and the seasonal flooding give the soil surface of the Subakhs a distinctive colour. It also causes salts to form on the surface. The salt appears on the aerial photographs as white spots whilst the

Facet	Name	Slope	Percentage Vegetation Cover	Soil Sample No.
1 a	al.Jabjub	profiles 1, 2 & 3	sites: 1 & 2 3 samples show 20-40 percent 5 samples show 40-60 percent	profiles: 1; 2 & 21
b	Graih al.Theeb al.Janubi	profiles: 4,5 & 6	sites: 3 & 4 4 samples show 20-40 percent 4 samples show 40-60 percent	profiles: 22, 27 & 28
c	Graih al.Theeb	profiles 7, 8 & 9	sites: 5 & 6 3 samples show 20-40 percent 5 samples show 40-60 percent	profiles: 23, 25 & 26
2	Graih al.Theeb al.Shamali	profiles: 7, 8 & 9	sites: 7 & 8 7 samples show 0-20 percent 1 sample shows 20-40 percent	profile: 3

TABLE 4.2 KHOR al.ZUBAIR TERRAIN SYSTEM: FACETS AND MEASUREMENTS TAKEN

Table 4.2 continued/

Facet	Name	Slope	Percentage Vegetation Cover	Soil Sample No.
3	Brej	profiles: 14, 15 & 17	site 10: slope surface element 4 samples show 0-20 percent site 9: base of slope element 3 samples show 20-40 percent 1 sample shows 40-60 percent sites: 11 & 12: flat element 4 samples show 20-40 percent 4 samples show 40-60 percent	profiles: 14: slope surface 19: base of slope 24: flat
4	Muwailhat	profiles: 16, 18 & 21 profiles: 19,20,22,23 & 24 are artificial slopes. They are included for the sake of the inventory and not for the facets recognition purpose.	site 14: slope surface element 4 samples show 0-20 percent site 13: base of slope element 3 samples show 20-40 percent 1 sample shows 40-60 percent sites 15 & 16: flat element 4 samples show 20-40 percent 4 samples show 40-60 percent	profiles: 7: slope surface 16: base of slope 15: flat

TABLE 4.2: MUWAILHAT al.JANUBIYA TERRAIN SYSTEM: FACETS AND MEASUREMENTS TAKEN

Table 4.2 continued/

Facet	Name	Slope	Percentage Vegetation Cover	Soil Sample No
5	al.Quabat	profile: 25	site: 17 4 samples show 40-60 percent	profiles: 9 & 6
6	Safwan-East	profile: 27	site: 18 4 samples show 20-40 percent	profile: 8
7	Safwan-North	profile: 26	site: 19 1 sample shows 20-40 percent 3 samples show 40-60 percent	profile: 13
8	al.Jufin	profile: 28	site: 20 4 samples show 40-60 percent	profiles: 12 & 37
9	Safwan	profiles: 29 & 30	site: 21 4 samples show 40-60 percent	profiles: 5a & 5b

TABLE 4.2: SAFWAN TERRAIN SYSTEM: FACET AND MEASUREMENTS TAKEN

Table 4.2 continued/

Facets	Name	Slope	Percentage Vegetation Cover	Soil Sample No.
11	Plateau of Sanam	profiles: 31, 32 & 33	site: 22 1 sample shows 0-20 percent 3 samples show 20-40 percent site: 23 4 samples show 20-40 percent	profiles: 18, 31, 32 & 33
12	Gullies of Sanam	profiles: 40, 41 & 42	site: 24: slope surface element 4 samples show 0-20 percent site: 25: Gully floor element 4 samples show 20-40 percent	profiles: 20: slope surface 17: floor
13	Wadis	profiles: 34, 35 36, 37, 38 & 39	sites: 26,27 & 28: wadi slope surface 12 samples show 0-20 percent sites: 29,30 & 31: wadi floor element 7 samples show 40-60 percent 5 samples show 20-40 percent	profiles: 29) 34)- 35) wadi slope surface profiles: 11) 10)_ 30)⁻ 36) wadi floor

TABLE 4.2: SANAM TERRAIN SYSTEM: FACETS AND MEASUREMENTS TAKEN

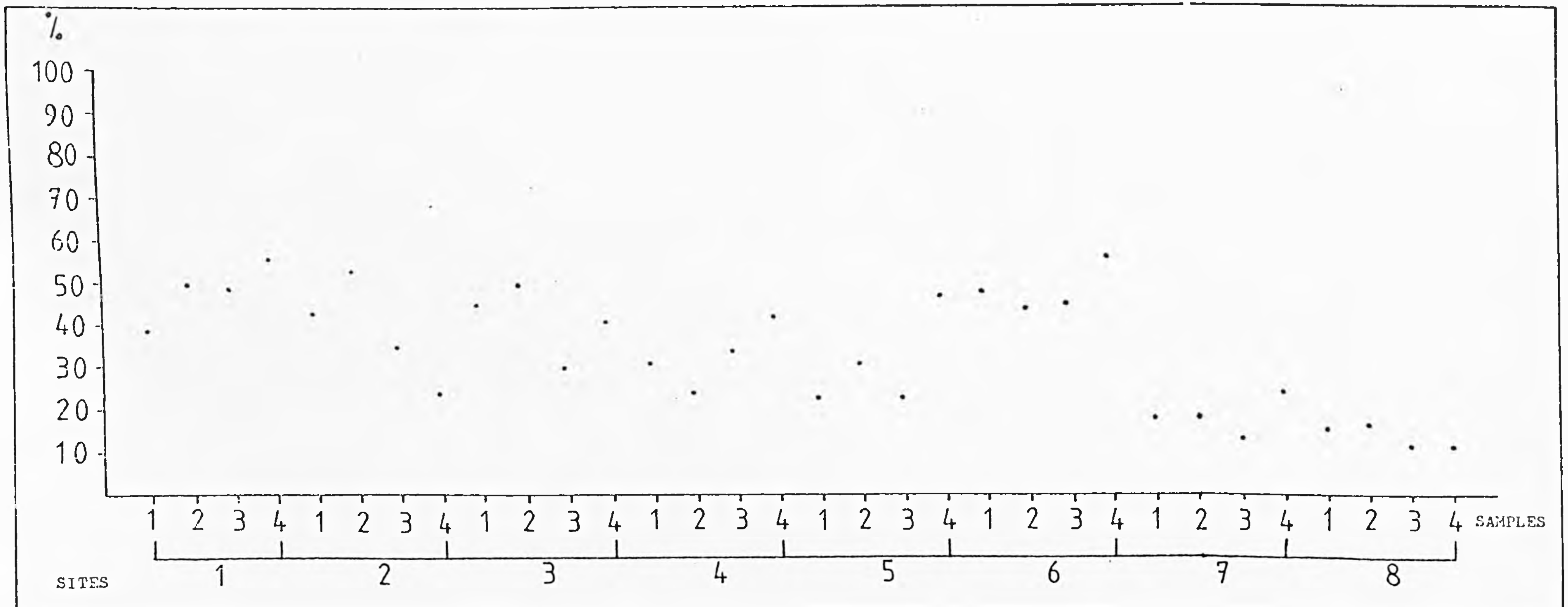


Fig. 4.6: Total percentage vegetation cover of all species of facet I (sites I-6) and facet 2 (sites 7-8) of Khor al.Zubair system.

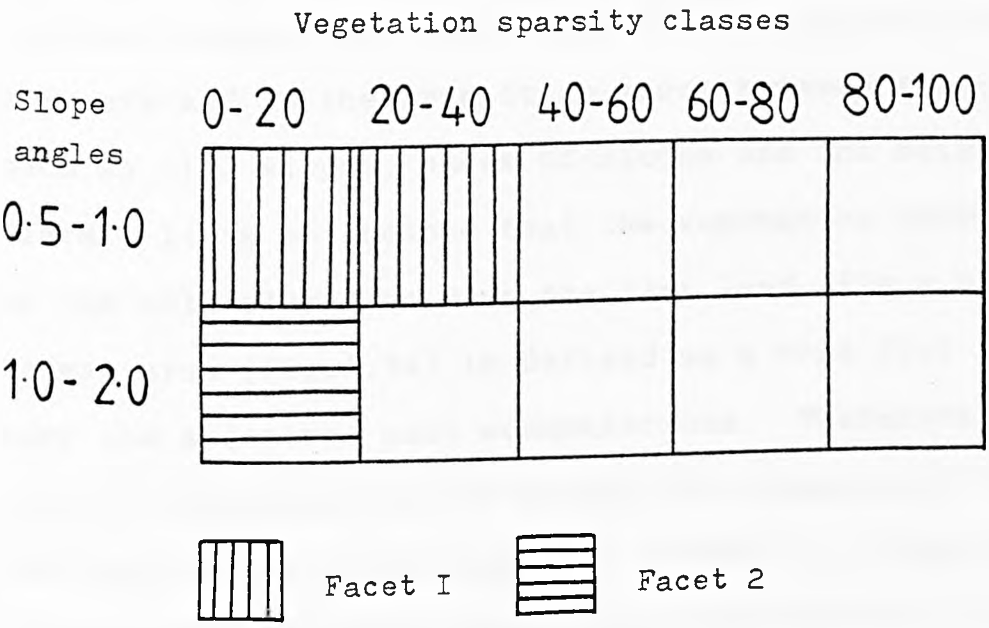


FIG: 4.7: A comparison of facets I&2 within Khor al.Zubair terrain system based on slope &vegetation sparsity classes.

Subakh has a dull grey colour. The facets within the Muwailha terrain system (Fig.4.22) occur throughout the terrain elements and in the transition zones between these elements, such as hill slopes, bases of slopes and the neighbouring flats. It is noticeable that the vegetation cover is sparser on the hill slopes than on the flat land.(Fig.4.9) The Safwan area (Fig.4.24) is defined as a vast flat area with very low scattered sand accumulations. Therefore, this area is recognised as one system. For simplicity this area has been divided into five facets. A large portion of this area is under agricultural utilisation. It is very easy to distinguish between this area and the Sanam area which is located to the west of it (Fig. 4.26). The latter appears as a dissected area where Jabel Sanam and its plateau are separated from the Safwan area by some wadis (see, for example, the ground photograph of the facet 8).

The Sanam area (Fig.4.26; the dissected area) reveals three distinctive facets. These were identified on the aerial photographs and checked in the field. They are the Sanam plateau, the gullies and the wadis. It was difficult to identify the gullies and wadi elements on the aerial photographs (gully or wadi slope and gullies or wadi floors) whilst in the field these elements were very easily recognised. The wadis appear broad with gentle slopes. Vegetation cover looks sparser on the gully/wadi slope surface but it becomes dense on the gully/wadi floors. Soil colour on the slope is usually a yellow orange whereas on the floor it is a dull orange. Because of the general aridity, water courses are ephemeral.

Field measurements clearly showed the occurrence of the facets within each terrain system in the study area. Within the Khor al.Zubair terrain system, the measured slope angles of facet 1 show they are almost of the level class whilst the slope angles of facet 2 show very gentle slopes (Appendix 3 and Fig. 4.3).

Dealing with percentage vegetation cover, facet 1 shows almost moderate cover (see Fig.4.6, sites 1-6) whereas the figure shows very sparse vegetation cover for facet 2 (Fig. 4.6, sites 7 and 8, see also Appendix 4 for both facets) The presence of facet 1 and facet 2 can be demonstrated in figure 4.7, which shows the difference between them on the basis of slope angles and percentage vegetation cover. The occurrence of these facets can be also demonstrated on the basis of soil texture (clay-silt and sand contents). Clay content is very low in most of the samples from facet 1 (seven samples against one sample), sand being the most predominant grain size component of all samples. In facet 2 the case is different for here the clay and silt percentages are approximately equal (Fig. 4.8 a & b). Appendix 2 and figure 4.3 show that facet 3 and 4 of the Muwailhat system are homogenous on the basis of their hill slope elements. Figure 4.9 presents a comparison between the vegetation percentage classes (see Appendix 3 , and Fig. 4.10), the hill slope, hill base slope and flat elements of facets 3 and 4. Figure 4.10 reveals the similarity of these elements on the one hand and the existence of facet 3 and 4 throughout their elements on the other. Figure 4.11 also shows the homogenity and occurrence of facets 3 and 4 within the Muwailhat al.Janubiya terrain system. The homogentiy of these facets

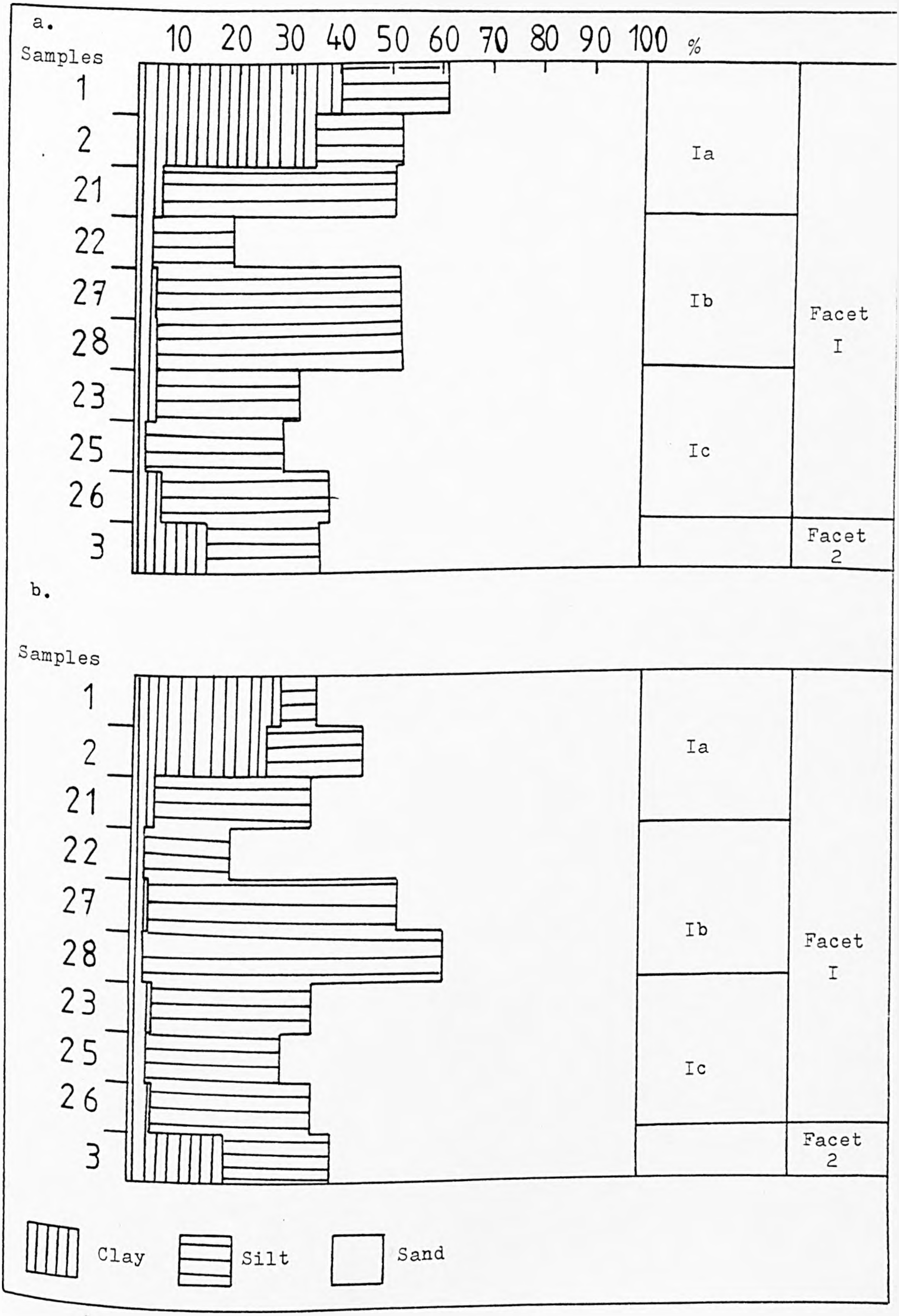


FIG. 4.8: A comparison of facets I& 2 within Khor al.Zubair terrain system based on soil texture(clay-silt-sand)at depths: a:0-15 b:15-30

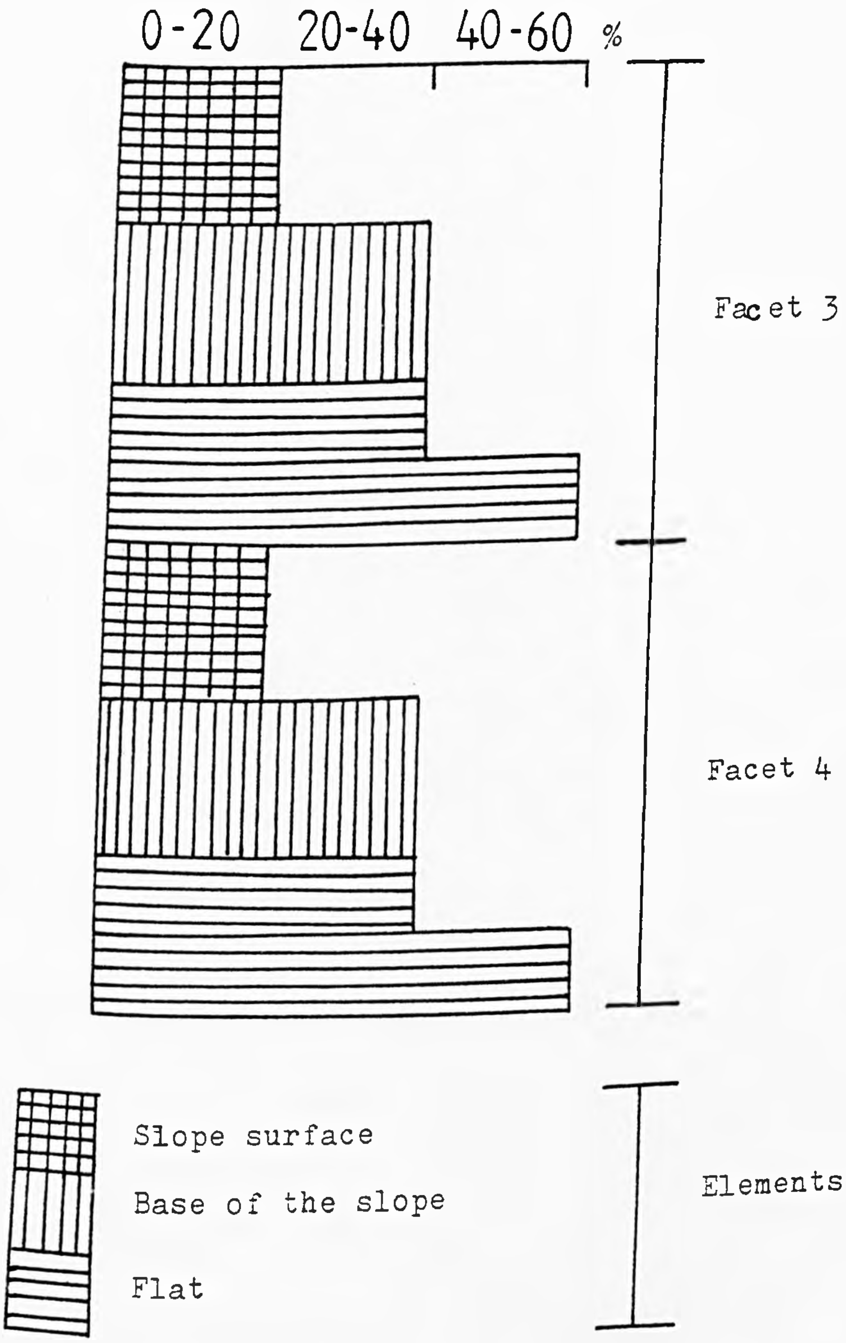


FIG.4.9: A comparison of facets 3&4 within Muwailhat al.Janubiya terrain system based on slope & vegetation sparsity classes.

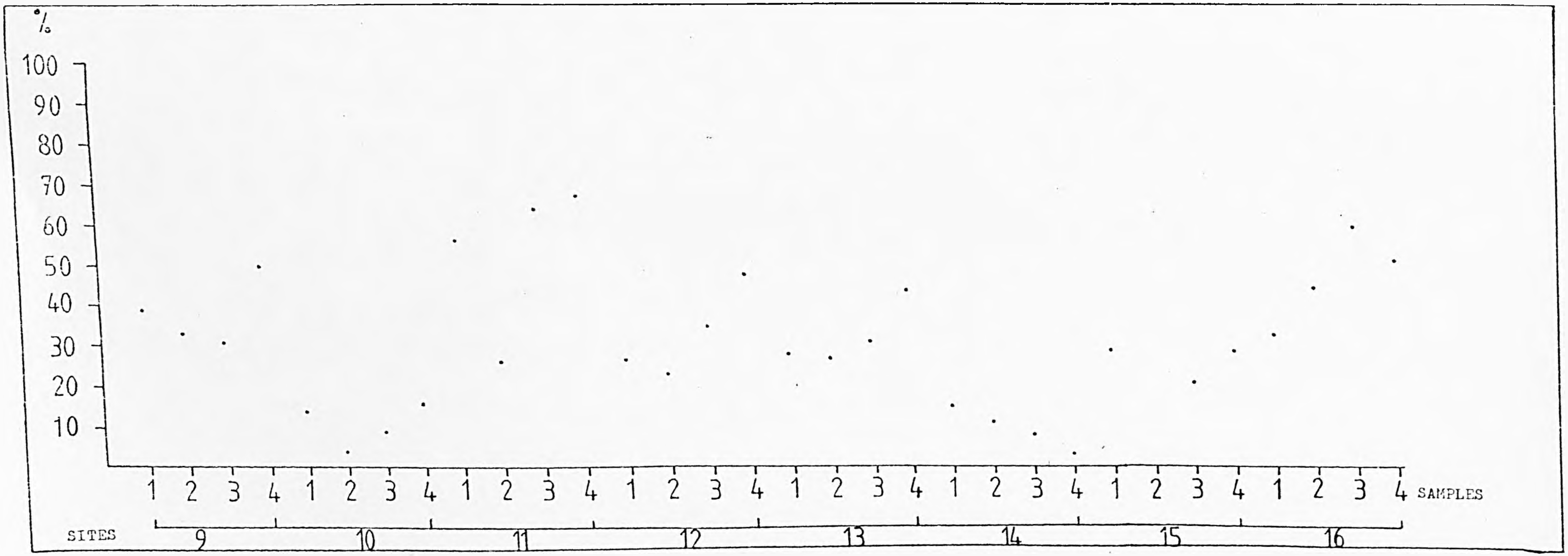


FIG. 4.10: Total percentage vegetation cover of all species of facet 3 (sites 9-12) and facet 4 (sites 13-16) of Muwailhat al. Janubiya system.

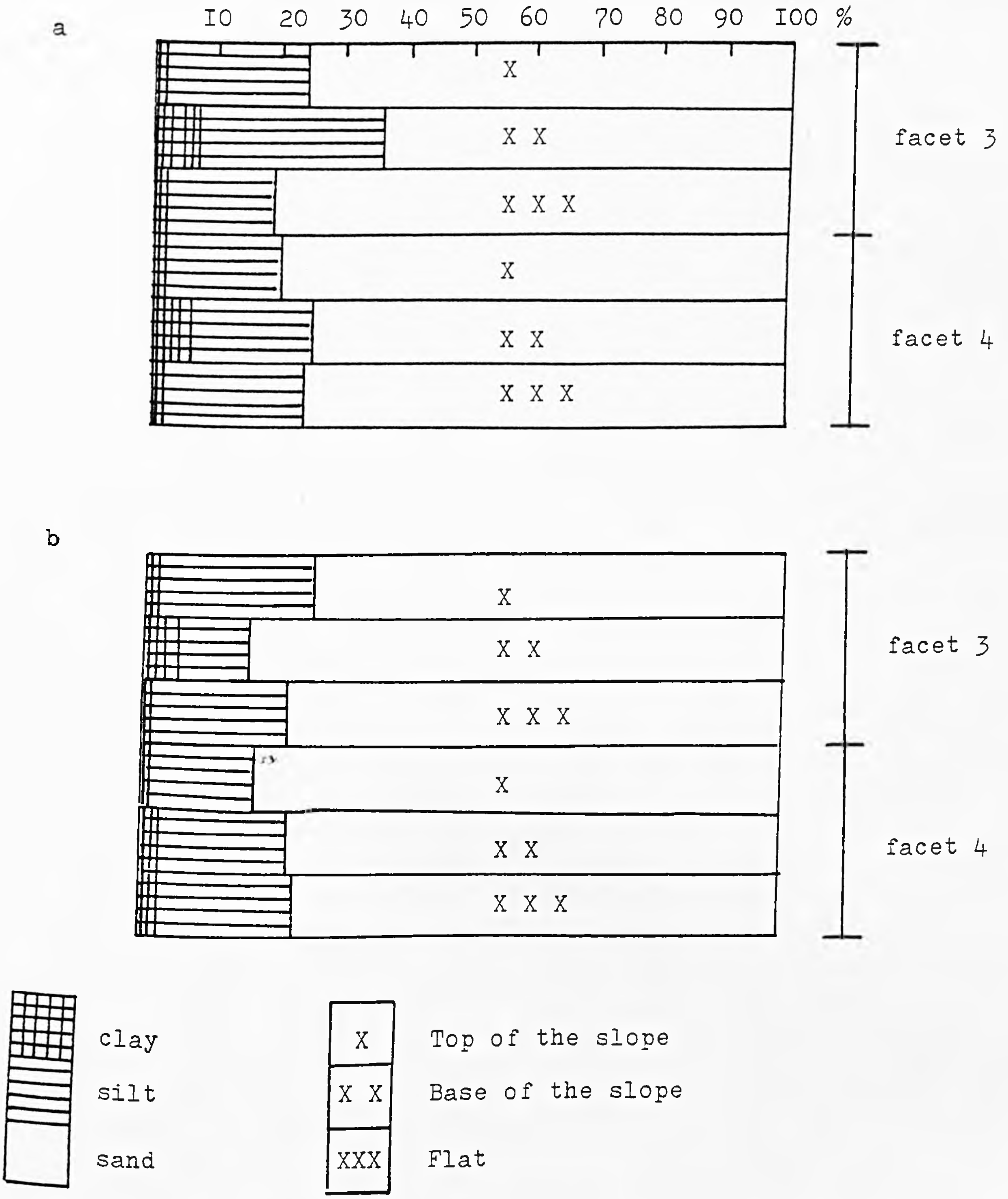


FIG. 4.11: A comparison of facet 3&4 of Muwailhat al.Janubiya terrain system on the basis of soil texture (clay,silt & sand) at depths : a. 0-I5 cm
b. I5-30 cm

is shown in figure 4.11a and b, based on soil texture (clay-silt and sand contents), for 0-15cm and 15-30cm depths.

Figure 4.3 (see also, Appendix 2) shows that the slopes of all facets making up the Safwan system possess very gentle slopes except facet 7 which has slopes in the "level class. The vegetation percentage classes (Appendix 3 and Fig.4.12), reveal that almost all the facets have a moderate vegetation cover. A comparison of the slope angles of these facets with the vegetation percentage classes reveals that all of them are homogenous except facet 6 which shows a sparse vegetation cover, but in its slope angles and soil texture shows similarity with the other facets of this system (see Fig.4.13).

Figure 4.14a and b also shows a similarity in all the facets of the Safwan system on the basis of soil texture. All the samples of the facets 5, 6, 7, 8, and 9, yield 69-79% sand content with the remaining percentages being those for clay and silt.

Appendix 2 and figure 4.3 show the slope angles of the Sanam plateau: slopes are moderate to gentle. The percentage vegetation cover measurements over this facet show that the vegetation percentage is sparse to very sparse (seven samples with 20-40% cover and one sample with a cover of 0-20%; Appendix 3 and Fig.4.15). The occurrence of this facet can be demonstrated on the basis of these slope angles and the percentage vegetation cover as shown in figure 4.16. The occurrence of these facets can also be demonstrated on the basis of soil texture (Fig.4.17). The slope angles of the gully slopes show that they are moderately steep (Appendix 2 and Fig.4.3). Percentage vegetation cover over the gully

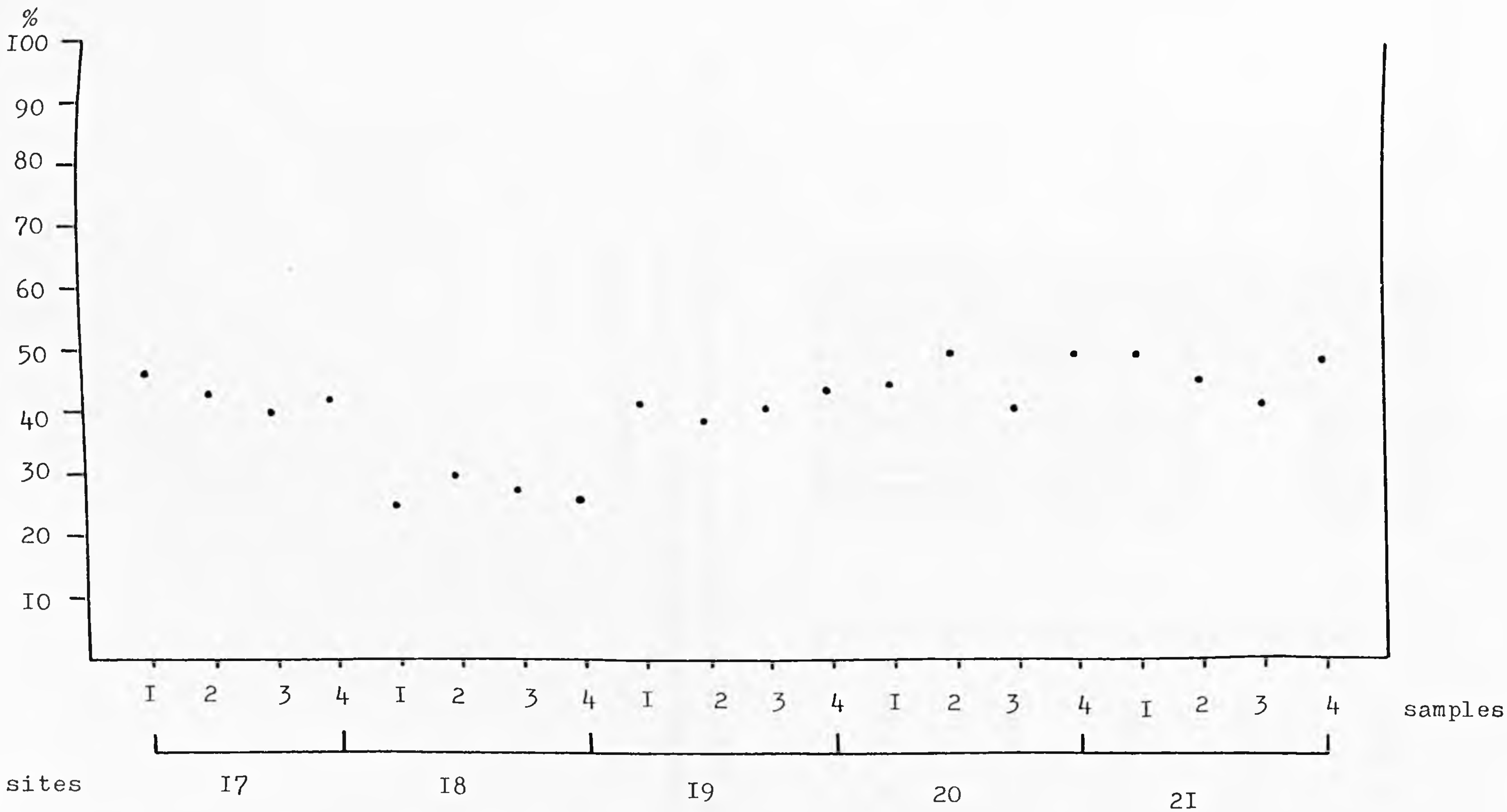


FIG.4.12:Total percentage vegetation cover of all species of facet 5 (site I7); facet 6 (site I8); facet 7 (site I9); facet 8 (site 20) and facet 9 (site 2I) of Safwan terrain system.

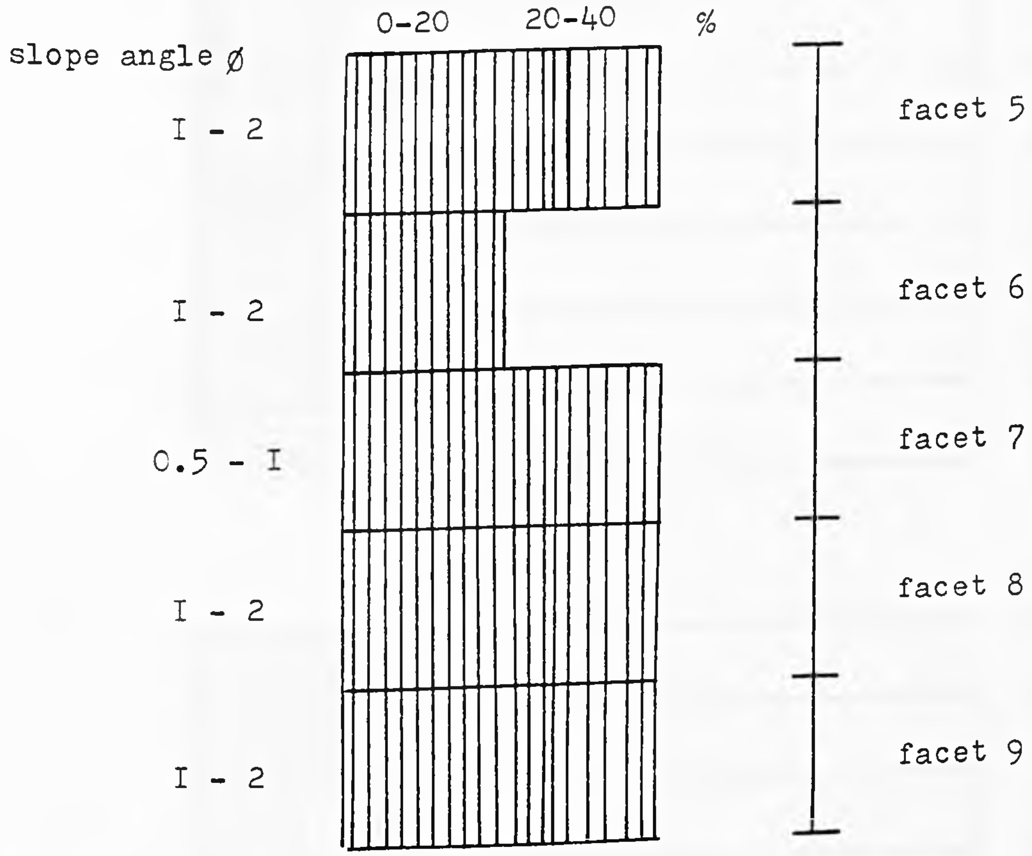


FIG. 4.13: A comparison of facets 5,6,7,8 &9 within Safwan terrain system based on slope & vegetation sparsity classes.

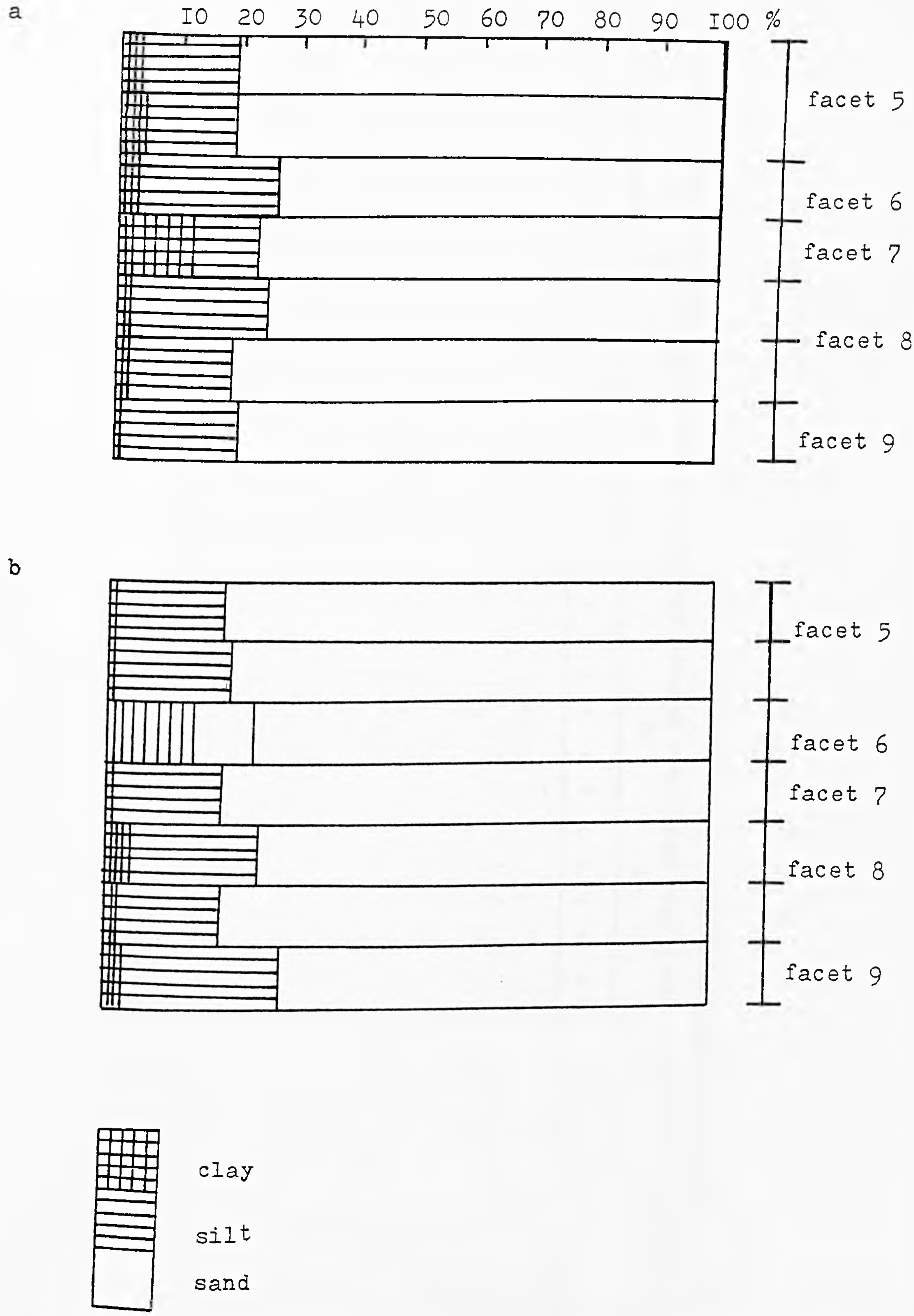


FIG. 4.14: A comparison of facets 5,6,7,8&9 within Safwan terrain system on the basis of their soil texture (clay,silt, sand) at depths : a: 0 - I5 cm b: I5 - 30 cm

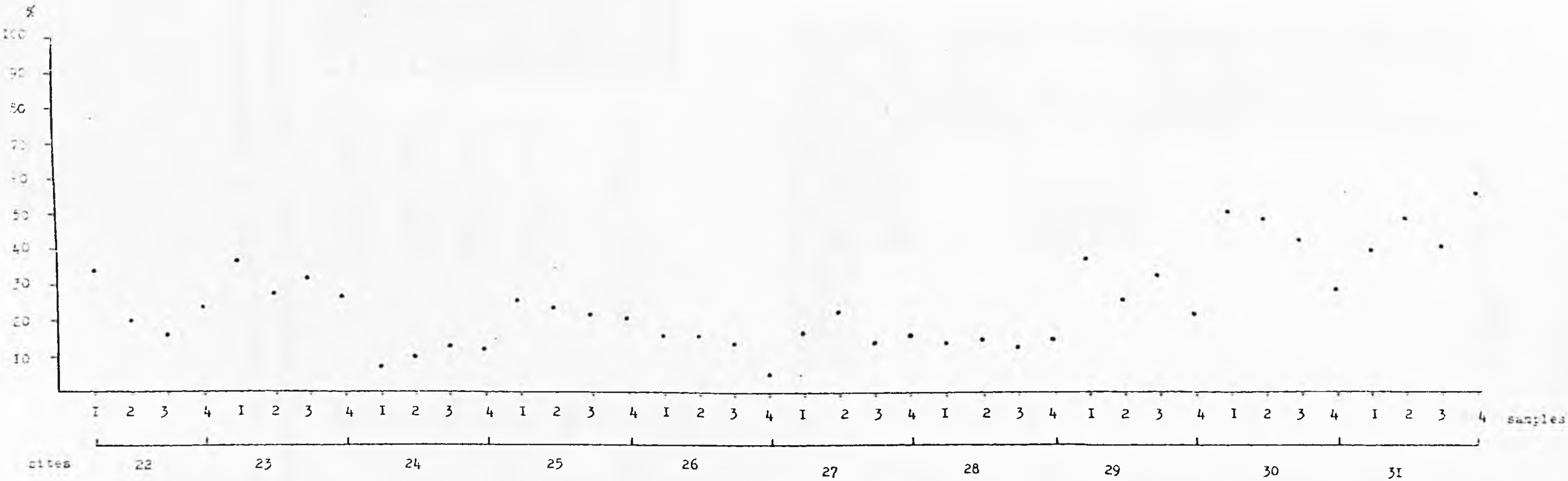


FIG.4.15: Total percentage vegetation cover of all species of facet II (sites 22& 23); facet I2(site 24: gully slope, site 25: gully floor)and facet I3 (sites 26,27&28 : wadi slope, sites 29,30&3I : wadi floor) of Sanam terrain system.

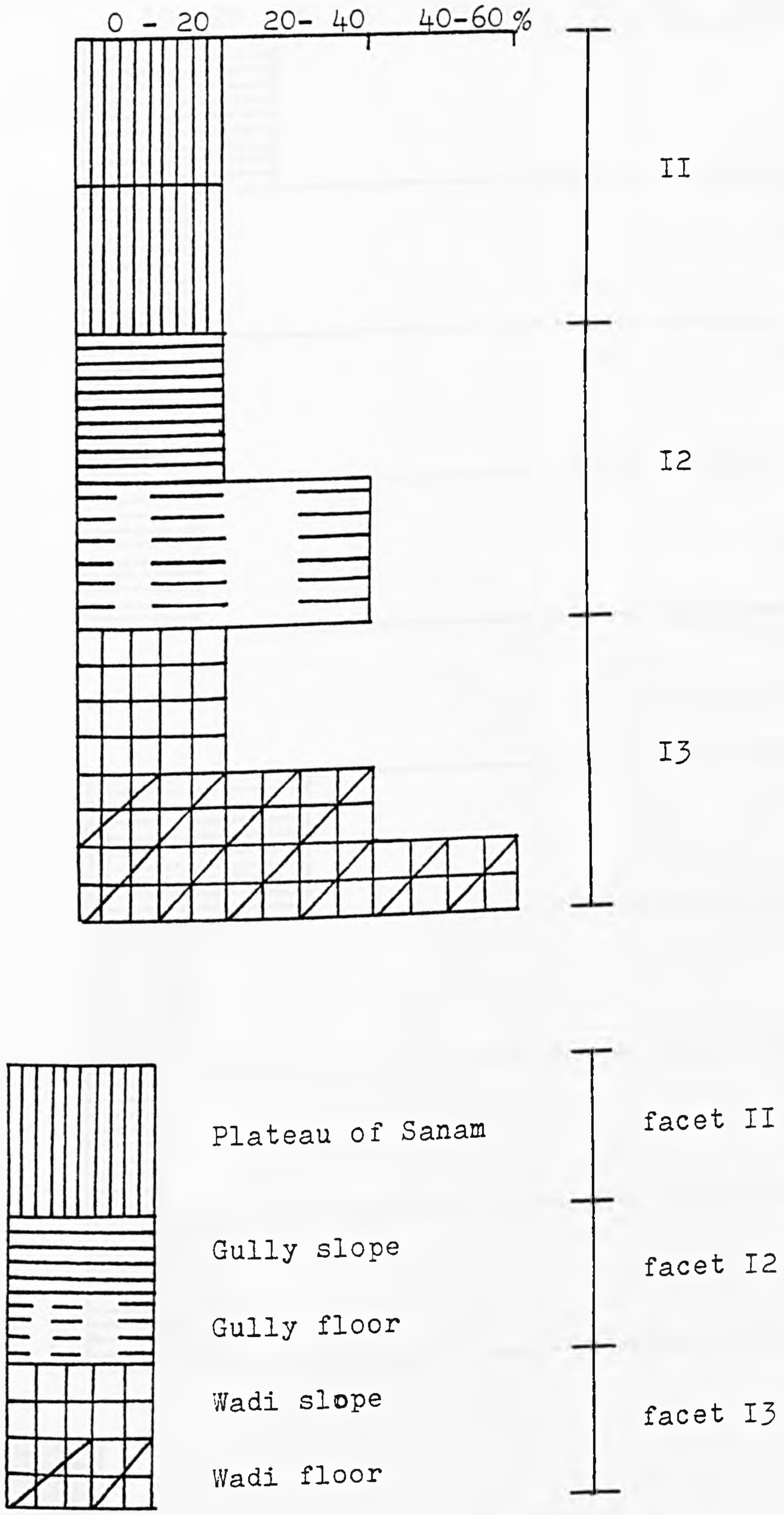


FIG. 4.16: Acomparison of facet I1, I2 & I3 within Sanam terrain system based on slope & vegetation sparsity classes.

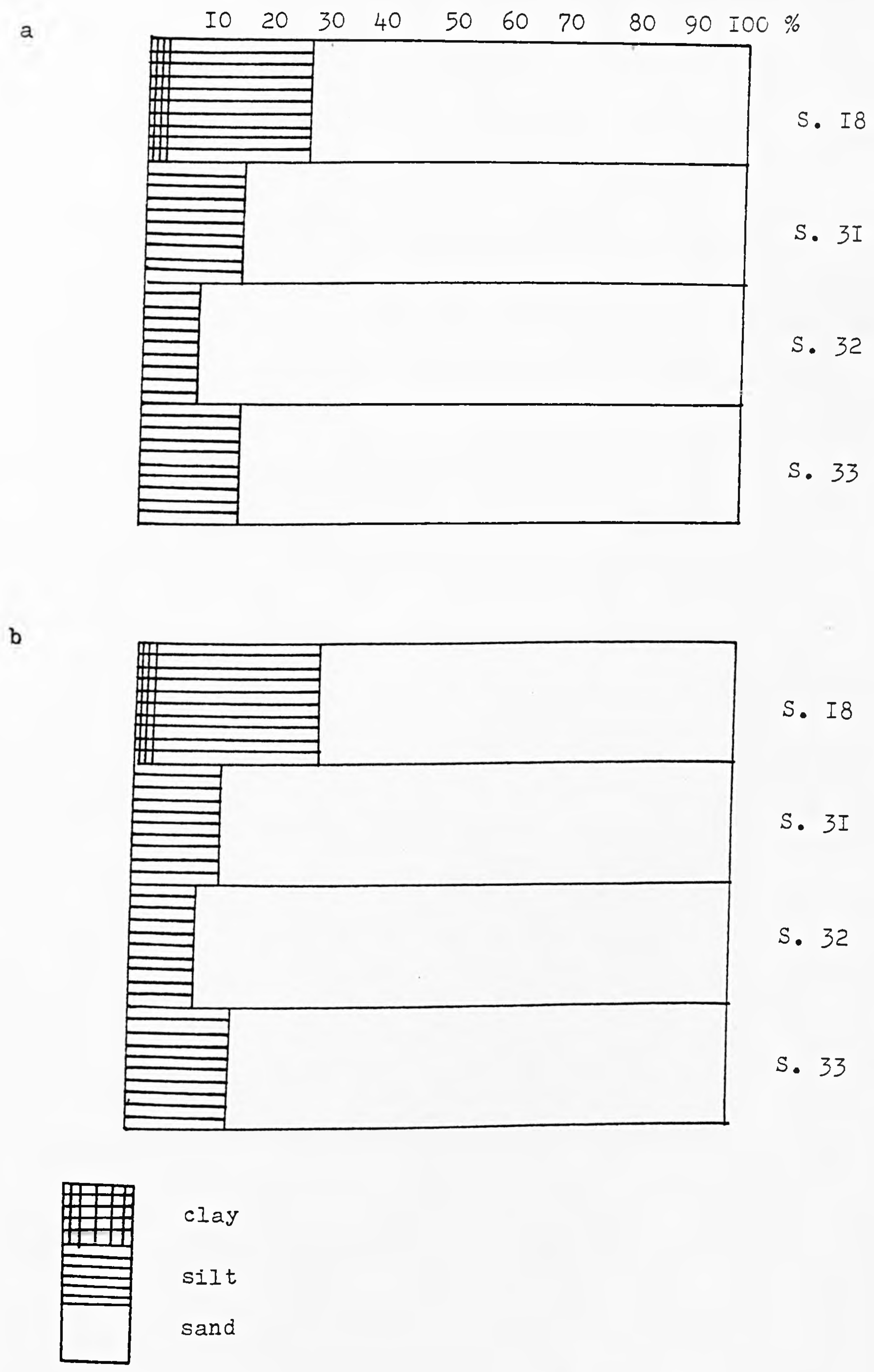


FIG.4.17 Acomparison of four samples I8,3I,32 &33 on the basis of their soil texture (clay,silt&sand) at depths : a: 0-I5cm b: I5-30cm

slopes show the vegetation to be very sparse (0-20%); whereas, the percentage cover on the gully floors is 20-40% (Appendix 3 and Fig.4.15).

The differences between the vegetation cover percentages on the gully slope surface and the gully floor (Fig.4.16) on the one hand and the soil textured classes (Fig.4.18) on the other confirm the validity of these elements forming facet 12 of the Sanam system.

The slope angles of the wadi elements are classified as gentle (Appendix 2 and Fig. 4.3). Vegetation cover percentages on the wadi slopes are very low indeed (o-20%; Appendix 3 and Fig.4.15), as compared to the wadi floor which has a moderate vegetation cover (seven samples moderate against five sparse, see Appendix 3 and Fig.4.15).

However, the differences between the wadi slope surface and wadi floor in terms of percentage vegetation cover (Fig.4.16) on the one hand, and on the basis of the soil textural classes (Fig.4.18) on the other confirm the validity of these elements making up facet 13 of the Sanam system.

4.6 THE TERRAIN SYSTEMS OF al.ZUBAIR DESERT

The final terrain system descriptions of the study area are summarised under the following headings: climate, geology, geomorphology, soil and land use. A general description of this information about the study area was given in Chapter 3.

Tabulations of the facet descriptions for each terrain system were carried out only for the facets of the detailed study area (Fig.4.27); where field measurements have been made. These tables give information concerning the facet number and name, landform description, surface materials including soils,

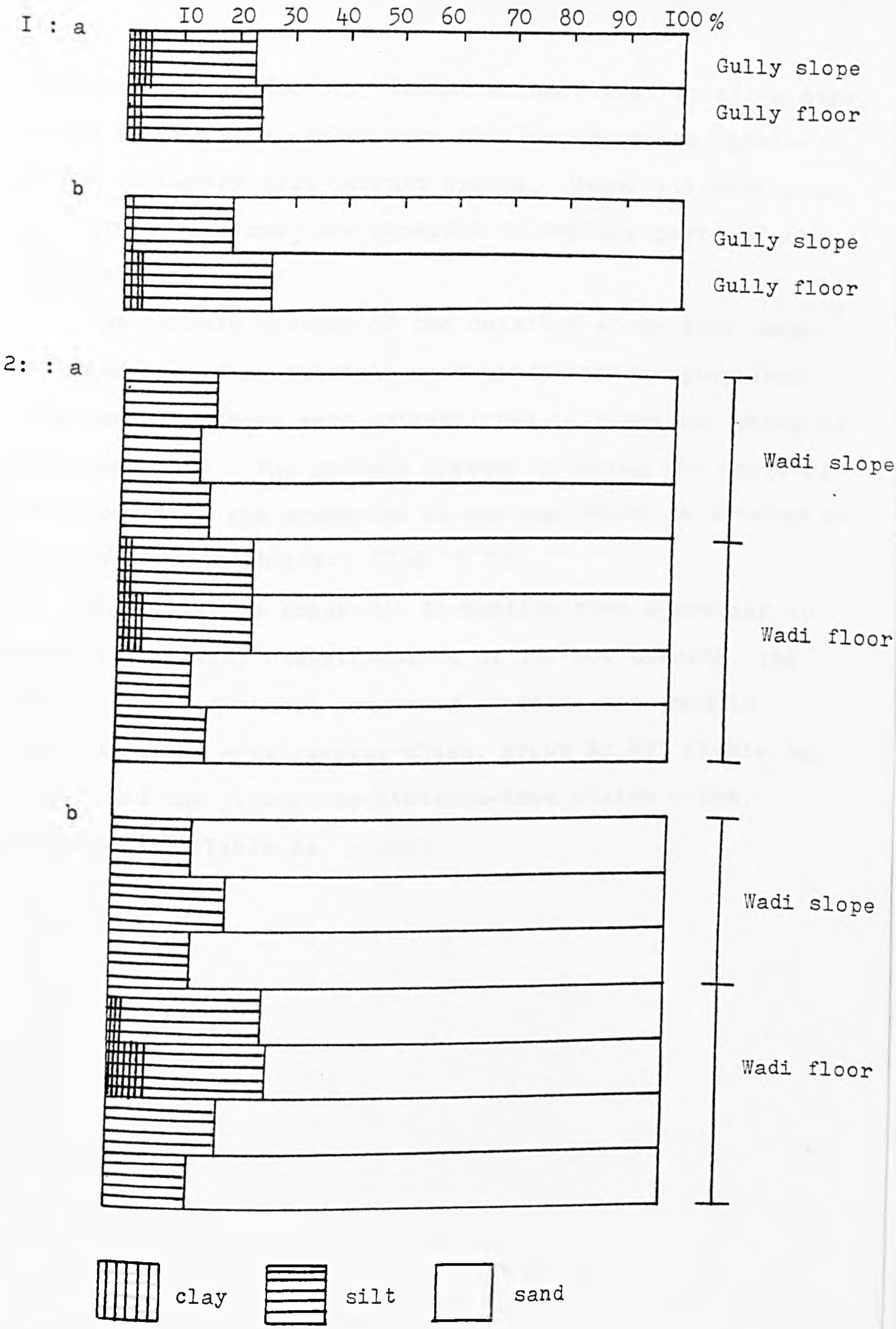


FIG.4.18: A comparison between :
I. Gully slope & Gully floor.
2. Wadi slope & Wadi floor.
on the basis of soil texture (clay,silt&sand) at depths:
a: 0-15 cm b: 15-30 cm

hydrology and landcover. Illustrations, i.e. location maps, aerial photographs, facet maps and ground (field) photographs accompany each terrain system. Other illustrations, e.g. cross sections, are provided to amplify parts of the description.

The terrain systems of the detailed study area were arranged according to their geological and topographical features, and these were extrapolated to cover the whole of the study area. The terrain systems covering the whole of the study area are presented in one map which is located at the end of this chapter, (Fig. 4.28).

Finally it is important to mention that according to Mitchell's (1973) classification of the hot deserts, the area is located within two broad classes: the 'middle alluvial areas - calcareous class; group No.43' (Table Az, p.194) and the 'Limestone-Dibdibba-Hasa plains class; group No.21' (Table Az, p.192).

1. *KHOR al.ZUBAIR TERRAIN SYSTEM*

Climate: Rainfall 100-150mm.

Geology: Recent - pleistocene. (alluvium formation).

Geomorphology: Flat depositional surfaces. Covered occasionally with flood and tidal water of Shatt al.Arab and Khor al.Zubair rivers. General gradient in the direction of the Arabian/Persian Gulf. Featureless plain apart from occasional small coastal dunes breaking the monotony of the landscape. Badly drained land. High water table.

Soils: Salorthids group of soils. Consisting a considerable clay especially near Khor al.Zubair river. High level of salinity. Different subakh soils. Salts may appear on the surface.

Vegetation: Halophytic community. Moderate vegetation cover. Perennial, but unfavourable for grazing.

Altitude: 0-100m approximately.

FIG. 4.19: STEREOGRAM SHOWING PART OF
KHOR AL.ZUBAIR TERRAIN SYSTEM

f1a
f1b
f1c

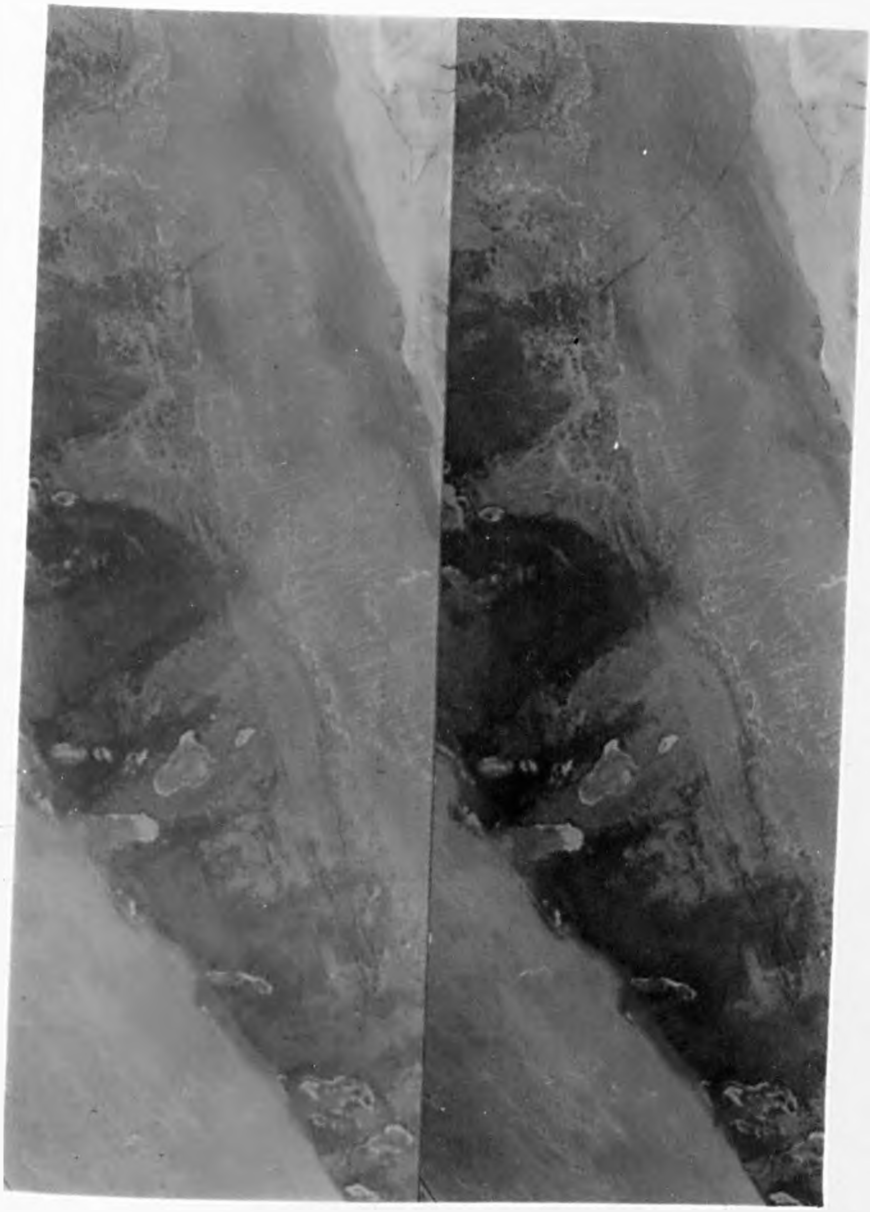
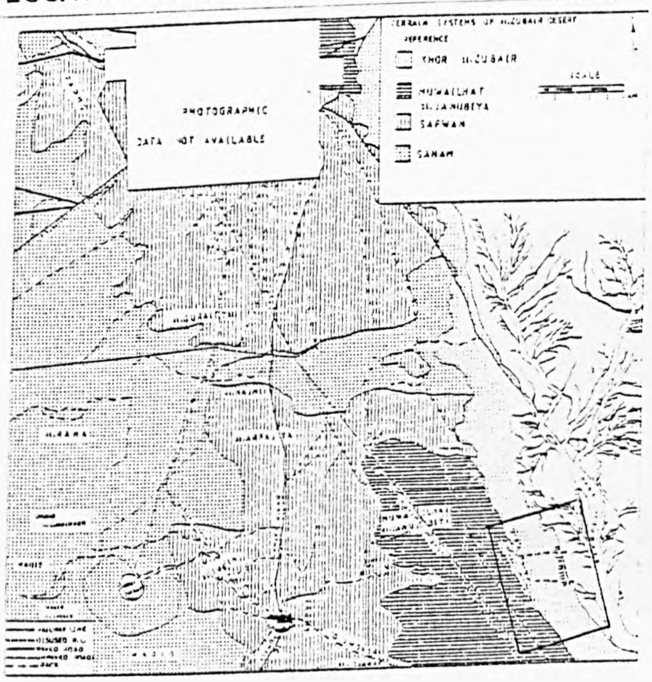
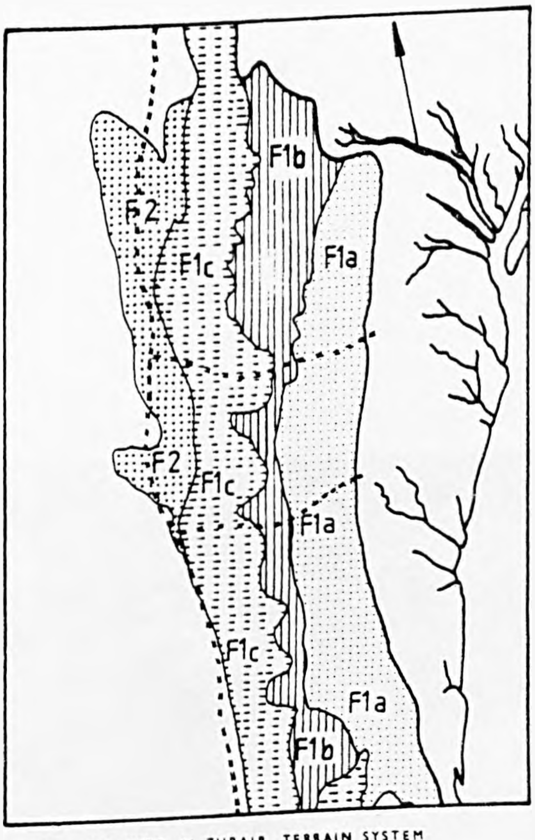


FIG. 4.19: STEREOGRAM SHOWING PART OF
KHOR AL.ZUBAIR TERRAIN SYSTEM

LOCATION MAP





FACETS OF KHOR AL-ZUBAIR TERRAIN SYSTEM
FOR LOCATION SEE ABOVE MAP

FIG. 4.20: Location map and terrain facets of Khor al. Zubair terrain system.

PLATE 4.1

FACET Ia ' al-Jabjub '

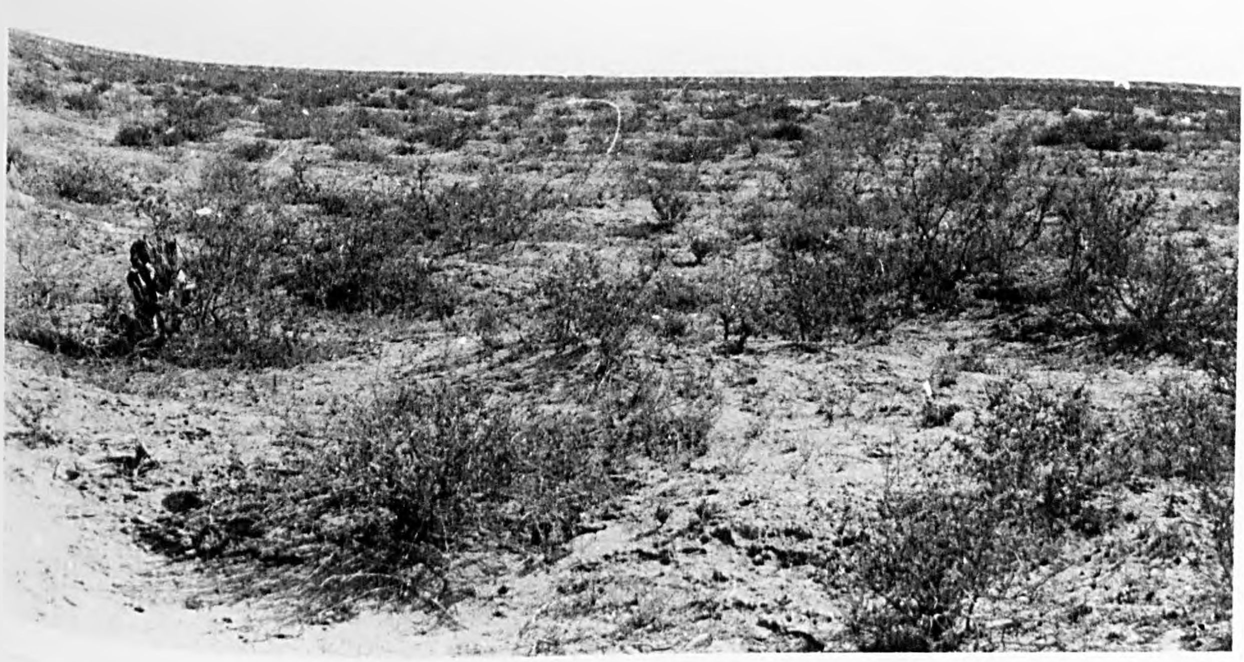


PLATE 4.2

FACET Ia ' al-Jabjub '

KHOR AL-ZUBAIR TERRAIN SYSTEM

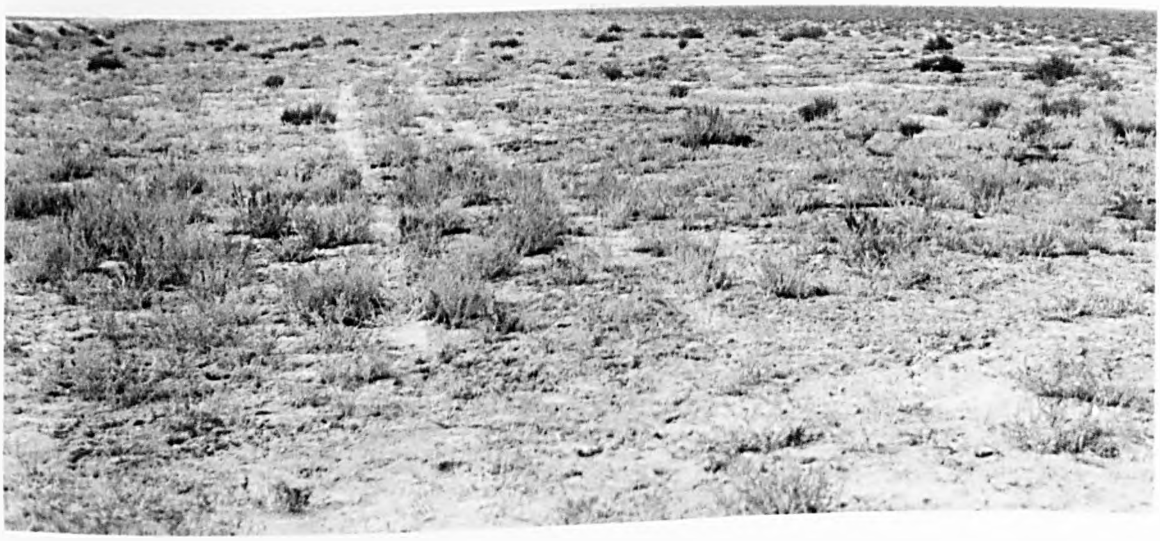


PLATE 4.3

FACET Ib ' Graih al-Theeb al-Janubi '

PLATE 4.4

FACET Ib ' Graih al-Theeb al-Janubi '

KHOR AL-ZUBAIR TERRAIN SYSTEM

PLATE 4.5

FACET Ic ' Graih al-Theeb '

PLATE 4.6

FACET Ic ' Graih al-Theeb '

KHOR AL-ZUBAIR TERRAIN SYSTEM

PLATE 4.7
FACET 2 ' Graih al-Theeb al-Shamali '

PLATE 4.8
FACET 2 ' Graih al-Theeb al-Shamali '

Facet No.	Name	Landform	Soils, Materials and Hydrology	Landcover
1a	al.Jabjub	Part of the flood plain. Flat and featureless except for some very low coastal dunes. Almost level slopes.	Alluvium soil. Brakish with salts appear on the surface especially near the Khor. Fine textured soil becoming coarser near the unpaved road. Clay loam and sandy loam soils. Almost dull yellowish brown (10 yr 5/4, 5/3, 4/3). Significant alkalinity-salinity. Ill-drained surface, influenced by the seasonal floods of Shatt al.Arab river.	Sparse to moderate vegetation cover (very small shrubs). Roots appear at depth 50-60cm
1b	Graih al.Theeb al.Janubi	Part of the flood plain. Featureless. Almost level slopes.	As Facet 1. Sandy loam to silt loam soils. Almost dull yellowish brown. (10 yr 4/3).	As Facet 1. Roots appear at depth 40-60cm.
1c	Graih al.Theeb	Flat. Featureless facet except for some sand accumulation (man made). Very gentle slopes.	As Facet 1. Sandy loam soils. Dull brown (7.5 yr 5/3 and 5/4)	As Facet 1.
2	Graih al.Theeb al.Shamali	Marginal facet of this system. Almost very gentle slopes.	Sandy loam soils. Small parts of it being flooded occasionally.	Sparse to very sparse vegetation cover (o-20 to 20-40%). Roots appear at depth 25-35cm.

2. *MUWAILHAIT al.JANUBIA TERRAIN SYSTEM*

Climate: Rainfall 100-150m.

Geology: Miocene (Dibdibba formation).

Geomorphology: Undulating Terrain. Broad hummocky hill slopes. Gradient in the direction of Khor al.Zubair. The hills are gentle slopes, thus they are insignificant on the aerial photographs. Water and wind erosion more effective on the hill slopes than on the flats. Sand and gravel on the hill slopes are cemented.

Soil: Quartzipsamments group of soils - sandy loam, poorly sorted.

Vegetation: Desert vegetation type. (Rhanterium Epapposum type). Mixed vegetation, perennial and annual. Grazing in the flat areas.

Altitude: 10-200mm approximately.

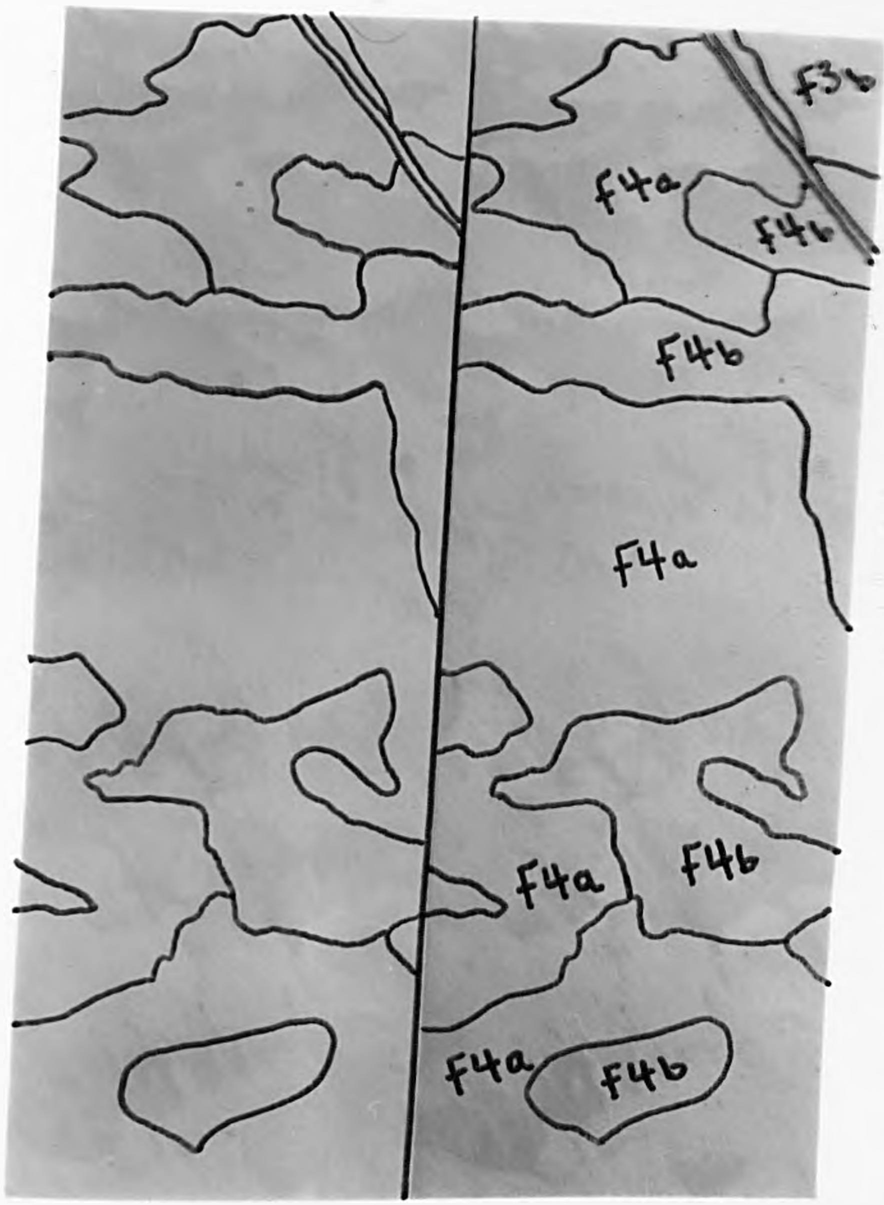


FIG. 4.21: STEREOGRAM SHOWING PART OF MUWAILHAT AL.JANUBIYA TERRAIN SYSTEM


F3b
F4a
F4b
F4b
F4a
F4a
F4b
F4a
F4b

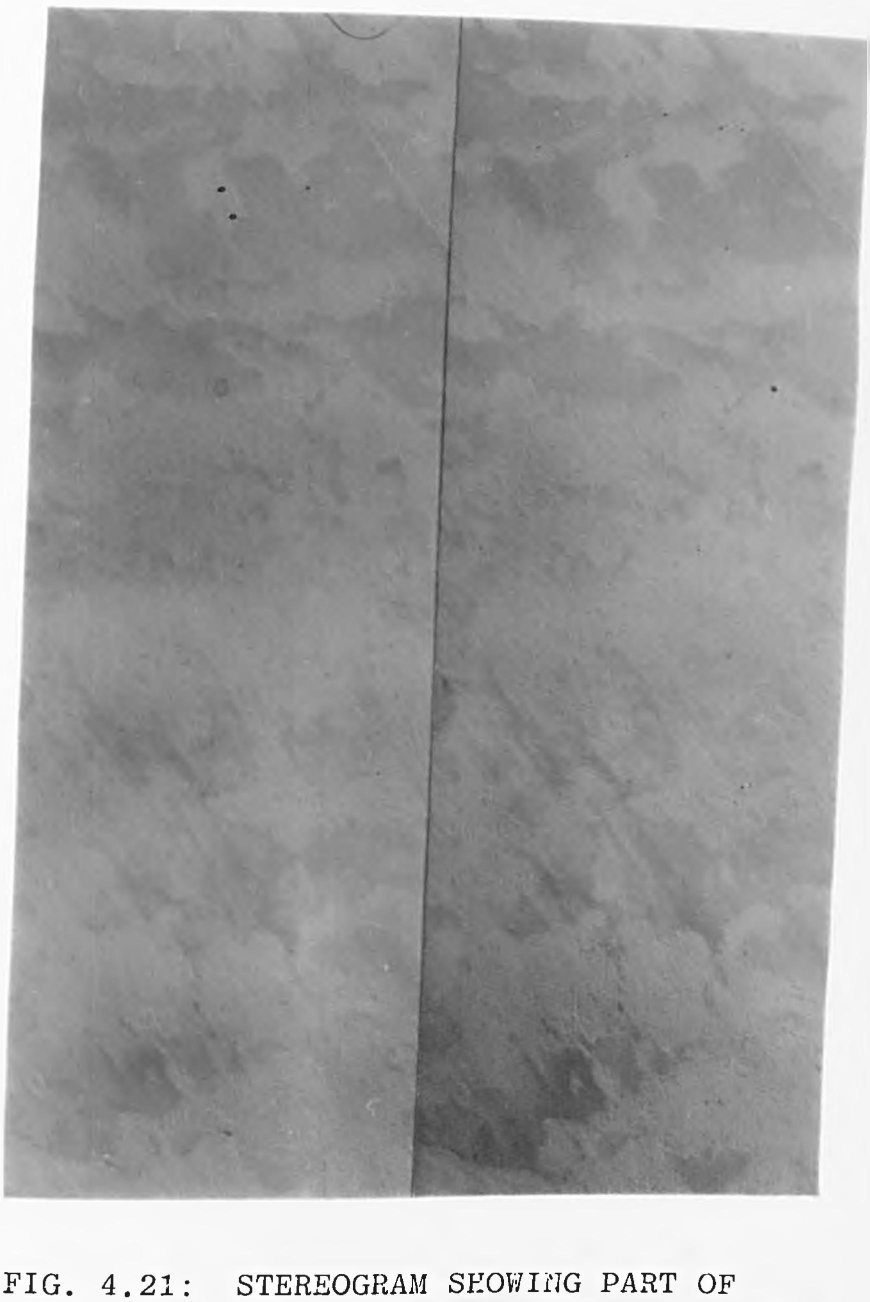
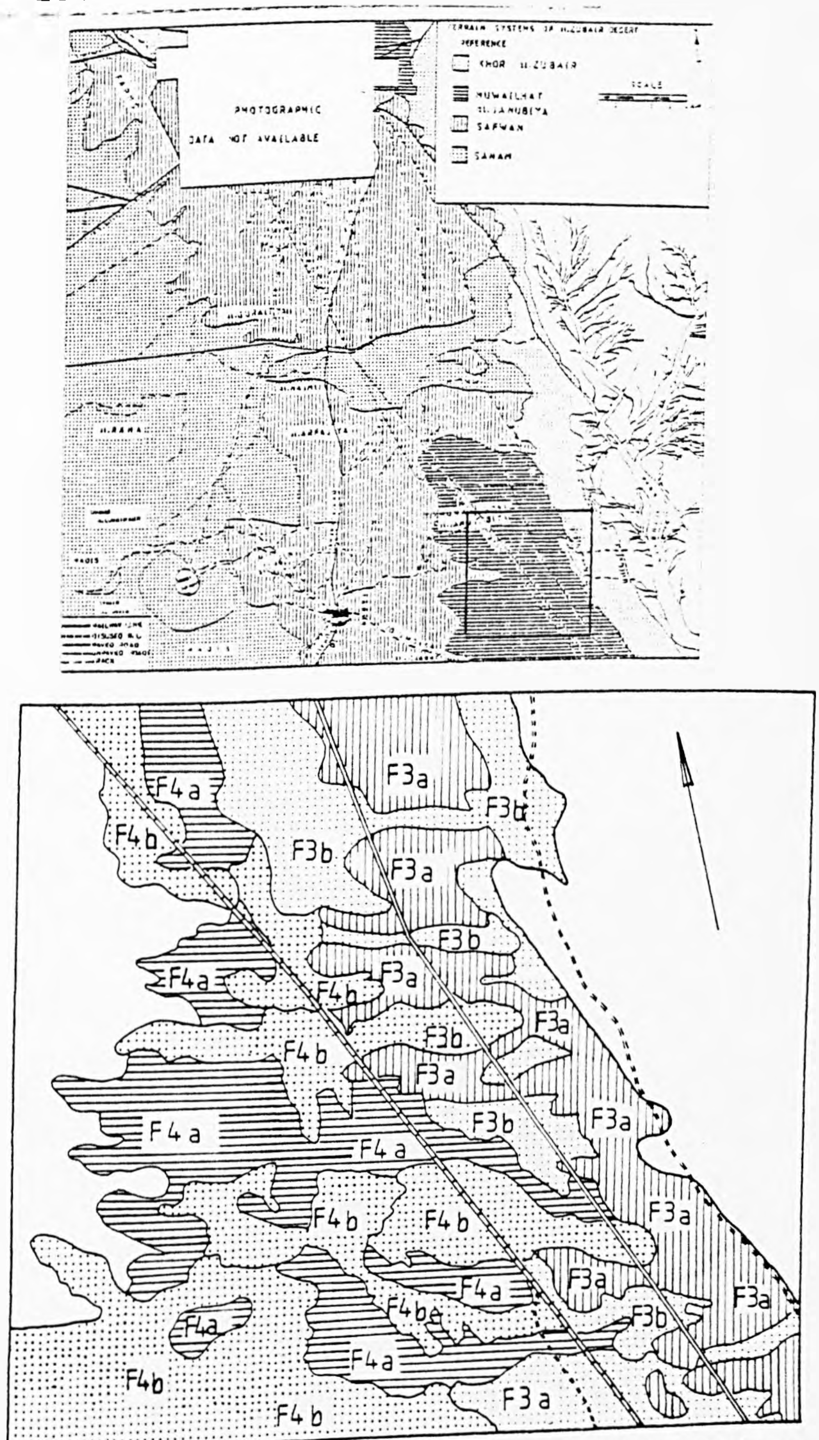


FIG. 4.21: STEREOGRAM SHOWING PART OF MUWAILHAT AL.JANUBIYA TERRAIN SYSTEM

LOCATION MAP



FACETS OF MUWAIHAT AL-JANUBIYA TERRAIN SYSTEM

FOR LOCATION SEE ABOVE MAP

FIG. 4.22: Location map and terrain facets of Muwailhat al.Janubiya terrain system.

MUWAILHAT AL-JANUBIYA TERRAIN SYSTEM

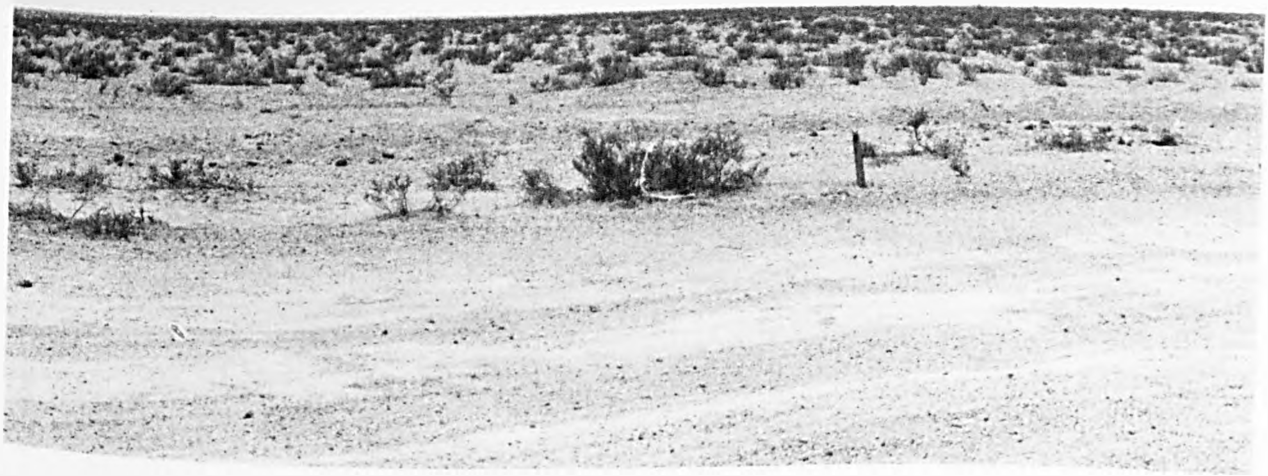


PLATE 4.9

FACET 3a ' Brej '

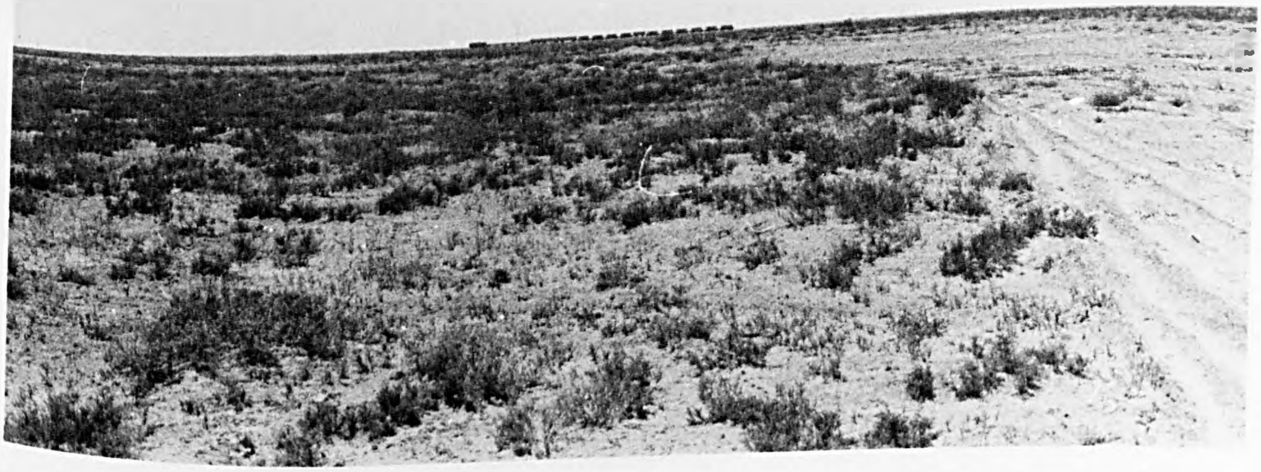


PLATE 4.10

FACET 3b ' Brej '

MUWAILHAT AL-JANUBIYA TERRAIN SYSTEM

PLATE 4.11

FACET 4a ' Muwailhat '

PLATE 4.12

FACET 4b ' Muwailhat '

Facet No.	Name	Landform	Soils, Materials and Hydrology	Landcover
3	Brej	(a) Hill Slopes: Flat, broad crests. Gentle slopes, gradual and straight. Wind and water (rainfall - seasonal, run off water) erosion plays an important role in modifying the slopes.	Sandy loam soils. Dull yellow orange and dull orange at depth (10yr 7/3 & 7.5 yr 7/3). Slightly alkaline soils. Sand and gravel material. Gravel or pebbles appear on the surface. Gravel is mixed with sand. Sand at depth	Short and stunted vegetation. Sparsity increasing towards the base of the slope.
		(b) Flat: Wind and erosion important in transporting fine material. Very low sand dunes accumulated around the vegetation.	Sandy loam soils. Dull yellow orange (10yr 6/4). Slightly alkaline soils. Finer material than the hill slopes.	Sparse to moderate sparse vegetation cover (0-20 to 20-40%) Used for sheep grazing.
4	Muwailhat	(a) Hill Slopes: Broad and flat crests. Short gentle slopes.	Sandy loam soil. Bright yellow brown/ becoming dull yellow orange at the base. Materials same as in Facet 3 (a).	Sparse and scattered vegetation cover.
		(b) Entirely Flat. as Facet 3(b)	Sandy loam. Dull orange. (7.5yr 7/4)	As Facet 3(b)

3. *SAFWAN TERRAIN SYSTEM*

Climate: *Rainfall 100-150mm.*

Geology: Miocene - (Dibdibba formation).

Geomorphology: Entirely flat and sloping in N.E. direction. Some deposits of wind-blown very longitudinal sand dunes. The system as a whole is one of four exclusive depressions located in the al.Zubair desert. Underground water is the most important water source, especially for agriculture.

Soils: Quartzipsamment group of soils. Sand size quartz is dominant.

Vegetation & Agriculture: Rhanterium Epapposum type of vegetation. Sparse to moderate vegetation cover. An important area for growing vegetable crops.

Altitude: 100-200m approximately.

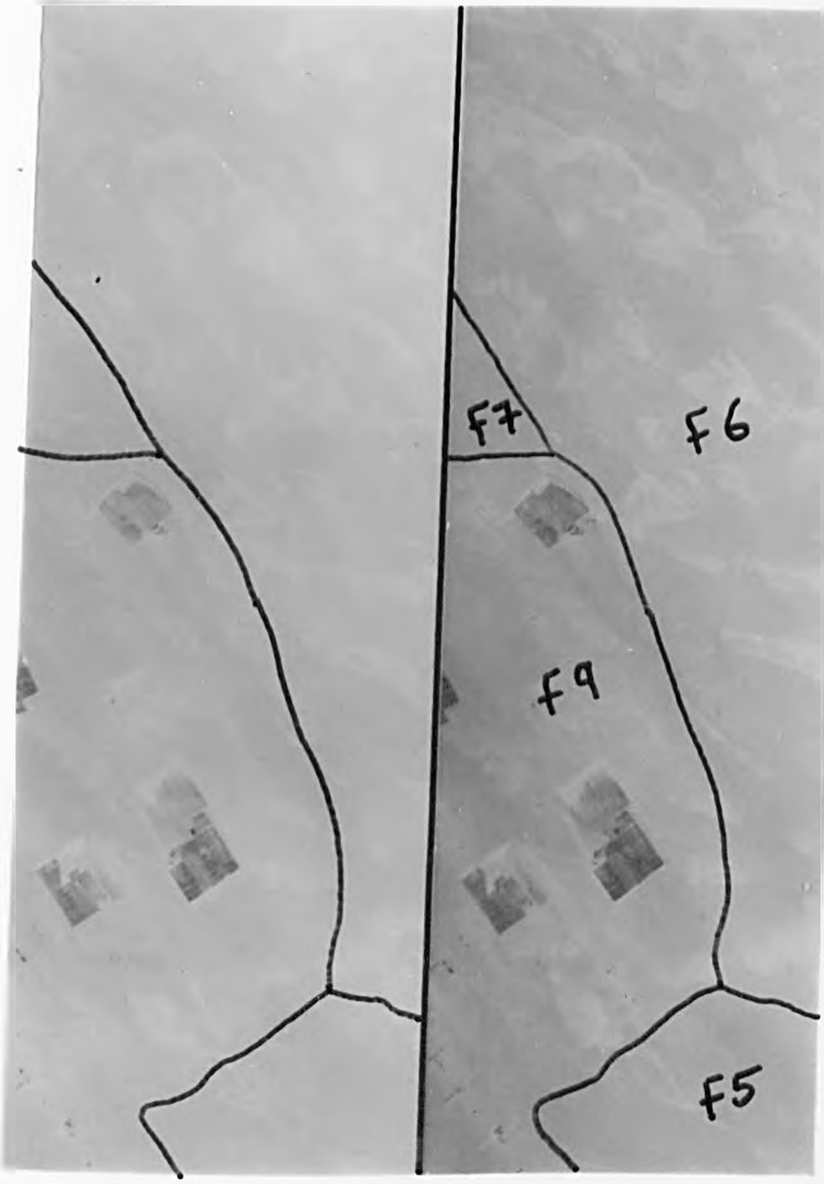
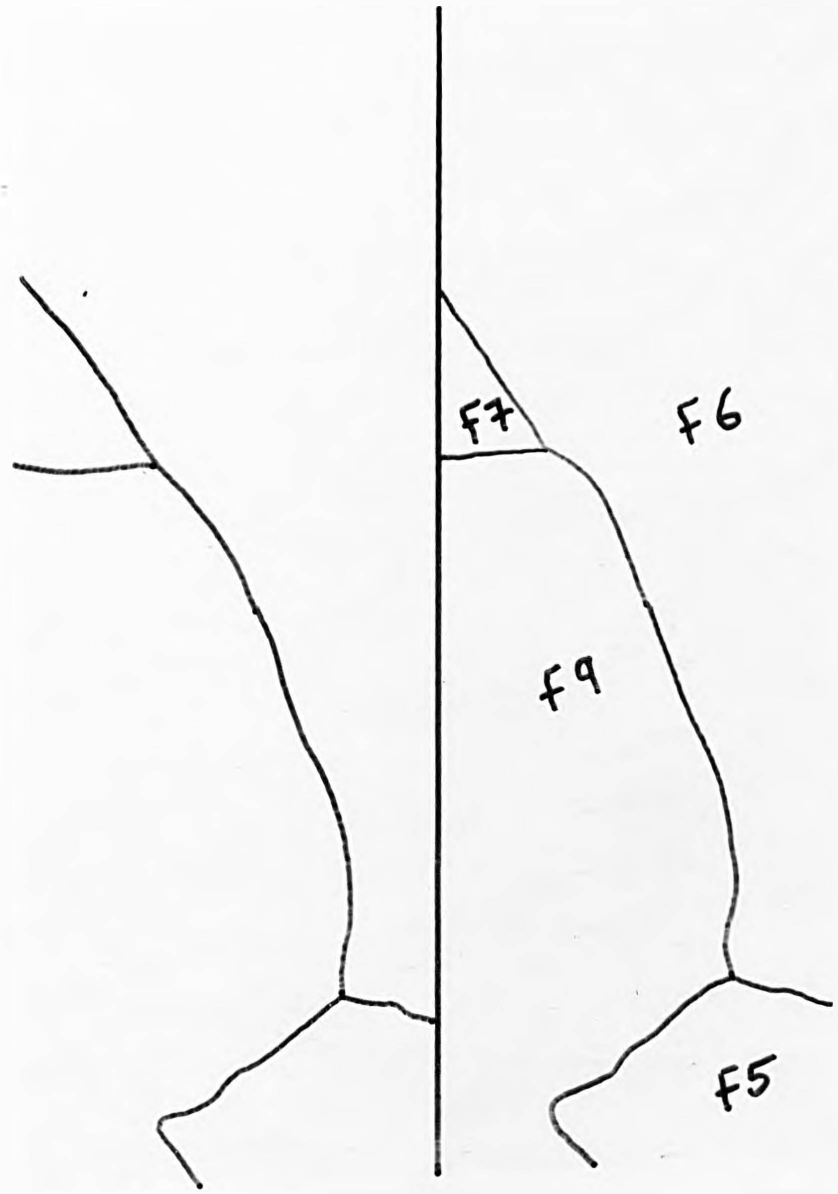


FIG. 4.23: STEREOGRAM SHOWING PART OF SAFWAN TERRAIN SYSTEM


F7
F6
F9
F5

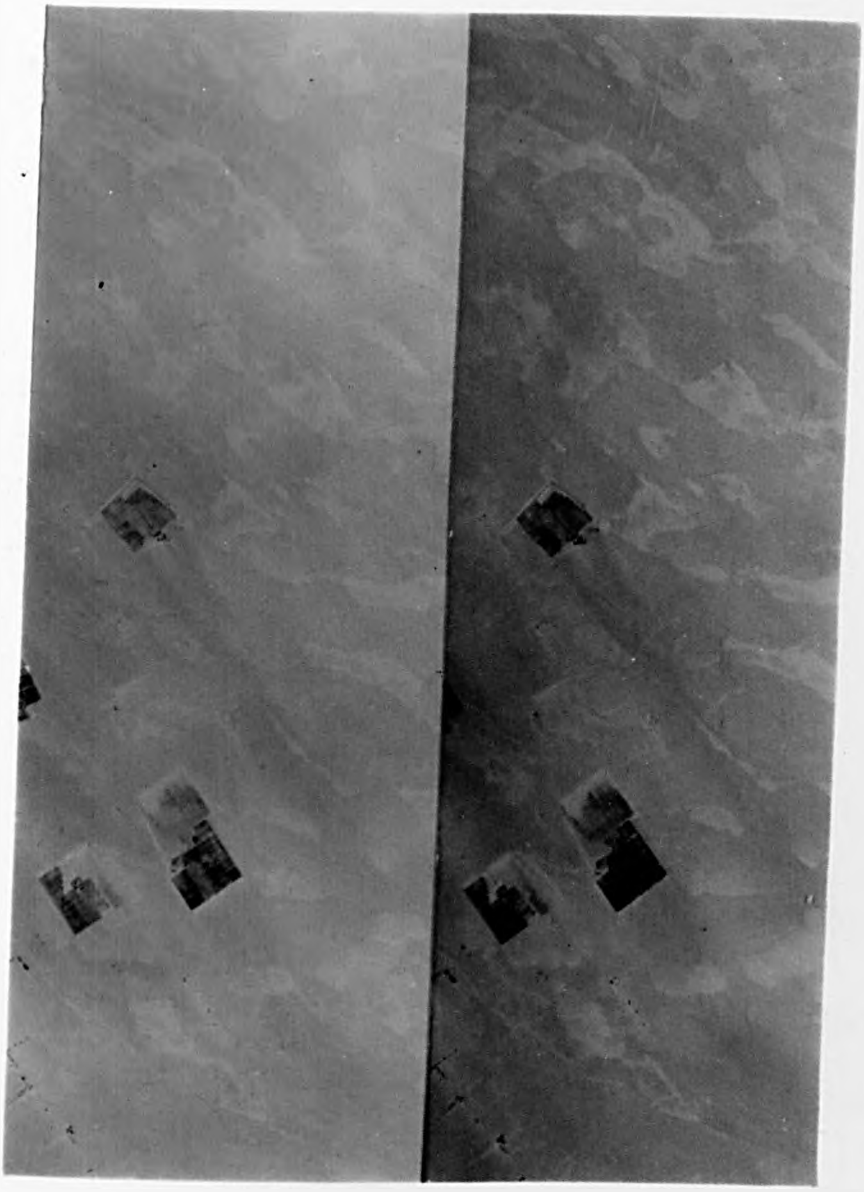


FIG. 4.23: STEREOGRAM SHOWING PART OF SAFWAN TERRAIN SYSTEM

LOCATION MAP

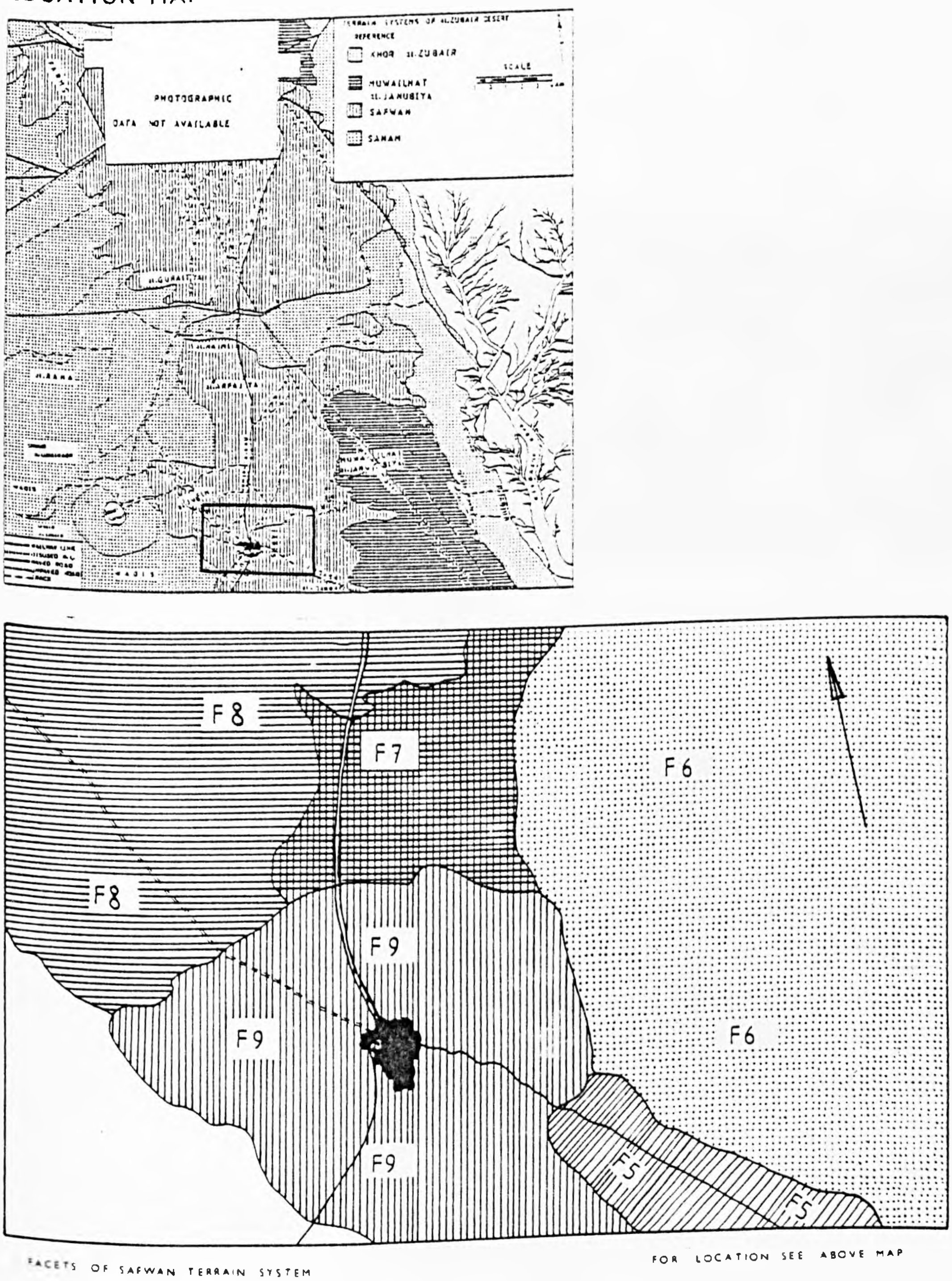


FIG. 4.24: Location map and terrain facets of the Safwan terrain system.

SAFWAN TERRAIN SYSTEM

PLATE 4.13

FACET 5 ' al-Quabat '

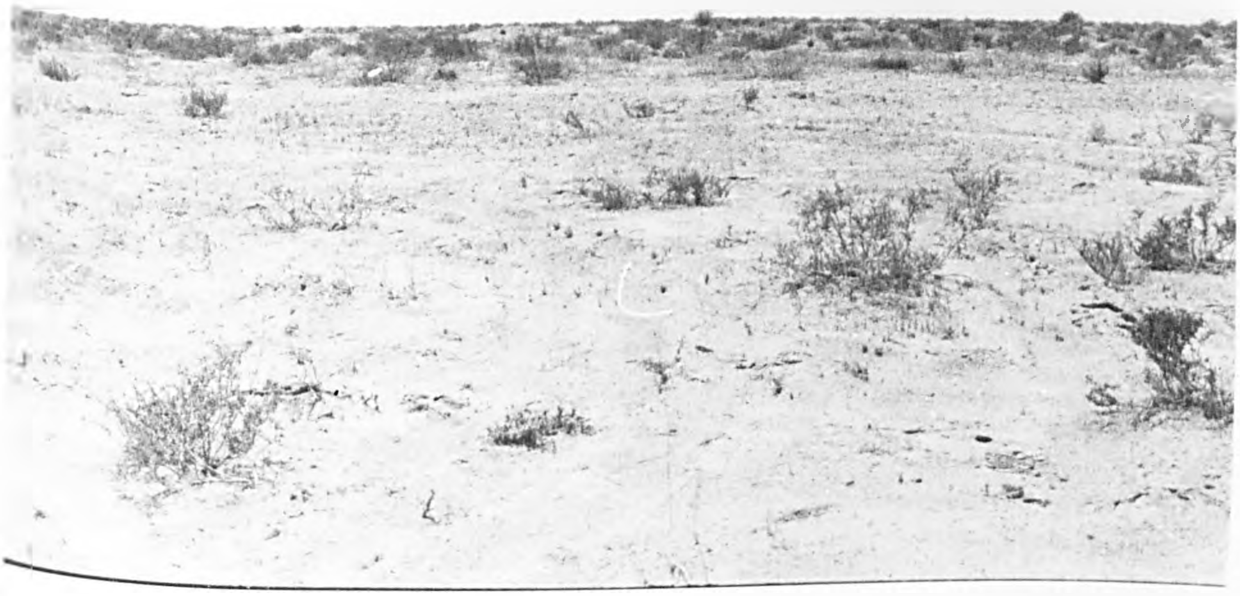


PLATE 4.14

FACET 6 ' Safwan-East '

PLATE 4.15

FACET 6 ' Safwan-East '

SAFWAN TERRAIN SYSTEM

PLATE 4.16

FACET 8 'al-Jufin '

PLATE 4.17

FACET 7 ' Safwan-North '

SAFWAN TERRAIN SYSTEM

PLATE 4.18

FACET 9 ' Safwan '

Facet No.	Name	Landform	Soils, Material and Hydrology	Landcover
5	Al.Quabat	Very gentle slopes	Sandy loam. Dull yellow orange to dull orange. Slightly alkaline to medium alkalinity. Fine sand on the surface, sand and gravels at depth. Underground water penetrated at 13m depths.	Sparse to moderate vegetation cover. Farming near the base of the gradient. Roots extend 10-20cm in depth.
6	Safwan-East	Very gentle slopes. Flat in extent. Very low sand dunes cover the surface.	Sandy loam soils. Dull yellowish brown to yellowish brown at depth. (10yr 5/4 and 10yr 5/6). Medium alkalinity. Sand and fine gravel.	Sparse vegetation cover.
7	Safwan-North	Flat. Sand plain.	Sandy loam soils. Dull yellow orange (10yr 6/4). Slight to medium alkaline soils at depth. Fine gravel mixed with sand. Wells predominate.	Almost moderate to sparse vegetation cover.
8	Al.Jufin	Very gentle slope and entirely flat in its extent.	Sandy loam soils. Dull yellow orange (10yr 6/4). Mixed sand and gravel at depth. Medium alkalinity. Underground water.	Moderately sparse vegetation cover. Grazing and agriculture facet.
9	Safwan	Very gentle slopes. Scattered sand accumulations.	Sandy loam soils. Dull orange to dull brown at depth (7.5yr 7/3 and 5/4). Medium alkalinity. Underground water. (13-14m deep in well.)	As facet 8

4. SANAM TERRAIN SYSTEM

Climate: Rainfall 100-150mm.

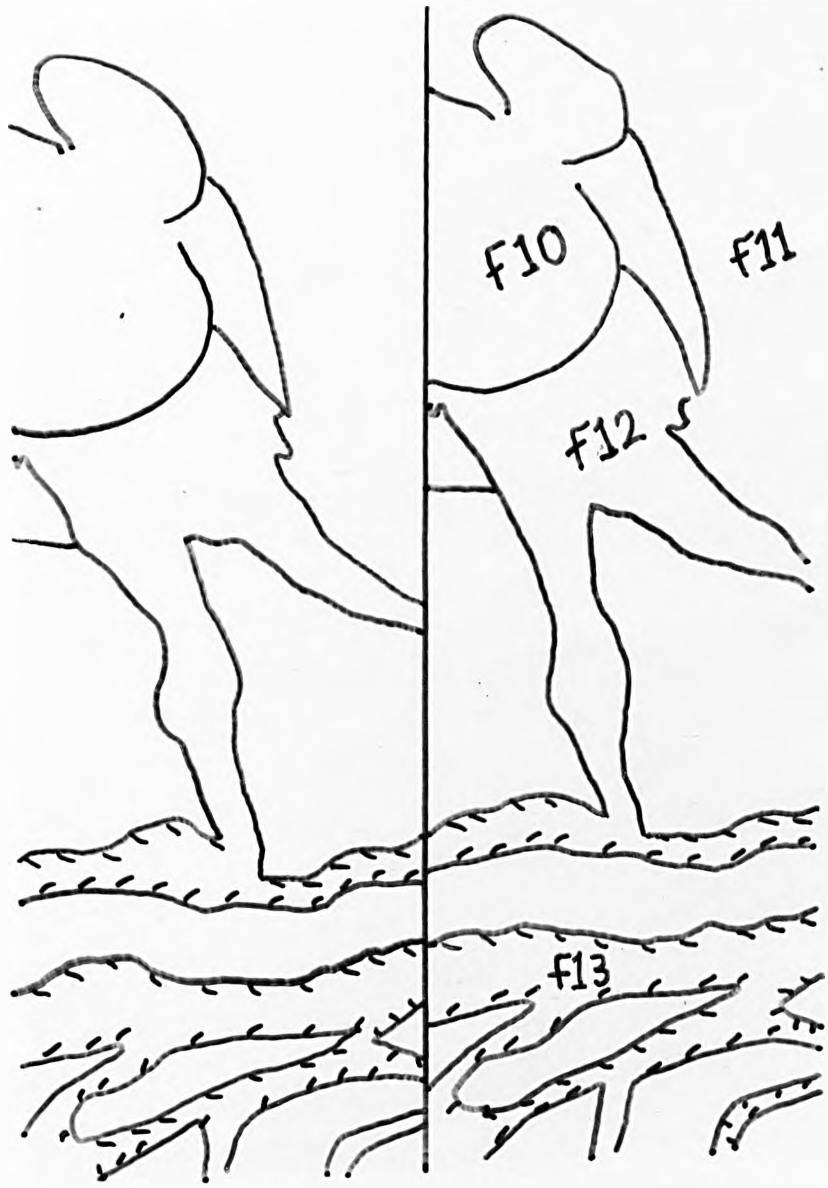
Geology: Miocene - (Dibdibba formation except Jabel Sanam (Jurassic)).

Geomorphology: A plateau surrounding the Jabel (hill) which is gullied with wadis dissecting the land to the south, west and north of the Jabel. general slope to the east and north-east following the overall topographic trend of the area. Pebbles occur freely on the plateau, gullies and wadis slop surface. Mixed sand and gravel materials at depth.

Soils: Calciorthid group of soils. High sand and pebble contents. Poorly sorted. High calcium carbonate and calcium sulphate (gypsum).

Vegetation: Rhanterium Epapposum community. Grazing in the wadi floors. (especially sheep, goats and camels).

Altitude: 100-200m approximately.


f10
f11
f12
f13

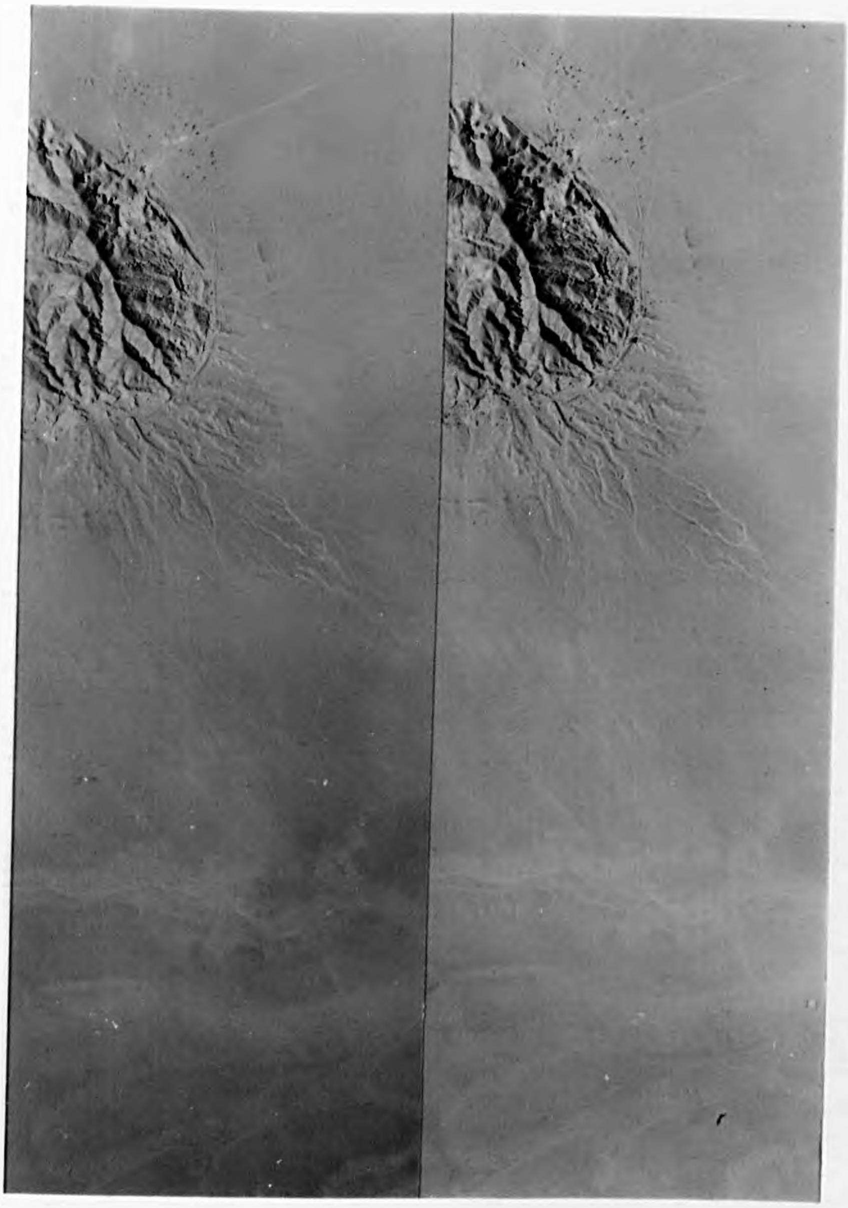


FIG. 4.25: STEREOGRAM SHOWING PART OF SANAM TERRAIN SYSTEM

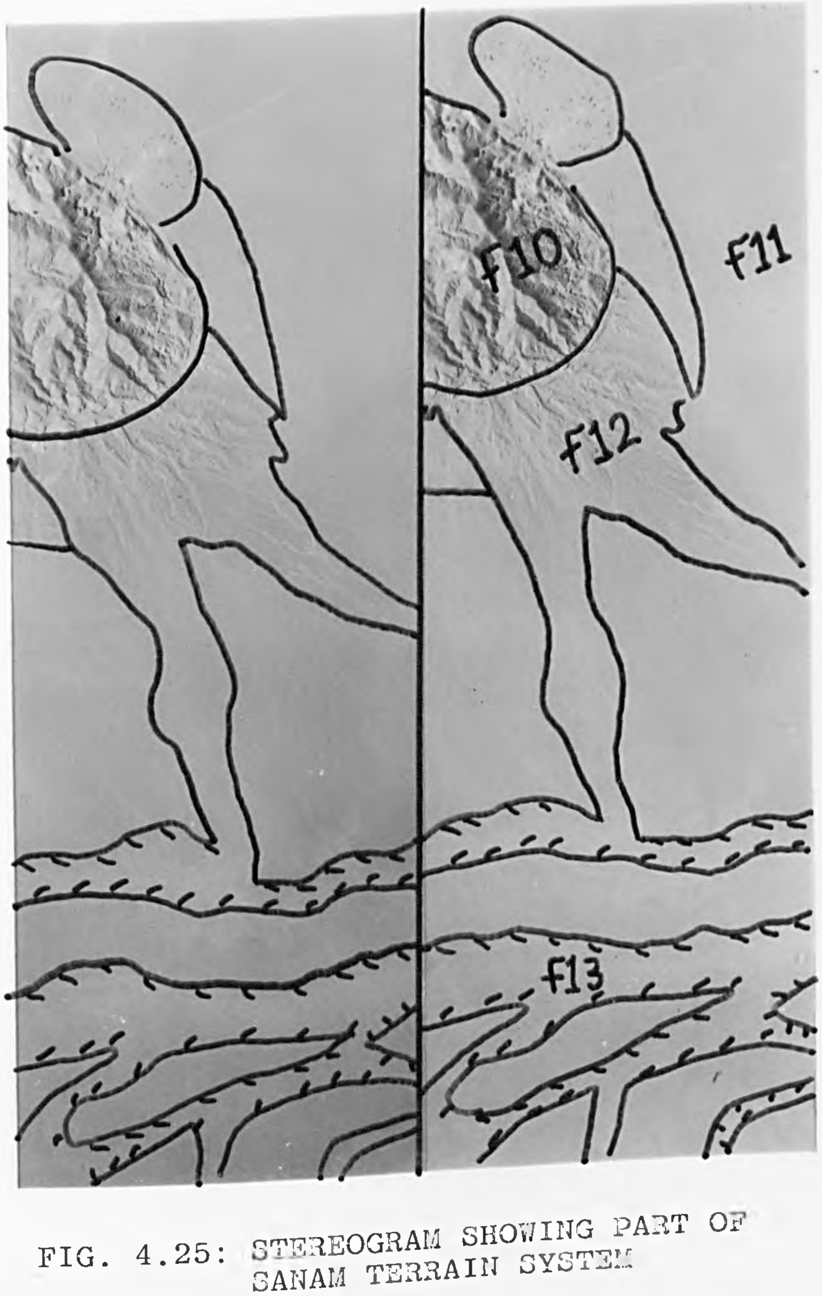


FIG. 4.25: STEREOGRAM SHOWING PART OF SANAM TERRAIN SYSTEM

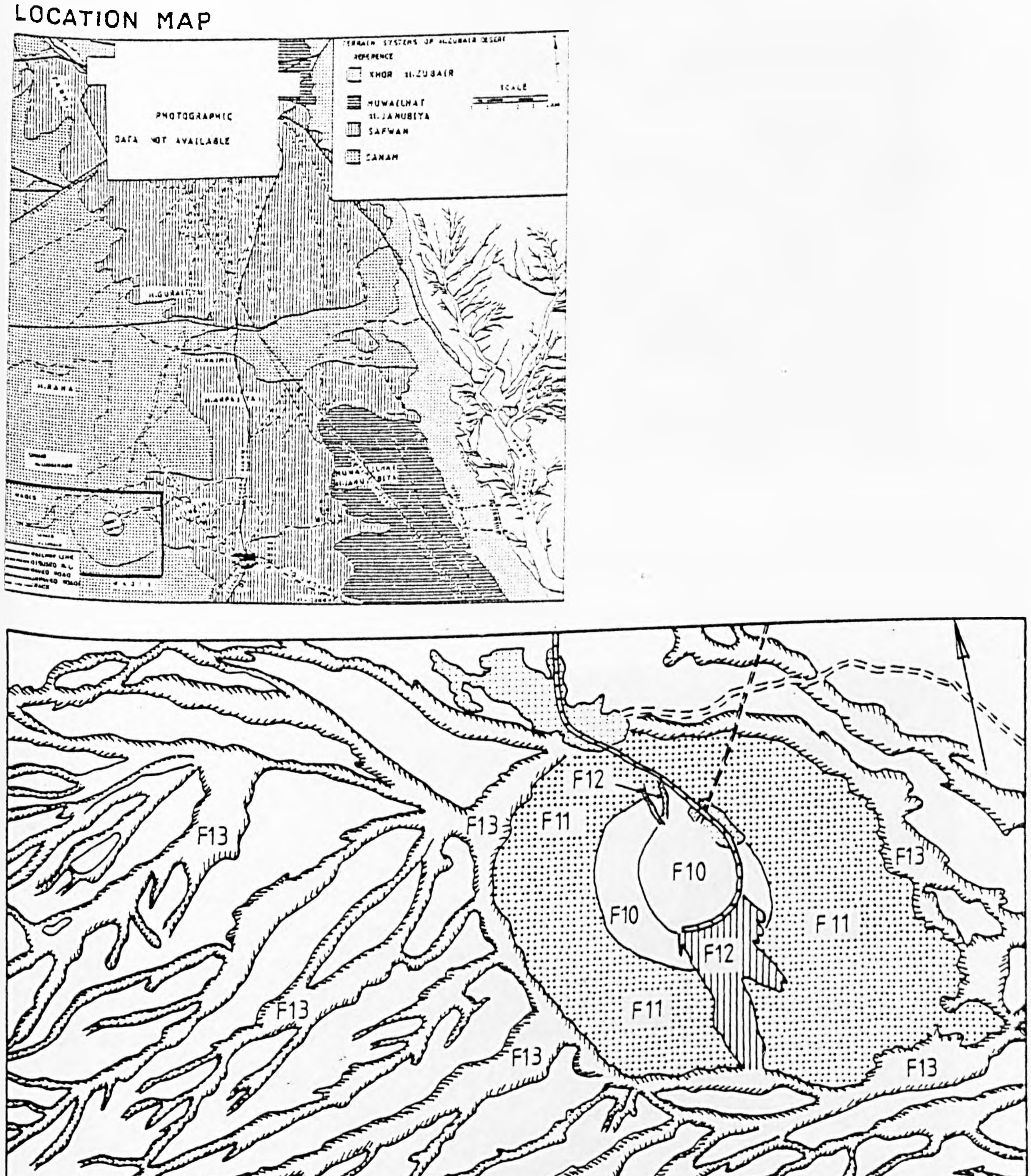


FIG. 4.26: Location map and terrain facets of Sanam Terrain system

SANAM TERRAIN SYSTEM

PLATE 4.19

FACETS IO&II ' Jabal Sanam & Sanam plateau '

PLATE 4.20

FACET II ' Sanam plateau '

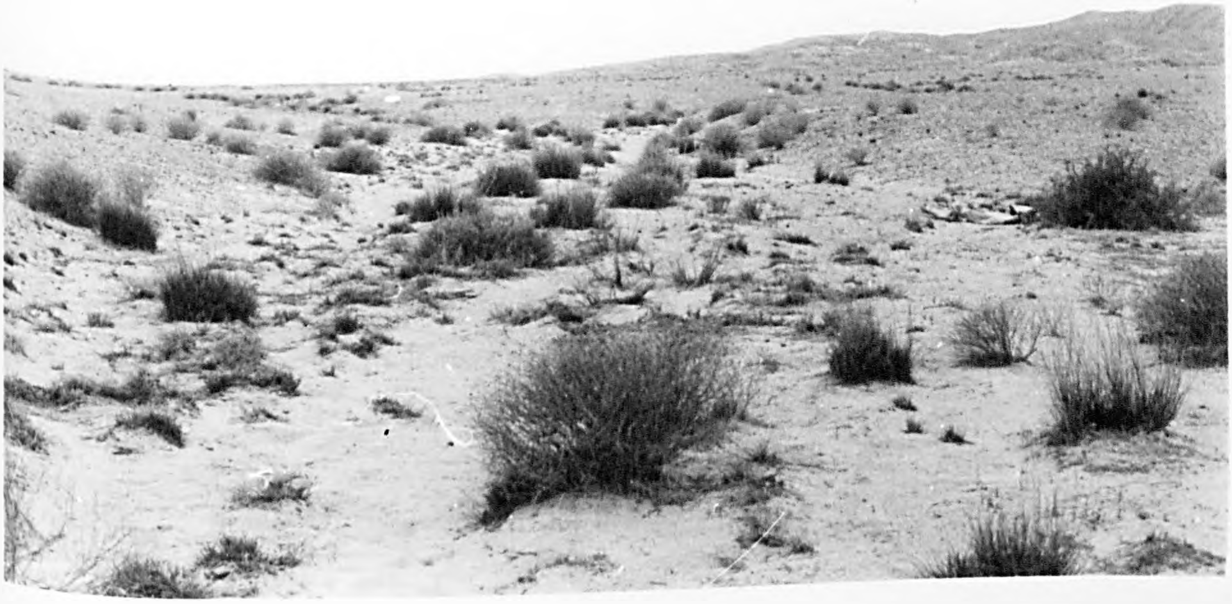


PLATE 4.21

FACET I2 ' Gullies '

PLATE 4.22

FACET I2 ' Gullies '

SANAM TERRAIN SYSTEM

PLATE 4.23

FACET I3a ' Wadi slope '

PLATE 4.24

FACET I3b ' Wadi floor '

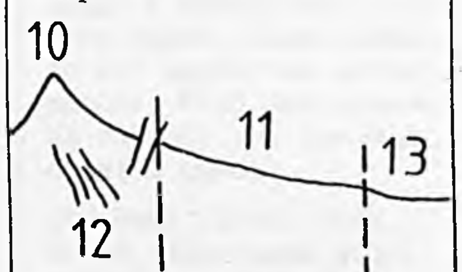
SANAM TERRAIN SYSTEM

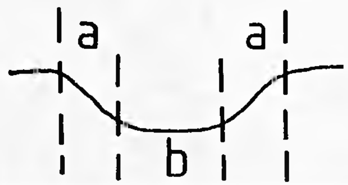
PLATE 4.25

FACET I3a ' Wadi slope '

PLATE 4.26

FACET I3b ' Wadi floor '

Facet No.	Name	Landform	Soils, Materials and Hydrology	Landcover
10 incl. facet	Jabel Sanam	Isolated and small but prominent hill about 150 metres high and 2 kms. long, above the low-lying Dibdibba plain	No soil. Basic igneous rocks, marl, gypsum and limestone materials. Dibdibba formation (sand and gravel on the masses' surfaces) Blown sand and residual gravel and alluvium on the wadis of the Jabel floor. A youthful radial drainage system has developed with individual wadis not exceeding the third order on the Jabel surface.	Bare.
11	Plateau of Sanam	Moderate to gentle almost straight slopes. 	Sandy loam soils. Dull yellow orange (10yr 6/4). Slight alkalinity blown sand and reworked gravel on the gradient of the plateau. Alluvium material in the floor of the small gullies. Sand and gravel mixed at depth.	Very sparse to sparse vegetation cover. No value for grazing. Roots extend to 10cm. at depth.

Facet No.	Name	Landform	Soils, Materials and Hydrology	Landcover
12	Gullies of Sanam	(a) Gully side-slope: moderately steep slopes - short slopes. (b) Gully floor: Flat, 10m approx. in width. 	Sandy loam soils. Dull brown (7.5yr 6/3). Medium alkalinity. Sand and gravel mixed at depth. Sand and fine gravel on the base. Sandy loam soils. Dull brown and yellowish brown (7.5yr 6/3 and 10yr 5/6) Slightly alkaline. Fine material. Gully floor is a dry water course.	Very sparse vegetation cover (0-20%). Sparse vegetation cover (20-40%).
13	Wadis of Sanam	(a) Wadi side-slope: Gentle slopes, convex. largely unnoticable and very broad. Slope sides do not appear on aerial photos. Wind and seasonal run off are the main erosion agent. (b) Wadi floor: Flat, broad floor some small gullies on these floors.	Sandy loam soils. Dull orange (7.5yr 7/3) to light yellow orange (7.5yr 8/3). Low organic matter. Mixed sand and gravel. Pebbles occur freely on surface. Sandy loam soils. Dull yellow orange (10yr 6/4) Slight to medium alkalinity. Sand and fine gravel at depth. Dry wadi courses*, and underground water.	Very sparse vegetation cover. Moderately sparse vegetation cover. Grazing element. Bedouin settlements.

*The wadi courses only carry water during the wet seasons or after heavy rainstorms. The wadis of this nature are locally known as 'Shuaib'.

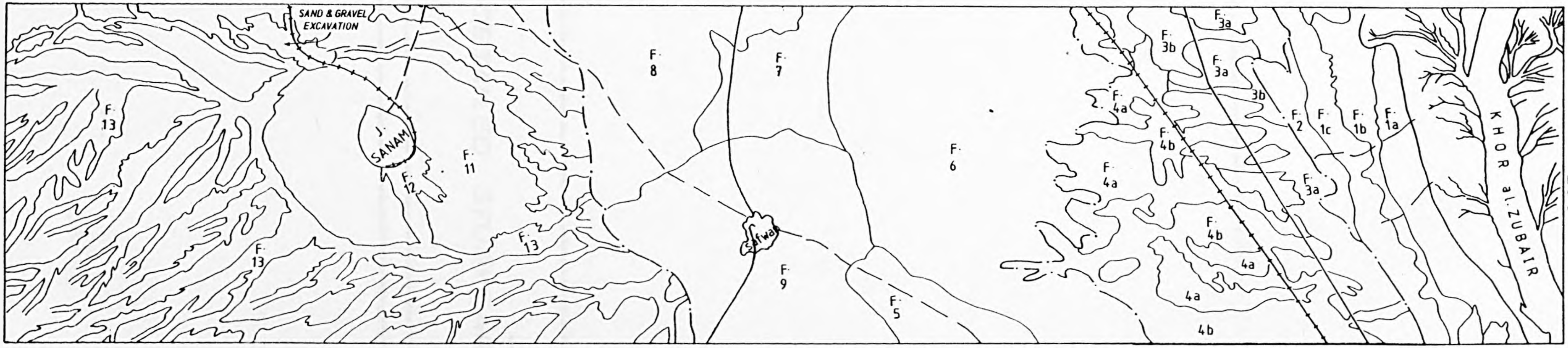


FIG. 4.27: TERRAIN FACETS OF THE DETAILED STUDY AREA.

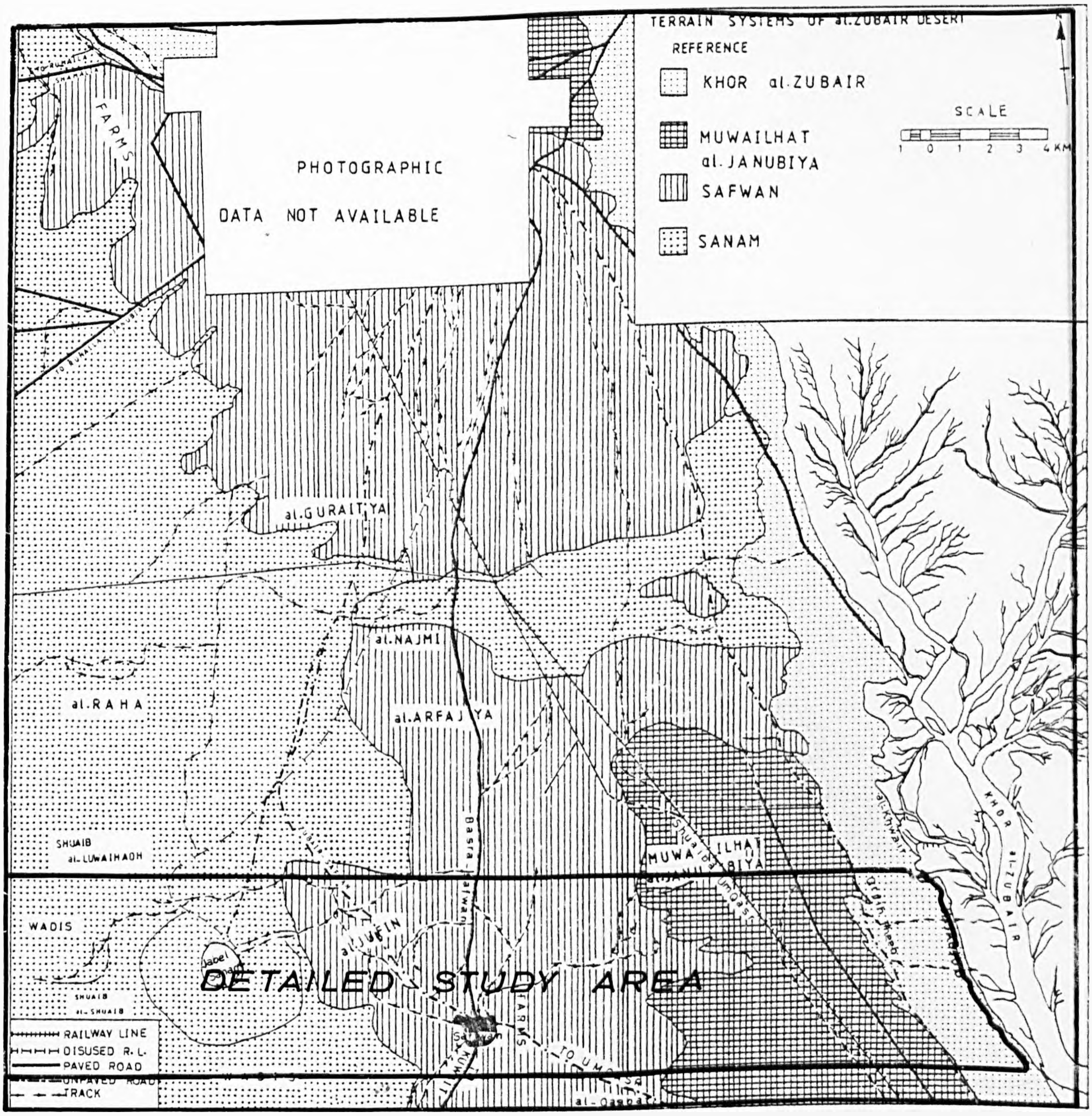
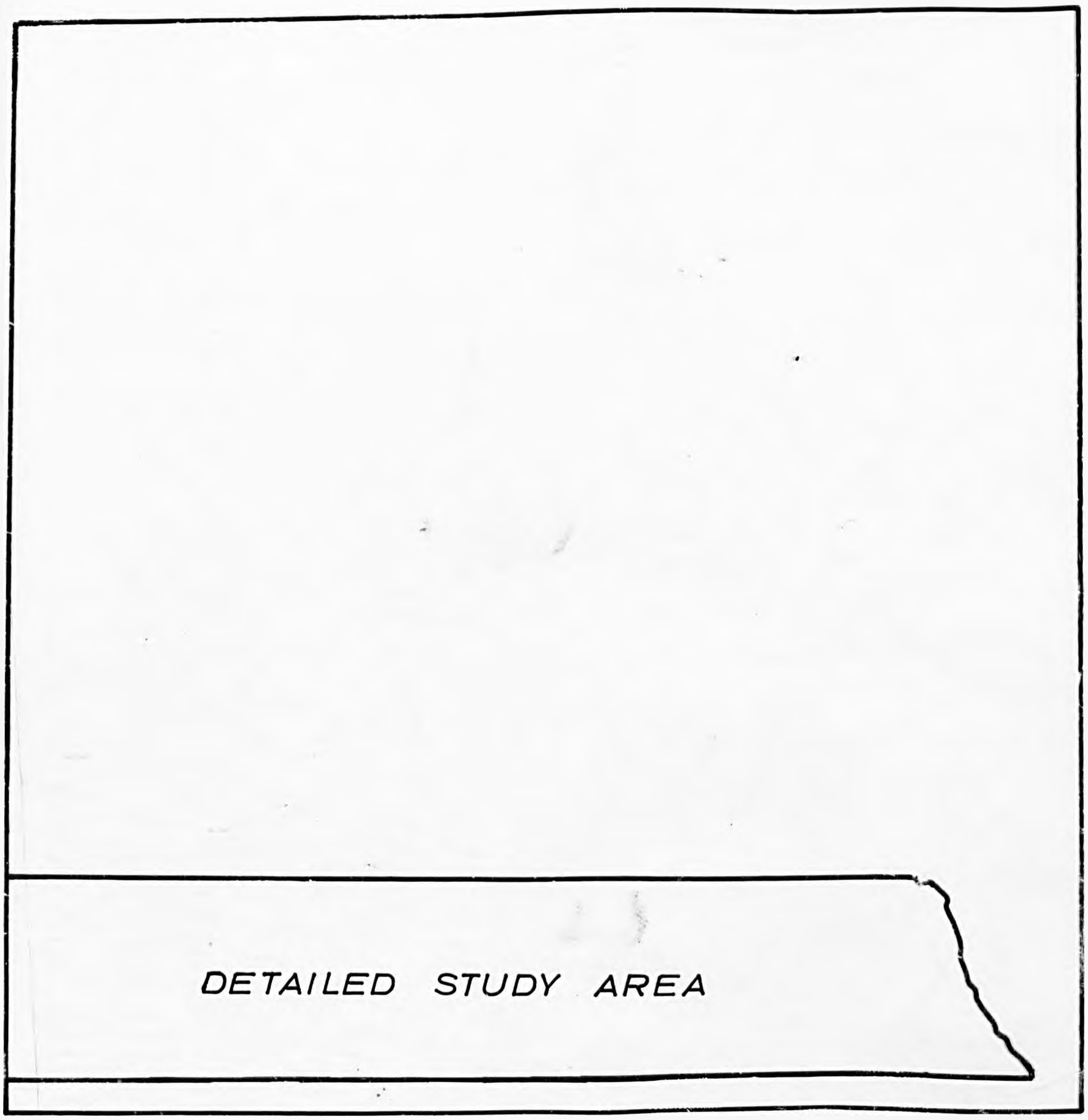


FIG. 4.28: Terrain systemsof al.Zubair Desert


DETAILED STUDY AREA

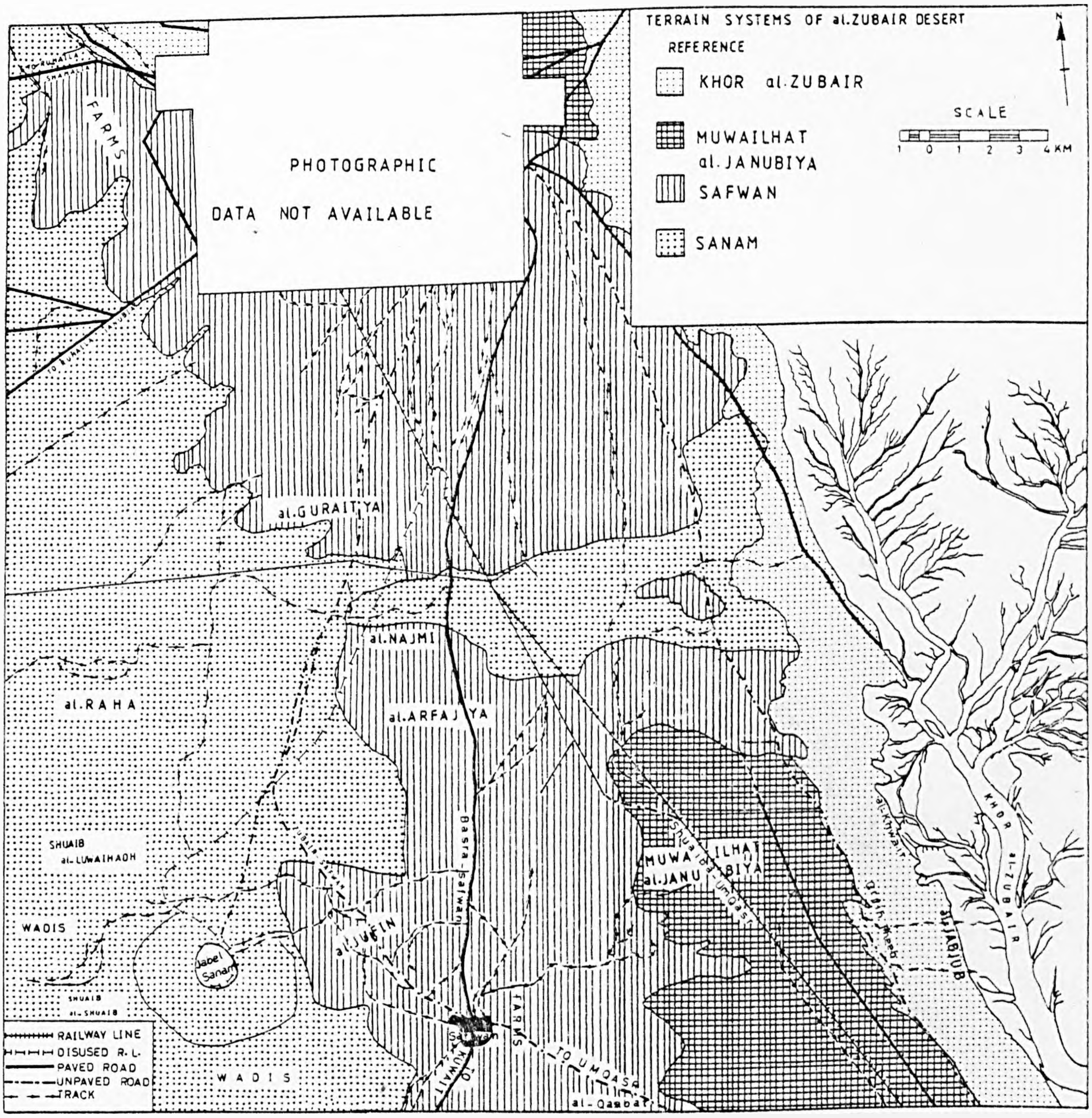


FIG. 4.28: Terrain systemsof al.Zubair Desert

CHAPTER V

PHYSICAL, MINERALOGICAL AND ORGANIC PROPERTIES OF THE SOIL.

PHYSICAL, MINERALOGICAL AND ORGANIC PROPERTIES OF THE SOIL

5.1 INTRODUCTION

Terrain systems and facets have been identified in the study area on a basis which is similar to that used for studies of this type carried out elsewhere. It has been noted (Section 4.3) that variations in the method of such identification can be expected according to the purpose for which the terrain classification is made. However, in all cases in which the landscape approach to terrain classification is adopted (as it has been here), it is fair to say that the terrain systems and facets are identified on the basis of general properties of landform, soil, vegetation etc. even though, commonly, modal values for some quantitative measures of terrain properties may be established. Specific and detailed properties of the terrain are not assessed in determining the classification. Yet, one use which may be made of such a terrain classification is to form the basis for prediction of more specific properties of the terrain. Such is the case in this study.

Attention is to be focussed on the value of the terrain classification for identifying significant variation in particular soil and surface material properties. A number of reasons exist for the choice of soil properties rather than any other landscape feature. Firstly, there is no doubt that in this area of limited topographic variety and sparse vegetation that soil represents the single most important landscape feature. Secondly, and following on from the first reason, it is variation in soil properties that can be expected to be most significant for determining the economic value of particular parts of the study area. Soil properties will be especially important for determining future agricultural land use potential, the availability of construction materials and the siting of engineering structures. Thirdly, through an understanding of the soil one can expect to develop a greater understanding of the genesis of the landscape. If a terrain system is to be seen as more than merely a convenient mapping unit and to comprise a group of genetically linked facets, then this should become more apparent from a study of soil properties. We may expect, therefore, that a study of the soil properties will help establish a stronger conceptual framework for the terrain classification already achieved. Fourthly, soils in Iraq have received little attention from soil scientists to date;hence a contribution to the understanding of the soil and surface materials within the study area is one of the most valuable contributions that a study of this type can make. Bearing in mind the limited amount of time and equipment, however, only selected properties are discussed in this chapter, namely particle size, shape and surface texture, organic matter content, pH, calcium carbonate content, clay mineral analysis and soluble salt determination. Pebble shape was assessed by axial measurements taken in the field and subsequent processing of the data. The size, shape and surface texture of the sand grade material was analysed in the laboratory (see Appendix 4), as were the other listed properties.

5.2 PEBBLE SHAPE

Pebble sample sites were chosen as much as possible according to the landform types of the study area, to test for location correlation between pebble shape and the physiographic divisions. The classification of these sites is shown in figure 5.1. From each site, 25 pebbles were selected randomly and the three axes (Long (L) or (a), Intermediate (I) or (b) and Short (S) or (c)), measured in the field using calipers.

A great number of researchers have discussed the angularity and roundness of pebbles and the question seems to be an old one. Many shape indices have been suggested for this purpose. In almost all of these different methods and indices, the three axes (a, b and c) provide the basic data.

Several attempts have been made, since 1880, to classify pebble shape. Sorby's attempt (1880) to classify sand grains may be considered the first one. This included both genetic and shape differences. Pettijohn et al (1972) point out that "Wadell (1932) and Krumbein (1934) are largely responsible for our present day concepts of roundness and the use of a chart to estimate it. Later Powers (1953) proposed a scale based on two sets of images for grains of different sphericity." (p.83). Concepts and indices of Wentworth (1919; 1922 a & b); 1923); Wadell (1932, 1933); Szadeczky-Kardoss (1933); Zingg (1935); Russell and Taylor (1937); Krumbein (1939, 1941 a & b); Krumbein and Pettijohn (1938); Cailleux (1945, 1947); Pettijohn (1949); Powers (1953); Rosenfeld and Griffiths (1953); Folk (1955, 1972, 1977); Kuenen (1956); Aschenbrenner (1956); Sneed and Folk (1958); Faber (1960); Holmes (1960); Lees (1964); Williams (1965); Sames (1966); Griffiths (1967); Müller (1967);

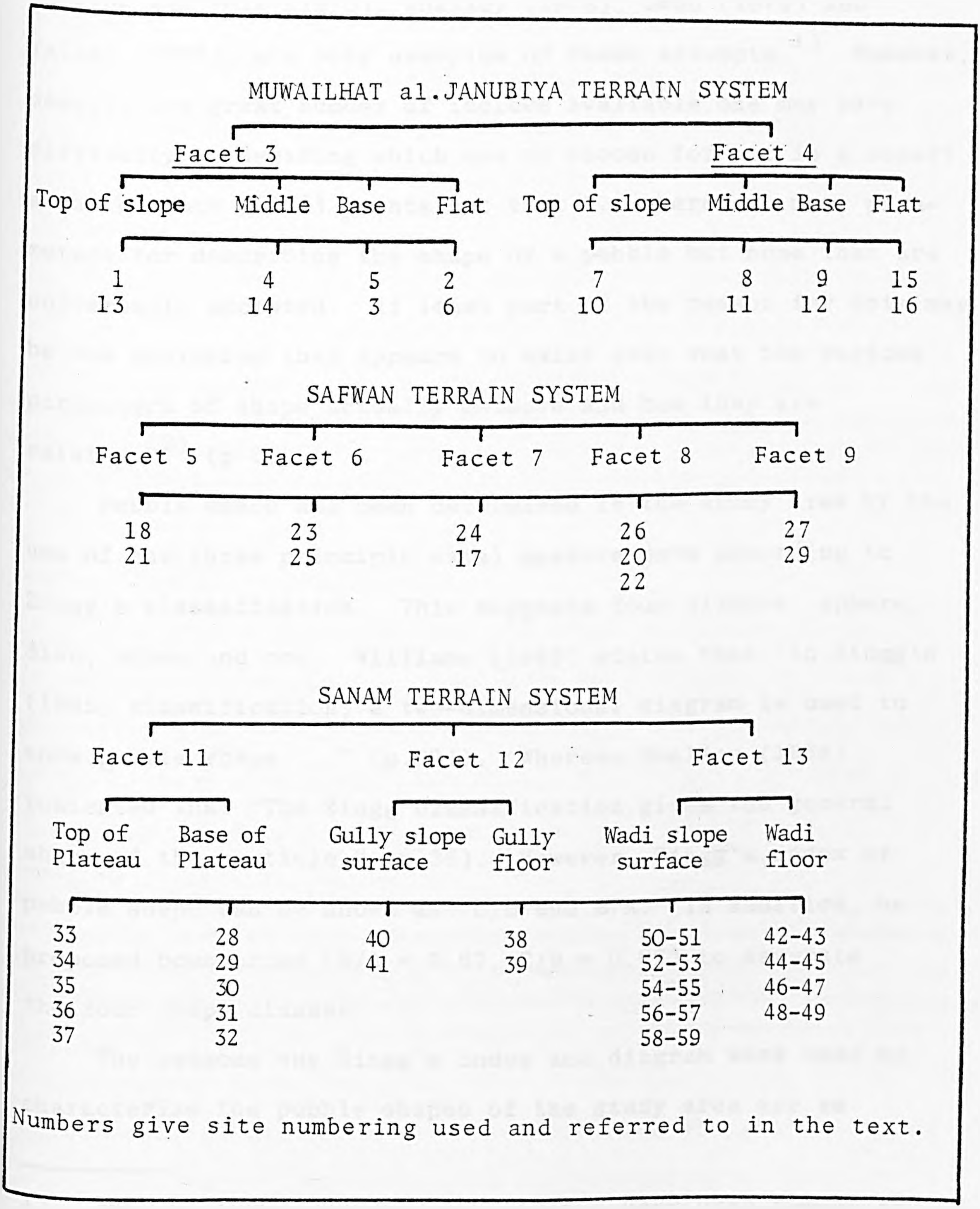


FIG.5.1: PEBBLE SAMPLING SITES IN THE DETAILED STUDY AREA.

Dobkins and Folk (1970); Whalley (1972); Swan (1974) and Taller (1976), are only examples of these attempts.[1] However, despite the great number of indices available one may have difficulty in deciding which one to choose for use in a desert area. Barrett (1978) points out that "...there are many parameters for describing the shape of a pebble but none that are universally accepted. At least part of the reason for this may be the confusion that appears to exist over what the various parameters of shape actually measure and how they are related."[2] (p.3). .

Pebble shape has been determined in the study area by the use of the three principle axial measurements according to Zingg's classification. This suggests four classes: sphere, disc, blade and rod. Williams (1965) states that "In Zingg's (1935) classification, a two-dimensional diagram is used to show pebble shape ..." (p.994). Whereas Smalley (1966) indicated that "The Zingg classification gives the general shape of the particle." (p.36). However, Zingg's index of pebble shape can be shown as: C/B and B/A. In addition, he proposed boundaries (B/A = 0.67, C/B = 0.67) to separate the four shape classes.

The reasons why Zingg's index and diagram were used to characterise the pebble shapes of the study area are as

---

1) Some of these concepts and indices have been summarised by, for example, al.Hamdan (1965) who gave a historical review of shape analysis, and the others were illustrated by Briggs (1977) and Barrett (1978).

2) The relationship between various aspects and the estimation of these parameters has been clarified by Barrett (1978).

follows:

1) Zingg's classification is probably best suited to beach and fluvial shingle description. As such it was considered acceptable for use on the pebbles of the wadis and flats of al.Zubair desert;
2) Zingg's classification has the practical advantage that it is time-saving, especially when the measurements are carried out in the field under the hot desert conditions;
3) Roundness can be easily estimated for measurements of axes and measurement of curvature are not necessary.

5.2.1 Results and Discussion

The results obtained from the axial measurements are presented in Appendix 5a. These data were plotted on Zingg's diagram (Appendix 5b) and the percentages of each of the four shape classes were calculated (Table 5.1). Also the mean of the C/B and B/A ratios were computed and then plotted on Zingg's diagram (Appendix 5c).

The total percentages (Table 5.2 and Fig.5.2) indicate that the disc shape makes up the highest percentages (average 33%) of the pebble shapes of the study area, whilst sphere shaped particles constitute lowest percentage of the population (average 19.18%). The remaining shapes (blade and rod) fall between the sphere and disc percentages (average 23.10% for blade shape and 24.8% for rod shape).

These pebble shapes differ slightly in their occurrence, i.e. within terrain systems and facets. Very few differences occur among the analysed shape values; for instance, the flat elements of Muwailhat al.Janubiya system reveal a high percentage of disc shaped material. Also disc-like pebbles form

Systems	Facets	Elements	% Sphere	% Disc	% Blade	% Rod
Muwailhat al. Janubiya	3	T.S.	18	22	32	28
		M.S.	14	44	16	26
		B.S.	14	20	24	42
		Flat	8	40	32	20
	4	T.S.	14	34	18	34
		M.S.	26	18	18	38
		B.S.	30	24	18	28
		Flat	12	36	28	24
Safwan	5		26	36	22	16
	6		16	36	30	18
	7		16	44	20	20
	8		21.3	26.6	22.7	29.4
	9		12	20	32	36
Sanam	11	T.S.P.	24	41.6	16	18.4
		B.S.P.	24	36.8	22.4	16.8
	12	G.S.	14	46	20	20
		G.F.	30	34	22	14
	13	W.S.	20	36.8	22.4	20.8
		W.F.	23	34	19.5	23.5

Illustration:

T.S. Top Slope
M.S. Middle Slope
B.S. Base Slope

T.S.P. Top slope of the plateau
B.S.P. Base slope of the plateau

G.S. & G.F. Gully slope and Gully floor
W.S. & W.F. Wadi slope and Wadi floor.

Table 5.1: Zingg shape class percentages for the pebbles of the detailed study area.

Terrain systems	% Sphere	% Disc	% Blade	% Rod
Muwailhat al. Janubiya	17	29.75	23.25	30
Safwan	18.30	32	25.30	24.40
Sanam	22.25	37.25	20.50	20.0

Table 5.2: Total Zingg shape percentages of the measured pebbles of the detailed study area.

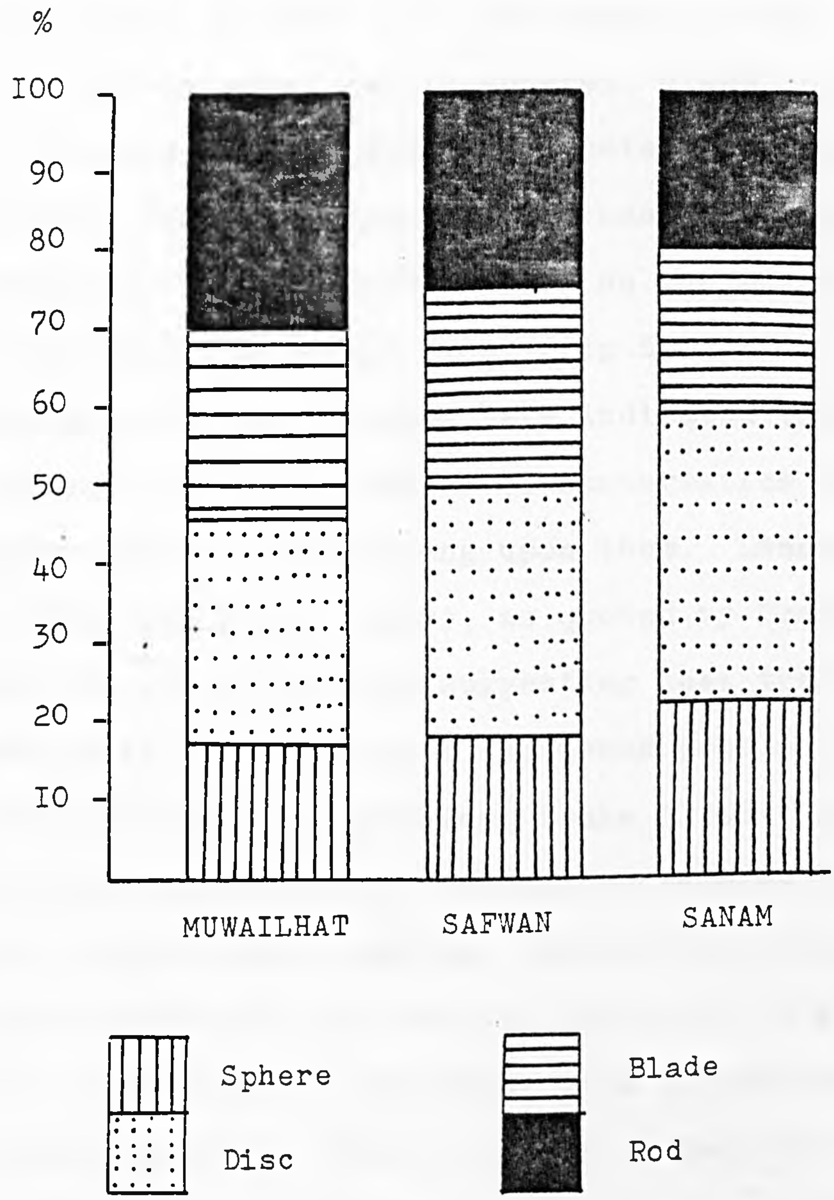
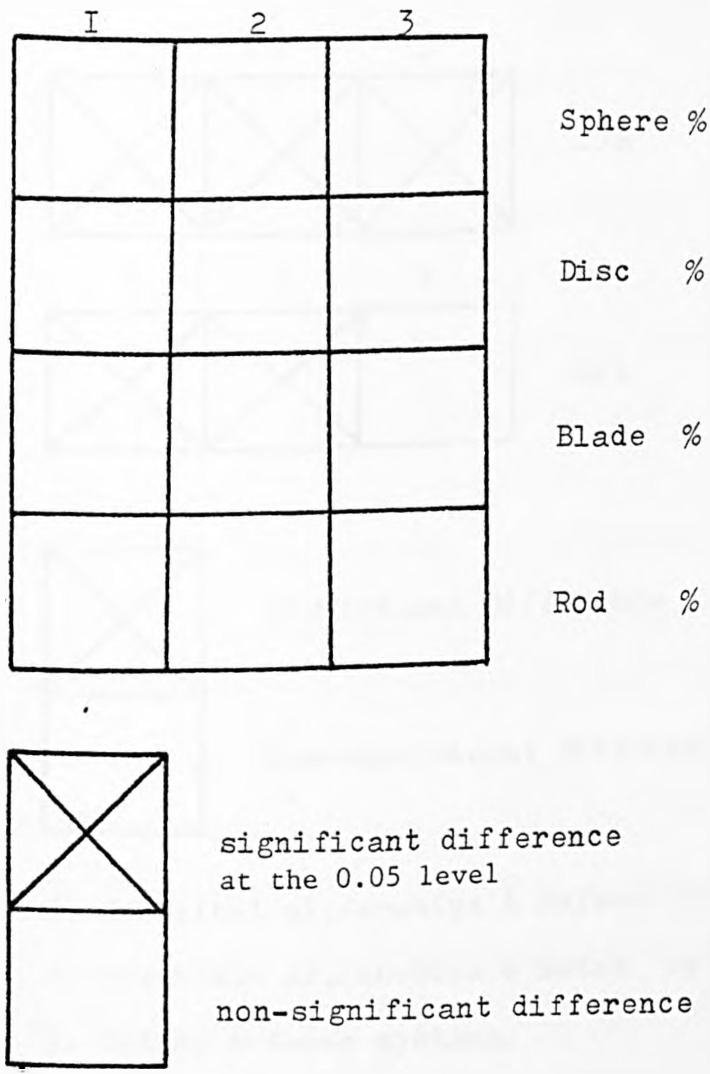


FIG. 5.2: Total Zingg shape percentages of the measured pebbles of the detailed study area.

a high percentage in Facet 7 of the Safwan system. None of these shape percentages, namely sphere%, disc%, blade% and rod% did show significant difference between systems (Fig.5.3). The only significant differences that can be discerned are those among the terrain systems based on the means of all values of C/B and B/A pebble axes. (Fig.5.4).

Nevertheless, many studies have indicated that pebble shapes reflect the environmental characteristics or processes which produce them or are acting upon them. Landon (1930), Russell (1939) and Blatt (1959), as quoted by Drake (1970), emphasised the above point by suggesting that the beach environment selectively favours flattened pebbles, and stream action favours rod shaped pebbles. Drake (1968) himself suggested that spherical and disc-shaped pebbles are favoured by glacial abrasion and crushing. Considering these studies and in conjunction with the results obtained, it seems that the desert environment of the study area favours the production of disc-shaped pebbles. This, of course, does not mean that pebbles of other shapes are unimportant. For instance, rod shapes have a relatively high percentage frequency especially in Muwailhat al.Janubiya (average 30%): this is probably as a result of fluvial action, when pebbles roll down from the top of the slope to the base and are progressively modified. It is believed that the shape of pebbles in the study area depends on a variety of factors, an important one being the nature of the rock material. It has been mentioned in chapter 3 that al.Dibdibba area comprises sand and sandy gravel materials. Sand may sometimes be mixed with fine gravel, but the layers sometimes contain occasional pebbles.[3] This pebble material obviously

3) Owing to the nature of the Khor al.Zubair terrain system which exhibits such fine material, no pebbles have been observed on the surface

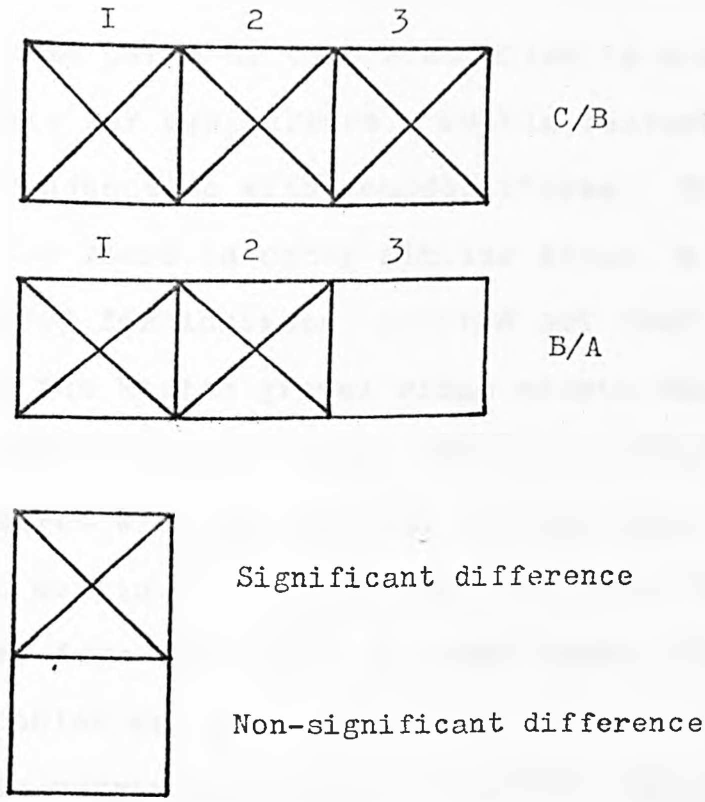


I. Muwailhat al. Janubiya & Safwan systems .

2. Muwailhat al. Janubiya & Sanam systems.

3. Safwan & Sanam systems.

FIG. 5.3: Comparison of three systems of the detailed study area based on Zingg shape class percentages for the pebbles of these systems. None of the comparisons show significant differences at the 0.05 level of Student's 't' test.



I. Muwailhat al.Janubiya & Safwan systems.

2. Muwailhat al.Janubiya & Sanam systems.

3. Safwan & Sanam systems.

FIG. 5.4 : Comparison of three systems of the detailed study area based on means of all measured C/B & B/A pebble axes for the facets of the above systems . Of the 6 comparisons,5 show significant difference at the 0.05 level of Student's 't' test.

covers some parts of this area which is considered as unsuitable for agriculture. Pebble features here mostly are in conjunction with rounded ridges. Such gravel ridges are found in other similar areas, e.g. Saudi Arabia. Holm (1960) for instance, pointed out that "... a gravel feature, the Wariah gravel ridge exists which is quite a puzzle. This ridge is about 100 kilometres long and 1 to 2 kilometres wide and extends east and west, along the southern margin of al.Dibdibba." He added that "It is protected from erosion by a heavy cover of coarse-to-medium sized cobbles and pebbles, and is about 10 to 20 metres above the surrounding plain." (p.1375). The origin of the pebbles is also important to their shape as is the nature of the area and its environmental characteristics. The origin of rock fragments, when they are removed from the bedrock, may help to determine the final shape of the pebbles. Sugden (1964) for example, suggested that the pebbles of the desert of southern Iraq (of which the present study area is a part) belong to a great variety of hard rocks of volcanic origin. They originate either from the Arabian shield area to the south-west of Iraq or from the Zagros mountains to the north-east of Iraq, and have been mixed with enormous quantities of pebbles of sedimentary origin e.g. the limestones of southern Iraq. He added that "At the present time pebbles of volcanic rock are not being transported to the Zubair region from outside, and it seems unlikely that circumstances differed in this respect during the Pleistocene." Similar criteria indicative of past climatic conditions in desert regions have been studied by Schoewe (1932). The observations on the pebbles of the study area support Sugden's (1964) observation. He pointed out that "Most of the pebbles clearly exhibit the smoothing effect of sand blast and a large proportion of them, particularly of the smaller sizes are facetted pebbles." (p.67). Examples of such facetted pebbles from the study area are shown in plates 5.1 and 5.2.

The facetted pebbles, however, show characteristics of both sub-aqueous and aeolian origin (i.e. rounded pebble shape and mechanical features on the surface of the pebbles), whereas those which are not facetted have shapes such as ordinarily result from grinding during water transport, any protruberances being well blunted and rounded thereby. The deposition of the embedded or loose pebbles are not related to the prevailing wind, and appeared to be distributed in a random manner. Thus, the facetted and unfacetted pebbles are moved and mixed during the processes of sand blasting as a major agent and water erosion (becoming water worn) as a minor agent. On the other hand, due to the nature of the study area (sandy and sandy pebble deposits), wind plays the most significant role in affecting the small particles (like the coarse and medium sand) of the desert area.

5.3 THE SANDS

5.3.1 Sand grain shape

A study of shape and surface texture of sand grains may be used to assess the importance of certain environmental influences and to characterise the sand grains in a desert area. There are several methods available for describing

PLATE 5.1

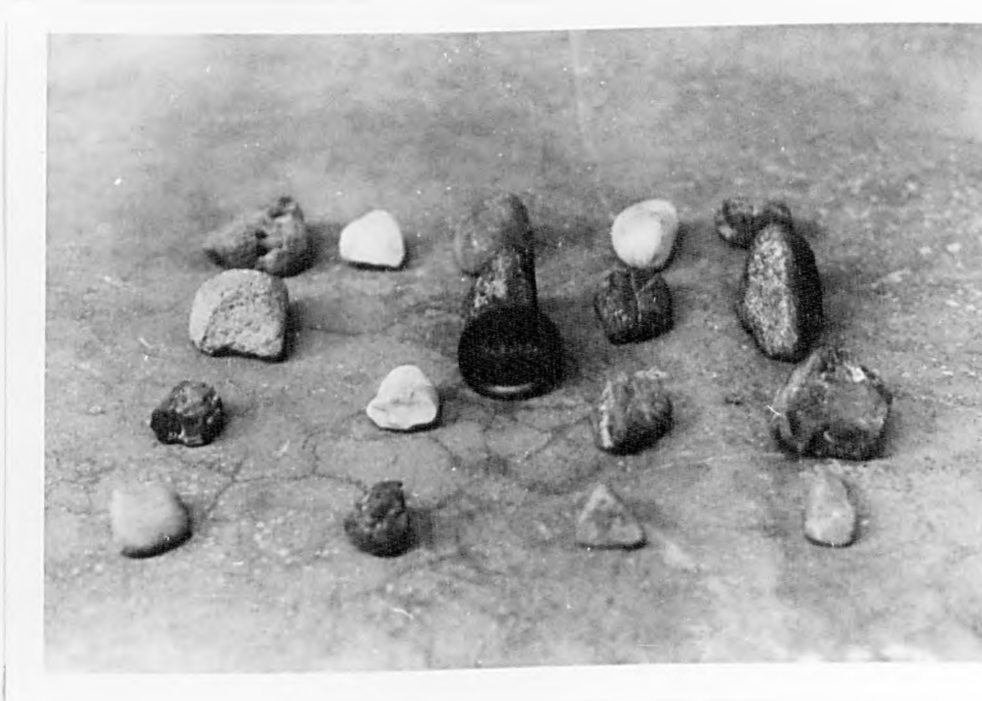


PLATE 5.2

Examples of surface pebbles from the study area the shape of a grain. Some of these involve comparing the grains with standard charts. Shakely (1975) pointed out that "These charts usually refer to the two most important characteristics of grain shape - the grain roundness and the grain sphericity." (p.46).

It is pointed out by Griffiths (1967) that "ultimately as in the use of size measurement, the requirement of shape measurement will terminate with a number of some scale, and the value of this scale in terms of information concerning some specified objective will determine whether the number has any meaning." (p.111).

However, it has been found that the sand grains of the study area show variable roundness: shape examination of 1158 sand grains selected from the samples to represent the different terrain systems was undertaken in an attempt to determine their degree of rounding. These grains have been studied under the microscope and compared with Powers' (1958) visual comparator chart (Fig. 5.5). Shackely (1975) stressed that this chart "... is the most widely used device for grain roundness description ... it is particularly used for quick shape description." (p.49). In addition, the sphericity of selected grains has been described according to the visual comparator chart of Rittenhouse (1943; see Fig.5.5). Results obtained from the microscopic examination of the shape of the sand grains have been tabulated in Appendix 6, and shown in figures 5.6 and 5.7 .

It can be seen from figure 5.6 a and b, that the study area is composed of a mixed population of rounded sand grains. Figure 5.6a and b also shows that the rounded and well-

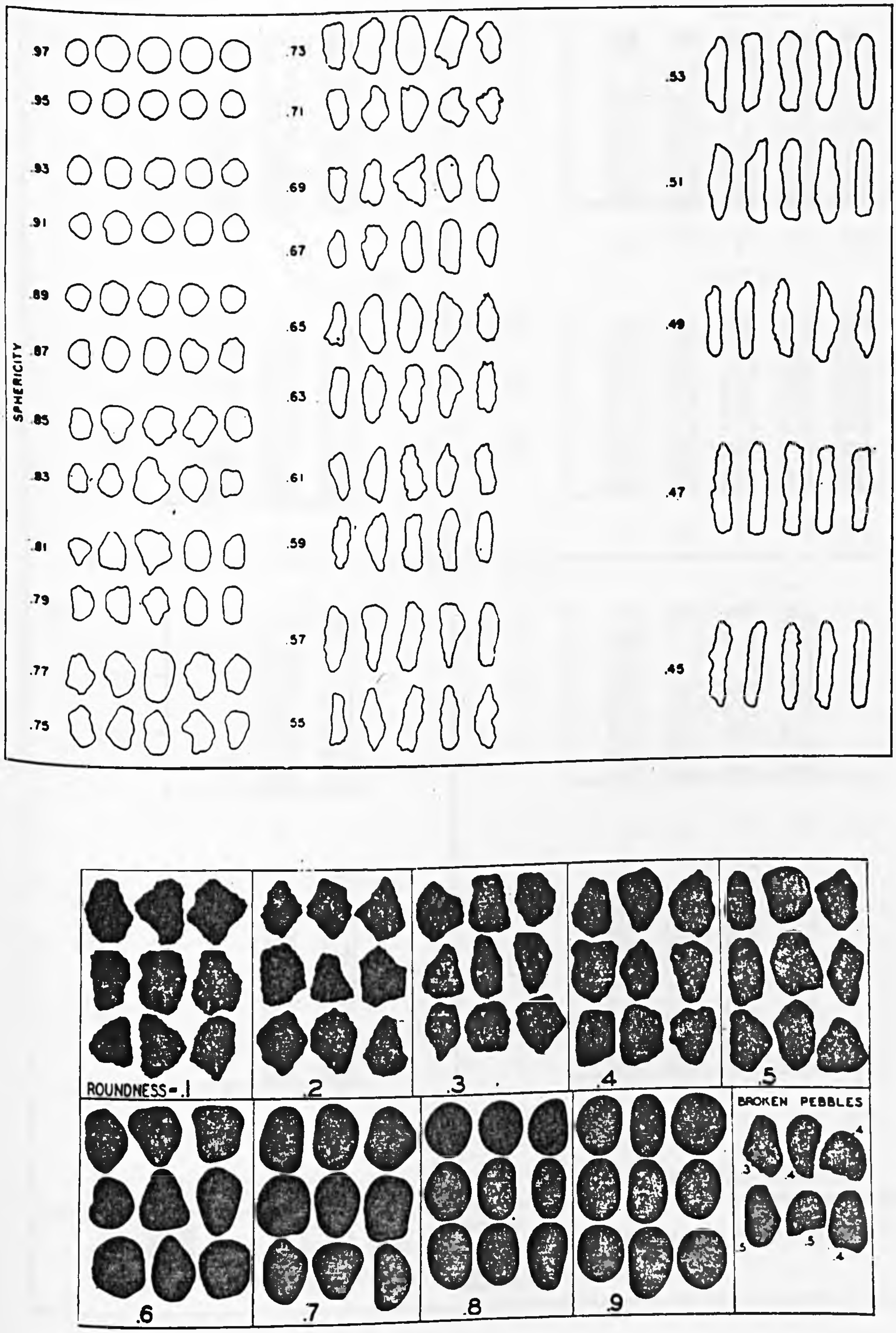


FIG. 5.5: ROUNDNESS CHART OF POWERS (1958), AND SPHERICITY CHART OF RITTENHOUSE (1943).

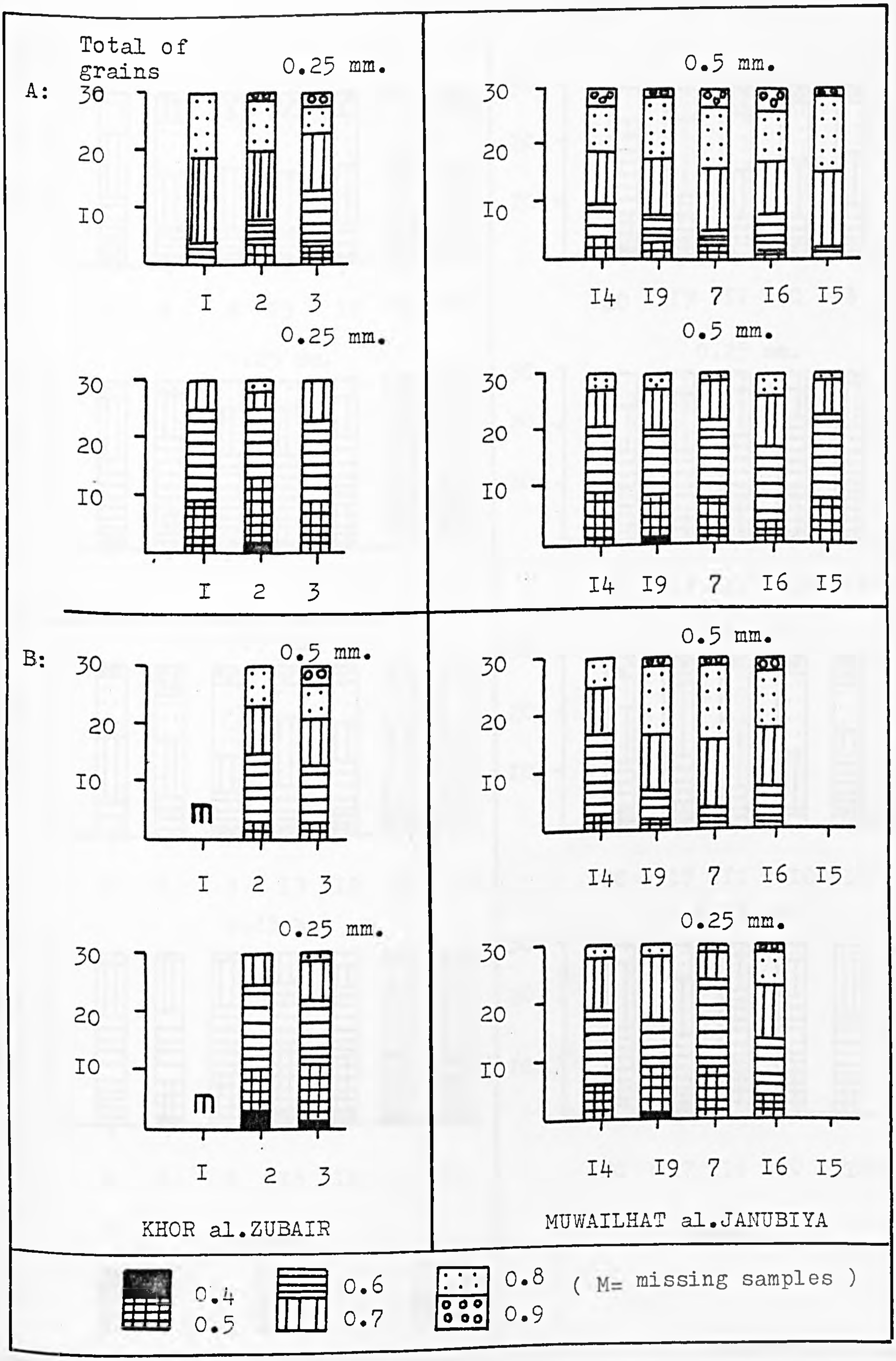


FIG. 5.6: ROUNDNESS OF SAND GRAINS USING LIGHT MICROSCOPIC EXAMINATION. SAMPLES WERE TAKEN AT DEPTHS: A: 0-15cm AND B: 15-30cm. BASED ON POWERS (1958) COMPARATOR CHART OF ROUNDNESS.

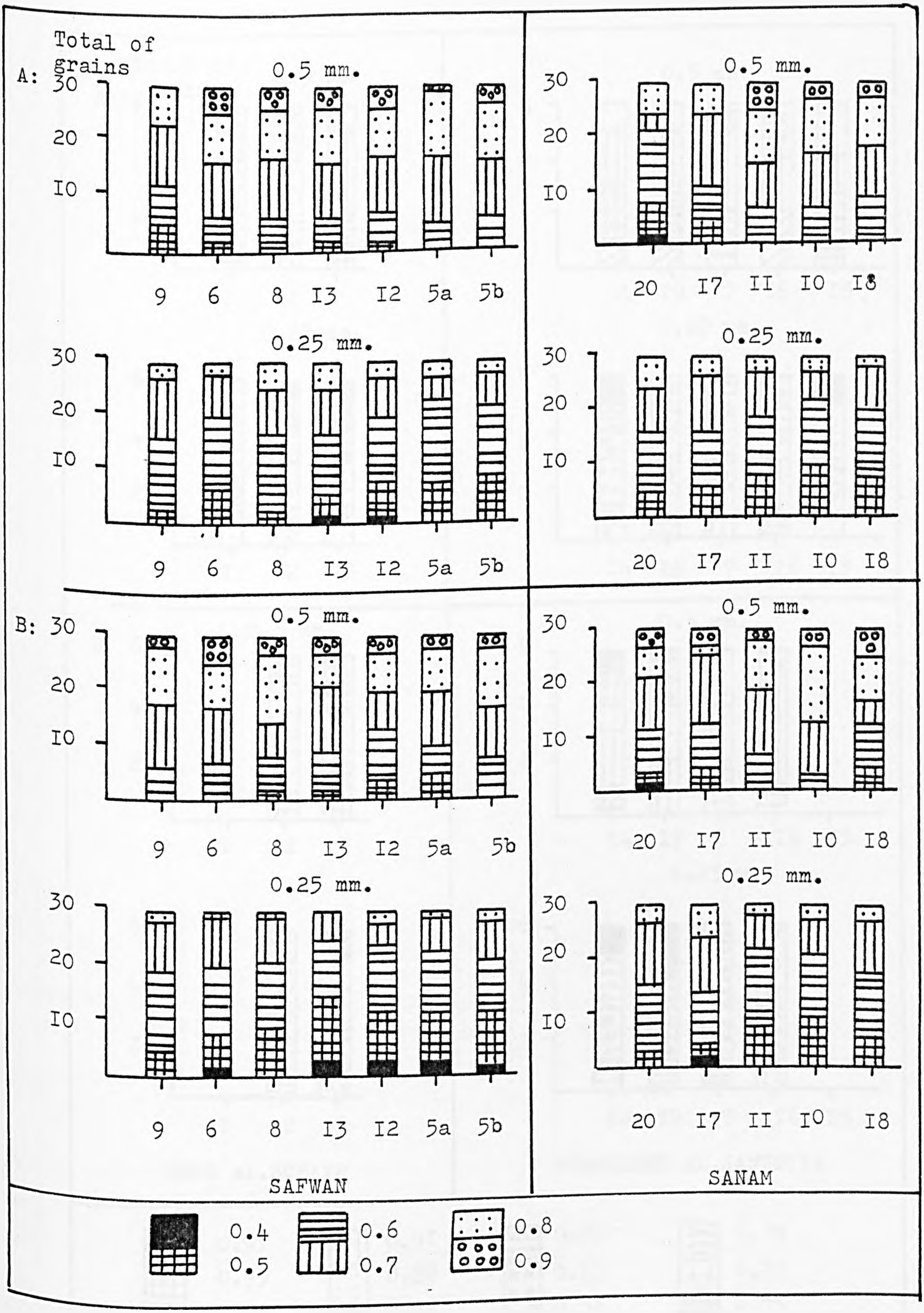


FIG. 5.6: CONTINUED.

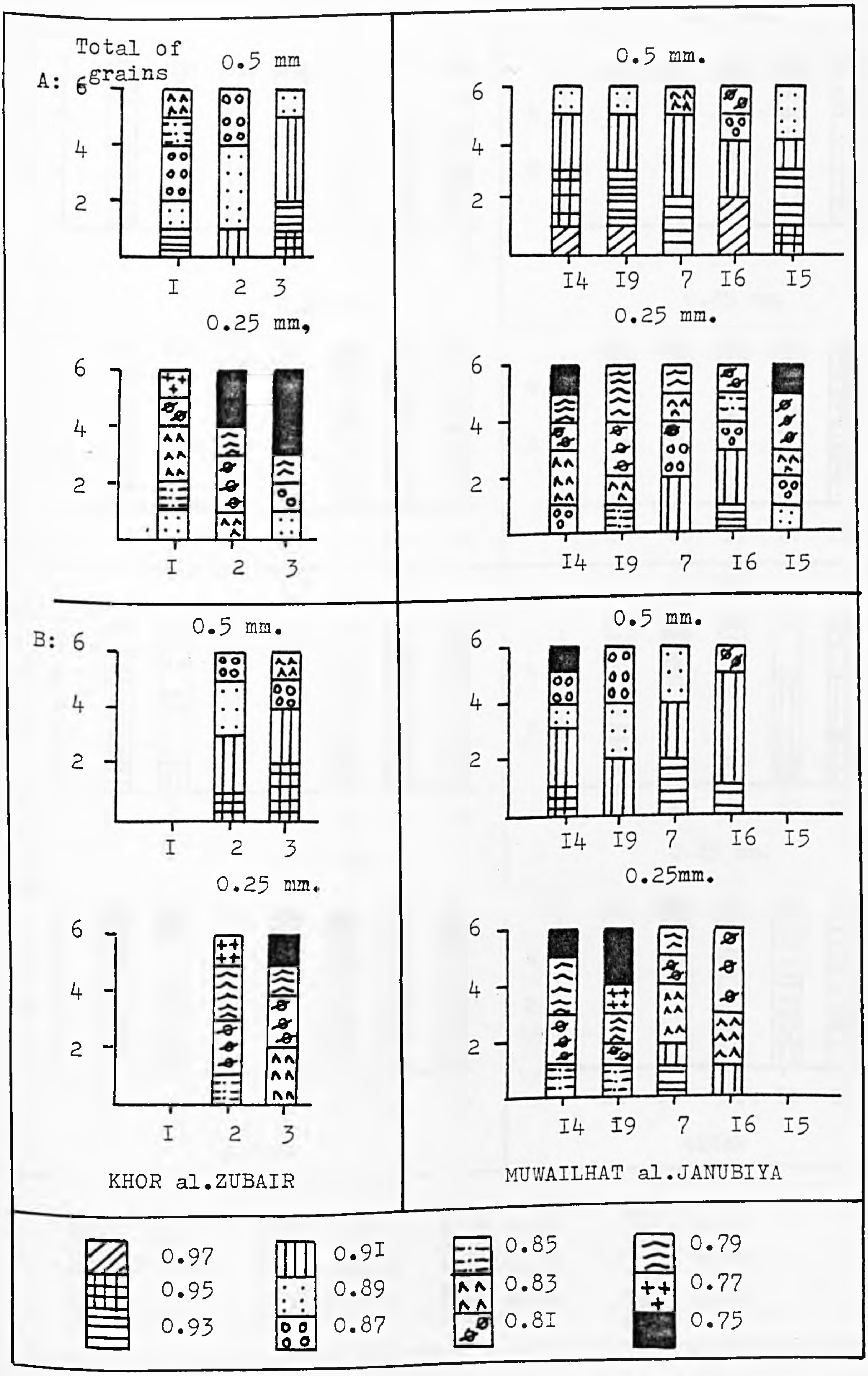


FIG. 5.7: SPHERICITY OF SAND GRAINS USING LIGHT MICROSCOPIC EXAMINATION. SAMPLES WERE TAKEN AT DEPTHS: A: 0-15cm AND B: 15-30cm. BASED ON RITTENHOUSE (1943) COMPARATOR CHART OF SPHERICITY.

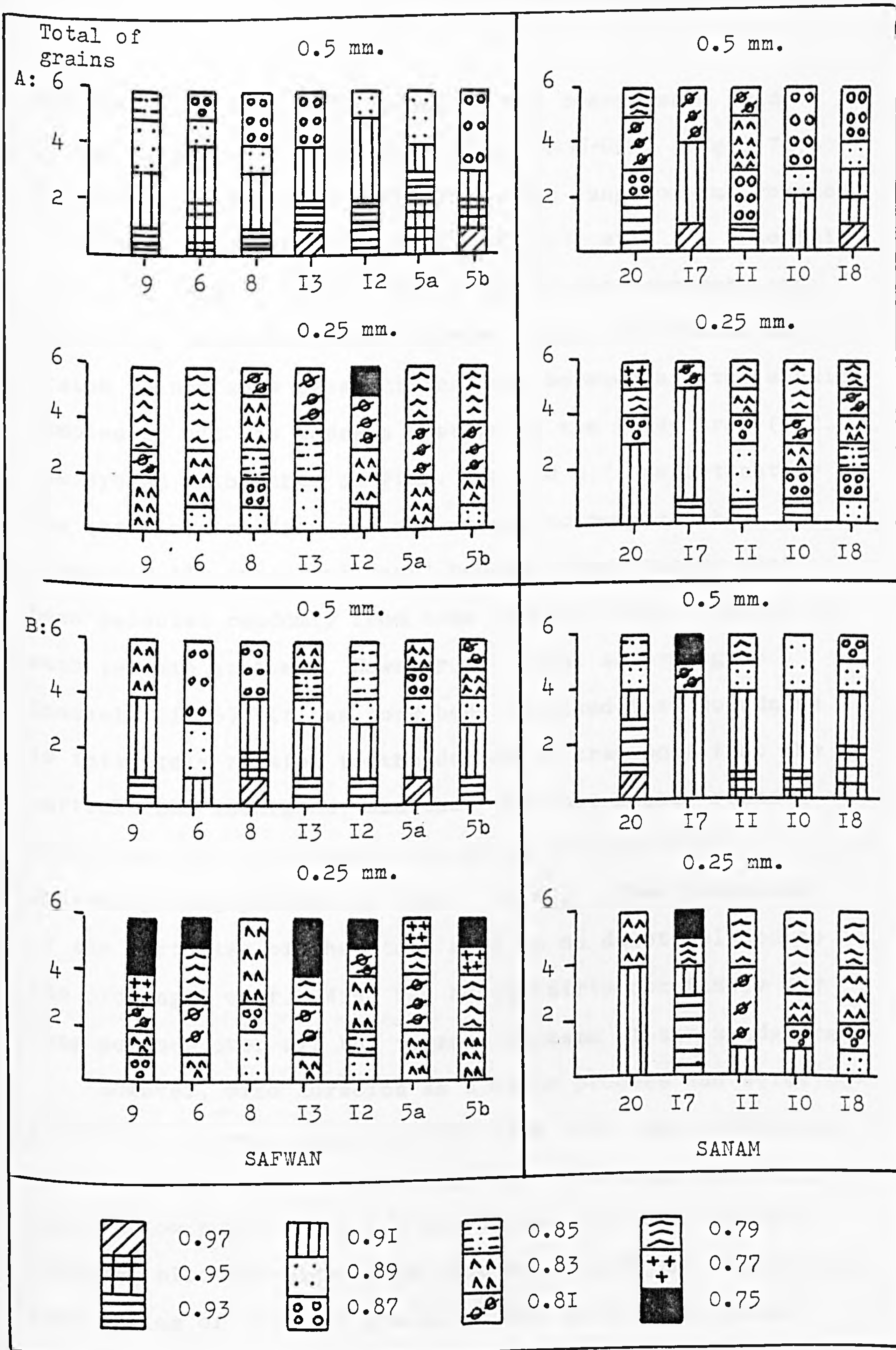


FIG. 5.7: Continued.

rounded grain (0.6-0.8) belong to the coarse sand grade (0.5mm) which have high sphericities (0.97-0.87) (Fig.5.7a,b). The medium sand grains fall within the range of sub-rounded to rounded grades (0.5-0.7) (Fig.5.6 a,b), with low sphericity (0.87-0.75) (Fig. 5.6a,b). The trend of the roundness and sphericity characteristics between coarse and medium sand grains do not show great differences between all the studied samples of all the terrain systems in the study area (c.f. one system with other on Figs. 5.6 and 5.7; unfortunately the quantitative data are not enough to compare them statistically (e.g. 't' test) because these grains have been selected randomly from some representative samples of each terrain system.). However, at least according to Shackely (1975) "It has long been realised that roundness is intimately related to the degree of transport that the particle has undergone, and that the most highly rounded particles have often been undergoing transport for extremely long periods of time." (p.50). Thus roundness of the particles of the study area is no doubt related to the prolonged wear. Wind has acted fairly constantly for long periods over all the terrain systems of the study area.

However, wind abrasion as a major process and solution-precipitation as a minor process have left their influence on the sand grains. Selected grains were examined initially under a low power (optical) microscope and later using a scanning electron microscope. The results of the microscopic examination of the sand grains of the study area reveal that 1116 out of 1140 grains have a frosted surface texture whilst the remaining 24 grains exhibit vitreous surface textures. This characteristic is thus universal and shows no significant variation from one part of the study area to another.

It has been suggested by Krinsley and Doornkamp (1973) that "The light microscope ... is not sufficient to resolve fine surface detail on quartz grain particles which are less than about 1mm in diameter." (p.3) and the scanning electron microscope has been increasingly used for examination of sand grain surface textures. (See, for example, Brown, 1973; and Whitney, 1979). The 'Atlas of quartz and surface textures' by Krinsley and Doornkamp (1973) is the most accessible general to guide the description of sand grains using the SEM. For this purpose, one hundred and sixteen coarse and medium sand grains were selected, examined and photographed. Two levels of magnification have been used in this analysis. These are 200x and 100x. Others, for example 20x, are used only for obtaining a general view of a group of grains. The photographs obtained by using the SEM reveal that almost all the grains are rounded, an expected result of wind abrasion.

Several factors affecting grain surface features must be considered when describing the surfaces of sand grains in the study area. Such factors were considered by Krinsley and Doornkamp (1973) and may be summarised as follows:

1) Solution and precipitation tend to modify the plates of the grain surface and produce a 'rolling' topography and, of course, the degree to which this occurs on grains is a function of the energy available especially in the hot desert environment.
2) The smoothness of the quartz sand grain surface may be related to the solution and precipitation processes especially when they are extreme. This smoothness is explained and described by Krinsley and Doornkamp (1973, p.16).

3) Well rounded grains without edges and especially the larger grains (0.5mm in diameter) are frequently spherical, e.g. plates 5.3,5.4,5.8,5.9,5.11 and 5.13. Some grains are elongated, but still rounded (plate 5.15). These shapes have probably been inherited from the source rock (see chapter 3, section 3.4.1).

4) Dish-shaped concavities are present on the surface of several of the examined grains (plate 5.24). "These are probably formed during periods of violent abrasion related to strong wind storms and represent conchoidal chips which have been broken from the surface by a single mechanical event. This process tends to decrease grain roundness. The surfaces of these depressions on hot desert grains usually contain solution-precipitation features." (Krinsley and Doornkamp, 1973, p.17).

5) Smaller, less rounded grains include flat upper and lower surfaces with irregular grain ends and may include conchoidal breakage features (plate 5.22). Such a grain is "... mostly carried in suspension in the aeolian environment and thus the never experiences the violent collisions which create the mechanical features on larger grains. Instead, they are attacked chemically ... (e.g. solution and precipitation) ... and with time become moderately rounded, although never as well rounded as the larger grains. Edges are still present although they may be more or less rounded." (Krinsley and Doornkamp, 1973, p.17). See plate 5.10.

6) Very few grains showed surface cracks (plate 5.21). This is a chemical phenomenon which results in irregular cracks ending in pits.

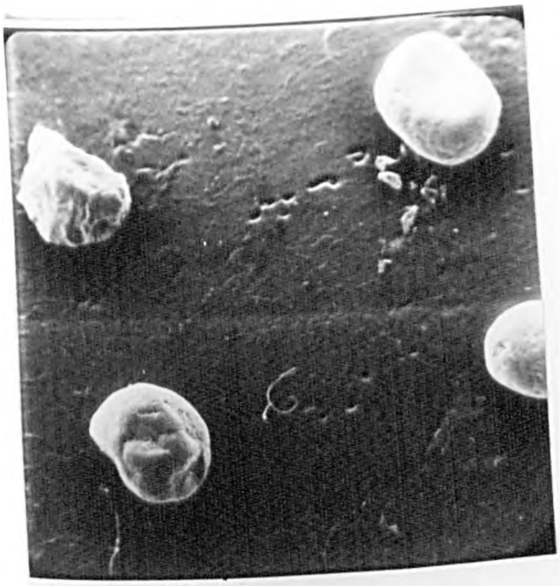


PLATE 5.3

A general view of grains showing surface smoothness and rounding.
Large grains (0.5mm in diameter) show the smoothness and rounding whilst the grain at the top-left (only 0.25mm in diameter) shows less rounding.

Mag. 20 X

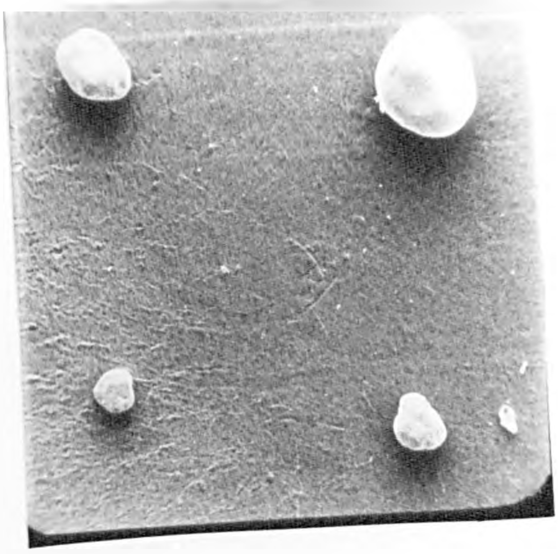


PLATE 5.4

Elongated grains with well developed edge rounding.

Mag. 20 X

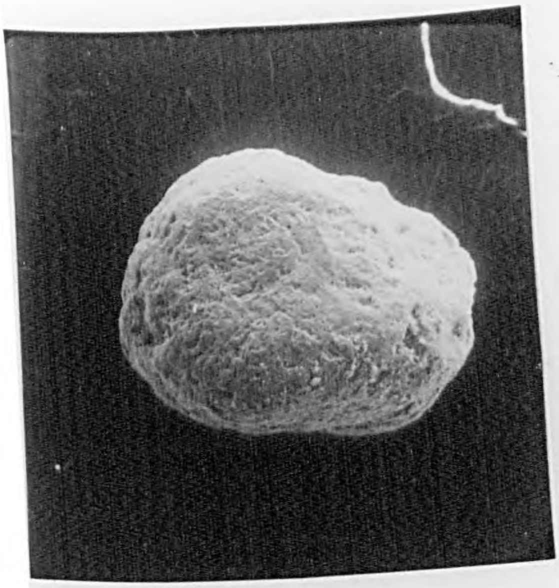


PLATE 5.5

Rounded grain with solution-precipitation.
This large grain (0.5mm in diameter) is well rounded but surface smoothing is the result of solution-precipitation.

Khor al.Zubair terrain system
Mag. 50 X

PLATE 5.6

Small rounded grain (0.25mm in diameter).
Surface of the grain shows several depressions which may be the product of mechanical process.

Khor al.Zubair terrain system
Mag. 200 X

PLATE 5.7

Upturned plates, solution and precipitation.
This large grain (0.5mm in diameter) has been transported either by wind or water and deposited in this area.

Khor al.Zubair terrain system.

Mag. 200 X

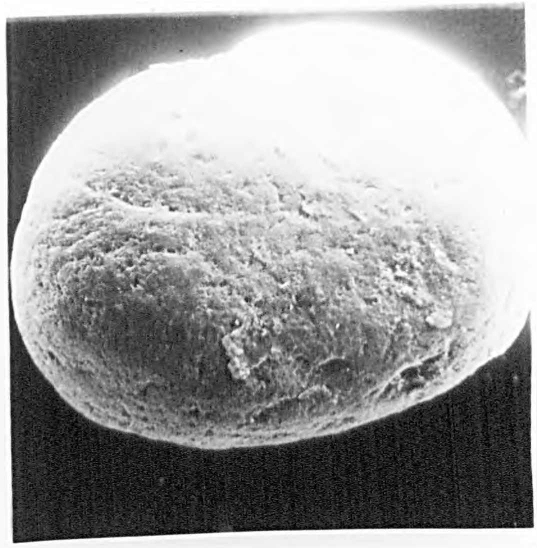


PLATE 5.8

This large grain (0.5mm in diameter) is well rounded. Some shallow depressions can be seen on the surface of the grain.

Khor al.Zubair terrain system.

Mag. 100 X

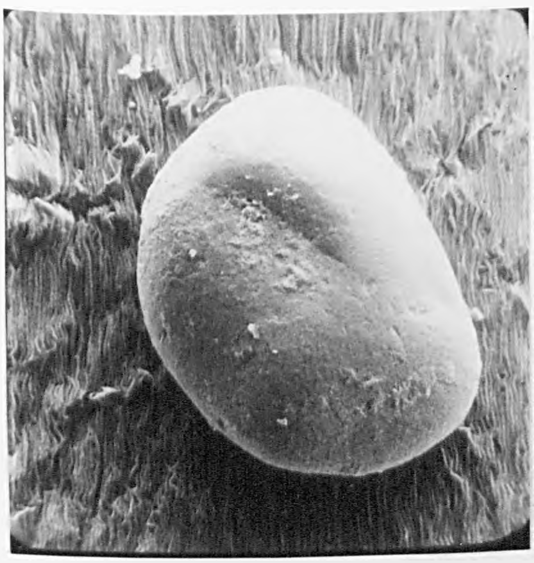


PLATE 5.9

Grains in the upper layers are usually well rounded. This large grain (0.5mm in diameter) is well rounded with a depression resulting from mechanical action, cf. Plate 5.10.

Muwailhat al.Janubiya terrain system

Mag. 100 X

PLATE 5.10

Large grain of sub-layer of the soil. It is also rounded but not as well rounded as the specimen in Plate 5.9. Some depressions can be seen, probably resulting from rapid chemical action.

Muwailhat al.Janubiya terrain system.

Mag. 100 X

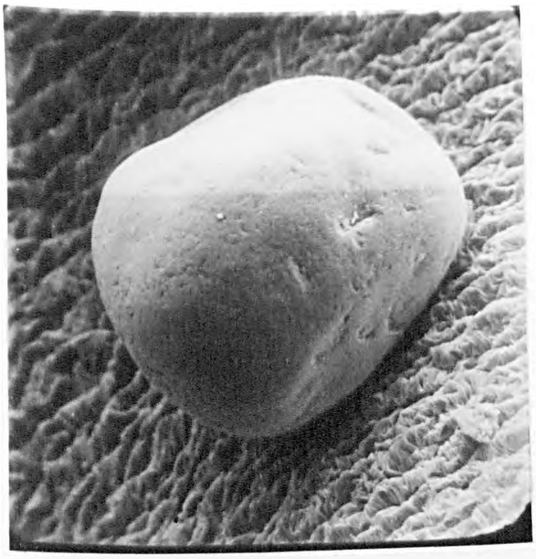


PLATE 5.11

Well rounded grain without sharp edges. Large grain (0.5mm in diameter).

Muwailhat al.Janubiya terrain system

Mag. 100 X

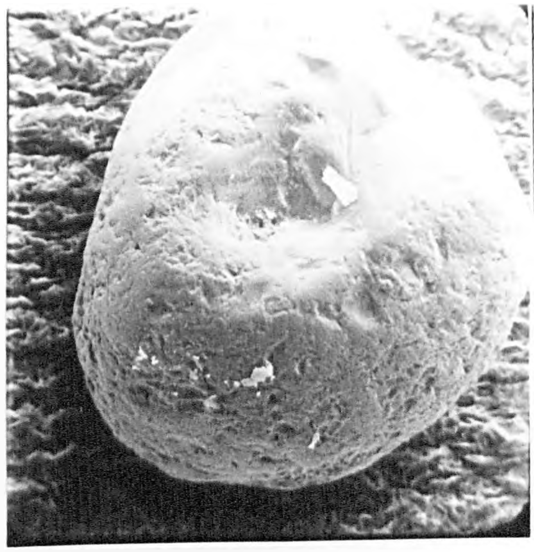


PLATE 5.12

Irregular dish-shaped concavity on large rounded grain (o.5mm in diameter). Large pit may be due to mechanical chipping during particularly powerful sand storms.

Muwailhat al.Janubiya terrain system

Mag. 200 X

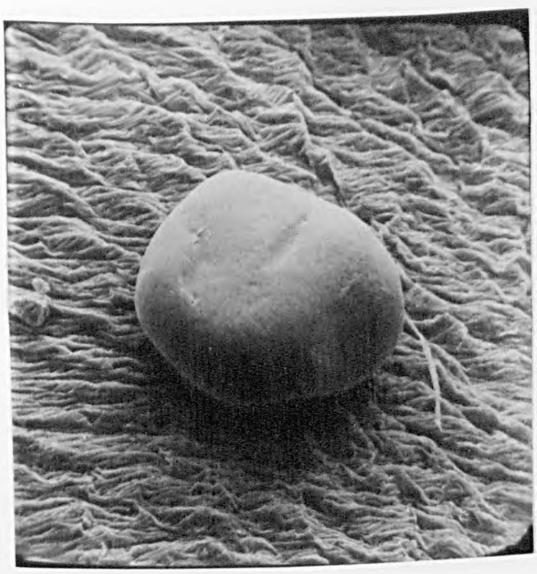


PLATE 5.13

Very well rounded grain as a result of transportation by wind for long periods. Influence of the wind can be seen in the scratches on the surface of the grain. Compare with Plate 5.5.

Muwailhat al.Janubiya

Mag. 100 X

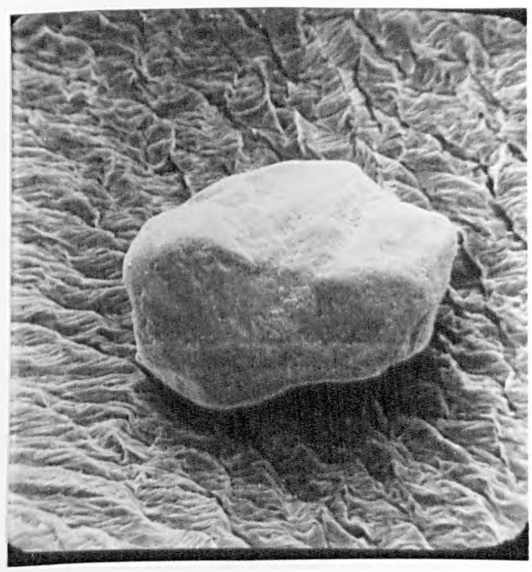


PLATE 5.14

Small grain (0.25mm in diameter). Although this grain is rounded it is not as modifying as the one above, and edges can still be seen.

Muwailhat al.Janubiya

Mag. 100 X

PLATE 5.15

Elongated and rounded small grain (0.25mm in diameter). Some depressions can be seen, probably due to mechanical action.

Safwan terrain system

Mag. 200 X

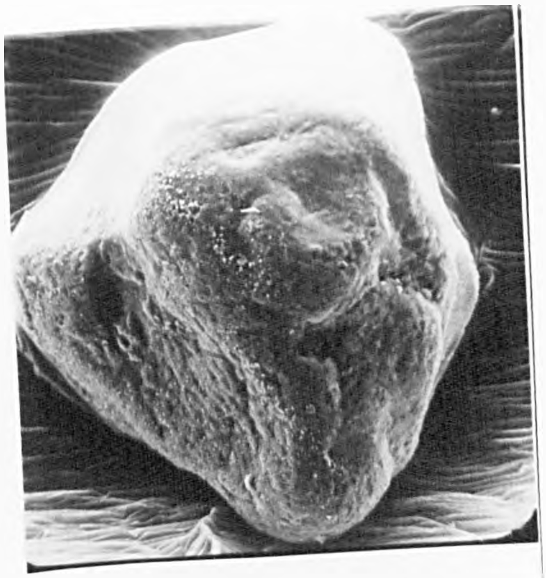


PLATE 5.16

Solution, precipitation and upturned plates on a small grain (0.25mm in diameter). The grain shows upturned plates around its edges, with some holes which are probably due to chemical action.

Safwan terrain system

Mag. 200 X

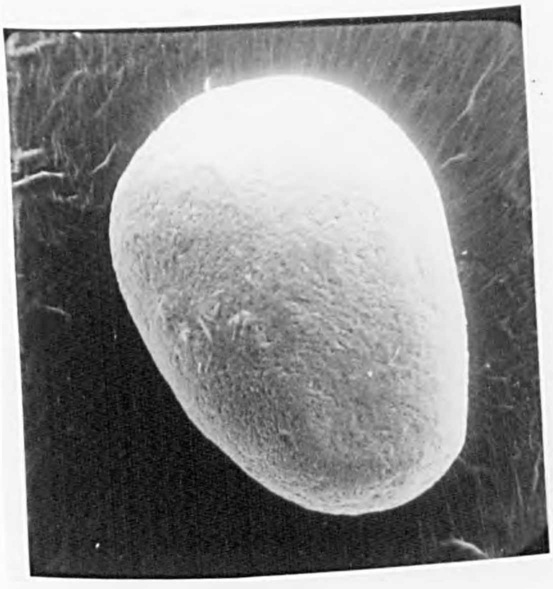


PLATE 5.17

A typical very well rounded grain (0.5mm in diameter) from the desert. Frosted surface texture can be clearly seen.

Safwan terrain system

Mag. 100 X

PLATE 5.18

Rounded grain with irregular depressions. Depressions are probably due to mechanical chipping during the transportation in particular by powerful sand storms.

Safwan terrain system

Mag. 100 X

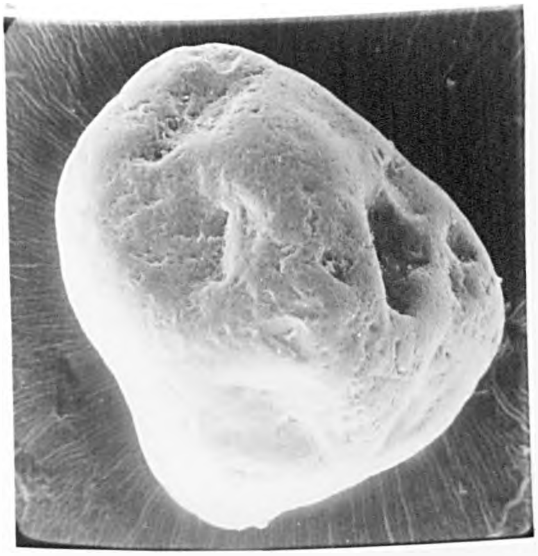


PLATE 5.19

Irregular depressions on a large rounded grain (o.5mm in diameter). Several irregular depressions can be seen; they are due to mechanical action.

Safwan terrain system

Mag. 100 X

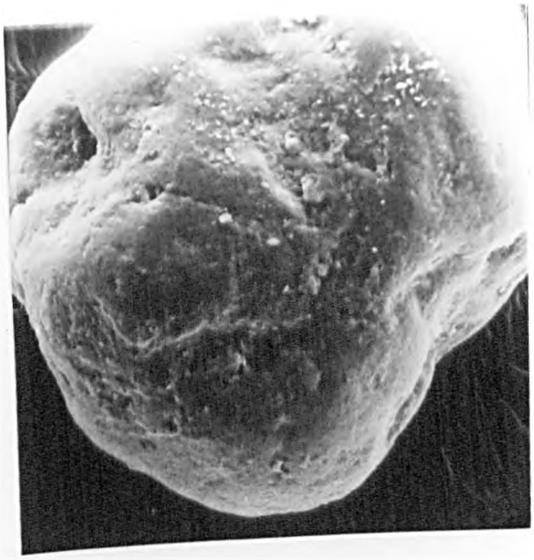


PLATE 5.20

Upturned plates, solution and precipitation on a small grain (0.25mm in diameter). Plates exposed by mechanical impact on grain. Depression can be seen on the left side of the micrograph.

Safwan terrain system

Mag. 200 X

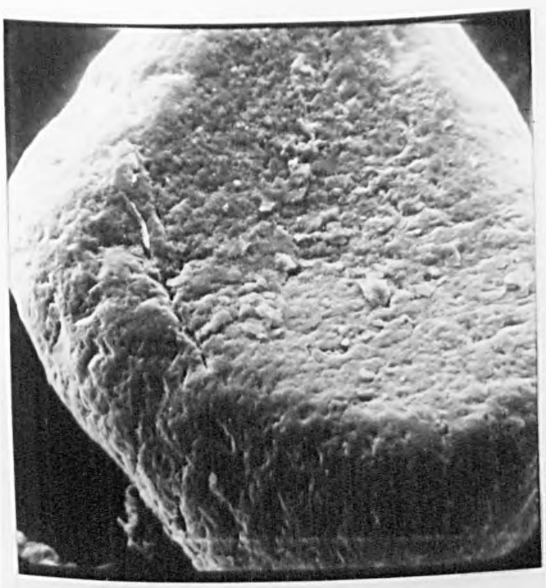


PLATE 5.21

A cracked grain (left side of photograph). Very few grains show such cracks. This one may be due to chemical action.

Sanam terrain system

Mag. 100 X

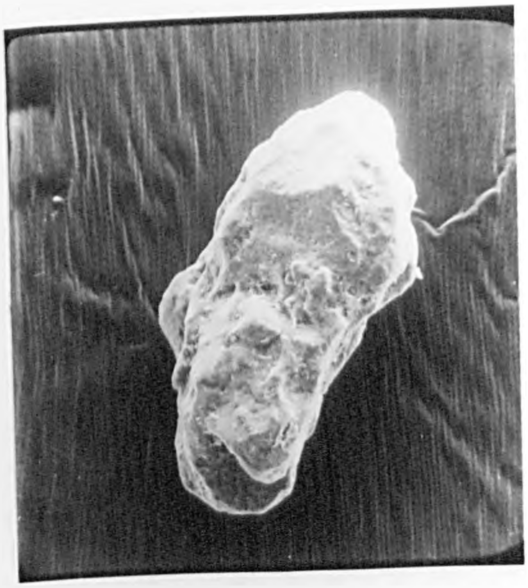


PLATE 5.22

Small grain (0.25mm in diameter) with flat upper and lower surface and irregular grain ends. Some conchoidal breakage features appear in the middle. This moderate rounding may be due to chemical attack.

Sanam terrain system

Mag. 100 X

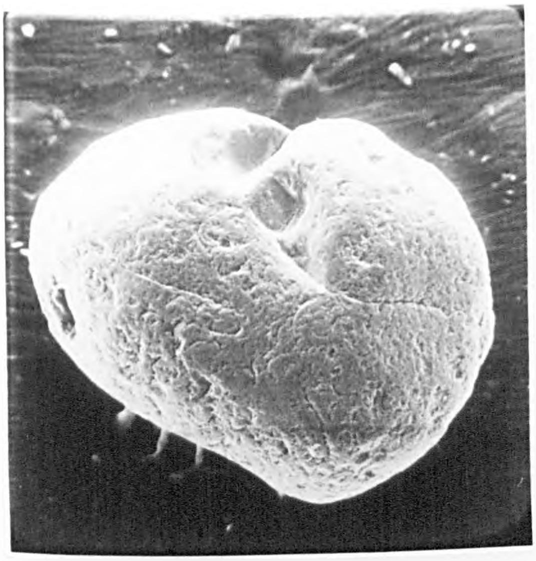


PLATE 5.23

Mechanical V-patterns on a rounded grain, with cracks and some depressions in the rounded portions of the grain.

Sanam terrain system

Mag. 100 X

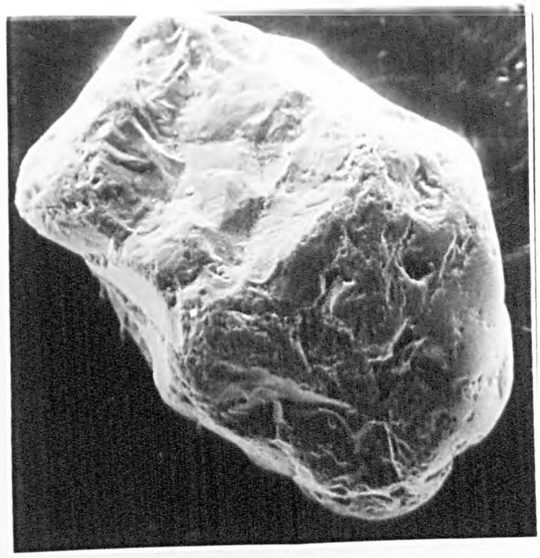


PLATE 5.24

A grain with an irregular outline and a few conchoidal breakage patterns. The rounding may be largely the product of solution and precipitation.

Sanam terrain system

Mag. 100 X

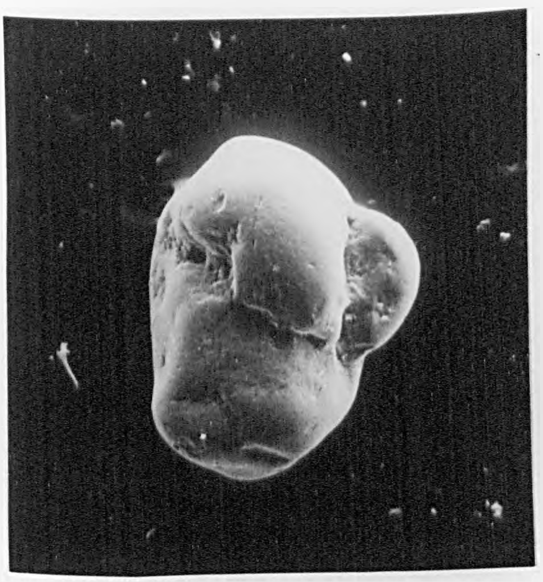


PLATE 5.25

Very smooth rounded grain with evidence of mechanical fracturing at some stage. The scratches and depression also suggest wind action.

Sanam terrain system

Mag. 100 X

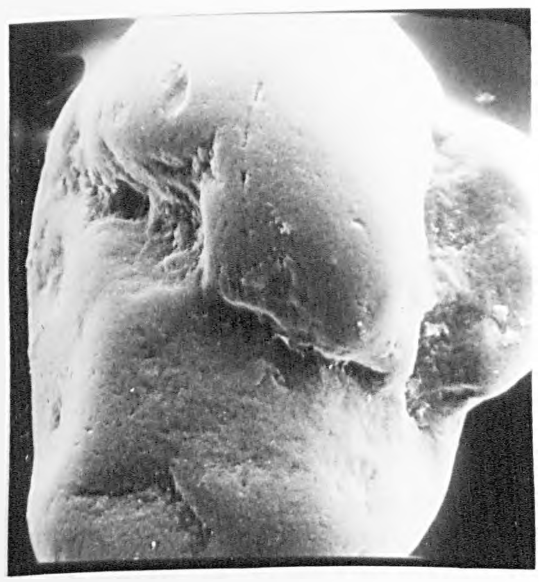


PLATE 5.26

Close-up of Plate 5.25 at a magnification of 200X

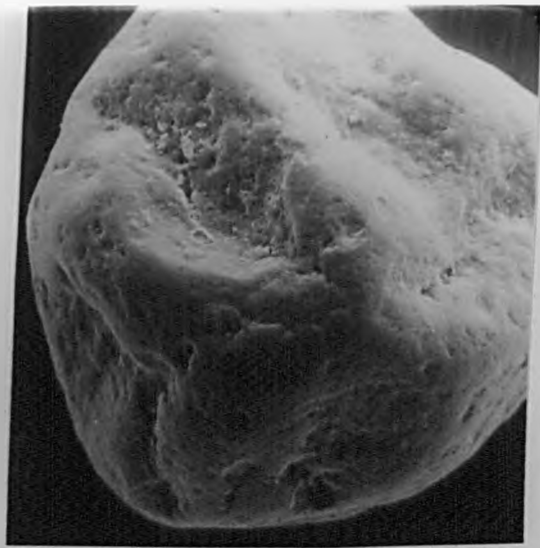


PLATE 5.27

Rounded grain showing solution and precipitation. A large depression is visible in the centre. The surface has been smoothed and rolling topography has resulted in response to solution and precipitation.

Sanam terrain system.

Mag. 200 X

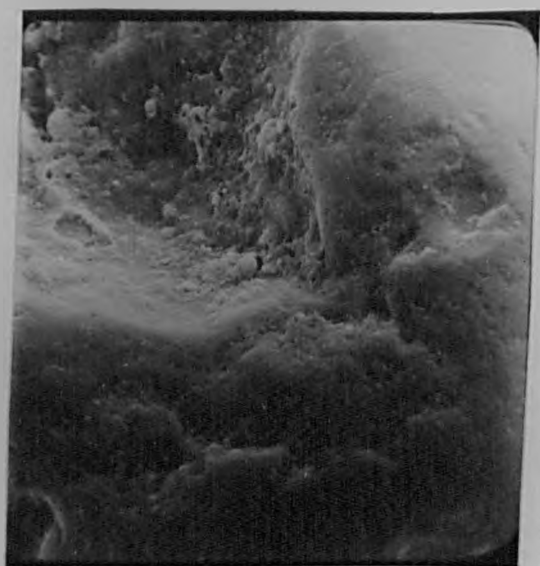


PLATE 5.28

Close-up of plate 5.27 at a magnification of 500 X

7) Other examples showing the various surface textures of the examined sand grains, together with brief descriptions, are given in the following plates: 5.5, 5.6, 5.7, 5.12, 5.14, 5.16, 5.17, 5.18, 5.19, 5.20, 5.22, 5.23, 5.24, 5.25, 5.25, 5.27 and 5.28

5.3.2 Sands: particle size

In the words of Dyer (1970) "The most commonly used method of displaying the results of grain size analyses is by a plot of cumulative percentage against grain size." (p.616). Particle size distributions were derived from dry sieving methods[4] (British Standard, 1377, 1975). Cumulative percentages were calculated and drawn against phi diameters on semi-log paper[5] (Appendix 7). Their particle size envelopes were shown in Figs. 5.8 - 5.11).

Sedimentological differences can be detected from one depth to another and from one terrain system to another. Such differences are also shown in the cumulative frequency distribution graphs (Appendix 7). The usual range for particle sizes in the samples[6] collected lies between -3.0 Ø and +6 Ø. (see also, Figs. 5.12 and 5.13).

It has been stated that "Parameters of particle size distributions are used routinely, but there is no general

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4) The dry sieving method has been used in preference to using wet sieving because no significant differences were obtained in a series of comparative tests on al.Zubair material using both wet and dry sieving analyses of the same samples.

5) Several different charts can be used for presenting particle size data (weight-frequency data). These can be found in the literature of sedimentology, for example, Krumbein (1934); Doeglas (1946); Spencer (1963); al.Hamdan (1965) and McGown (1971). In this study, semi-logarithmic paper was used.

6) 118 samples from four different depths (0-15cm, 15-30cm, 30-45cm and 45-60cm) were analysed.

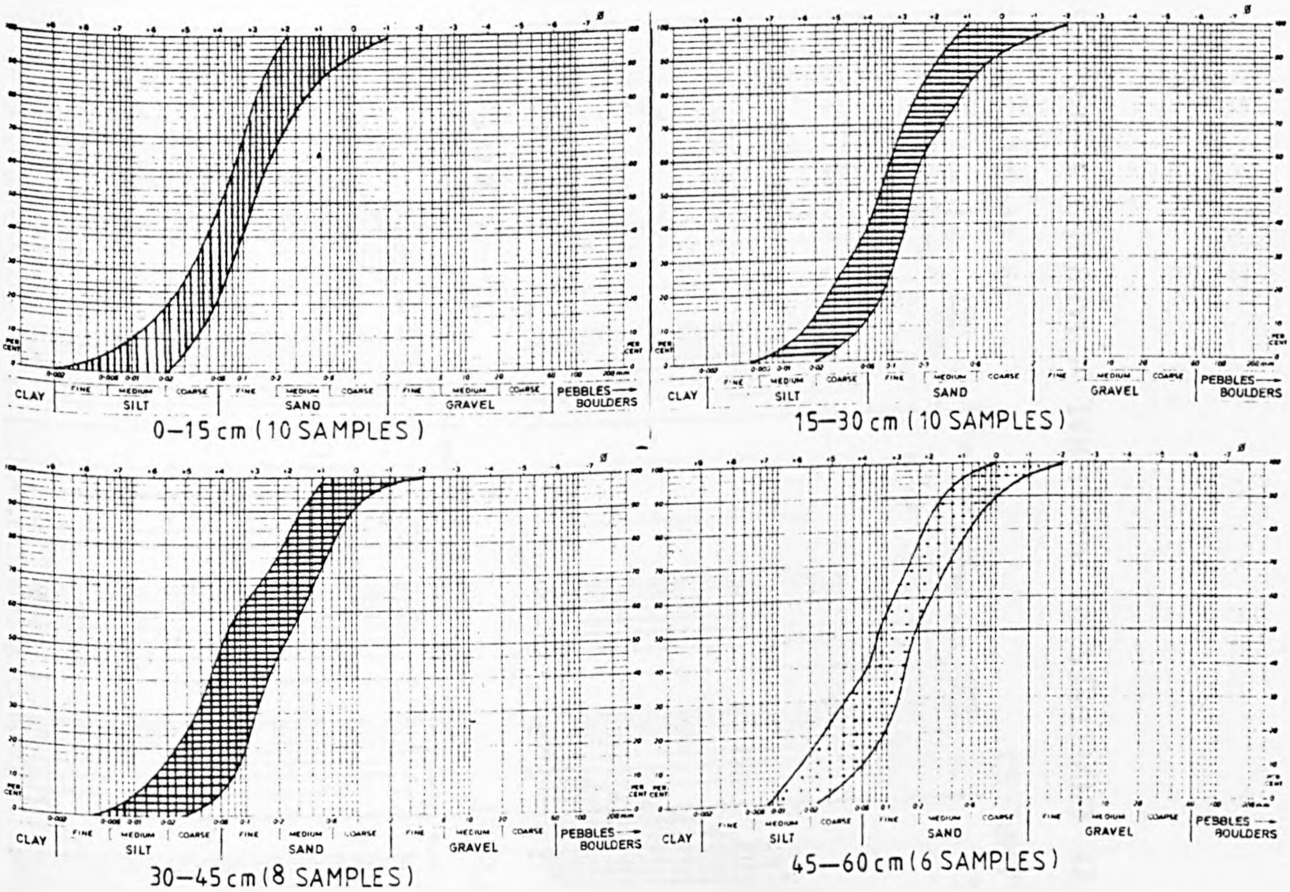


FIG. 5.8 PARTICLE SIZE ENVELOPES OF KHOR al.ZUBAIR TERRAIN SYSTEM SAMPLES

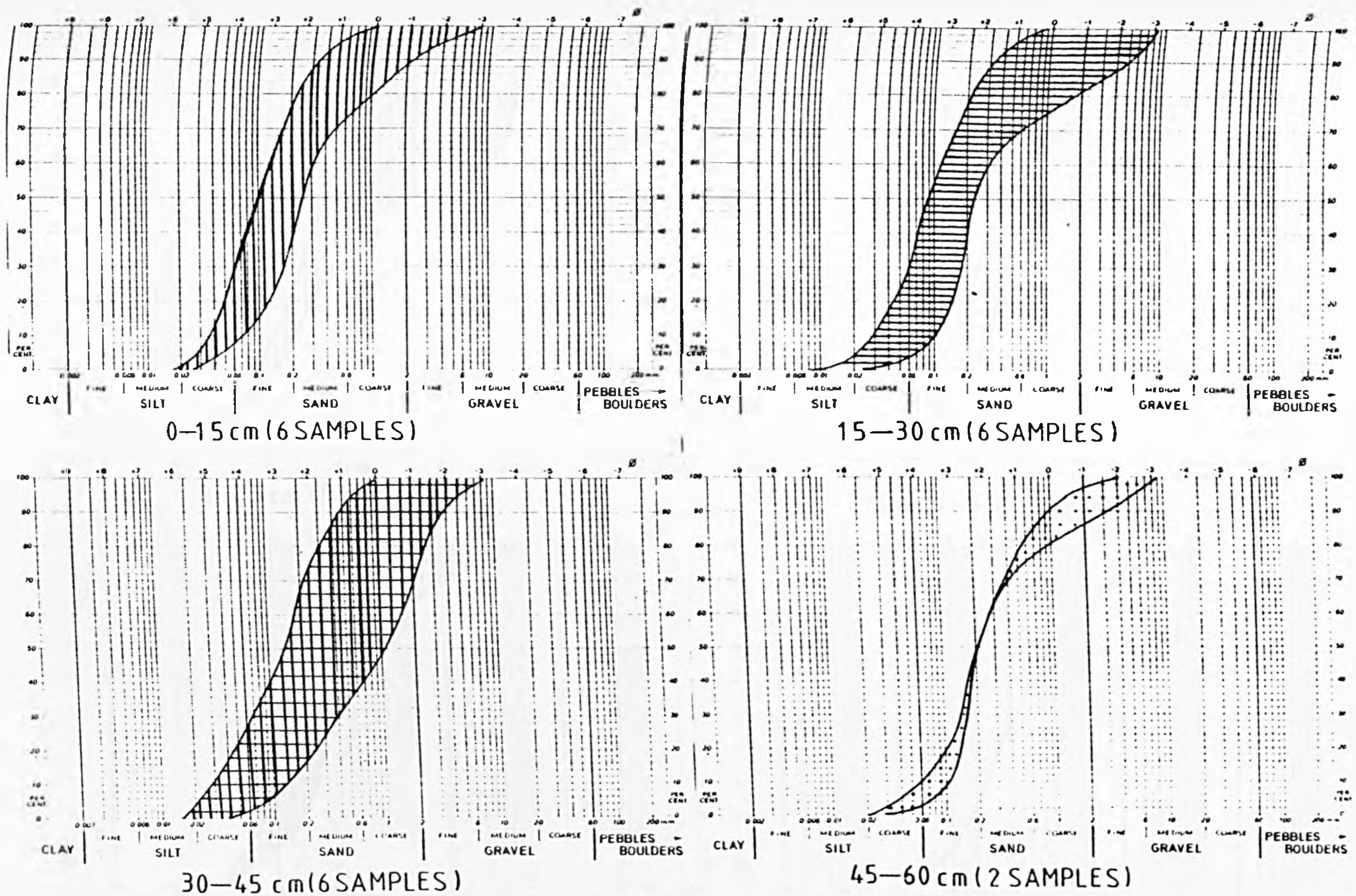


FIG.5.9 PARTICLE SIZE ENVELOPES OF MUWAILHAT al.JANUBIYA TERRAIN SYSTEM SAMPLES.

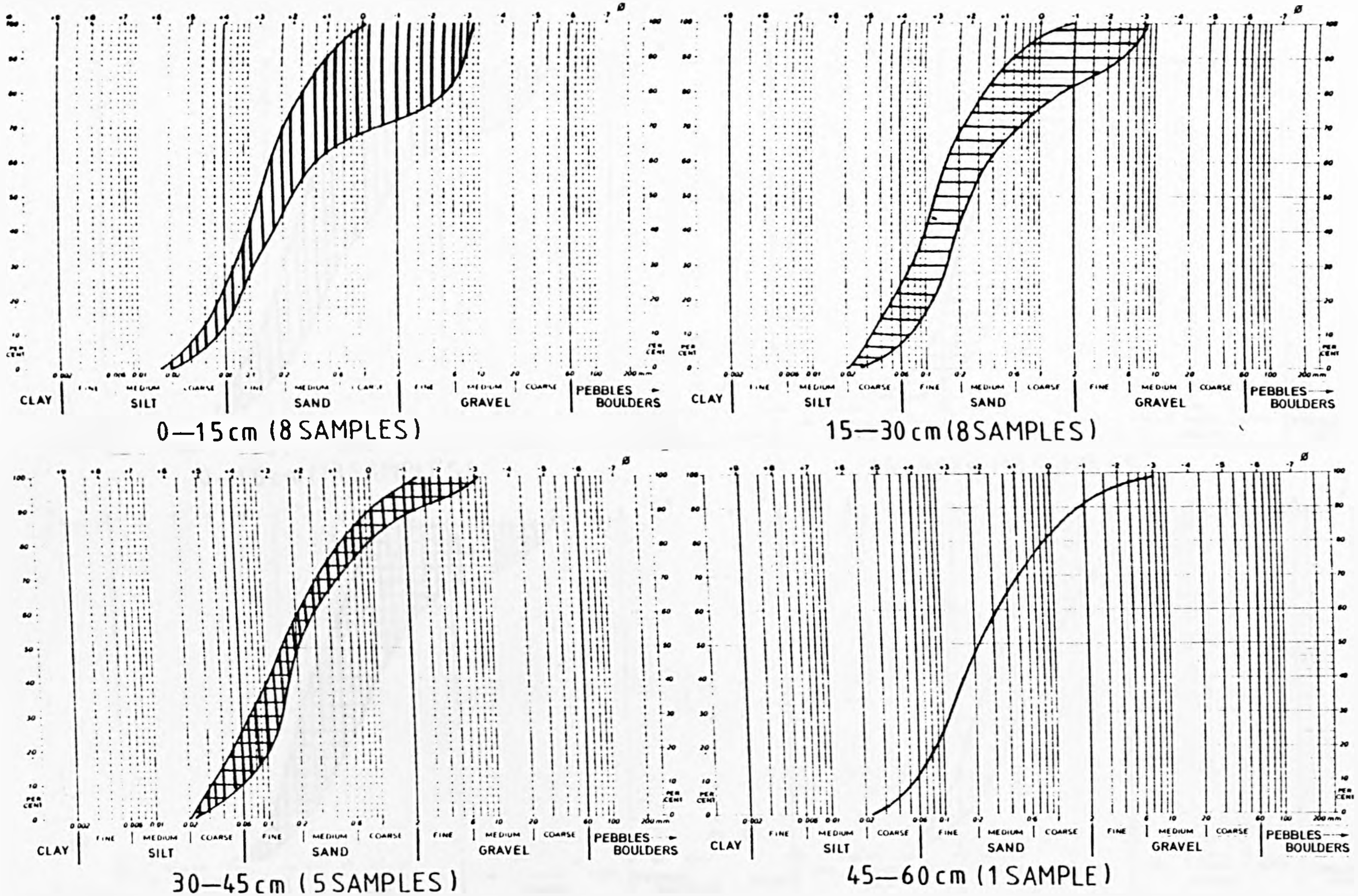


FIG. 5.10 PARTICLE SIZE ENVELOPES OF SAFWAN TERRAIN SYSTEM SAMPLES.

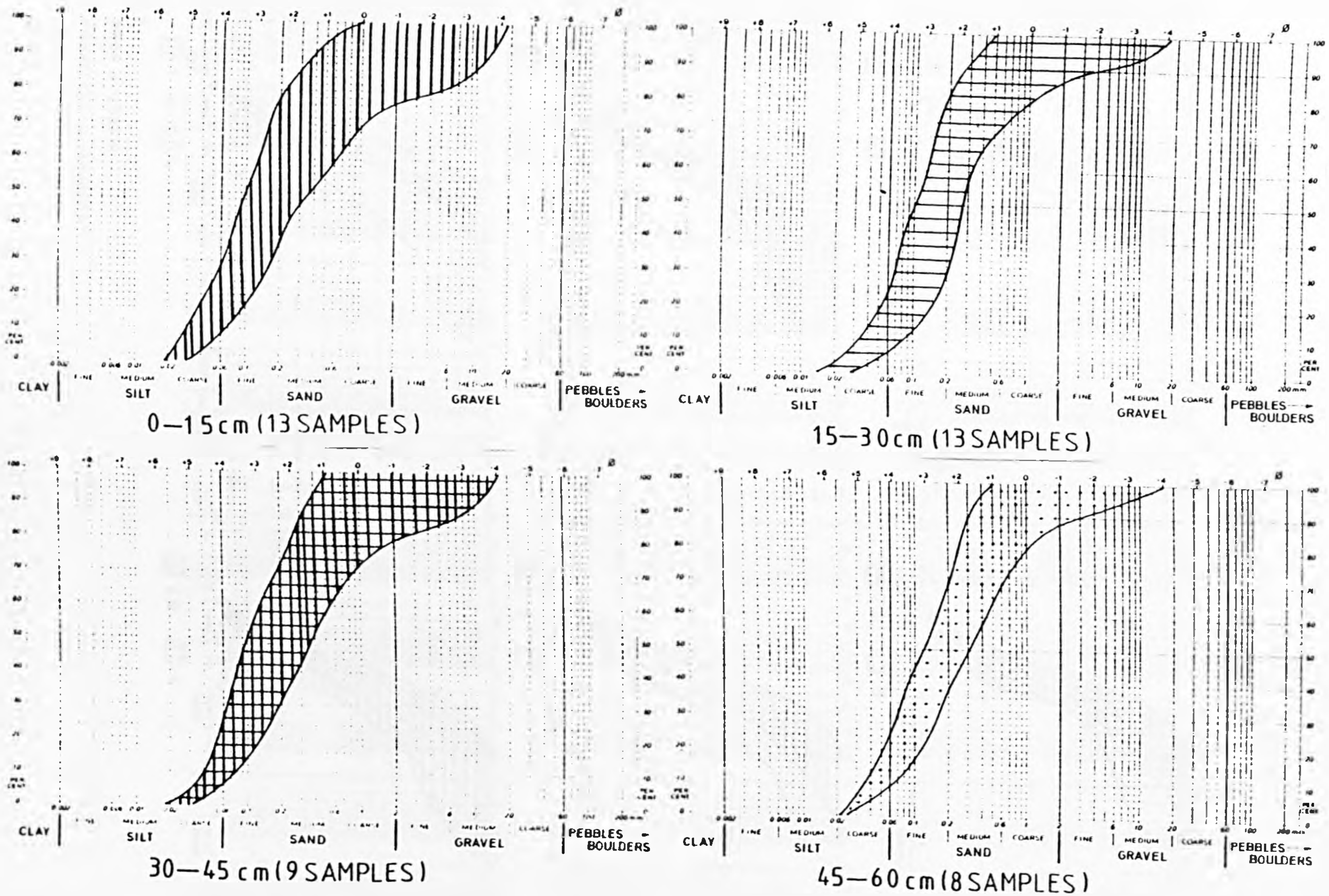
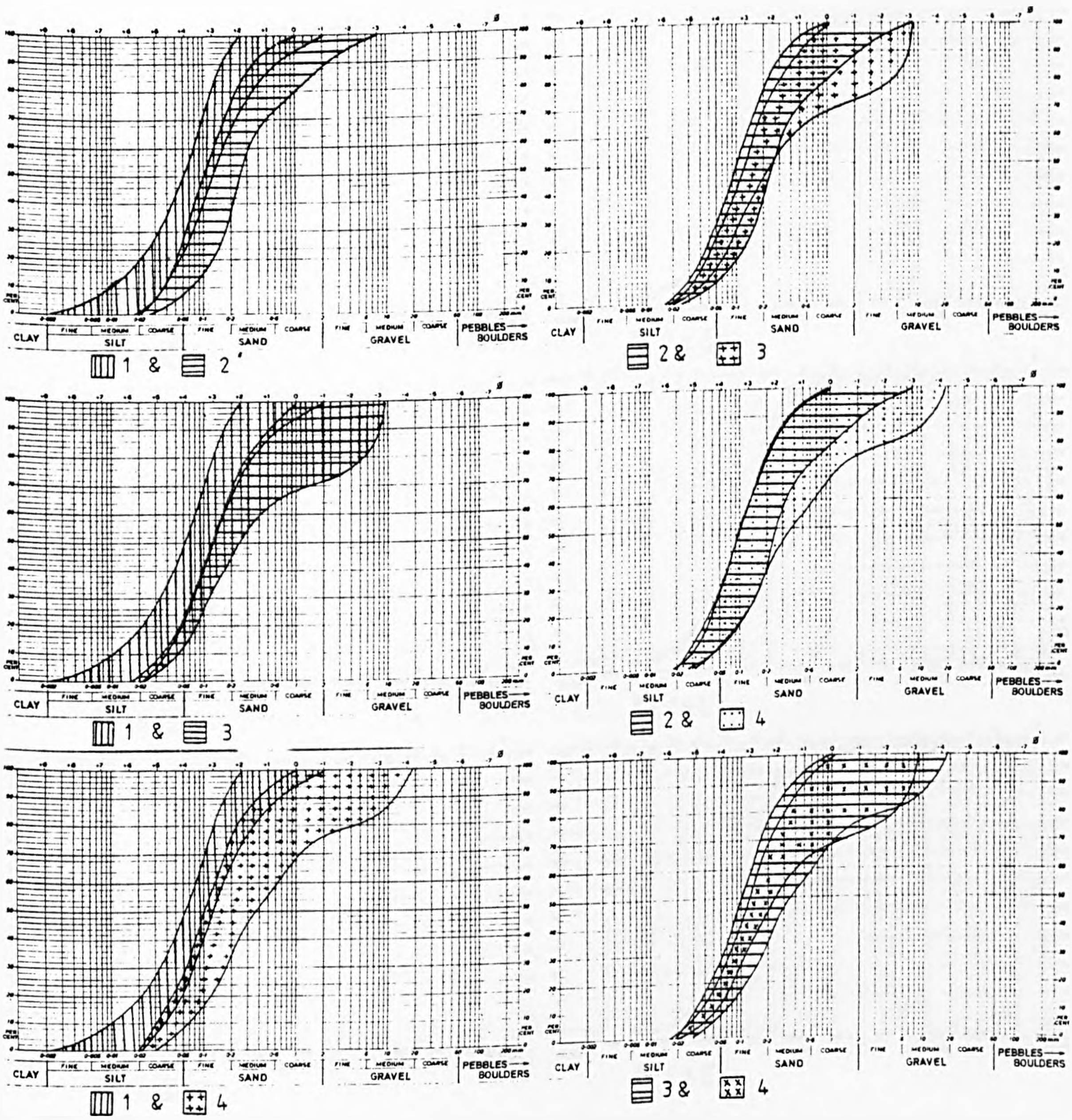


FIG. 5.1: PARTICLE SIZE ENVELOPES OF SANAM TERRAIN SYSTEM SAMPLES



KEY

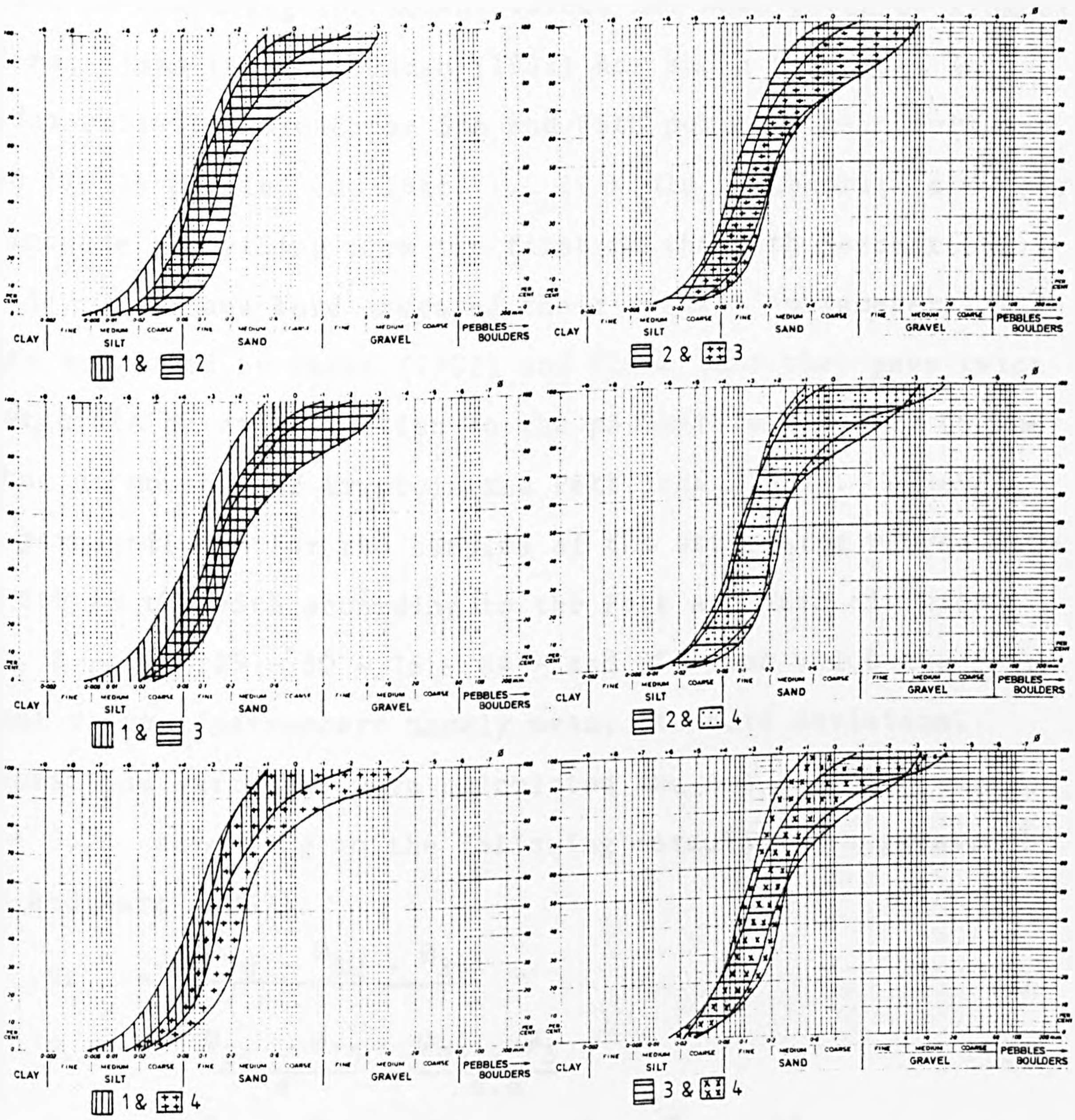
1 KHOR al-ZUBAIR

2 MUWAILHAT al-JANUBIYA

3 SAFWAN

4 SANAM

FIG.5.12 PARTICLE SIZE ENVELOPES OF THE TERRAIN SYSTEMS SAMPLES OF THE STUDY AREA AT DEPTH 0 – 15 cm.



KEY

1 KHOR al.ZUBAIR
2 MUWAILHAT al. JANUBIYA
3 SAFWAN
4 SANAM

FIG. 5.13 PARTICLE SIZE ENVELOPES OF THE TERRAIN SYSTEMS SAMPLES OF THE STUDY AREA AT DEPTH 15—30 cm.

agreement as to how they should be estimated or how the distribution should be described." (Jones, 1970, p.1204). The results were drawn according to percentiles showing the four moments (mean, standard deviation, skewness and kurtosis). One method of computing the moment values has been given by Krumbein and Pettijohn (1938). Inman (1952) has shown that data is seldom reliable beyond the 5th and 95th percentiles. Folk and Ward (1957) pointed out that "... it would be theoretically best to include everything from the first to the 99th percentiles." (p.13). Folk and Ward compared their results (parameters) with those suggested by Inman (1952) and found that they gave twice as accurate an approximation to the parameters computed by the method of moments of Krumbein and Pettijohn (1938). However, the percentiles[7] for the samples of the study area ranged from the 5th to the 95th according to the Folk and Ward division (i.e. 5 - 16 - 25 - 50 - 75 - 84 - and 95) from which the four moment values (parameters namely mean, standard deviation, skewness and kurtosis) were calculated and are given in figures 5.8 - 5.11 according to the following formulas as suggested by Folk and Ward (1957):

$$Mz = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \quad (1)$$

$$\sigma_1 = \frac{\phi_{84} - \phi_{15}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \quad (2)$$

$$SK = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)} \quad (3)$$

$$KG = \frac{\phi_{95} - \phi_5}{2.44\ (\phi_{75} - \phi_{25})} \quad (4)$$

The results of the four moments (parameters) of samples from the study area were computed accordingly and are

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7) See Appendix 8.

presented in tables 5.3 - 5.6. These results are drawn graphically, against the different samples (at different lengths) from the study area, according to the classification suggested by Folk (1968) (see Fig.5.14).

5.3.2.1 Mean Size

Samples of the study area vary in their mean size with location (intra- and inter-terrain system). The phi graphic mean size ranges between 1.0 Ø (medium sand) and 4.0 Ø (very fine sand) with an average of 2.63 Ø (fine sand). The distributions of all these samples are obtained and show graphic means falling within the ranges medium sand, fine sand and very fine sand. Of 37 samples taken from a depth of 0-15cm, 12 samples have medium sand means, 13 samples have fine sand means and 12 samples have very fine sand, while for 37 samples taken from a depth of 15-30cm this range read as follows: 11 samples (medium sand), 15 samples (fine sand) and 11 samples (very fine sand) (see Fig.5.14). Of 28 samples taken from a depth of 30-45cm, 10 samples fall within the range of medium sand, 11 samples lie within the fine sand range, and only 7 samples are finer (very fine sand) (Fig.5.14). Of 17 samples taken from a depth of 45-60cm, 6 samples fall within the medium sand range, 6 samples are within the fine sand range, and only 5 samples lie within the very fine sand range (Fig.5.14).

It may be that the variations in the mean size at different depths within each sample are results of the depositional nature of sand of the study area, where the medium and fine sand could be found in the deepest layers whilst the finer sand tended to occur in the surface layers. The mean size of sand grains increases from sloping to dominantly flat area. Compare for example, the mean size

Sample No.	Mean M (In φ)	S.D. σ_1	Skewness SK_1	Kurtosis KG	Remarks		CLAY %	SILT %	SAND %	CLASS	O.M. %	PH	$CaCO_3$	SOIL COLOUR	SOLUBLE SALTS ppm Na	K	Mg	Ca	Total Soluble Salts
1	4.3	1.53	0.12	1.02	poorly sorted	Mesokurtic	30	32	37	Sandy Clay Loam	28.0	8.3	3.2	10yr 4/3 dull yellow brown	7500	75	16.7	178.5	7770.2
2	4.0	1.49	0.15	1.10	" "	"	35	17	47	Sandy Clay	12.0	8.1	6.8	10yr 5/3 dull yellowish brown	9000	117	40.0	178.5	9335.5
21	3.4	1.34	-8.83	0.80	" "	Platykurtic	5	46	49	Sandy Loam	7.4	8.2	4.2	10yr 5/4 " " "	3856	42.2	11.5	350	4259.7
22	3.1	1.78	-0.28	1.02	" "	Mesokurtic	4	16	80	Loamy Sand	10.2	7.8	5.0	10yr 4/3 " " "	1920	37	19	496	2472.0
27	1.8	-1.26	-3.06	0.14	V.well "	V.Platykurtic	4	48	48	Sandy Loam	16.9	7.9	4.7	10yr 4/3 " " "	3729	54	17	443	4243.0
28	2.5	-1.09	-3.06	0.13	V.well "	V. "	4	52	44	Silt Loam	19.9	7.9	7.5	10yr 4/3 " " "	5257	59	39	493	5848.0
23	3.7	1.27	0.24	1.10	Poorly "	Mesokurtic	4	32	64	Sandy Loam	10.2	7.5	4.4	7.5yr 5/3 dull yellow orange	1350	24	11.7	586	1971.7
25	3.2	1.04	0.23	0.87	Poorly "	Platykurtic	4	26	70	Sandy Loam	5.6	7.5	3.3	7.5yr 5/4 dull brown	1010	20	9.3	680	1719.3
26	3.2	1.09	0.17	1.05	Poorly "	Mesokurtic	5	33	62	Sandy Loam	13.5	7.6	2.5	7.5yr 5/4 " "	4342	53.8	18.0	610	5023.8
3	3.1	1.74	5.11	1.47	" "	Leptokurtic	15	22	63	Sandy Loam	6.9	7.7	6.4	10yr 7/4 dull yellow orange	30	6.6	10.9	162.07	209.5
14	2.1	2.16	-0.26	0.94	V.Poorly sorted	Mesokurtic	2	23	75	Loamy Sand	1.6	7.9	10.0	10yr 7/3 dull yellow orange	3.6	2.8	2.9	160	169.3
19	2.4	1.65	-0.16	1.18	Poorly sorted	Leptokurtic	7	29	64	Sandy Loam	8.2	7.9	11.6	10yr 6/4 " " "	4.1	8.0	5.0	131.4	148.5
24	3.3	1.24	-0.12	0.98	" "	Mesokurtic	2	19	79	Loamy Sand	6.9	7.5	6.2	10yr 6/4 " " "	25.0	6.6	3.0	151.0	185.6
7	2.1	2.04	-0.29	1.05	V.Poorly sorted	"	2	18	80	Loamy Sand	3.2	8.0	4.7	10yr 7/6 bright yellow brown	4.0	4.0	6.0	181.3	195.3
16	1.9	1.97	-0.35	0.99	Poorly sorted	Mesokurtic	6	19	75	Sandy Loam	8.0	8.1	8.3	10yr 6/4 dull yellow orange	5.8	2.6	3.0	134.9	146.3
15	1.8	1.91	-0.23	1.24	" "	Leptokurtic	2	24	74	Sandy Loam	12.6	7.4	8.0	7.5yr 7/4 dull orange	22.0	1.7	3.0	139.9	166.6
9	2.3	2.44	-0.42	3.36	V.Poorly sorted	Extremely Leptokurtic	4	16	80	Loamy Sand	7.4	8.1	8.6	10yr 7/4 dull yellow orange	7.0	1.2	2.7	29.2	40.1
6	2.9	1.52	5.68	1.10	Poorly sorted	Mesokurtic	4	16	80	Loamy Sand	7.2	8.1	8.6	7.5yr 7/3 dull orange	7.0	5.0	5.0	28.5	45.5
8	2.6	1.75	-0.11	1.18	" "	Leptokurtic	4	23	73	Sandy Loar	7.6	8.5	9.8	10yr 5/4 dull yellowish brown	5.0	5.9	3.5	106.3	120.7
13	3.0	1.63	-1.30	1.22	" "	"	12	11	77	Sandy Loam	10.3	8.4	6.8	10yr 6/4 dull yellowish orange	6.7	7.6	2.4	150.6	167.3
12	1.3	3.0	-0.31	0.64	V.Poorly sorted	V.Platykurtic	3	23	74	Loamy Sand	17.2	8.6	1.2	10yr 6/4 dull yellow orange	15.0	31.0	4.2	155.6	205.6
37	1.7	-1.17	-2.49	0.17	V.Well sorted	V.Platykurtic	3	17	80	Loamy Sand	16.0	8.5	9.7	10yr 6/4 dull yellow orange	32.0	9.3	5.0	49.0	95.3
5a	2.7	1.89	0.18	0.85	Poorly sorted	Platykurtic	1	6	93	Sand	12.8	8.1	9.3	7.5yr 5/4 dull brown	9.0	3.0	4.8	79.2	96.0
5b	2.5	1.51	-0.13	0.95	" "	Mesokurtic	1	20	79	Loamy Sand	14.8	8.1	4.6	7.5yr 7/3 dull brown	10.0	1.2	2.7	91.3	105.2
18	2.7	1.45	9.33	1.09	Poorly sorted	Mesokurtic	2	26	72	Sandy Loam	4.6	7.9	4.1	10yr 6/4 dull yellow orange	2.7	2.5	4.9	46.4	56.5
31	3.0	1.20	0.12	0.74	" "	Platykurtic	1	16	83	Loamy Sand	6.4	7.7	7.4	10yr 6/4 dull yellow orange	8.2	6.6	2.4	48.0	65.2
32	3.1	-0.19	-10.11	-4.31	V.Poorly sorted	V.Platykurtic	1	9	90	Sand	5.9	7.7	4.9	10yr 6/4 dull yellow orange	7.6	7.1	2.4	42.0	59.1
33	2.2	1.71	-9.25	0.88	Poorly sorted	Platykurtic	0	16	84	Loamy Sand	7.4	7.9	14.0	10yr 6/4 dull yellow orange	8.5	7.0	1.5	16.0	33.0
20	3.2	1.63	2.06	1.55	" "	V.Leptokurtic	4	15	77	Loamy Sand	8.0	7.7	7.4	7.5yr 6/3 dull brown	2.7	2.8	2.0	36.4	43.9
17	2.7	2.20	-0.25	1.29	V.Poorly sorted	Leptokurtic	2	22	76	Loamy Sand	10.9	7.8	13.4	7.5yr 6/3 dull brown	8.6	3.8	3.9	27.8	44.1
29	2.1	1.78	-9.39	1.15	Poorly sorted	Leptokurtic	0	18	82	Loamy Sand	5.8	7.2	0.6	7.5yr 8/3 light yellow orange	8.2	6.8	2.8	141.0	158.8
34	2.3	1.50	-5.33	1.02	" "	Mesokurtic	0	14	86	Loamy Sand	7.3	7.3	2.4	7.5yr 7/3 dull orange	8.6	6.7	2.6	139.0	156.9
35	1.0	2.58	-0.23	0.96	V.Poorly sorted	"	0	17	83	Loamy Sand	8.6	7.4	2.0	7.5yr 7/3 dull orange	7.9	6.7	2.0	130.0	146.6
11	2.7	1.84	-0.12	0.81	Poorly sorted	Platykurtic	3	22	75	Loamy Sand	10.6	7.7	4.8	10yr 6/3 dull yellow orange	7.1	6.7	1.9	20.7	36.4
10	1.4	3.26	-0.46	0.89	V.Poorly sorted	"	4	21	75	Loamy Sand	12.5	7.7	11.9	10yr 6/4 " " "	7.2	6.0	4.6	36.3	54.1
30	2.9	1.57	-0.24	0.78	Poorly sorted	"	1	13	86	Sand	12.9	7.6	9.9	10yr 6/4 " " "	7.8	6.6	1.4	20.0	35.8
36	3.0	1.54	-0.35	0.78	" "	"	2	16	82	Loamy Sand	13.1	7.8	8.7	10yr 6/4 " " "	7.7	7.0	1.5	13.0	29.2

Table 5.3: RESULTS OF THE SOIL PROPERTIES ANALYSES OF THE DETAILED STUDY AREA AT DEPTH OF 0-15cm.

1	3.2	1.24	0.14	0.93	Poorly sorted	Mesokurtic	29	7	64	Sandy Clay Loam	20.6	7.8	3.2	7.5yr 5/4 dull brown	2200	22	11.8	171.3	2405.1
2	3.5	1.51	0.36	1.12	" "	Leptokurtic	26	20	54	Sandy Clay Loam	15.0	8.1	6.8	7.5yr 5/4 " "	2800	40	20.0	160.6	3020.6
21	3.5	1.32	-6.89	0.92	" "	Mesokurtic	4	31	65	Sandy Loam	10.1	8.1	4.2	10yr 4/3 dull yellowish brown	1176	20	7.3	377	1580.3
22	3.2	-0.67	3.76	0.13	V.well "	V.Platykurtic	3	17	80	Loamy Sand	8.3	7.6	5.0	10yr 6/4 dull yellowish orange	1725	36	34	955	2750.0
27	2.8	-0.85	-3.19	0.11	" "	" "	4	49	47	Sandy Loam	14.7	7.6	4.7	10yr 5/3 dull yellowish brown	3226	46	15	416	3703.0
28	2.4	-1.25	-3.00	0.13	" "	" "	3	59	38	Silt Loam	18.2	7.2	7.5	10yr 4/4 brown	2889	39	16	343	3287.0
23	3.7	1.40	8.50	0.97	Poorly sorted	Mesokurtic	4	32	64	Sandy Loam	11.7	7.4	4.4	10yr 4/6 brown	1113	21.1	9.1	495	1638.2
25	4.0	1.08	-0.46	0.70	" "	Platykurtic	4	26	70	Sandy Loam	8.6	7.5	3.3	7.5yr 5/4 dull brown	933	19.2	10.0	614	1576.2
26	3.4	1.30	0.22	1.17	" "	Leptokurtic	4	31	65	Sandy Loam	9.6	7.5	2.5	10yr 6/4 dull yellow orange	1676	22.3	14.0	609	2321.3
3	2.6	1.68	-0.20	1.37	" "	Leptokurtic	18	21	61	Sandy Loam	3.4	7.6	6.4	10yr 7/4 dull yellow orange	31	12	14.9	158.5	216.4
14	2.5	1.95	-0.24	1.03	Poorly sorted	Mesokurtic	2	24	74	Loamy Sand	1.4	7.8	9.0	7.5yr 6/3 dull brown	4.2	5.3	4.9	156.3	170.7
19	2.0	1.80	-0.18	1.17	" "	Leptokurtic	5	21	74	Sandy Loar	12.7	7.6	6.8	7.5yr 7/3 dull orange	12.0	12.0	7.2	125.6	156.8
24	3.4	1.36	-5.84	0.94	" "	Mesokurtic	1	21	78	Loamy Sand	10.2	7.5	9.3	10yr 6/3 dull yellow orange	8.9	8.4	4.9	129.0	151.2
7	1.2	2.11	-0.52	1.05	V.poorly sorted	"	1	16	83	Sandy Loam	1.1	8.2	0.3	10yr 7/6 bright yellow brown	3.7	3.8	3.0	125.6	136.1
16	2.4	1.55	-0.48	1.82	poorly sorted	V.Leptokurtic	2	20	78	Loamy Sand	12.8	7.9	4.5	5yr 7/3 dull orange	2.6	2.6	2.0	115.7	122.9
15	2.1	1.29	-0.40	1.34	" "	Leptokurtic	2	21	77	Loamy Sand	14.4	7.8	4.7	7.5yr 6/4 dull orange	1.9	1.7	6.4	169.2	179.2
9	2.9	1.86	-0.19	1.10	Poorly sorted	Mesokurtic	2	18	80	Loamy Sand	6.8	8.1	8.6	10yr 6/3 dull yellow orange	11.0	1.2	2.7	34.2	49.1
6	2.5	1.97	-0.31	1.34	" "	Leptokurtic	2	19	79	Loamy Sand	5.2	8.1	8.6	7.5yr 6/4 dull orange	17.0	5.0	6.3	28.5	56.8
8	2.5	1.53	-0.15	1.18	" "	"	14	11	75	Sandy Loam	7.3	8.5	9.8	10yr 5/6 yellowish brown	12.0	2.0	2.5	34.2	50.7
13	1.9	1.47	-6.66	0.98	" "	Mesokurtic	2	18	80	Loamy Sand	6.6	8.4	6.8	10yr 7/3 dull yellow orange	9.8	2.0	3.7	150.6	166.1
12	1.3	2.33	-0.37	1.03	V.poorly sorted	"	4	21	75	Sandy Loam	9.9	8.6	1.2	7.5yr 7/3 dull orange	16.7	7.2	2.1	163.5	189.5
37	2.1	-0.64	-5.52	0.36	V.well sorted	V.Platykurtic	3	18	79	Loamy Sand	8.4	8.5	9.7	10yr 6/4 dull yellow orange	41.2	6.9	4.4	31.0	83.5
5a	2.7	1.91	-0.30	1.14	poorly sorted	Leptokurtic	1	23	76	Loamy Sand	8.8	8.1	9.3	7.5yr 5/4 dull brown	17.0	7.3	4.3	65.6	94.2
5b	1.8	2.07	-0.27	1.04	V.poorly sorted	Mesokurtic	3	27	70	Sandy Loam	7.2	8.1	4.6	7.5yr 5/3 dull brown	3.0	3.6	3.5	152.7	162.8
18	3.0	1.47	0.25	0.89	Poorly sorted	Platykurtic	2	29	69	Sandy Loam	5.0	7.9	4.1	10yr 7/4 dull yellow orange	2.9	2.7	4.8	65.6	76.0
31	3.2	1.06	-7.48	0.77	" "	"	1	14	85	Loamy Sand	6.6	7.7	7.4	10yr 6/4 dull yellow orange	8.2	6.6	1.8	39.0	55.6
32	1.5	1.84	-0.26	1.47	" "	Leptokurtic	0	7	93	Sand	5.6	7.7	4.9	10yr 6/4 dull yellow orange	7.9	6.8	2.4	42.0	59.1
33	3.0	1.42	-0.19	0.98	" "	Mesokurtic	0	17	83	Loamy Sand	8.2	7.9	14.0	10yr 6/4 dull yellow orange	7.6	7.2	0.6	15.0	30.4
20	3.3	1.17	0.10	1.03	" "	"	2	18	80	Loamy Sand	7.5	7.7	7.4	7.5yr 7/4 dull orange	1.3	0.8	2.8	27.1	32.0
17	3.0	1.55	5.89	1.40	" "	Leptokurtic	3	23	74	Loamy Sand	9.7	7.9	13.4	10yr 5/6 yellowish orange	5.2	5.2	2.3	111.3	124.0
29	1.8	1.81	-0.16	1.19	" "	"	0	15	85	Loamy Sand	7.4	7.2	0.6	7.5yr 8/4 light yellow orange	49.0	6.6	12.0	145.0	212.6
34	2.3	1.73	-0.10	0.83	" "	Platykurtic	0	21	79	Loamy Sand	7.6	7.3	2.4	7.5yr 7/6 orange	7.8	6.7	2.4	134.0	150.9
35	1.7	2.20	-0.20	1.47	V.poorly sorted	Leptokurtic	0	16	84	Loamy Sand	9.2	7.4	2.0	7.5yr 8/3 light yellow orange	5.2	6.7	2.6	140.0	154.5
11	2.8	1.60	2.94	0.97	Poorly sorted	Mesokurtic	3	25	72	Sandy Loam	13.0	7.7	4.8	10yr 6/4 dull yellow orange	11.0	7.1	6.5	17.6	42.2
10	2.5	1.57	-3.50	1.43	" "	Leptokurtic	4	22	72	Sandy Loam	12.0	7.7	11.9	7.5yr 5/4 dull brown	7.8	6.8	3.1	27.0	44.7
30	2.8	1.52	-0.14	0.75	" "	Platykurtic	1	18	81	Loamy Sand	12.8	7.6	9.9	10yr 6/6 bright yellow orange	7.9	7.2	2.4	10.0	27.5
36	2.8	1.53	-0.20	0.87	" "	"	2	14	84	Loamy Sand	11.6	7.8	8.7	10yr 6/4 dull yellow orange	7.2	6.7	2.6	17.1	33.6

Table 5.4: RESULTS OF THE SOIL PROPERTIES ANALYSES OF THE DETAILED STUDY AREA AT DEPTH OF 15-30cm.

Sample No.	Mean M_z	S.D. σ_I	Skewness SK_I	Kurtosis KG	Remarks		Clay %	Silt %	Sand %	Class	O.P. %	PH	$CaCO_3$	Soil Colour	Na	K	Mg	Ca	Total Soluble Salts
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	3.3	1.72	0.32	1.04	poorly sorted	Mesokurtic	22	15	63	Sandy Clay Loam	24.0	7.8	0.6	5yr 5/3 dull reddish brown	2200	30	30	161.3	2421.3
21	3.3	1.46	6.52	0.87	" "	Platykurtic	5	29	66	Sandy Loam	9.3	7.9	3.2	7.5yr 5/4 dull brown	1706	29	8.1	392	2135.1
22	3.2	-0.75	3.68	0.11	V.well sorted	V.Platykurtic	2	18	80	Loamy Sand	10.5	7.1	7.8	10yr 5/3 dull yellowish brown	1293	28	32	505	1858.0
27	2.8	-1.23	-2.72	0.13	" " "	" "	2	54	44	Silt Loam	20.6	7.3	10.1	10yr 4/4 brown	3626	58	16	525	4225.0
28	1.7	-0.48	27.4	-1.20	" " "	" "	1	48	51	Sandy Loam	21.6	7.2	9.4	10yr 6/4 dull yellow orange	1993	31	13	480	2517.0
23	3.3	1.12	-0.16	0.77	poorly sorted	Platykurtic	2	28	70	Sandy Loam	7.2	7.5	5.9	7.5yr 5/4 dull brown	949	7.6	5.3	472	1433.9
25	3.7	0.7	3.90	-0.16	Mod.sorted	V.Platykurtic	2	27	71	Sandy Loam	8.8	7.5	2.2	7.5yr 5/4 " "	816	15.7	25.0	575	1431.7
26	5.7	0.44	-3.5	-3.14	W.sorted	" "	2	43	55	Sandy Loam	11.5	7.6	11.5	10yr 5/3 dull yellowish brown	2000	28.6	17.0	482	2527.6
3	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
14	2.3	1.95	-0.32	1.03	poorly sorted	Mesokurtic	3	26	71	Sandy Loam	3.0	8.0	7.7	7.5yr 6/4 dull orange	5.0	5.4	9.3	122.8	142.5
19	0.4	1.93	0.22	0.84	" "	Platykurtic	7	20	73	Sandy Loam	8.9	7.8	2.4	7.5yr 7/4 dull orange	34.0	5.4	6.9	133.5	179.8
24	3.0	1.55	0.13	0.85	" "	"	1	25	74	Loamy Sand	12.3	7.2	11.8	10yr 5/3 dull yellow brown	53.0	3.4	6.7	129.0	129.1
7	1.6	1.57	-0.51	1.08	" "	Mesokurtic	1	13	86	Sand	1.3	8.1	0.0	10yr 8/3 light yellow orange	3.7	2.0	3.3	138.5	147.5
16	2.2	1.09	-0.39	1.45	" "	Leptokurtic	1	20	79	Loamy Sand	7.6	7.9	3.0	10yr 7/4 dull yellow orange	1.4	1.3	2.4	114.9	120.0
15	2.6	1.17	-0.31	1.95	" "	V.Leptokurtic	3	22	75	Loamy Sand	7.4	7.7	2.9	7.5yr 7/4 dull orange	2.4	2.0	4.9	160.9	170.2
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	2.7	1.87	-0.13	0.88	poorly sorted	Platykurtic	0	10	90	Sand	4.6	8.6	7.5	10yr 5/6 yellowish brown	-	-	-	-	-
13	2.4	1.83	-9.0	1.17	" "	Leptokurtic	2	20	78	Loamy Sand	5.0	8.1	10.0	10yr 6/4 dull yellowish orange	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	2.5	1.60	-0.26	1.07	poorly sorted	Mesokurtic	2	19	79	Loamy Sand	8.5	7.8	7.0	10yr 6/4 dull yellow orange	49	6.9	2.8	31.0	89.7
5a	1.9	1.90	-0.44	1.03	" "	Mesokurtic	2	19	79	Loamy Sand	7.7	7.9	6.0	7.5yr 5/4 dull brown	16	8.3	9.4	126.3	159.0
5b	2.1	1.70	-0.21	1.08	" "	"	3	25	72	Loamy Sand	6.2	7.9	5.0	7.5yr 5/4 dull brown	103	10.6	1.7	164.2	279.5
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	4.4	0.36	-4	-4.30	well sorted	V.Platykurtic	1	9	90	Sand	5.7	7.6	6.4	10yr 6/4 dull yellow orange	7.8	6.7	1.3	33	48.8
32	1.9	1.59	-0.14	1.66	poorly sorted	V.Leptokurtic	1	9	90	Sand	5.2	7.5	10.2	10yr 6/4 dull yellow orange	7.9	6.7	1.2	90	105.8
33	3.0	1.47	-0.30	1.10	" "	Mesokurtic	1	12	87	Sand	7.7	7.7	11.6	10yr 6/4 dull yellow orange	7.6	7.2	2.4	11	28.2
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	2.4	1.48	-1.72	1.46	poorly sorted	Leptokurtic	3	31	66	Sandy Loam	12.0	-	-	7.5yr 7/6 orange	4.0	2.5	1.0	142.0	149.5
29	0.8	2.56	-0.31	1.20	V.poorly sorted	"	0	15	85	Loamy Sand	8.0	7.4	1.1	7.5yr 7/6 orange	31.2	6.7	4.8	143.0	185.7
34	1.9	1.98	-0.29	1.11	poorly sorted	Leptokurtic	1	13	86	Sand	6.9	7.4	0.9	7.5yr 7/8 light yellow orange	1.5	6.6	2.7	140.0	156.8
35	1.6	1.76	8.18	0.86	" "	Platykurtic	1	10	89	Sand	6.8	7.3	0.5	7.5yr 8/3 light yellow orange	8.2	6.7	2.6	142.0	159.5
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	2.7	1.49	-0.15	0.85	poorly sorted	Platykurtic	2	13	85	Loamy Sand	11.6	7.7	13.9	7.5yr 6/4 dull orange	7.6	7.3	1.0	11.0	26.9
36	2.7	1.48	-0.22	0.87	" "	"	2	16	82	Loamy Sand	12.3	7.3	12.4	10yr 6/3 dull yellow orange	7.4	7.0	2.4	13.0	29.8

Table 5.5: RESULTS OF THE SOIL PROPERTIES ANALYSES OF THE DETAILED STUDY AREA AT DEPTH OF 30-45cm.

1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	2.9	1.42	4.16	1.09	poorly sorted	Mesokurtic	3	31	66	Sandy Loam	14.0	7.9	3.7	7.5yr 5/3 dull brown	1146	19	12	417	1594.0
22	3.4	-0.77	2.70	0.11	V.well sorted	V. Platykurtic	2	18	80	Loamy Sand	12.2	7.7	8.3	10yr 5/6 yellowish brown	1442	27.9	54	480	2003.9
27	2.7	-1.21	-3.08	0.12	" " "	" "	3	53	44	Silt Loam	19.6	7.6	7.8	10yr 6/4 dull yellow orange	1862	36	11.2	440	2349.2
28	-	-	-	-	-	-	-	-	-	-									
23	3.4	1.22	-0.18	0.93	poorly sorted	Mesokurtic	0	0	100	Sand	11.7	7.8	3.6	7.5yr 5/4 dull brown	663	8.6	8.0	520	1199.6
25	4.0	0.96	7.18	-9.10	Mod.sorted	V.Platykurtic	2	27	71	Sandy Loam	15.8	7.8	4.9	7.5yr 5/4 dull brown	742	9.4	20.0	500	1271.4
26	4.2	-0.72	8.29	-4.87	V.well sorted	V. "	3	42	55	Sandy Loam	19.0	7.8	5.5	10yr 6/4 dull yellow orange	980	18.6	10.7	500	1498.6
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	2.2	1.57	-0.14	1.08	poorly sorted	Mesokurtic	5	26	69	Sandy Loam	2.9	8.0	4.8	7.5yr I dull orange	37	4.1	14	151.3	206.4
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	1.7	1.81	-0.57	1.27	poorly sorted	Leptokurtic	2	17	80	Loamy Sand	11.0	7.9	2.4	7.5yr 7/3 dull orange	5.0	1.2	3.3	157.0	166.5
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	1.6	2.21	-0.23	1.00	V.poorly sorted	Mesokurtic	2	18	80	Loamy Sand	8.5	7.9	5.5	10yr 6/4 dull yellow orange	28	6.6	3.5	32	70.1
5a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	3.6	0.68	3.47	0.12	V.well sorted	V.Platykurtic	0	9	91	Sand	2.3	7.6	6.4	10yr 6/4 dull yellow orange	7.7	6.8	1.6	36	52.1
32	2.9	1.27	0.12	0.67	poorly sorted	Platykurtic	0	10	90	Sand	3.2	7.5	10.2	10yr 6/4 dull yellow orange	7.9	7.4	2.6	63	80.5
33	2.8	1.64	-0.16	1.05	poorly sorted	Mesokurtic	0	13	87	Sand	4.2	7.7	11.6	10yr 6/4 dull yellow orange	7.5	7.2	3.0	93	110.7
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	2.1	2.03	-0.50	1.30	V.poorly sorted	Leptokurtic	0	14	86	Sand	8.5	7.4	1.1	7.5yr 7/4 dull orange	14.4	6.7	4.8	143.0	168.9
34	1.6	1.90	-9.56	1.06	poorly sorted	Mesokurtic	1	17	82	Loamy Sand	9.1	7.4	0.9	7.5yr 7/8 light yellow orange	17.1	7.5	7.0	108.0	139.6
35	1.9	1.98	-0.27	1.30	" "	Leptokurtic	1	15	84	Loamy Sand	6.4	7.3	0.5	7.5yr 8/4 light yellow orange	9.3	6.7	2.8	126.0	144.8
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	2.7	1.53	-0.18	0.83	poorly sorted	Platykurtic	2	22	76	Loamy Sand	10.8	7.7	13.9	10yr 6/4 dull yellow orange	7.5	7.2	2.4	8.0	25.1
36	2.8	1.41	-0.19	0.90	" "	Mesokurtic	2	16	85	Loamy Sand	12.0	7.3	12.4	7.5yr 6/4 dull orange	8.4	7.6	0.8	10.0	26.8

Table 5.6: RESULTS OF THE SOIL PROPERTIES ANALYSES OF THE DETAILED STUDY AREA AT DEPTH OF 45-60cm.

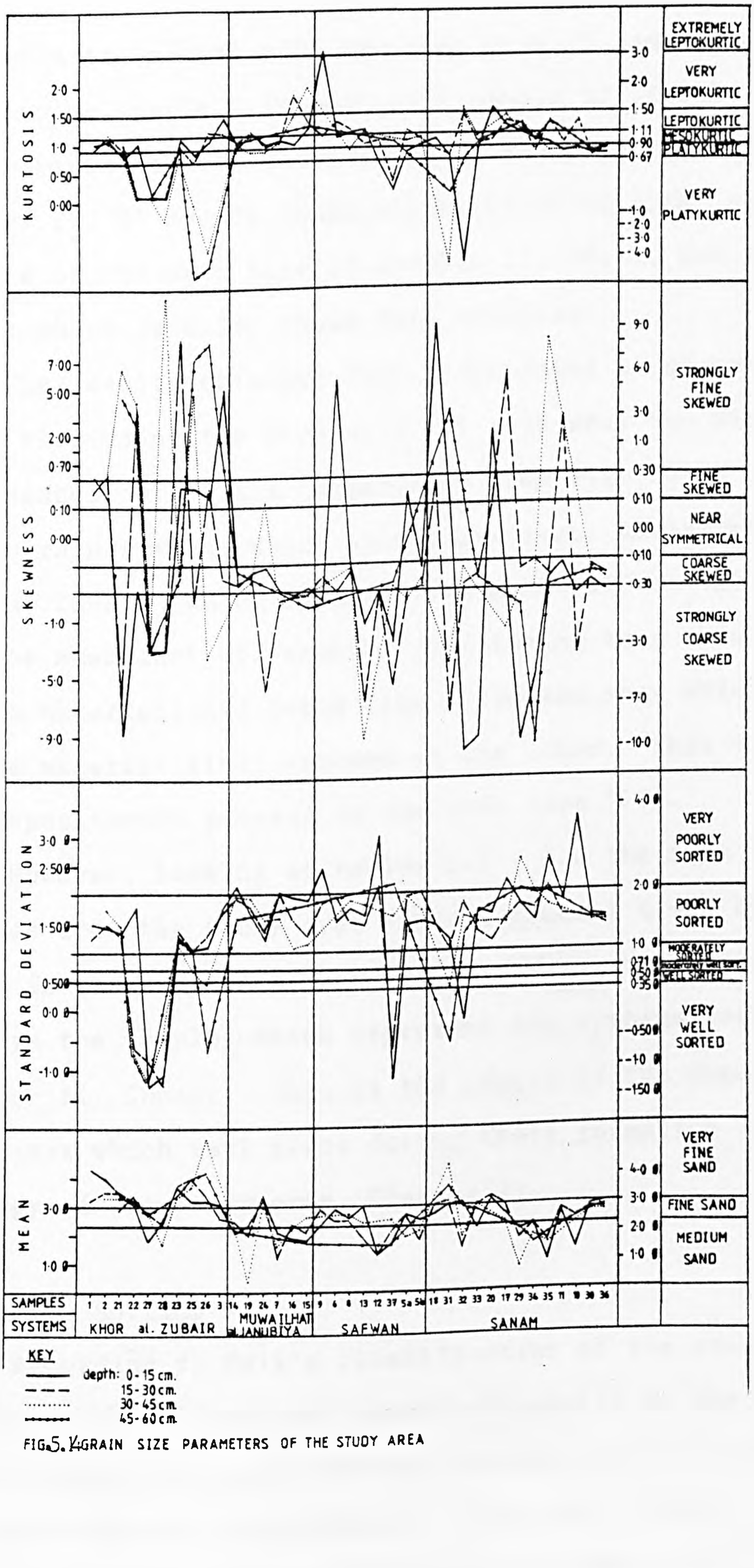


FIG.5.14 GRAIN SIZE PARAMETERS OF THE STUDY AREA

of sample 14 (slope) with the mean size of sample 24 (flat), and compare sample 7 (slope) with sample 15 (flat). Also, a comparison between the average of the mean size of samples 29, 34 and 35 (wadi slope) which is 1.8Ø, and the average of the mean size of samples 11, 10, 30 and 36 (wadi floor) which is 2.5Ø, shows this increase.

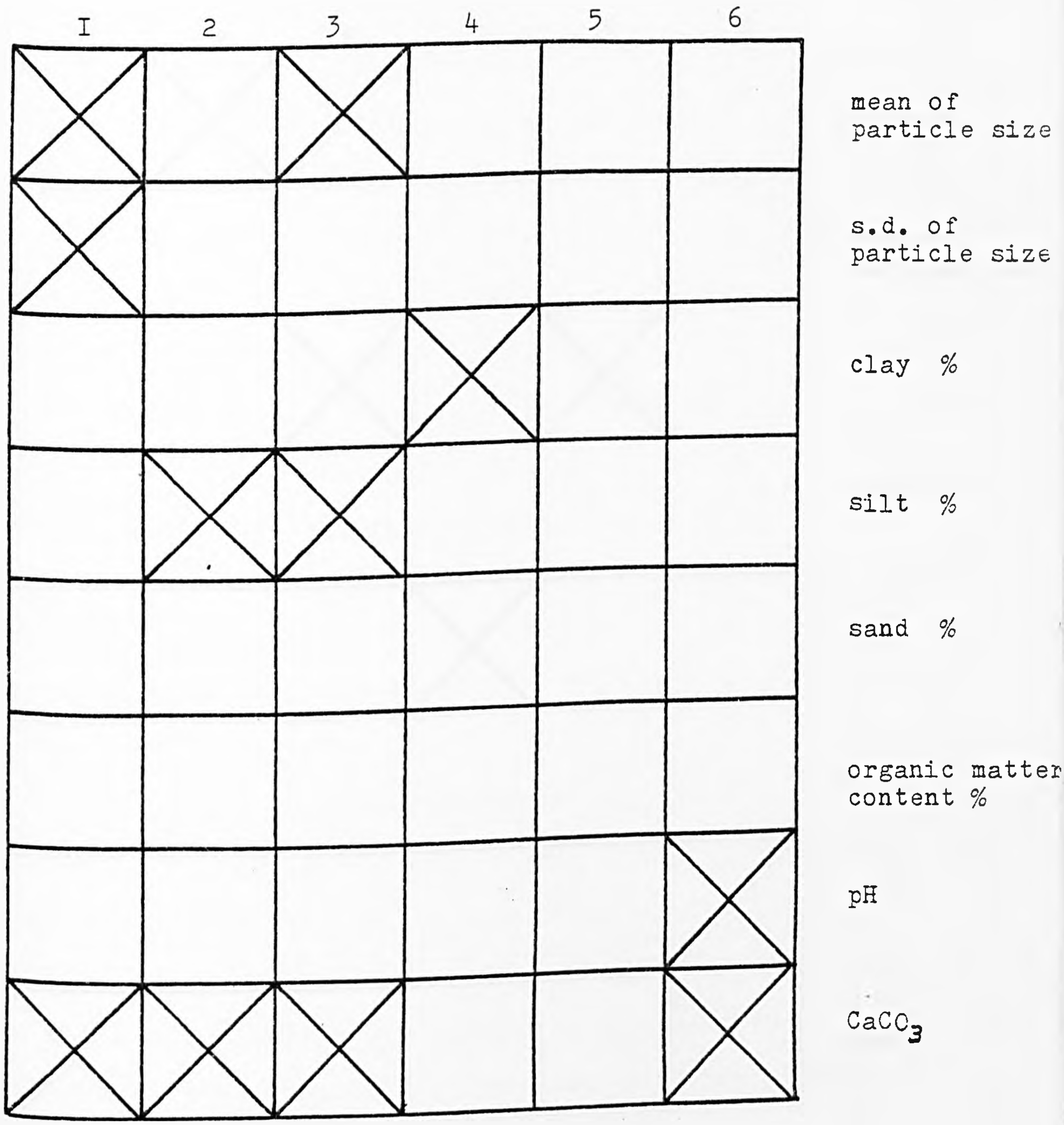
The results obtained from comparisons based on mean grain size using the Student's 't' test show two significant differences out of six comparisons (see Figs. 5.15 and 5.16). The terrain systems which show significant differences are Khor al.Zubair (which consist fine material) on the one hand and the Muwailhat al.Janubiya (undulating area which has coarse material) and Sanam (the dissected area which has coarse material also) systems on the other. This is due to the depositional process in the area (see 3.3).

However, looking at tables 5.3 - 5.6 the mean size of samples from the study area shows a general trend from fine sizes in the samples of the Khor al.Zubair to a coarser size in the samples which represent the systems located west of Khor al. Zubair. This is the result of the depositional processes which took place during their formation (see the geology of the study area, Chapter 3).

5.3.2.2. Sorting

According to Folk's classification of the standard deviation (1968), sorting values of samples of the study area range between very well sorted and very poorly sorted (standard deviation values range between - 1.26 and 2.58 Ø).

The average sorting value for the samples is 1.27 Ø



☒ significant difference at the 0.5 level. ☐ non-significant difference

I. Khor al.Zubair & Muwailhat systems
2. Khor al. Zubair & Safwan systems
3. Khor al. Zubair & Sanam systems
4. Muwailhat& Safwan systems
5. Muwailhat & Sanam systems
6. Safwan & Sanam systems

FIG. 5.15 Comparison between the systems of the study area based on their soil properties at 0-15 cm depth for all recorded observations of all facets wherever they occur within the terrain systems.

	I	2	3	4	5	6
mean of particle size		X	X			
s.d. of particle size	X					
clay %			X		X	
silt %						
sand %				X		
organic matter content %						
pH						X
$CaCO_3$	X					

☒ significant difference at the 0.05 level. ☐ non-significant

I. Khor al.Zubair & Muwailhat systems
2. Khor al.Zubair & Safwan systems
3. Khor al.Zubair & Sanam systems
4. Muwailhat & Safwan systems
5. Muwailhat & Sanam systems
6. Safwan & Sanam systems

FIG. 5.16 Comparison between the systems of the study area based on theirsoil properties at I5-30cm depth for all recorded observations of all facets wherever they occur within the terrain systems.

falling within the poorly sorted class. This means that the majority of samples have sorting values within the poorly sorted class. For example, while 26 samples out of 37 samples from 0-15 cm depth are poorly sorted, only 8 samples are very poorly sorted and 3 samples are very well sorted (negative values, see Fig. 5.14). Nearly the same situation applies to the other sample depths. For instance, at depth of 15-30 cm, 29 samples out of 37, group within the poorly sorted class with the remaining samples being either very poorly sorted or very well sorted (Fig. 5.14). The moderately sorted class can be applied only to two samples from the study area at depths of 30-45 cm and 45-60 cm, while only two samples (depths 30-45 cm) are well sorted (Fig. 5.14).

However, a comparison between the terrain systems based on their standard deviation values (using the Student's 't' test) at depths 0-15 cm and 15-30 cm, shows only one significant difference for each depth out of 12 analyses (see Figs. 5.15 and 5.16). This may be due to the fact that, although the poorly sorted class is the predominant one, the Khor al.Zubair locality (which yields finer mean sizes than the others) is slightly better sorted than other localities and includes two samples at each depth which are very well sorted (see Fig.5.17A).

5.3.2.3 Skewness

Sample skewness values range between +9.33 and -9.53 with an average of +0.06. However, the majority of the samples are either strongly coarse skewed or coarse skewed. These are from the 0-15 cm depth. Eleven samples are strongly

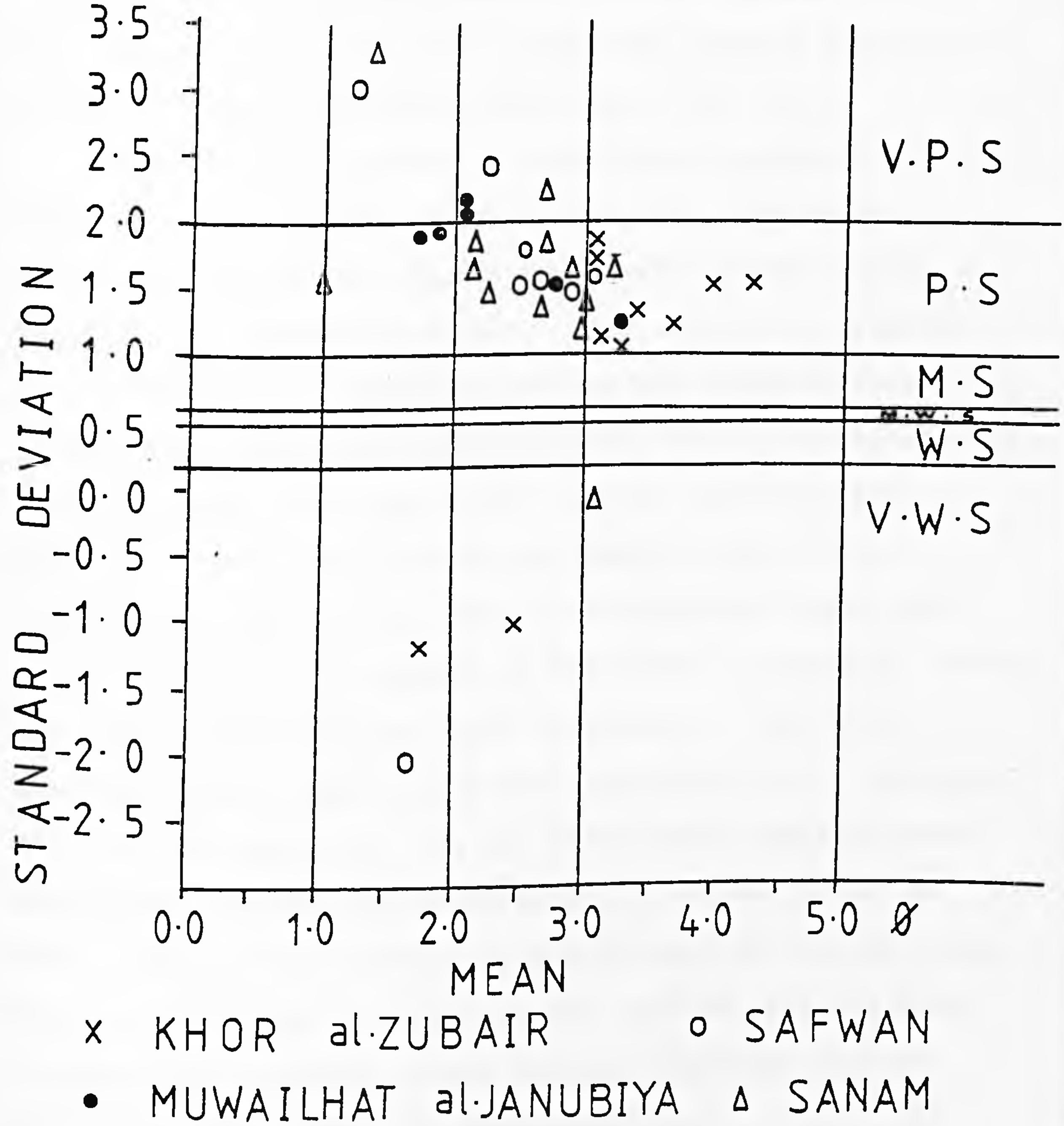


FIG. 5.17A: GRAPHIC MEAN SIZE VERSUS STANDARD DEVIATION; SCATTER PLOT DIAGRAM; AT DEPTH 0-15cm.

coarse skewed and 12 samples are coarsely skewed, only six samples are finely skewed with five samples appearing in the strongly fine skewed class (see Fig. 5.14).

Theoretically, perfectly symmetrical curves have a skewness value of zero, those with excess fine material having positive values whilst those with excess coarse material yeild negative values. Thus, generally, samples of the Muwailhat al.Janubiya, Safwan and Sanam terrain systems give negative skewness values, while the majority of Khor al.Zubair (finer material) samples show positive skewness values (for instance six samples out of ten samples, see Fig. 5.17B). This is as mentioned above due to the fact that the samples of Muwailhat al.Janubiya, Safwan and Sanam terrain systems have an excess of the coarse material whilst samples from Khor al.Zubair have an excess of the fine material. On the other hand, negative skewness values (excess coarse material) is obtained in Khor al. Zubair samples and this may be due to wind action over this terrain system which transports the coarser material from the west and northwest (other systems) into this system. This is in the surface and subsurface depths, whilst the negative skewness values relate to the depositional nature of Khor al.Zubair which becomes coarser at depth (see also section 5.3.3.).

5.3.2.4 Kurtosis

Theoretically, leptokurtic curves (better sorted in the central portion of the distribution than in the tails) will have KG values over 1.00, while platykurtic curves that have their tails better sorted than the central portion will have

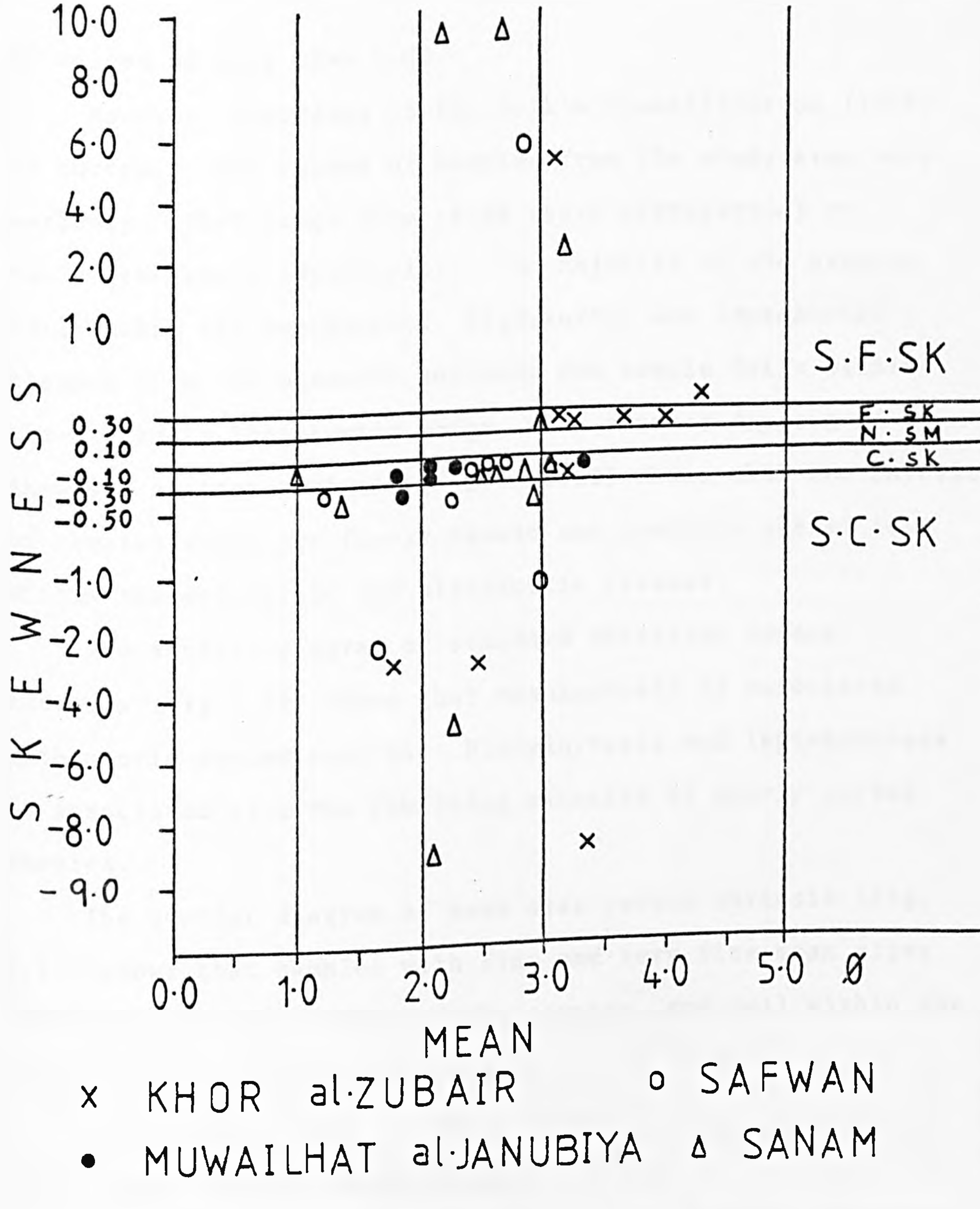


FIG. 5.17B: GRAPHIC MEAN SIZE VERSUS SKEWNESS; SCATTER PLOT DIAGRAM; AT DEPTH 0-15cm.

KG values of less than 1.00.

However, according to the Folk's classification (1968) of kurtosis, the values of samples from the study area vary markedly. They range from -4.86 (very platykurtic) to +3.36 (extremely leptokuric). The majority of the samples fall within the mesokurtic. Platykurtic and leptokurtic classes form the minority and only one sample falls within the extremely leptokurtic range. The scatter diagram of skewness against kurtosis (Fig. 5.18) shows that the majority of samples which are finely skewed and coarsely skewed fall within the mesokurtic and platykurtic classes.

The scatter diagram of standard deviation versus kurtosis (Fig.5.19) shows that mesokurtosis is associated with poorly sorted samples. Platykurtosis and leptokurtosis is associated with the remaining minority of poorly sorted samples.

The scatter diagram of mean size versus kurtosis (Fig. 5.17C) shows that samples with fine and very fine mean sizes form quite a large number of the samples, and fall within the mesokurtic and platykurtic range.

5.3.3 Soil Texture: Discussion.

Texture is largely the result of soil forming processes. Furthermore, certain important soil physical properties that influence growth, development and yield of crops are the result of soil texture and are taken into consideration in land management and land reclamation. For example, permeability, available water-holding capacity and structural status depend to a great degree on soil texture. Also, the effect of cultivation and the influence of cultivating

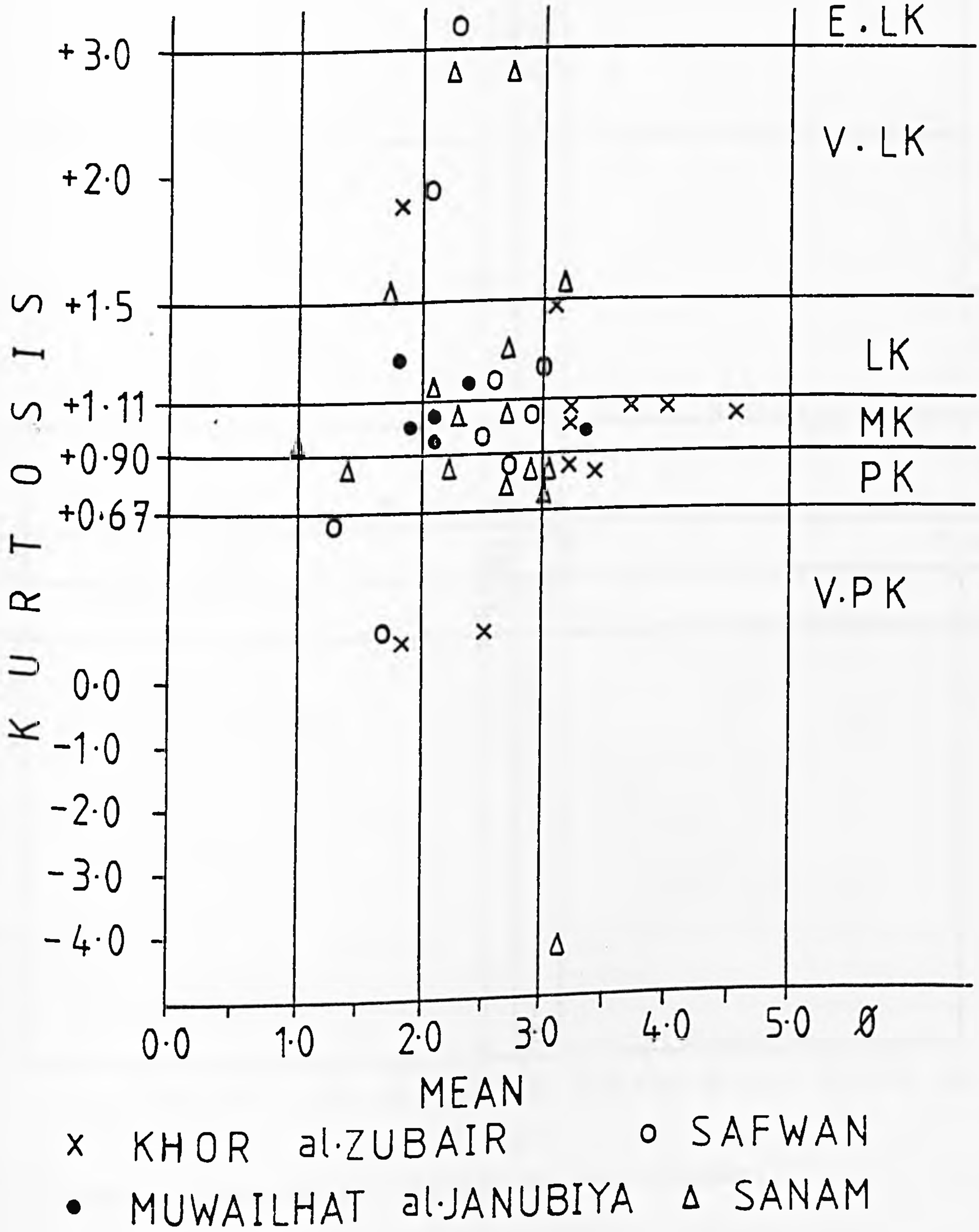


FIG. 5.17C: GRAPHIC MEAN SIZE VERSUS KURTOSIS; SCATTER PLOT DIAGRAM; AT DEPTH 0-15cm.

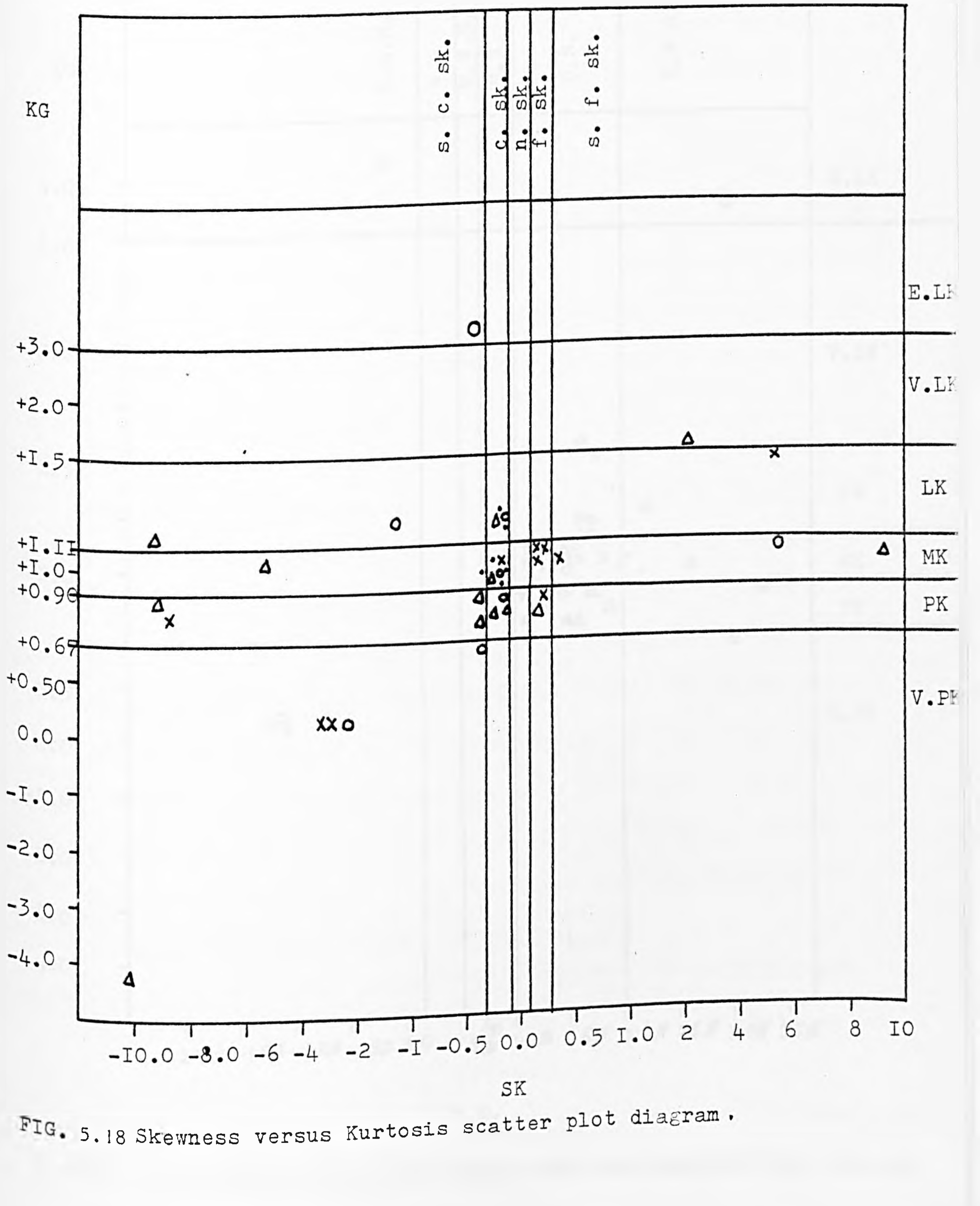


FIG. 5.18 Skewness versus Kurtosis scatter plot diagram.

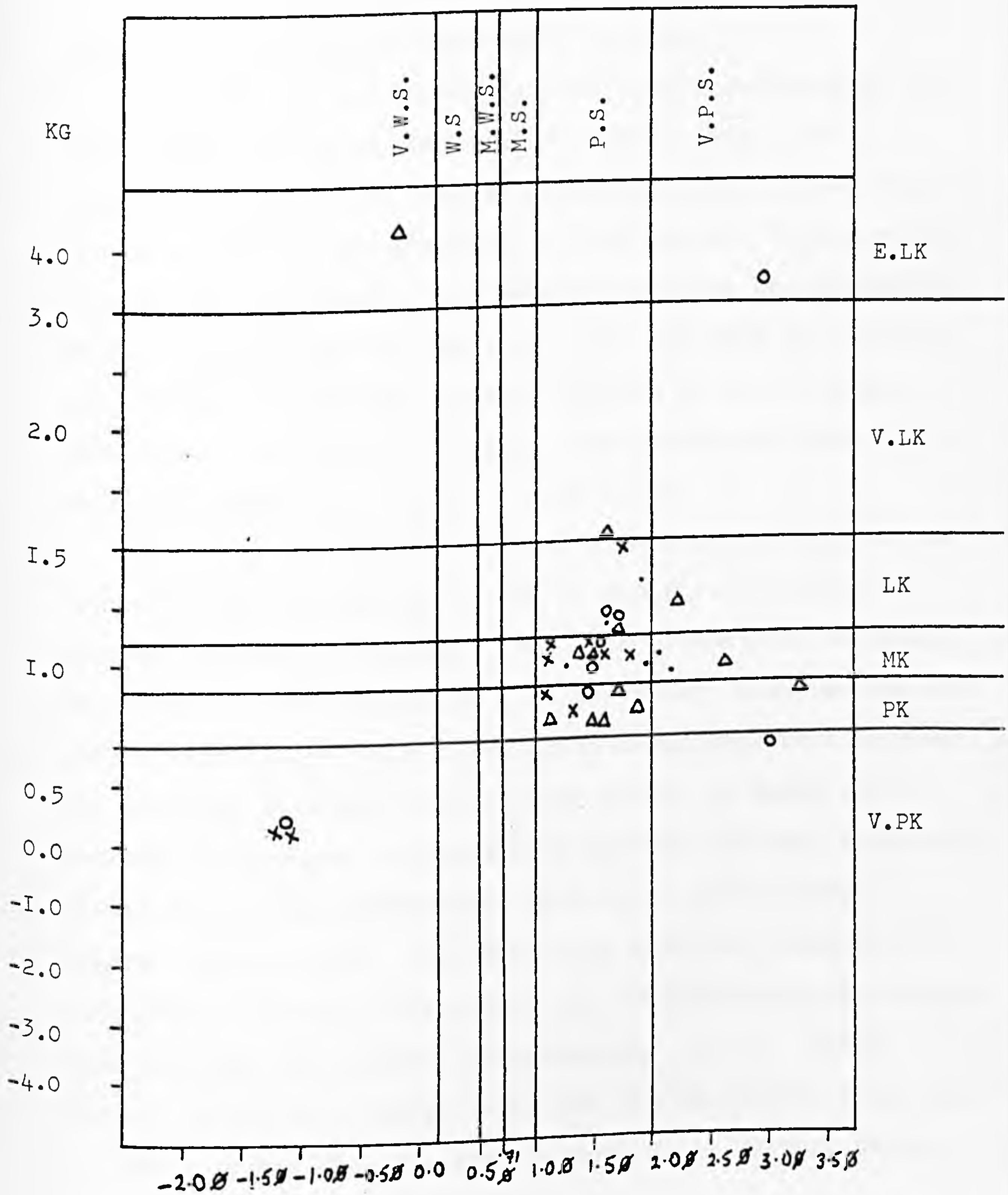


FIG. 5.19 Standard deviation versus Kurtosis scatter plot diagram.

machines on soil are influenced by texture.

The American soil investigation system outlined in the soil survey manual of the U.S.D.A. (1951) (Fig.5.20) is adopted in Iraq. Soil textural classification of the study area was carried out according to this system. The particle size of the soil samples was determined using the hydrometer method. Percentages of the clay, silt and sand were calculated using an existing computer program in the Geography Department, University of Keele. The results of these soil texture classes are shown in tables 5.3-6.

In order to visualize general trends and groupings, the textural class percentage values in tables 5.3-6 have been plotted on ternary diagrams, then later summarized as groups according to their depths on similar ternary diagrams and bar graphs (Figs.5.21-5.24). Evaluation using graphical methods was employed in order to assess the extent to which soil texture differences correlate with terrain systems, especially as marked textural differences were by no means always evident in the field. The laboratory analyses, however, do reveal soil textural differences and whether these differences appear within the systems or between the system. These results as shown in tables 5.3-6 and the bargraphs (Figs.5.21 - 5.24) reveal that the sand percentage is highest in all the samples from the study area.

These results as can be seen from figures 5.21-5.24 also indicate that sandy loam, loamy sand and sand form the major soil texture classes in the study area. Exceptions (i.e. sandy clay loam, sand clay and silt loam) are from the Khor al.Zubair locality. According to the system outlined in the 'soil survey manual of U.S.D.A. (1951)' the samples from the

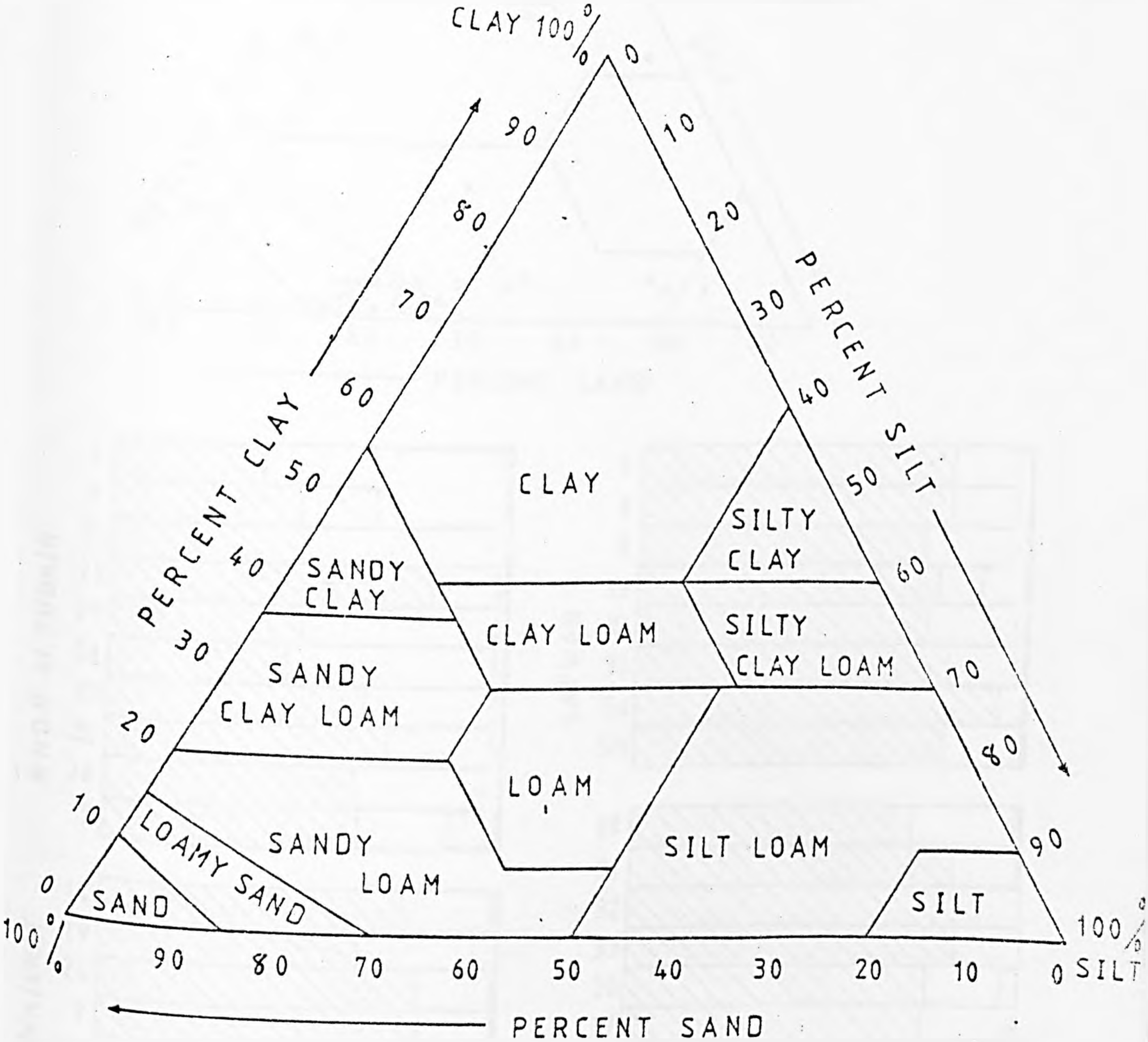


FIG. 5.20 U.S.D.A. SPECIFICATION SOIL TEXTURE DIAGRAM.

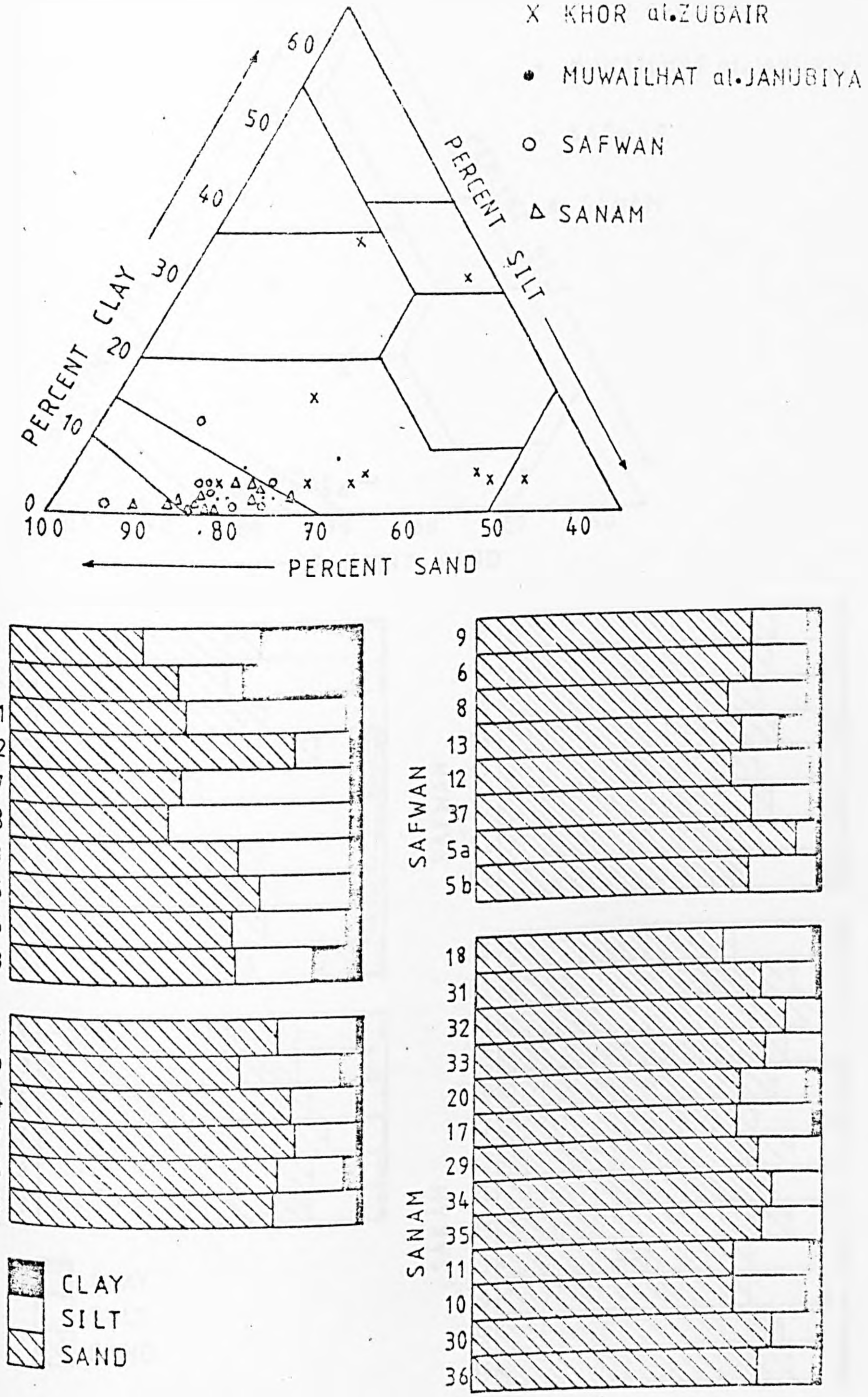


FIG. 5.21 PARTICLE SIZE: PERCENTAGE COMPONENTS CLAY, SILT & SAND AT DEPTH 0-15cm.

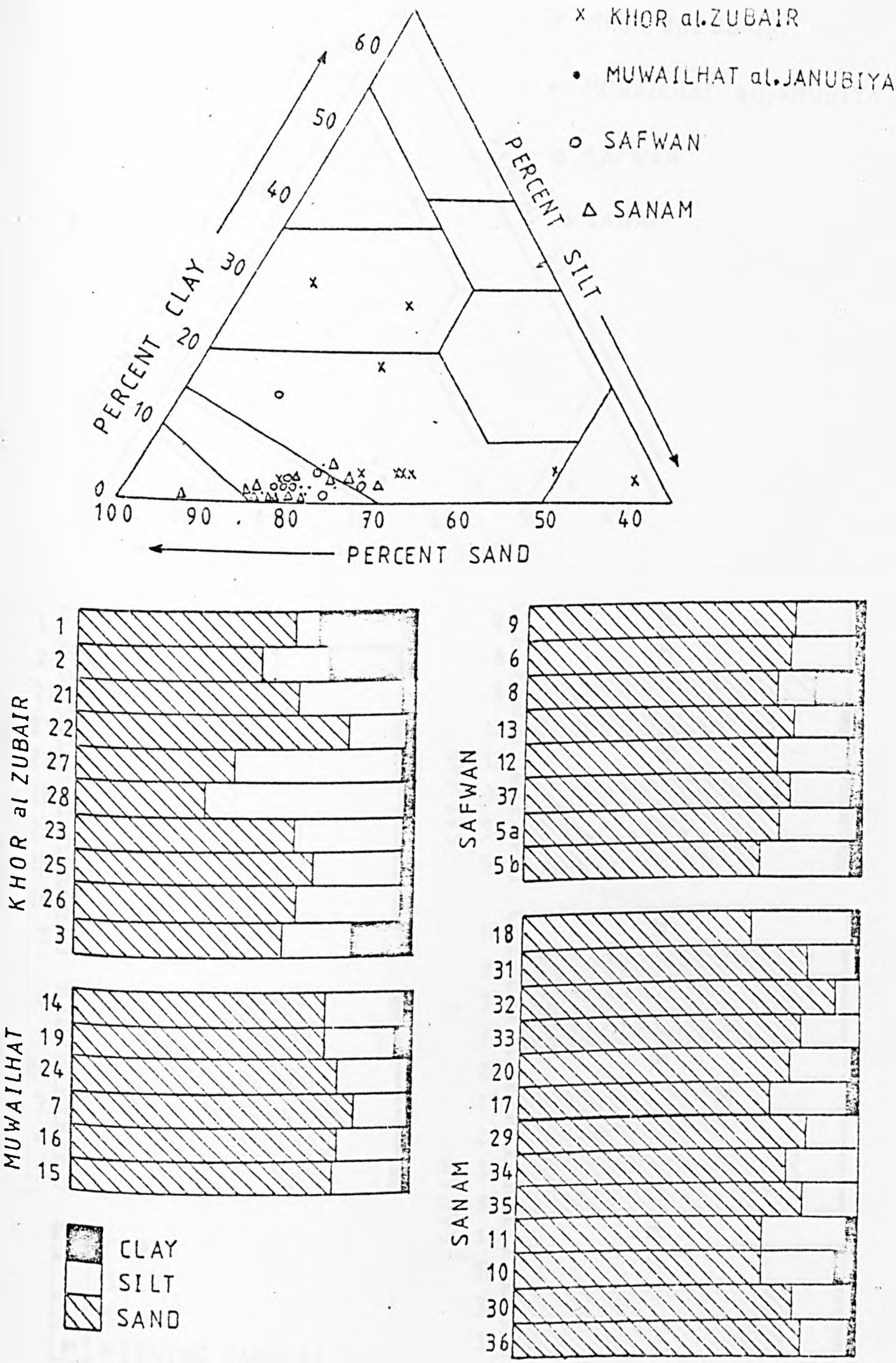


FIG. 5.22 PARTICLE SIZE: PERCENTAGE COMPONENTS CLAY, SILT & SAND AT DEPTH 15-30 cm.

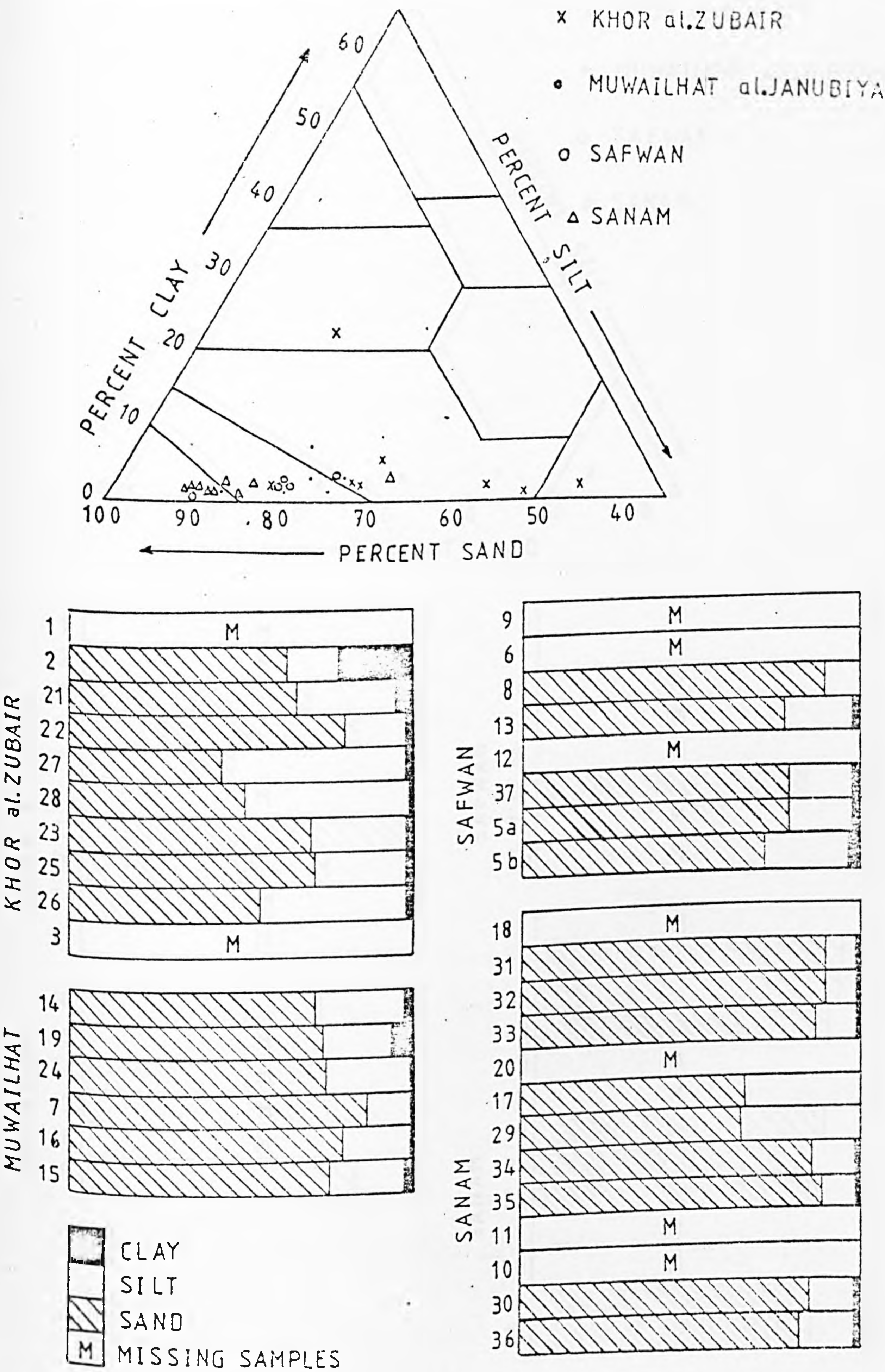


FIG. 5.23 PARTICLE SIZE: PERCENTAGE COMPONENTS CLAY, SILT & SAND AT DEPTH 30-45 cm.

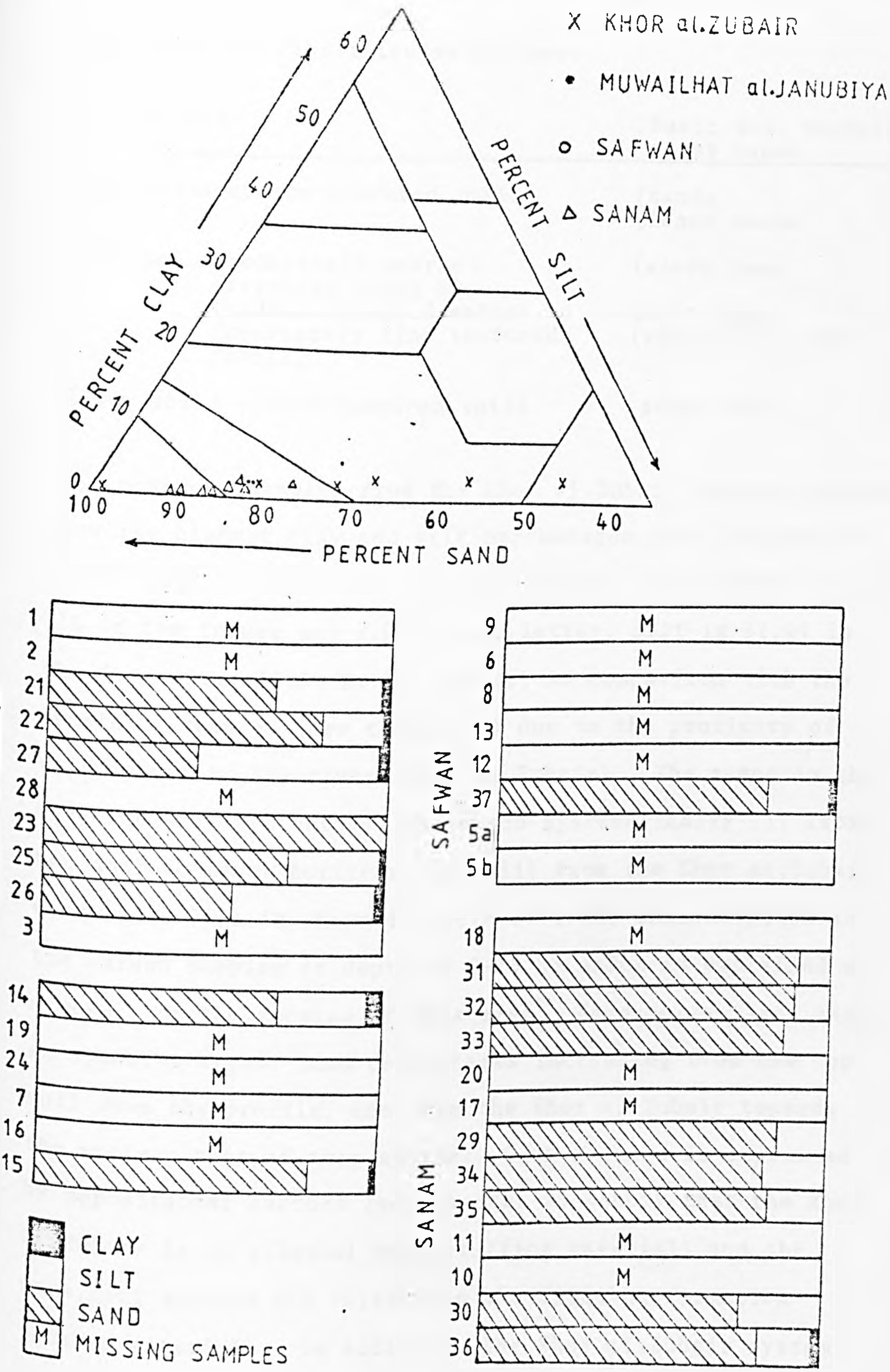


FIG. 5.24 PARTICLE SIZE: PERCENTAGE COMPONENTS CLAY, SILT & SAND AT DEPTH 45-60 cm.

study area are classified as follows:

General term	Basic soil textural class names
sandy soils-coarse-textured soils	(sands (loamy sands
loamy soils (moderately coarse- (textured soils 8)	(sandy loam
(medium-textured soils	(silt loam
(moderately fine textured (soils).	(sandy clay loam
Clayey soils - fine-textured soils	sandy clay

However, samples from the Khor al.Zubair terrain system show the highest clay and silt percentages (for instance at depths 0-15 cm and 15-30 cm , the average clay content is 11% in the former and 9.9% in the latter, silt is 32.4% in the former and 29.3% in the latter) in comparison with the remaining samples (see table 5.7) due to the proximity of this system to the river (Khor al.Zubair). The trend in the clay and silt percentages decreases systematically (i) from top soil to lower horizons, and (ii) from the Khor al.Zubair westward. This is shown in table 5.7; the one exception is the Safwan samples at depth of 0-15 cm which is explained as a result of the forming of this area. Sand percentages show an opposite trend, sand percentages increasing from the top soil down the profile, and from the Khor al.Zubair towards the western part of this system. Such a trend is explained by depositional factors (see Chapter 2) namely that the Khor al.Zubair is an alluvial deposit (fine material) and the remaining systems are related to the Dibdibba formation (coarse material). In addition, the Khor al.Zubair system

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8) In Iraq, 'moderately coarse-textured soils' are usually combined with 'medium-textured soils' (see, for example, Moltchanov et al , 1976).

DEPTH	KHOR al. ZUBAIR			MUWAILHAT			SAFWAN			SANAM		
	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %
0.15	11	32.4	56.4	3.5	22	74.5	4	16.5	79.5	1.5	17.6	80.8
15-30	9.9	29.3	60.8	2.1	20.5	77.3	3.8	19.3	76.7	1.5	18.3	80.1
30-45	4.2	29.1	55.5	2.6	21.0	76.3	1.8	18.6	79.6	1.3	14.2	84.4

Table 5.7: Average percentages of clay, silt and sand of the samples of the detailed study area.

is increasingly affected by wind transport towards the west.

Comparison between the terrain systems of the study area (using the Student's 't' test) based on their clay, silt and sand content percentages, show no significant differences in most of the comparisons (see Fig. 5.15). That is probably due to the sand content predominance over all the terrain systems of the study area. Other evidence which seems sufficient to indicate that differentation is valid on the basis of the tenary diagrams (soil texture) and bargraphs as in figures 5.21-5.24. Nevertheless, it could be concluded that sandy soil textures are dominant over most of the study area. Such dominance shows in high percentages in the samples of the Muwailhat al.Janubiya, Safwan and Sanam terrain systems and it becomes lower in the samples from the Khor al. Zubair terrain system.

5.4 ORGANIC MATTER AND SOIL COLOUR

Organic matter has an important influence on the structural properties of the soil. This effect, may however, differ from one environment to another. Organic matter can affect the soil in two ways: first, by holding together the soil particles and, second, by influencing the chemical fertility of the soil. Humus is the product of decomposition of soil organic matter.

Weir (1949) stated that "the quantity of organic matter in soils varies widely, from a comparatively small percentages in poor sands to more than 70 per cent in peat soils. The rate of natural accumulation of organic matter is determined largely by the nature of the vegetable growth, temperature precipitation, and drainage" (p.69). Arid soil can maintain a sparse cover of vegetation thus producing very little organic matter. Under such conditions and according to Thompson (1952)[9] the soils of the study area can be referred to as mineral soils.

With a very few exceptions, samples from the study area contain less than 20 per cent organic matter. These samples with higher organic contents were all taken from the Khor al. Zubair terrain system. The percentage values of the studied samples vary from one depth of another. The results of these percentages are listed in tables 5.3-6. They range between 28 percent and 1.6 percent (Fig.5.25).

The highest average percentages of organic matter were obtained from the Khor al.Zubair terrain system (12 percent and 15 percent at depths of 0-15cm and 30-45cm. The lowest percentages of organic matter were recorded from the Muwailhat al.Janubiya terrain system where percentage values average 6.7 at a depth of 0-15cm and 8.7 at a depth of 15-30cm. In the Khor al.Zubair system, samples taken nearer to the river (Khor) yielded higher percentages than those from sites away from the river (compare for example samples No.1 and 2 with the samples No.21, 25 and 3). The percentages of the samples which have been taken from the Muwailhat al.Janubiya terrain system also vary from one location to another. Samples from the top of slopes for instance, show a percentages range between 1.1 and 3.2, whilst samples from the slope base show a range of between 8.0% and 12.8%.

However, organic matter contents shows a clear trend within the Khor al.Zubair and the Muwailhat al.Janubiya

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9) Thompson (1952) suggested that soil containing more than 20 percent organic matter be designated as an organic soil, whereas those with less than 20 percent are mineral soils.

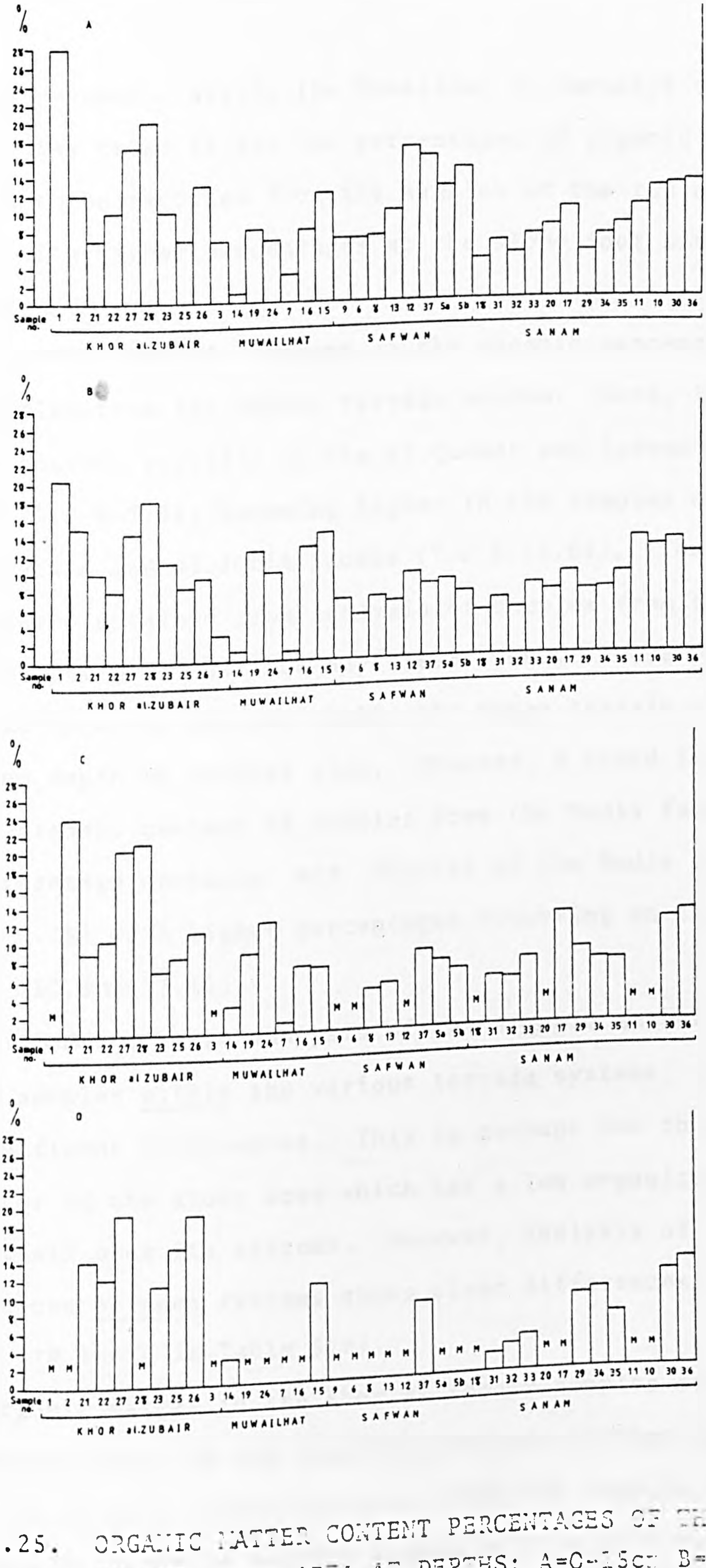


FIG. 5.25. ORGANIC MATTER CONTENT PERCENTAGES OF THE SAMPLES OF THE STUDY AREA AT DEPTHS: A=0-15cm B=15-30cm C=30-45cm D=45-60cm. (M = missing samples).

terrain systems. Within the Muwailhat al.Janubiya terrain system, the trend is for low percentages of organic matter content to be recorded from the samples at the top of the slopes with higher percentages at the slope foot sites (flat elements).

A clear trend is evident in the organic percentages of the samples from the Safwan terrain system. Here, low organic matter content prevails in the al.Quabat and Safwan-east facets (5.2 & 7.4%) becoming higher in the samples of the North-Safwan and al.Jufin facets (7.2 & 14.8%). The percentages obtained from analysis of samples from the Sanam terrain system do not show any clear trend. These values vary from one facet to another within the Sanam terrain system and from one depth to another also. However, a trend is evident in the organic content of samples from the Wadis facet, where low percentage contents are typical of the Wadis slope (5.8 to 9.2%) with higher percentages occurring on the Wadi floors (10.6 to 13.1%).

Student's't' test analysis of the organic matter content of the samples <u>within</u> the various terrain systems, revealed no significant differences. This is perhaps due to the arid character of the study area which has a low organic matter content all over its systems. However, analysis of differences <u>between</u> systems shows clear differences (average values are shown in Table 5.8).

Organic matter in the Khor al.Zubair samples are clearly higher than those in the remaining terrain systems (see Table 5.8). It is also noticeable that slope-top samples in the Muwailhat al.Janubiya terrain system or from Wadi slopes in the Sanam terrain system are much poorer in organic matter

DEPTH (cm)	KHOR al. ZUBAIR		MUWAILHAT al. JANUBIYA		SAFWAN		SANAM	
	O.M.	pH	O.M.	pH	O.M.	pH	O.M.	pH
0.15	13.0	7.8	6.7	7.8	11.6	8.3	8.7	7.6
15-30	12.0	7.6	8.7	7.8	7.5	8.3	8.9	7.6
30-45	14.1	7.4	6.7	7.7	6.4	8.0	8.4	7.4
45-60	15.3	-	8.4	-	8.5	-	7.0	-

Table 5.8: Average organic matter content percentages and soil pH values in the detailed study area.

than slope-foot samples or samples from the flats in the Muwailhat al.Janubiya and those from Wadi floors in the Sanam terrain system.

It has been pointed out by Weir (1949) that the quantity of organic matter in soils depends on some other factors, e.g. the existence of a vegetation cover, temperature and precipitation regimes on one hand and the soil texture on the other hand.

A definite relationship, for instance, between the organic matter content and the soil colour can be shown in the case of the study area (Table 5.3). For example, samples with high organic matter content have a dull yellow brown (10yr 4/3) colour or dull yellowish brown (10 yr 5/3, 5/4 and 4/3), whilst samples with lower percentages of organic matter are dull yellow orange (10yr 7/3 or 6/4) in colour.

However, considerable significance has always been attached to soil colours due to their relationship to the other soil properties. For instance, in the matter of soil temperature, black soils are usually higher in clay content and therefore stay moist longer and warm up more slowly than light coloured sandy soils, because the black soils absorb heat, while lighter coloured soils reflect heat (Thompson, 1952).

Variations in soil texture (i.e. relative proportions of clay, silt and sand) affect the soil colour. This variation could be seen with depth and from one terrain system to another. For example, the sand content increases from the top soil to the lower depths and is accompanied by a colour change from dull yellow brown (10yr 4/3) to dull yellowish brown (10yr

5/3) or dull yellow orange (10yr 6/4). At the same time high percentages of the sand in the samples accord with a dull yellow orange (10yr 6/4) or light yellow orange (7.5yr 7/8 and 8/3) colour (see tables 5.3 - 5.6).

5.5 SOIL pH

Measurements of sample pH are discussed in the appendix (4) dealing with laboratory techniques. The pH values of these samples are listed in tables 5.3-6. The pH values of the studied samples vary from one sample to another according to location. The pH values range from 7.1 to 8.6. They have been drawn graphically against Brady's (1974) and Thompson's (1952) scales of alkalinity (Fig .5.26). The pH values of Safwan and Sanam samples vary from slightly alkaline (7.0-8.0) for the Sanam, and medium in range (8.0-8.5) for the Safwan samples. In both terrain systems these values remain constant at depths of 0-15cm and 15-30cm. The pH values for the Khor al.Zubair and Muwailhat al.Janubiya samples fall in the range of medium to slightly alkaline at a depth of 0-15cm, and similar values are obtained at a depth of 15-30cm (compare on Fig. 5.26). The majority of pH values representing the samples of all terrain systems fall within the range of very slightly to slightly alkaline at depths of 30-45cm and 45-60cm. The remaining values correspond to a medium alkaline range at depth of 30-45cm (Fig.5.26).

The high pH values of the Khor al.Zubair terrain system may be explained by locational factors, the seasonal floods and high water table being responsible (Daghistani et al , 1972). The pH values of the analysed samples from all systems of the study area have been compared within and between

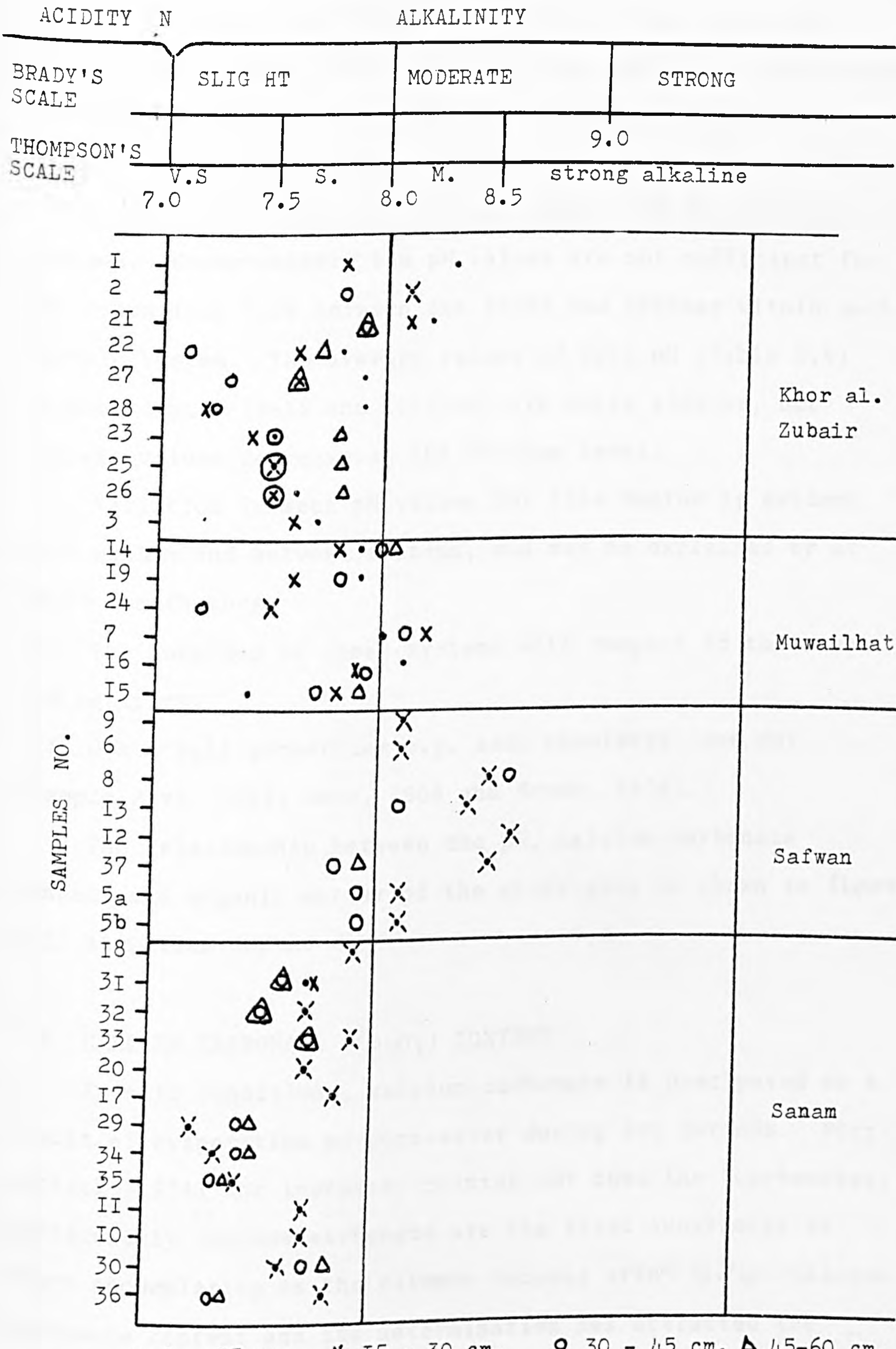


FIG. 5.26 pH values of the studied samples of the study area according to Brady's(I974)& Thompson's(I952) scales of alkalinity.

systems by using the Student's 't' test for both depths of 0-15cm and 15-30cm. The test shows non-significant differences between the systems except for one (the Sanam and Safwan. (Figs. 5.15 and 5.16). This may be accounted for by the general alkalinity which appear in all the samples of the terrain systems. Unfortunately the pH values are not sufficient for the comparison test between one facet and another within each terrain system. The average values of soil pH (Table 5.8) at both depths (0-15 and 15-30cm) are quite similar, but average values decrease at the 30-45cm level.

Variation in mean pH values for like depths is evident both within and between systems, and may be explained by at least two factors.

(i) The location of these systems with respect to the river and aquifers.

(ii) Other soil properties e.g. soil chemistry (see, for example, Puri, 1949; Bear, 1964 and Brady, 1974).

The relationship between the pH, calcium carbonate content and organic matter of the study area is shown in figure 5.27 at 0-15cm depth.

5.6 CALCIUM CARBONATE ($CaCO_3$) CONTENT.

In arid conditions, calcium carbonate is precipated as a result of evaporation of pore-water during dry periods. Fitz-Patrick (1974) for instance, pointed out that the "carbonates, particularly calcium carbonate are the first substances to start accumulating as the climate becomes arid" (p.71). Calcium carbonate content and its determination has attracted the attention of many authors, e.g. Clements (1957) who studied the determination of the $CaCO_3$ content of different playa

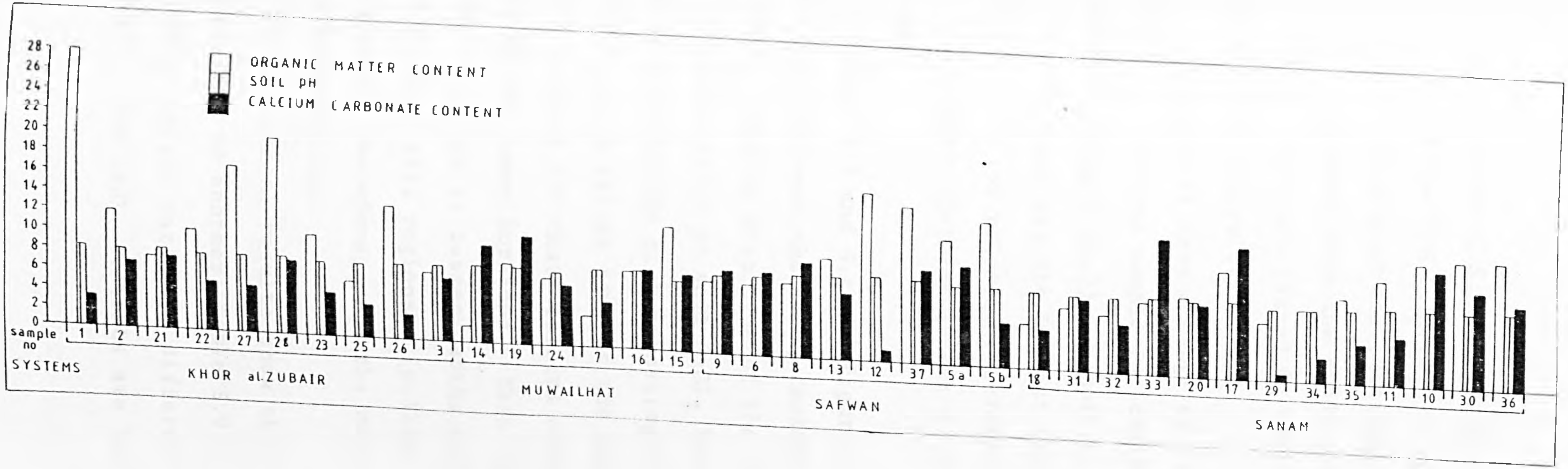


FIG. 5.27: THE RELATIONSHIP OF THE THREE SOIL PROPERTIES: ORGANIC MATTER, SOIL pH AND CALCIUM CARBONATE OF THE STUDY AREA AT DEPTH OF 0-15cm.

sediments in the U.S.A. Similar work has been carried out in parts of the U.S.S.R. deserts (Lobova, 1960).

The method used for obtaining the $CaCO_3$ percentages from samples obtained from the study area is discussed in Appendix 4. The results are listed in tables 5.3-6 and shown diagrammatically in figure 5.28.

The results have a range of between 0.3 percent and 14 percent. Only one sample (at depth 30-45cm) has no calcium carbonate (sample no.7). Sample no.33 of facet 11 (Sanam terrain system) has the highest $CaCO_3$ content (14 percent), while a very low value (0.3 percent) was obtained from sample no.7 (at depth 15-30cm) (facet 4, Muwailhat al.Janubiya terrain system).

Tables 5.3 and 5.4 and figure 5.28a and b show the similarity between the $CaCO_3$ content at depths of 0-15cm and 15-30cm. This is also true of the 30-45cm and 45-60cm levels.

Concentration of soil $CaCO_3$ in the study area can be demonstrated by the high percentages in the upper layers and the decline in values towards the lower soil layers. Bear (1964) pointed out that "calcium carbonate occurs in many soils in the lower horizons. This form of calcium is found is soil horizons at lesser depths as one traverses from more humid to more arid regions". (p.129). al.Zubair desert corresponds, therefore, with the most arid part of Bear's climatic gradation.

The analytical results show that $CaCO_3$ content differs from one area to another (Table 5.9). This table also shows that $CaCO_3$ content varies in different particle size fractions. The $CaCO_3$ contents are low in the samples with a

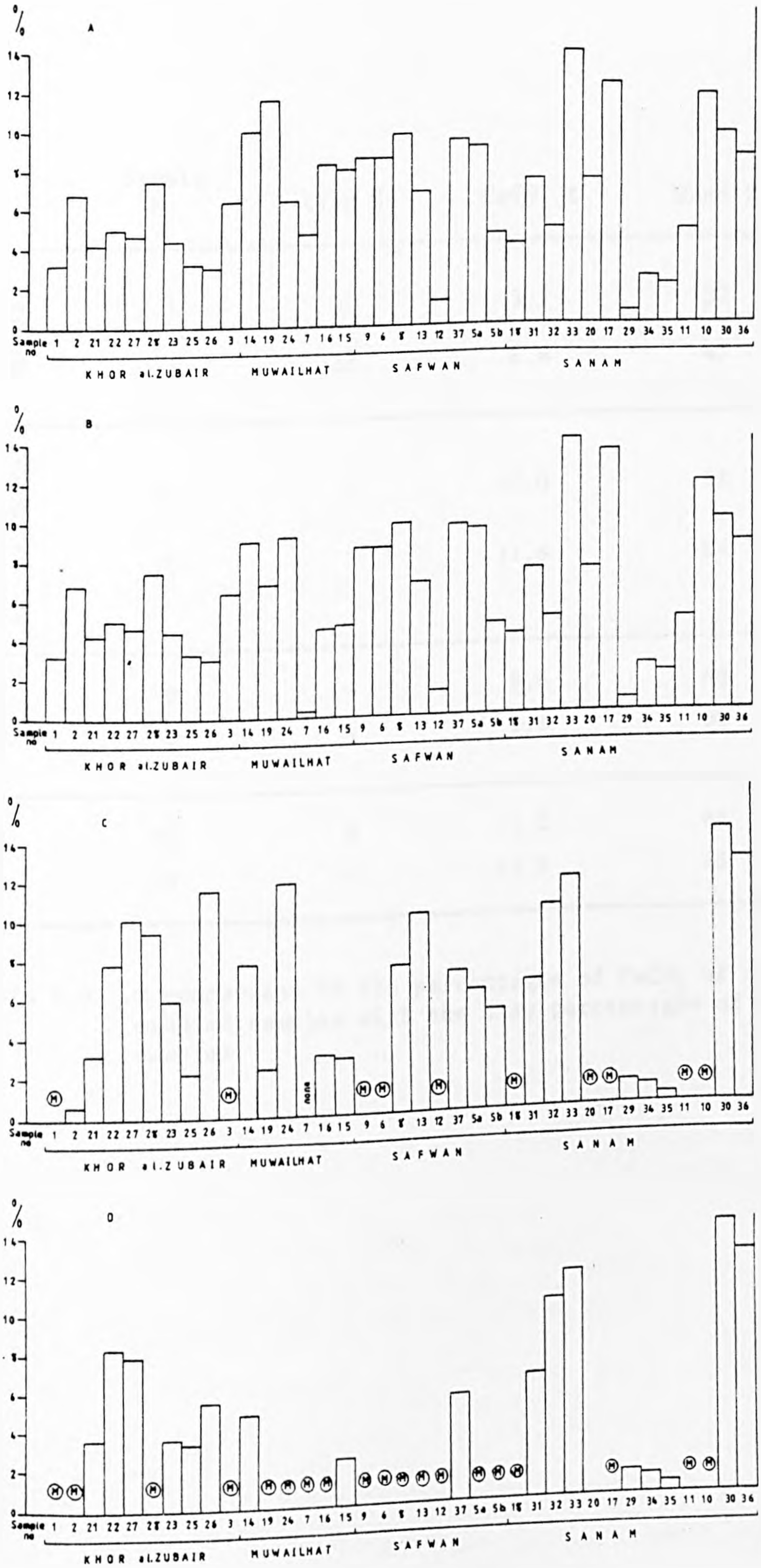


FIG. 5.28: CALCIUM CARBONATE PERCENTAGES OF THE SAMPLES OF THE STUDY AREA AT DEPTHS: A: 0-15cm; B: 15-30cm; C: 30-45cm; D: 45-60cm. (M = missing samples).

	Sample No	Clay %	$CaCO_3$ %	Sand %
KHOR al. JUBAIR	1	30	3.2	37
	2	35	6.8	47
MUWAILHAT al. JANUBIYA	14	2	10.0	75
	19	7	11.6	64
SAFWAN	9	4	8.6	80
	8	4	9.8	80
SANAM	33	0	14.0	84
	10	4	11.9	75

Table 5.9: A comparison of the percentages of $CaCO_3$ of some studied samples with the clay percentages of these samples.

high percentage of clay and vice versa. This is contrary to the findings of other workers. Lobova (1967), for example, related the high content of $CaCO_3$ to the heavy clay in some studied profiles of the U.S.S.R. deserts. Also, according to the results obtained from the Arabian Gulf area it has been found that the high amount of $CaCO_3$ present is in the finer fractions (Fookes et al, 1975; Kukal and Saadallah, 1970a and 1973).

On the other hand, Kukal and Saadallah (1970b) found an unexpectedly high carbonate content in the coarsest fractions. Similar results have been obtained by al.Habeeb (1969). According to al.Habeeb, the high amount of carbonate in the coarsest fraction indicates the presence of local clastic carbonates. It can be concluded that the amount of $CaCO_3$ content varies from one area to another according to the particle size fractions and the soil type. Variation in $CaCO_3$ content is significant between terrain systems (Fig. 5.15), but each facet has not been represented enough with $CaCO_3$ data to have a comparison between them within each terrain system, nevertheless, qualitative assessment suggests no significant differences.

5.7 X-RAY IDENTIFICATION OF CLAY MINERALS.

The mineralogy of Iraqi soils is not well known in general and a search of the literature has revealed no detailed information for the present study area. Accordingly, this study has been undertaken so as provide some preliminary information for this desert region.

The x-ray identification of the clay grade minerals of

21 selected samples was achieved using standard methods (see Appendix 4). The diffractograms representing untreated, glycolated and heated samples are shown in the following figures 5.29-5.32.

Each significant peak on the diffractogram was measured and converted to Å to give the d spacings. According to Brown (1961) and an unpublished thesis by D.L. Salter (quoted by Derbyshire, 1967)

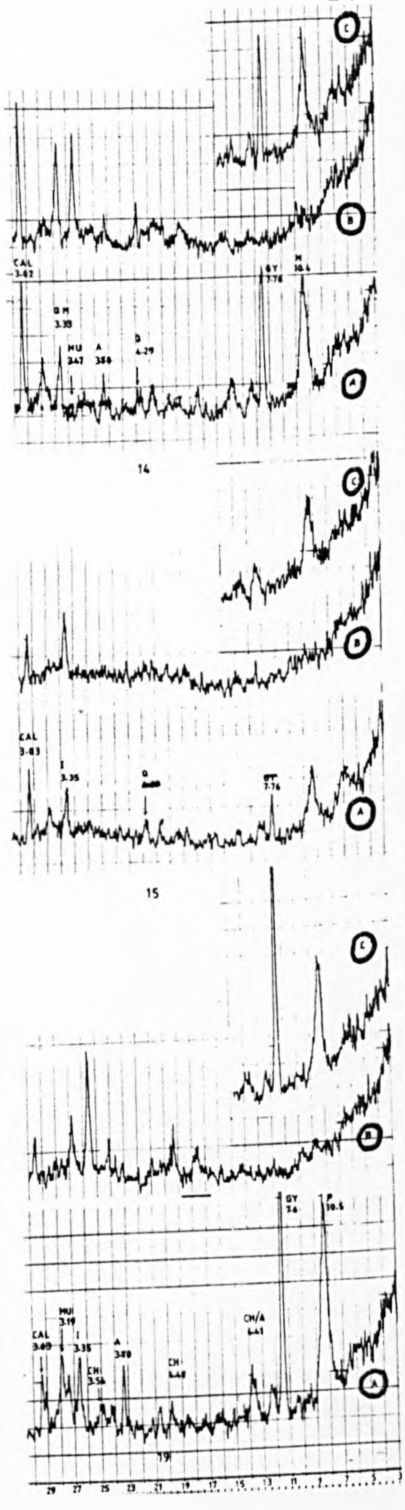
> "...peaks were identified from their d spacings. Any unidentified peaks are presumed to be weak, low angle reflections of non-clay minerals, the main peaks of which reflect at much higher angles." (p.163).

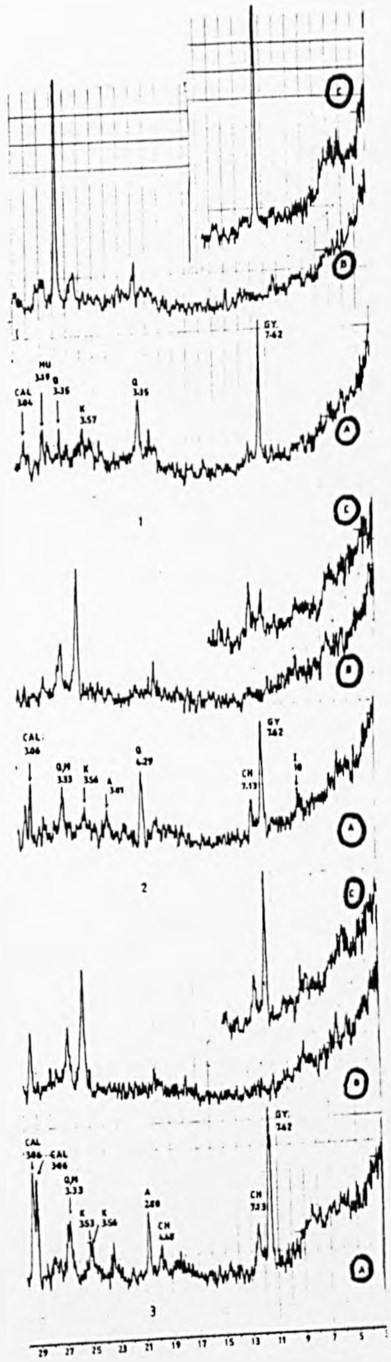
The exact position of each peak was measured by reference to a reference point (the diffractogram angles). However, the measured diffraction angles and d spacings of the studied samples were compared with other clay mineral values in the literature (e.g. Carroll, 1970; Carver, 1971; Procter, 1962; Berry et al, 1970; al.Taie, 1968; Grim, 1953; Jeffries, 1947 and Birkeland and Janda, 1971).

The common clay minerals and non-clay minerals which have been identified are listed in table 5.10.

The x-ray diffraction curves indicate four main clay grade minerals which dominate the samples from the study area. The main groups of clay minerals so far identified are kaolinite, chlorite, mica and palygorskite. The results of the clay mineralogical analyses of the study area can be summarized as follows.

Kaolinite is one of the clay minerals which is present in all of the samples and was identified by its peak at 3.56 Å . Procter (1962) pointed out that Illite was the most





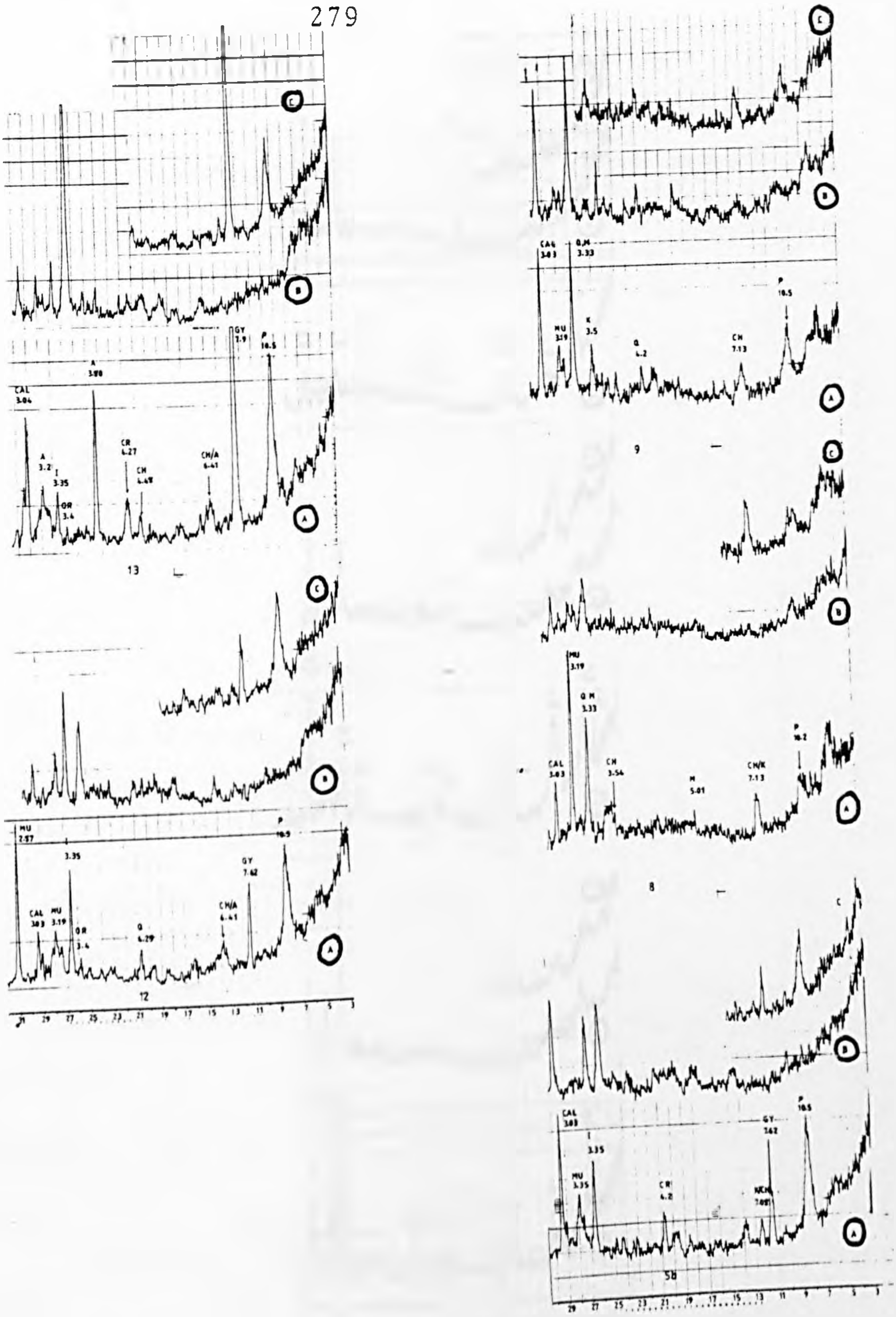
KEY

GY	GYPSUM
Q	QUARTZ
K	KAOLINITE
MU	MUSCOVITE
CAL	CALCITE
A	ALBITE
I	ILLITE
P	PALYGORSKITE
CR	CRISTOBALITE
OR	ORTHOCLASE
AN	ANALCITE
V	VERMICULITE
MO	MONTMORILLONITE
G	GIBBSITE
CH	CHROLITE

Ⓐ UNTREATED
Ⓑ HEATED
Ⓒ GLYCOLATED

FIG. 5.30: X-RAY DIFFRACTOGRAMS FOR THE <2 μm SIZE FRACTION OF THE SAMPLES TAKEN FROM MUWAILHAT al.JANUBIYA TERRAIN SYSTEM.

FIG. 5.[illegible]: X-RAY DIFFRACTOGRAMS FOR THE <2 μm SIZE FRACTION OF THE SAMPLES TAKEN FROM KHOR al.ZUBAIR TERRAIN SYSTEM.

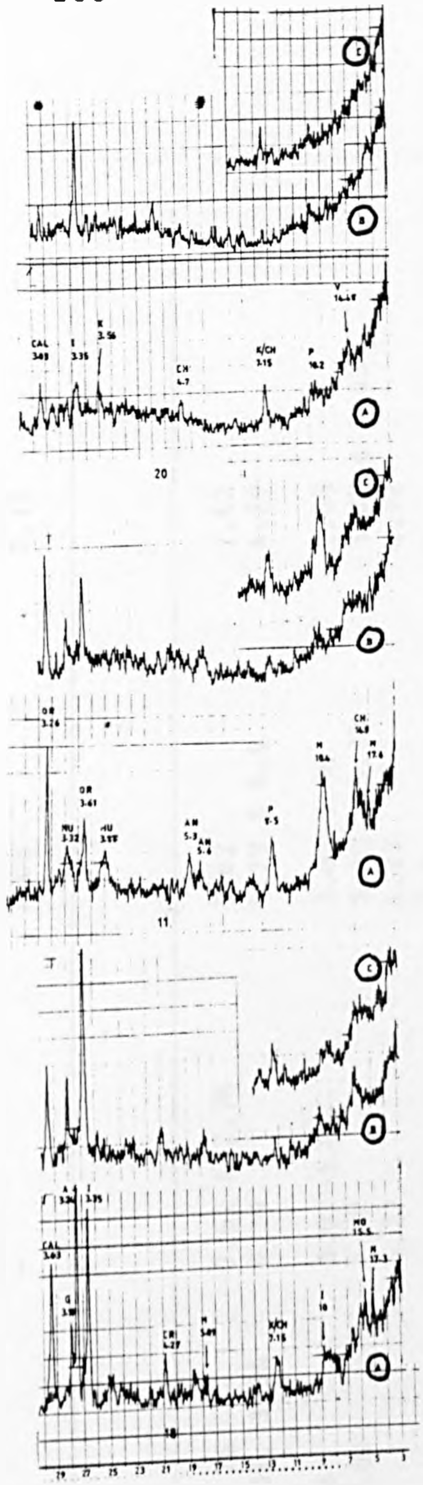


KEY

GY	GYPSUM	CR	CRISTOBALITE
Q	QUARTZ	OR	ORTHOCLASE
K	KAOLINITE	AN	ANALCITE
MU	MUSCOVITE	V	VERMICULITE
CAL	CALCITE	MO	MONTMORILLONITE
A	ALBITE	G	GIBBSITE
I	ILLITE	CH	CHROLITE
P	PALYCORSKITE		

Ⓐ UNTREATED
Ⓑ HEATED
Ⓒ CLYCOLATED

FIG. 5.31: X-RAY DIFFRACTOGRAMS FOR THE < 2 μM SIZE FRACTION OF THE SAMPLES TAKEN FROM SAFWAN TERRAIN SYSTEM.



KEY

GY	GYPSUM	CR	CRISTOBALITE
Q	QUARTZ	OR	ORTHOCLASE
K	KAOLINITE	AN	ANALCITE
MU	MUSCOVITE	V	VERMICULITE
CAL	CALCITE	MO	MONTMORILLONITE
A	ALBITE	G	GIBBSITE
I	ILLITE	CH	CHROLITE
P	PALYGORSKITE		

(A) UNTREATED
(B) HEATED
(C) GLYCOLATED

FIG. 5.32: X-RAY DIFFRACTOGRAMS FOR THE <2 μm SIZE FRACTION OF THE SAMPLES TAKEN FROM SANAM TERRAIN SYSTEM.

CLAY MINERALS	KHOR al. ZUBAIR Å	MUWAILHAT al. JANUBIYA Å	SAFWAN Å	SANAM Å
Kaolinite	3.56 & 3.53	3.56 & 7.19	3.56	3.56
Muscovite	3.19, 3.47 & 2.86	3.19, 3.47 & 3.86	3.19, 3.47 & 3.86	3.19, 3.88 & 3.32
Illite	10	3.35	3.35	10 & 3.35
Chlorite	7.13 & 4.48	7.13, 4.48 & 3.54	7.13, 4.48, 3.54 & 14.7	7.13, 4.7, 6.3 & 14
Mica	5.01	10.4 & 5.01	5.01	5.01, 10.4, 17.3 & 17.6
Q,M	3.33	3.33	3.33	-
Palygorskite	10.5	10.5	10.5, 10.2 & 10.6	10.2, 10.5 & 8.5
Montmorillonite	-	13.8	-	15.7 & 15.5
Vermiculite	-	-	-	14.48
ch/Alpite	-	6.41	6.41	6.41
k/ch.	-	-	7.08	7.15
NON-CLAY MINERALS				
Gypsum	7.62 & 7.76	7.62 & 7.76	7.62	7.62
Quartz	4.29, 4.31, 3.34 & 2.28	4.29	4.29 & 4.9	4.29
Calcite	3.03-3.06	3.02-3.06	3.02-3.06	3.03
Albite (low)	3.80 & 3.81	3.80	3.80 & 3.20	3.80 & 5.43
Cristobalite	-	4.27	4.27	4.27
Feldspar	-	-	3.1	-
Orthoclase	-	-	3.45	3.61 & 3.26
Gibbsite	-	-	-	3.18
Analcite	-	-	-	5.64 & 5.40

Table 5.10: Clay and non-clay minerals detected by x-ray and identified from their D-spacings, of selected samples of the study area.

common clay mineral present and that it is also found to be more abundant in semi arid sites than in humid sites. It is identified by its reflection peak at 10 Å which did not shift when the sample was glycolated or after heat treatment (550°C).

Muscovite, as Carroll (1970) pointed out, is "the most ubiquitous micaceous mineral in soils. Sedimentary rocks, and unconsolidated deposits of mineral matter are related to muscovite". (p.15). It was identified in the samples from its reflection peaks at the following spacings: 3.19 Å and 3.47 Å .

Chlorite was identified in nearly all of the studied samples. It was identified from its reflection peaks at the following spacings: 7.13 Å , 4.48 Å , 3.54 Å , 6.3 Å , 14.0 Å and 14.9 Å .

Palygorskite has a basal reflected peak at 10.5 Å which, after heat treatment to 550°C, is replaced by a broad band (halo), (see, for example, the diffractogram of samples No.3, 19, 12 and 11). al.Taie (1968) pointed out that this mineral is considered as the principal clay mineral in desert soils. According to al.Taie (1968), who identified palygorskite in the terraces and Mesopotamian plain samples, "...under the Mediterranean climatic conditions of North-East of Iraq, palygorskite is absent or only traces are present" (p.223).

Montmorillonite is considered as an important clay mineral in relation to the hydraulic conductivity of irrigation water in Iraq. McNeal (1968) reported (as quoted by al.Rawi et al, 1969) that "...soils containing a high percentage of montmorillonite on a whole-soil basis exhibit a reversible hydraulic conductivity attributable to reversible in situ swelling of expansible phyllosilicate minerals as a function of the salt content of irrigation water". (p.485). Referring to McNeal, it was expected by al.Rawi et al, (1969) that some soils in Iraq would prove to be extremely sensitive to the salinity of the irrigation water.

Montmorillonite was identified in the samples which belong to the flat element of Muwailhat al.Janubiya terrain system, plateau of Sanam of Sanam terrain system and Gully floor of Sanam terrain system on the study area. On the other hand, the identification of the montmorillonite mineral could be doubtful in areas as arid as the study area.

The results of the x-ray identification of the clay-grade minerals of the study area reveal some non-clay minerals and mixed layer types. They are listed in table 5.10. The main non-clay minerals can be summarized as follows. Gypsum is present in many soils in the study area. It has been detected by x-ray and identified from its reflection peaks at d-spacings of 7.62 Å and 7.76 Å.

Quartz is the dominant non-clay mineral in the studied samples. It was identified from its reflection peaks at different d-spacings (see table 5.10).

Calcite was identified from its reflection peaks at the d-spacings of 3.03 and 3.06 Å.

The results of the x-ray identification of the clay minerals of the studied samples in conjunction with the terrain classification of the study area yields the following associations.

(a) Clay minerals and non-clay minerals are commonly identified from the studied samples.

(b) Although each of the four main clay mineral groups were found in all areas they do vary in their relative importance in the different terrain systems e.g.kaolinite is more widespread in the samples from the Khor al.Zubair terrain system than in any other terrain system, whilst palygorskite was identified in almost all of the Safwan samples.

Illite was identified almost equally in samples of the Muwailhat al.Janubiya, Safwan and Sanam terrain systems. Muscovite and chlorite were identified equally in the samples of all the systems. Mica was identified mainly in the samples of the Sanam and Muwailhat al.Janubiya terrain systems. The non-clay minerals like calcite were identified in almost all of the studied samples. Gypsum and quartz were also identified but only in small amounts in most of the studied samples from all systems.

Other non-clay minerals like albite were identified in all the studied samples, but it was found to be abundant only in the samples from the Khor al.Zubair and Muwailhat al.Janubiya terrain systems.

(c) Vermiculite was scarcely identified in the samples, only one sample (no.20, Sanam system) containing this clay-mineral. Gibbsite, analcite and orthoclase are other non-clay minerals that were identified also only in a very few samples belonging to the Sanam terrain system.

(d) A precise and successful identification of the distribution of the clay and non-clay minerals in the study area would require much more extensive analysis.

5.8 SOLUBLE SALTS ANALYSIS

The salinity in the Iraqi soils and especially those of the alluvial plain is recognized in the soil literature (for example, Buringh, 1960; Dieleman, 1963; Russel et al, 1964 and Lees, 1931). It has been agreed that, characteristically, most of the landscape is covered by acid soils in humid regions, and by saline/alkaline[10)] soils in arid regions.

The climatic conditions (low rainfall and high rate of evaporation), proximity to the sea and the sea water, and the high ground water-level, all contribute to the salinity of the soils in the study area.

Nevertheless, soil salinity is a condition that results from the accumulation of soluble salts in soils. Saline soils contain soluble salts in quantities great enough to interfere with the growth of most crop plants.

It has been suggested that the determination of soluble salts is a part of the wider topic of the diagnosis and examination of saline soils. The estimation of soluble salts is helpful in obtaining a clearer picture of the chemical constitution of the soil. Some of the reasons for the determination of soluble salts are discussed clearly by the Soil Bureau of the New Zealand Department of Scientific and Industrial Research (1961). The results of the soluble soils analysis of the soils of the study area show that the cations of the sodium (Na), calcium (Ca) and magnesium (Mg) and the anion of potassium (K) are most common. For the method used

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10) Saline and alkaline soils and other terms like sodic (non saline-alkali) soils are examined by many authors (for example Bear, 1964, and Black, 1946). These terminologies vary from one country to another. However, saline and alkaline soils here are generally discussed together and the same meaning according to both terms since they normally occur in similar climatic conditions which are arid.

see Appendix 4.

The results (Tables 5.3 - 5.6) vary with respect to (i) the differences in the proportion of Na - Ca - Mg and K within each sample, and (ii) differences in these elements between and within the terrain systems.

The averages of total soluble salts found in the studied samples are presented in table 5.11.

It will be noted that a large amount of soluble salts occurs in the soils of the alluvial flood plain (Khor al. Zubair terrain system). It is in fact much higher than that for al.Dibdibba plain (Muwailhat, Safwan and Sanam terrain systems). This is due to the proximity to the Khor al. Zubair (which follows the same system of Shatt al.Arab in its flood) on the one hand, and the influence of the tides of the Arabian Gulf on the other hand. The low-lying soils suffer impeded drainage and this allows the ground water gradually to accumulate high concentrations of salts. In fact, such salt can clearly be seen in the surface layers of the Khor al.Zubair soils. Further to the west of this system, however, the results indicate a decrease in the soluble salt concentrations.

It has been agreed that in such an arid area as the one studied, the samples affected by salts generally occupy the lower parts of the soil profile. According to Bear (1964) "During periods of higher than average precipitation, the more soluble salts are frequently leached from more permeable and high-lying soils. These salts-charged waters find their way to lower lying soils." (p.306). With the exception of the Khor al.Zubair soils, examination of the soils of the study area support such a contention. Sodium salts make up the highest

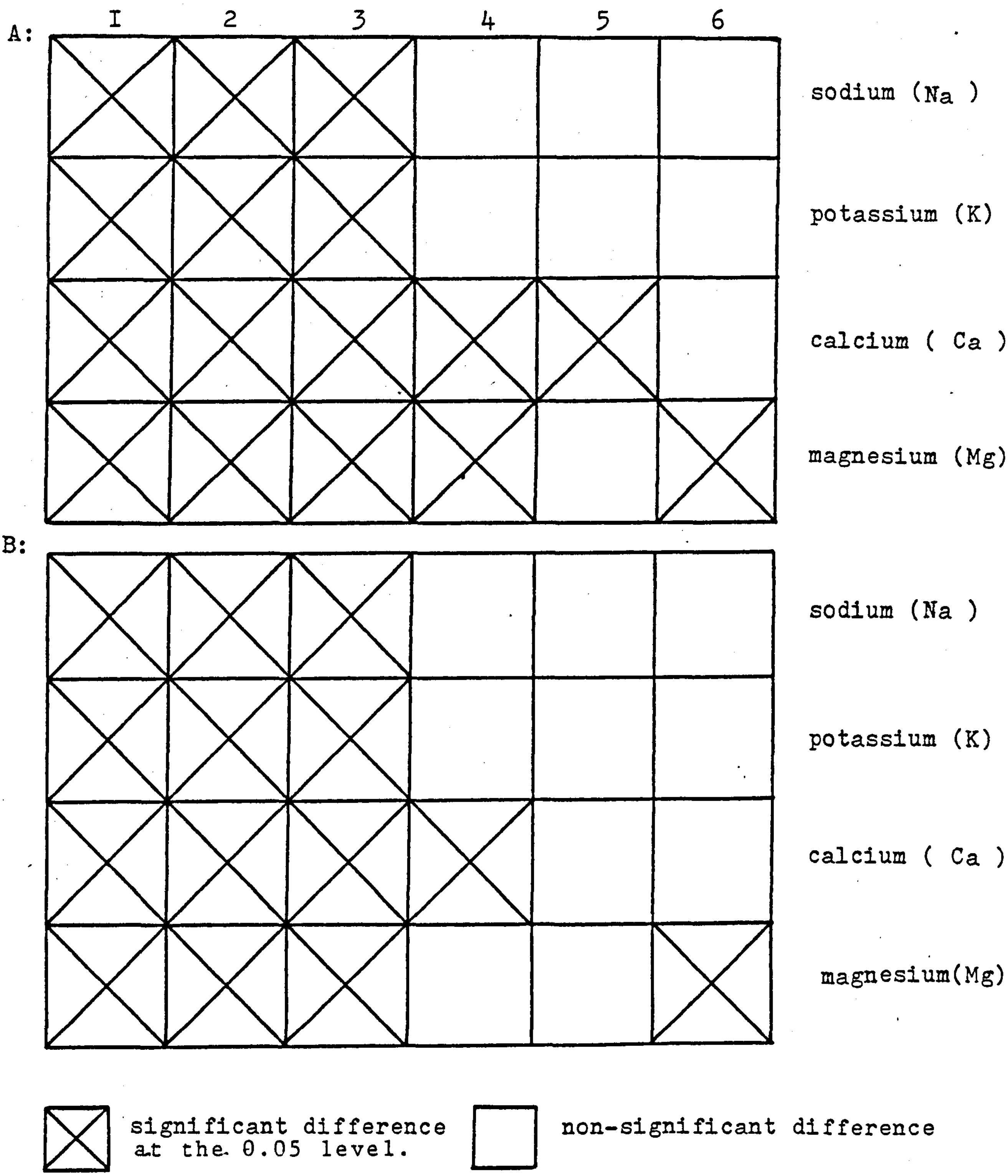
Soil depth (cm)	0-15	15-30	30-45	45-60	Systems
p.p.m.	4285.27	2249.81	1854.96	1652.78	Khor al. Zubair
p.p.m.	168.60	152.81	148.18	186.45	Muwailhat al. Janubiya
p.p.m.	109.48	94.08	176.06	-	Safwan
p.p.m.	70.73	80.23	60.93	93.61	Sanam

Table 5.11: Averages of total soluble salts p.p.m. in the study area

proportion of the total soluble salts present. This appears especially in the soils of the Khor al.Zubair, where soils are highly saline. The results for the remaining systems of the study area indicate a high proportion of calcium which explains the more alkaline character of their soils. However, since the soils of the study area differ in their soil texture, the relationship of the soluble salts concentration on the one hand, and the soil texture on the other is highlighted. Once again, the alluvial flat plain with its fine grained soils shows higher total amounts of soluble salt than the coarse textured soils of the Muwailhat, Safwan and Sanam systems.

At least according to the suggestions of Hellwing (1974) it seems that, because of prevailing evaporation, the salts become concentrated in certain soil layers. This is certainly true in those parts of the study area which contain a high percentage of sand because soils with a high clay content and high capacities tend to hold larger quantities of ionized salts giving a soil pH which is neutral to alkaline. Coarse-textured soils being excessively well drained, tend to become leached of their salts (see, for example, Laskowski and Lavalle, 1966). The 't' test between the systems of the study area show the validity of such trend (Fig.5.33).

The influence of the hydrogen ion (pH) of the samples is a function of the concentration and type of salt present. It has been found that high pH readings occur in these samples having a high cencentration of sodium carbonate. This accords with the findings of Clements (1957) on the dry lakes of the California deserts. The relationship, between the average of



I. Khor al.Zubair & Muwailhat systems
2. Khor al.Zubair & Safwan systems
3. Khor al.Zubair & Sanam systems
4. Muwailhat & Safwan systems.
5. Muwailhat & Sanam systems.
6. Safwan & Sanam systems.

Fig. 5.33 Comparison between the systems of the study area based on their soil property (soluble salt) at depths of A:0-I5cm and B:I5-30cm for all recorded observations of all facets wherever they occur within the terrain systems.

the total soluble salts and the pH can be seen in tables 5.8 and 5.11.

Gypsum constration may be as a result of evaporation of the ground water which contains fair amounts of calcium and sulphate ions (Daghistani, 1972). The clay mineralogy results indicate that gypsum is found in the surface layers of the soils of the study area. Although soil samples were not taken at depths greater than 60cm some comparison with work carried out in neighbouring areas is possible. In these areas, investigations by other workers suggest that the low content of gypsum in the deeper layers in the vicinity of groundwater can be explained by the fact that here precipitated gypsum will dissolve again in the fluctuating saline groundwater particularly as this water contains a high concentration of sodium choride which increases the solubility product of gypsum (see, for example, Daghistani, 1972).

Finally, the artificial use of gypsum has been extensively studied, since it is considered as the most suitable method for reclaiming alkali soils (as an acidifying agent) (Unesco 1977; Hardan and Halim, 1975; Hardan and al.Ani, 1975).

5.9 SUMMARY AND CONCLUSIONS

The soil properties of that part of al.Zubair desert selected for study include particle size distribution, pebble shape, sand grain shape, sand grain surface texture, soil pH, organic matter, calcium carbonate content, major clay mineral constituents and soluble salt content. These properties were analysed either in the field, e.g. pebble axial measurements and soil colour identification, or in the laboratory. The laboratory methods employed are discussed in Appendix 4. The detailed results of pebble measurement and sand grain surface texture description can be found in Appendices 5 and 6, while details of the remaining soil properties are shown in tables 5.3-5.6.

There are three types of conclusions that can be drawn from the results of the analysis. The first is concerned with the relationship between the terrain facets/systems and their soil properties; the second type of conclusion is concerned with the geomorphological significance of the analysis of the soil properties; and the third type concerns the applicability of the analysed samples for some land use purposes.

5.9.1 Terrain facets/systems and soil properties.

(i) The particle size results (mean, standard deviation, skewness and kurtosis) show a clear trend from the coarse sand to the fine sand with depths. The reverse of this trend can be observed where the finer material occurs in the Khor al. Zubair surface and sub-surface sample groups, whilst the coarse materials occur in the surface and sub-surface sample groups of the remaining terrain systems. There is also discernable trend from dominantly coarse material on slope elements to relatively finer modes on gentle slopes and flats. The particle size analysis showed that most of the Muwailhat, Safwan and Sanam samples yield negative skewness value due to their coarse material contents in comparison with those of Khor al.Zubair which yield positive skewness values (excess fine material). The former findings thus conflict with those of Friedman (1961) who suggested that desert sands have positive skewness and are only rarely negatively skewed.

Sand is the most dominant particle size (see Figs. 5.21 and 5.24) in most of the samples studied. The variation in soil texture in the study area is most likely due to the depositional nature of this area (see for support the general description of the study area, chapter 3). Whereas the Khor al. Zubair system displays relatively high clay and silt percentages, the converse is true in the other systems.

As a result of process factors (see the geology and geomorphology section, chapter 3), sand percentages increase from the top layers to the lowest layers, and also decrease from the sloping to the dominantly flat and wadi floor elements.

(ii) The arid soils of the study area maintain only a sparse cover of vegetation, thus producing very little organic matter. The organic matter percentages of those samples analysed showed a decrease from the Khor al.Zubair (river) towards the west. At the same time the samples from the top of the gradients of Muwailhat al.Janubiya terrain systems or wadi slope of Sanam terrain system are much poorer with respect to their organic matter content than samples from the slope foot sites or flats in the Muwailhat al.Janubiya system and the wadi floor sites in the Sanam terrain system. The relationship between the organic matter content and the soil colour is such that those samples which have a high percentage of organic matter generally show dull yellow brown (10yr 4/3) in colour, or dull yellow brown (10yr 5/3, 5/4 and 4/3); those samples with lower percentages are usually a dull yellow orange (10yr 7/3 or 6/4) in colour.

(iii) As a consequence of the aridity, $CaCO_3$ concentrations reflect evaporation of pore water during dry periods. Calcium carbonate content is higher in the upper soil layers and decreases with depth. The concentration of $CaCO_3$ in the studied samples varies in different particle size fractions and also with soil type. These differences indicate that variation between terrain systems are significant, whereas no determined significance is obtained within systems.

(iv) A preliminary study of clay minerals in the soils established that the dominant families were kaolinite, Chlorite, muscovite and palygorskite. Kaolinite is present in all areas, but is particularly evident in the Khor al. Zubair system. Vermiculite is rare. Montmorillonite may be present in some samples but can not be unequivocally confirmed. Non-clay minerals identified include quartz, calcite, feldspar, gypsum, gibbsite, analcite and albite.

5.9.2 Geomorphological significance of the analysis of the soil properties.

(i) Although the origin of the pebbles has a bearing on their shapes, their origin has, in fact, not been determined and this remains a controversial subject. Pebbles are found on the surface in all terrain systems. They are considered to be a residual of wind action.

(ii) It is widely accepted that pebble shape reflects the process environments of the pebble.

In the study area disc-shaped pebbles are the dominant type (average 33%) whilst the remaining shapes e.g. rod, blade and sphere form the minority of the observed pebbles (average 24.8%, 23% and 19.18%). However, there is clear variation from one terrain system to another. It can be shown that rod shapes, for instance, form quite high percentages among the total shapes percentages of the study area. This is probably due to fluvial action, which helps in rolling the pebbles on the surface in some areas e.g. Muwailhat (Fig. 5.2).

The roundness indices of the pebble and sand grain particles reveal that, although differences in roundness grade exist, all are rounded regardless of precise location. This is accounted for by the widespread incidence of wind action which affects all materials exposed at the surface.

Sand grains at depths of 0-15cm are more rounded and have higher sphericity than those at depths of 15-30cm. This again reflects the importance of abrasion at or near the soil surface.

Analysis of surface texture of sand grains using the SEM confirmed this and also indicates that mechanical abration is more marked in the coarse sand size (0.5mm in diameter). It is also clear that the surface features of sand grains of 0.25mm diameter are a result, at least in part, of the solution-precipitation process.

(iii) The pH values of samples fall within the range 7.0 to 8.5 (Fig.5.26). The high values of soil pH are probably due to their proximity to the Khor al.Zubair on one hand and to presence of a high water table on the other.

(iv) Salinity has been well documented with respect to Iraqi soils and especially those of the alluvial plain. It has been stated that the main salts are of sodium which in turn form the highest proportion of the total salts present. This appeared especially in the samples analysed from the Khor al. Zubair (which is characterized with a fine texture, periodic flooding and a high water table) ensuring that these soils are extremely saline in character. In the remaining systems of the Muwailhat, Safwan and Sanam (in keeping with their soil characteristics e.g. coarse textured soils and with high percentages of sand) soluble salts are concentrated in certain sand layers only as a result of high evaporation and good permeability.

5.9.3 Applicability of the soil analysis results.

The applied value of the test results is considered the most important aspect of the work. As such it forms the subject matter of the following chapter.

CHAPTER VI

LAND SUITABILITY ANALYSIS

LAND SUITABILITY ANALYSIS

6.1 INTRODUCTION

The aim of this chapter may be summarized as follows.

(i) To classify and map what are possibly some of the most significant soil properties e.g. soil texture, organic matter, calcium carbonate content, pH and soluble salts, which are valuable for land use potential e.g. agriculture and grazing. Other properties such as the clay mineral types are also important especially for the engineering constructions and structures, but unfortunately the results of Chapter 5 indicate that mapping on the basis of terrain systems and facets is not reliable.

(ii) To give some examples of surveys which have been carried out in the neighbouring countries of the study area (as well as some land problems from West Pakistan). These chosen areas have relatively similar environmental characteristics to the present study area. It is intended to look at the methods of analysis employed in these surveys and their applications in terms of land capability or land suitability for the areas studied.

(iii) Following on the first aim and learning from the experience of the second, it is possible to develop terrain suitability maps for the land use potential of the detailed study area.[1)]

(iv) Since all the planning in Iraq including the study area has to be achieved by the Government, it is worthwhile to introduce and examine the Government's plan for this area in this chapter.

6.2 MAPPING OF SOIL PROPERTIES

Soil properties vary significantly from one terrain facet/system to another over the study area. Soil properties are given in Chapter 5. Some of these properties can be mapped for

1) Only this part of al.Zubair desert has been studied in detail

the terrain suitability purposes and some of them not. Those properties like soil texture, organic matter, $CaCO_3$, pH and soluble salts are mapped here, whilst the remaining properties (namely particle size and clay mineral types) are neglected from the mapping purposes due to their great variation within facet/systems or unreliability of results.

The properties which need to be mapped are then grouped according to their representative facets (see Chapter 4). Then they are classified either according to previously defined classes (in the case of soil texture classes and pH [see Chapter 5]) or class boundaries are newly defined as seems appropriate for the available data (in the case of organic matter, $CaCO_3$ and soluble salts). Since there are no complete sets of values available for soil properties at depths of 30-45cm and 45-60cm (Tables 5.5 and 5.6), the soil class maps are only made for those values obtained for depths of 0-15cm and 15-30cm.

These maps are first drawn at a scale of 1:35000 and then reduced to A4 size for the purpose of presentation. These maps include those of:

(i) soil texture classes (Figs.6.1 & 6.2)

(ii) organic matter classes (Figs.6.3 & 6.4)

(iii) calcium carbonate classes (Figs.6.5 & 6.6)

(iv) alkalinity and salinity classes (Figs.6.7 & 6.8).

The legend and class limits are included with the maps.

6.3 EXAMPLES OF SELECTED SURVEYS AND LAND PROBLEMS.

It was pointed out by Wright (1971) that "Integrated

FIG. 6.1: SOIL TEXTURE CLASSES OF THE DETAILED STUDY AREA AT DEPTH 0-15cm.

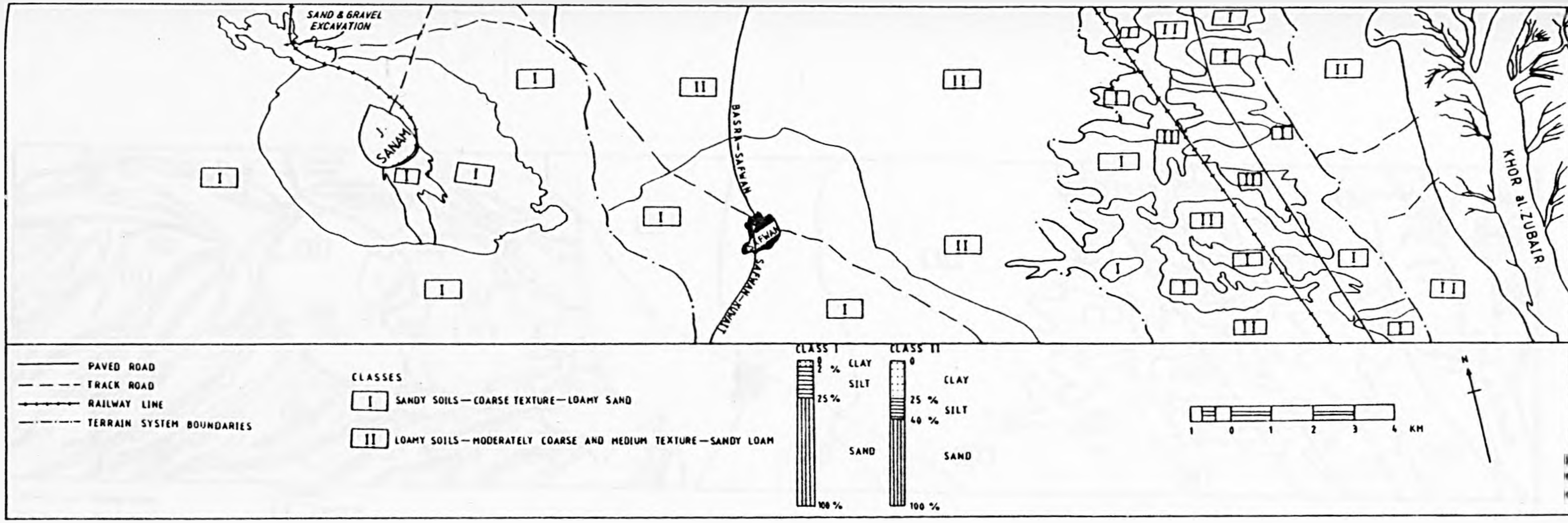


FIG.6.2: SOIL TEXTURE CLASSES OF THE DETAILED STUDY AREA AT DEPTH 15-30cm.

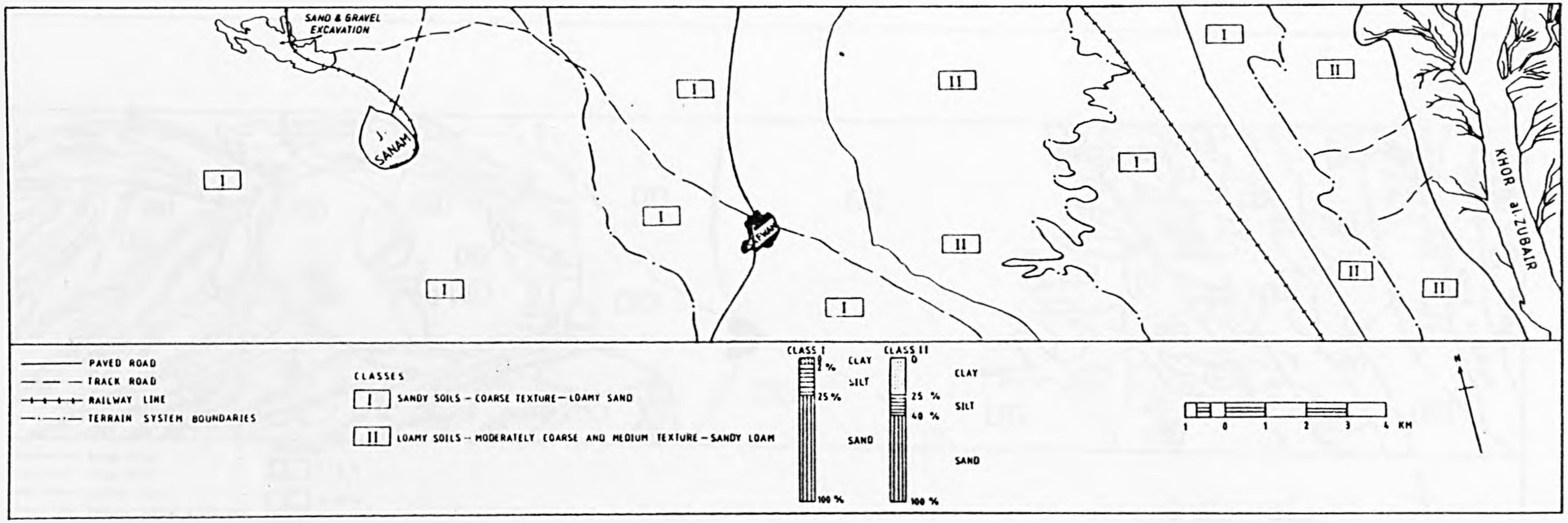


FIG.6.3: ORGANIC MATTER PERCENTAGE CLASSES OF THE DETAILED STUDY AREA AT DEPTH 0-15cm.

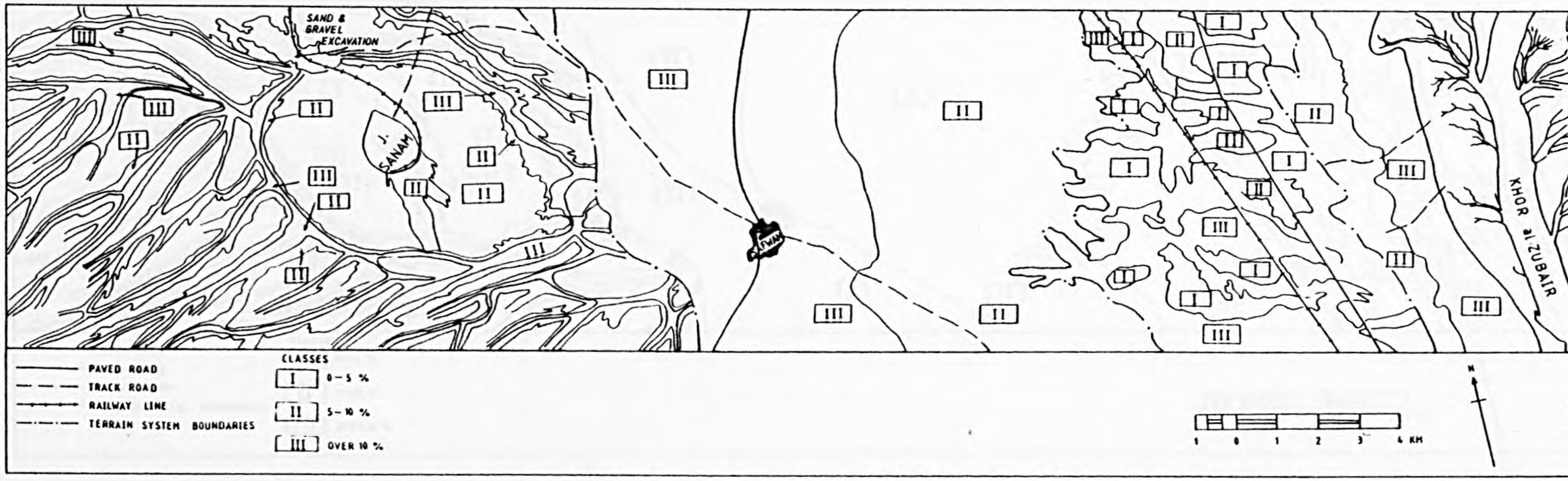


FIG.6.4: ORGANIC MATTER PERCENTAGE CLASSES OF THE DETAILED STUDY AREA AT DEPTH 15-30cm.

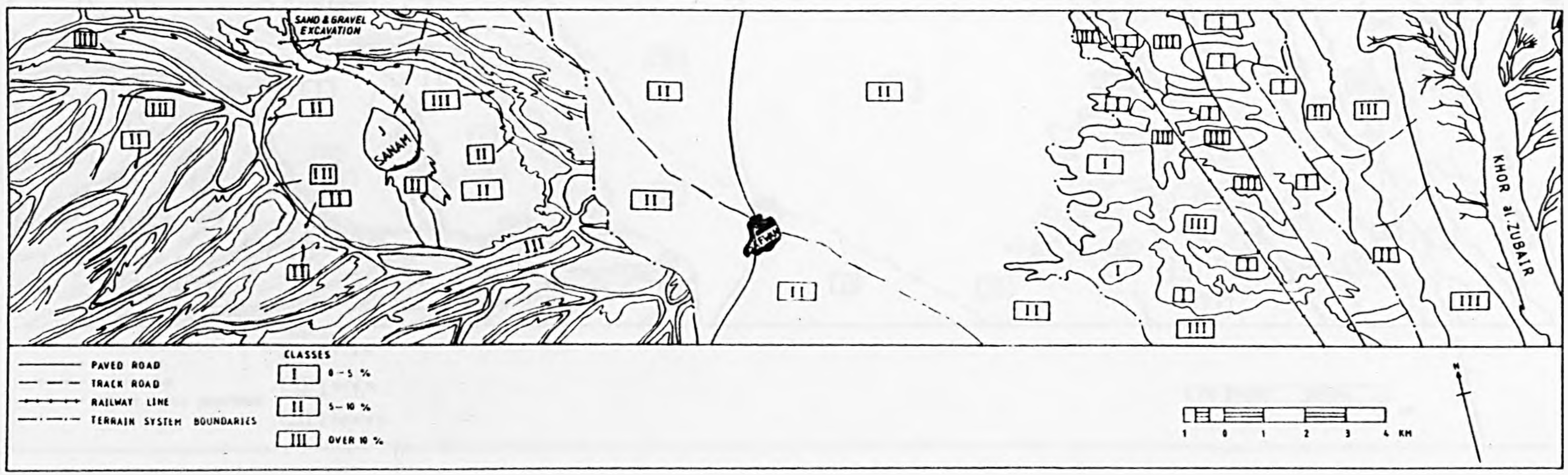


FIG.6.5: CALCIUM CARBONATE PERCENTAGE CLASSES OF THE DETAILED STUDY AREA AT DEPTH OF 0-15cm.

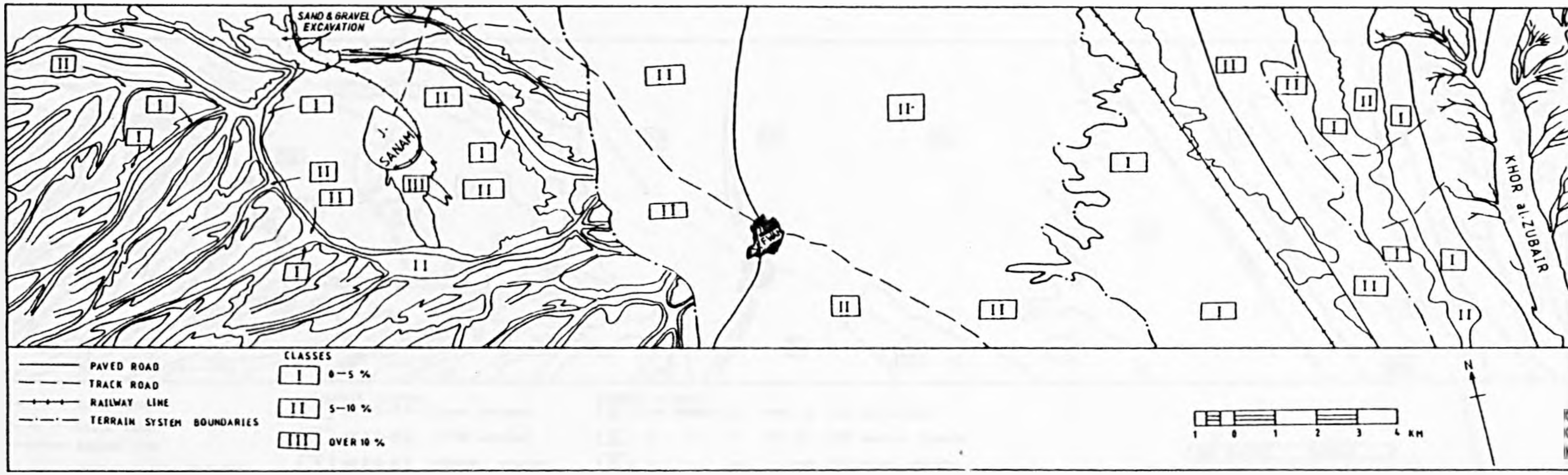


FIG.6.6: CALCIUM CARBONATE PERCENTAGE CLASSES OF THE DETAILED STUDY AREA AT DEPTH OF 15-30cm.

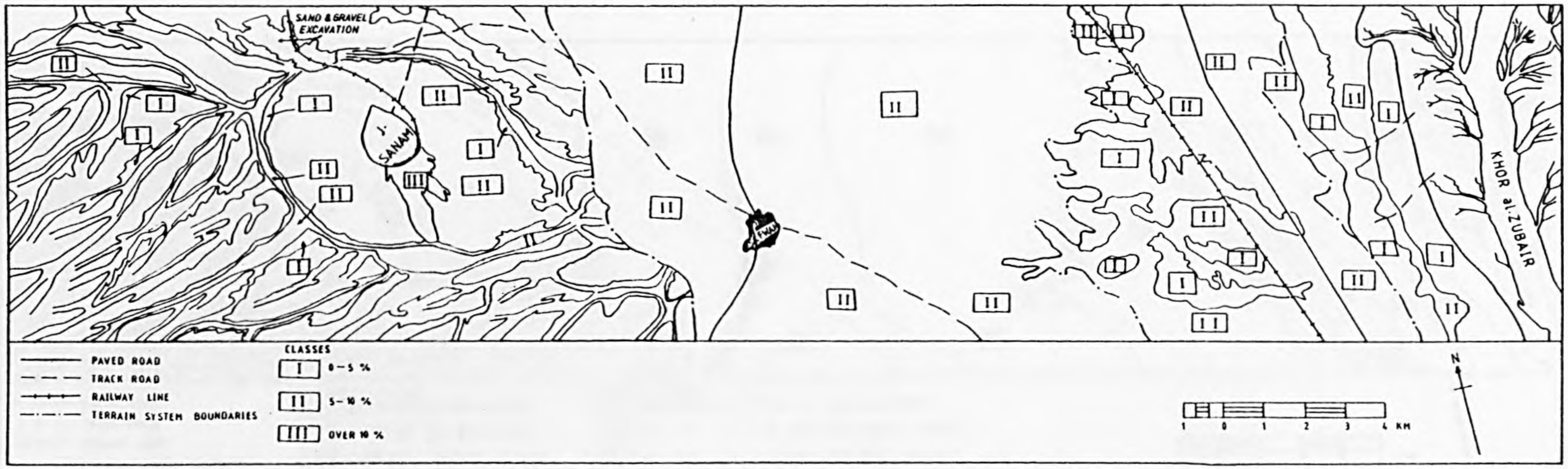


FIG.6.7: ALKALINITY AND SALINITY CLASSES OF THE DETAILED STUDY AREA, AT DEPTH OF 0-15cm.

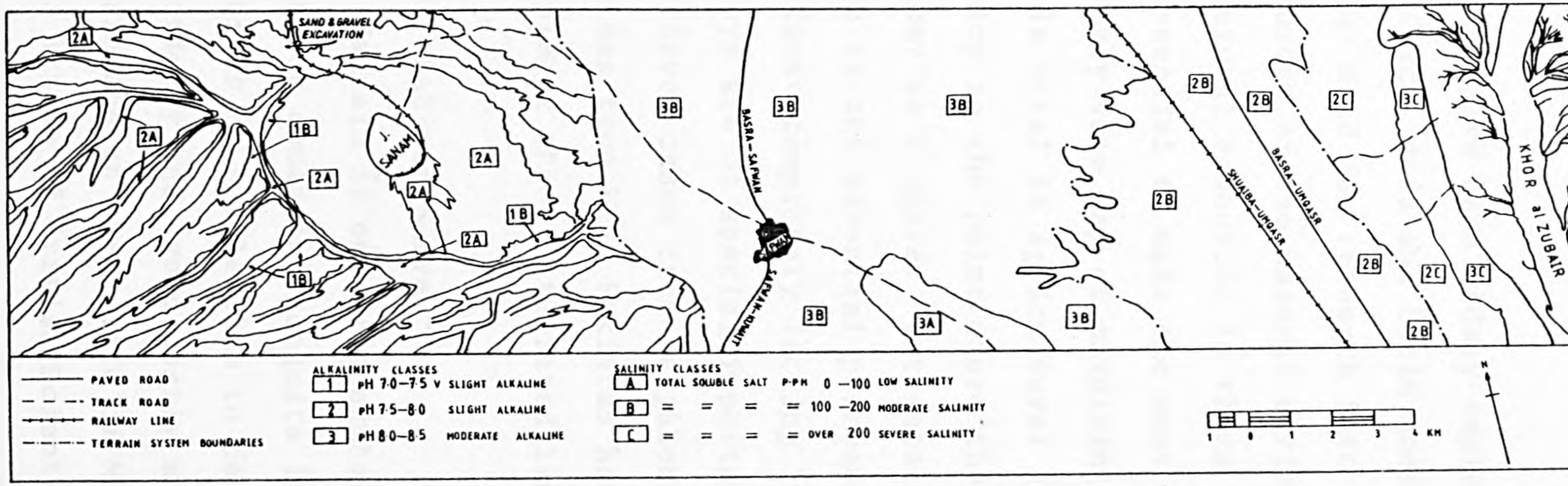
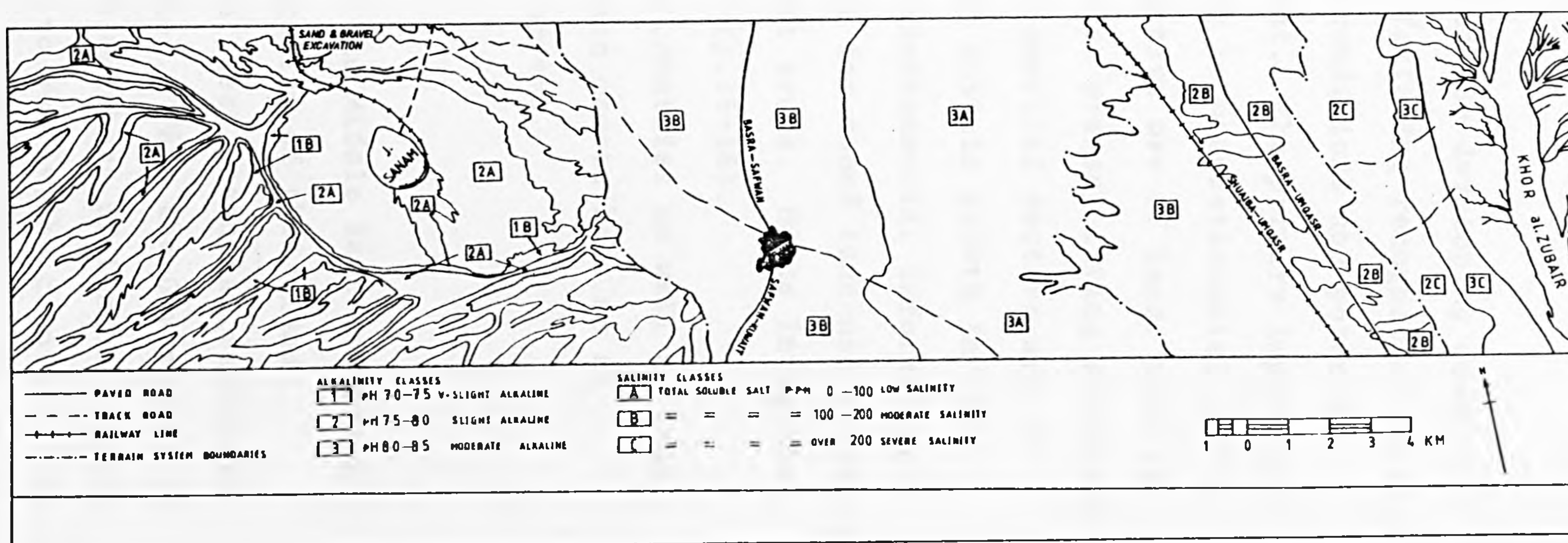


FIG.6.8: ALKALINITY AND SALINITY CLASSES OF THE DETAILED STUDY AREA, AT DEPTH OF 15-30cm.



surveys have been widely employed in the developing countries of Africa, Asia and Latin America following recognition of the urgent need for research into the conditions and potential resources of the natural environment. The primary importance of natural resources in these areas is unquestionable, and it is essential to make the most effective use of land: this is the only sure way of maintaining even present living standards and is vital if agricultural and commercial sectors are to develop to the point where they can sustain growth in the economy as a whole. But detailed environmental information, which is the essential prerequisite for sound land-use planning, is almost completely lacking in most areas. Hence integrated surveys are of special importance" (p.15-16).

Seven cases from neighbouring countries as well as some problems from West Pakistan have been chosen here as an examples of these integrated land surveys.

6.3.1 Bahrain Survey[2)]

Bahrain is one of a number of the Middle East countries which are demanding adequate inventories of their land resources to enable them to develop these potential resources effectively and avoid costly mistakes. Thus the Government of Bahrain and on the advice of Messrs. Sandberg of London commissioned a team of British Scientists to survey the country. The survey was carried out during 1974 to 1976. The survey mainly concentrated on the larger group of Bahrain's Islands because of the focus of contemporary economic activity. However, the survey was intended to provide a rapid reconaissance survey of:

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2) A book of the survey will be published by mid 1980 (in press), see Doornkamp et al., in the references.

(1) solid geology and structure;

(2) geomorphology and surface materials;

(3) soils;

(4) land capability for agriculture; and

(5) hazard to construction.

Comments on the major aspects of the survey.

(1) The survey faced in the beginning several difficulties. These are probably common to such areas. Difficulties arise from the fact that the survey is the first ever undertaken in this area, thus there was poor literature, maps or aerial photographs to aid the surveyors.

(2) It has been pointed out by Brunsden et al (1979) that the geomorphological study was to form the basis for the rest e.g. stratigraphic succession, geological structure, geochemical analysis and pedological descriptions.

(3) The geomorphological study of the Bahrain survey provided a geomorphological map at a 1:10000 scale in order to illustrate the complex landform/materials of Bahrain.

(4) The survey revealed an important terrain problem in Bahrain which concerns the land capability classification for agriculture and building foundation engineering. This problem is the presence of salts in the soil of Bahrain especially those which occur at or very close to the ground surface.

6.3.2 Survey of some parts of Jordan.

6.3.2.1 The soil survey of Wadi Ziqlab.

This survey has been undertaken by a team from the University of Durham at the request of the Government of Jordan and with the help of the United Nations Special Fund project, 1965.

The project was intended to provide the basic information regarding watershed management of the Wadi Ziqlab in northern Jordan. As stated by Fisher <u>et al</u> (1966) it included:

"(i) the carrying out of a detailed soil survey of the watershed area to provide a detailed soil map,

(ii) the assembling of data on the characteristics of the soils, both as a measure of soil fertility and as an indicator of soil erosion, both past and potential,

(iii) the production of maps of land use and land capability as a basis for further research and further management planning" (p.1).

<u>Comments on the survey</u>.

(1) The survey has provided some very professional maps which are of comparative use for the present study e.g. soil types, land use and land capability maps.

(2) The survey revealed that water erosion (sheet erosion and gully erosion) in the catchment of the Wadi Ziqlab is of greater importance than erosion by wind. The opposite however obtains for the present study area.

Although the survey emphasised that there are many factors to be taken into account in designating soil erosion zones e.g. slope, soil type, amount and intensity of rainfall, vegetation cover and land use, it has proved more successful to designate soil erosion zones primarily on the basis of the slope information alone.

In the present study where the information to designate the erosion potential is not sufficient, the recommendations for erosional potential are given in Section 7.2 rather than in the form of a detailed map.

(3) In the final conclusion of the field survey of Wadi Ziqlab the information relating to soils and slopes were assimilated to produce a map of the land capability.

(4) The slope characteristics have played an important role in the recommendations of the Wadi Ziqlab. This appeared for instance on the recommendation concerning erosion potential, cultivation and grazing of the area. The steep slopes and the scanty nature of the vegetation cover lead, for example, to a rate of soil truncation and degradation which is described as alarming. Measures need to be introduced to check the removal and loss of soil over these slopes. Also it has been recommended that the present cultivation (cereal cropping) on slopes of over 22^{o} ought to be stopped due to the rapid rate of erosion on these slopes. Similarly, uncontrolled grazing is almost as dangerous on such slopes as cultivation.

Further recommendation included construction of gully plugs in some of Wadi bottom which prove to be effective in reducing sediment yield.

The required socio-economic changes comprised the remaining part of the recommendations. It has been pointed out that "The aim would be threefold. First, to encourage the emergence in the village of socio-economic leaders of a non-traditional kind. Secondly, to encourage the normal processes of emulation to build up into communal effort, particularly in the production of cash crops such as olives and fruit and the construction (under advice) of siltation dams, soil wash stone barriers etc. Thirdly, to increase the economic integration of the villages with the rest of the country through small-scale, ultimately co-operative, trade" (Fisher et al ,1966, p.59-60). More basic information concerning detailed soil investigations e.g. soil moisture and evaporation rates etc. is recommended for any further work to be undertaken.

6.3.2.2 The Wadi El Hassa survey.

This project has been carried out by a survey team from the University of Durham (see Willimott, 1963).

The main interesting findings of this project relate to the land types, soils and land classification. It was by sub-dividing the Wadi El Hassa morphologically and taking into account surface characteristics and vegetation, that nine land types were distinguished. Soil pits together with supporting auger holes between the pits were considered as the base of the survey. Each soil pit extended to a depth of 100cm or more. Samples were collected by the team of the survey and detailed laboratory analyses were conducted in the Durham School of Agriculture.

The results of these soil analyses and land classification were finally assembled to produce one land capability map. It has been found finally that more than 70 per cent of the studied area was unsuited to arable cultivation. The area is only capable of supporting limited animal husbandry during the grazing season.

The limitations of soil and climate made the area unsuitable for intensive afforstation, but limited stands of trees for protection, shade and amenity were recommended if development projects are initiated. A detailed ecological survey of the natural vegetation as well as a social survey are needed.

6.3.2.3 Soil conservation survey of Wadi Shueib and Wadi Kufrein.

The survey has been completed by a British team from the University of Durham in 1966. This project was aimed at achieving a data base for considerable activity in watershed management. The objectives of this survey are listed in Atkinson, et al (1967) and read as follows:

"(i) a detailed soil survey of the watershed area following the criteria already established for the Wadi Ziqlab survey of 1965.

(ii) production of data relating to the various soil types present as they affect soil fertility and management, and also erosion, both in the past and possibly in the future.

(iii) the formulation of proposals and advice regarding land use and capability so as to assist further research and future management planning" (p.1).

Two beneficial concepts have been adopted in this survey. The first is the soil survey which included: (i) recognising the soil classes occurring within the area of the watersheds (ii) mapping the distribution of each class and (iii) assessing the properties of each class with respect to both the erosion hazard and agronomic potential. These items were discussed with the respect to six soil types that have been distinguished in Wadi Shueib and Kufrein. The second is the land capability analysis of those two Wadis. It has been stated by Atkinson et al (1967) that the capability classes were based on three criteria. These are "(a) slope characteristics, (b) soil properties, (c) the presence of absence of specific crop limitation e.g. stoniness, depth, salinity" (p.41).

6.3.2.4 Land classification as Wadi Qatrana and Wadi Sultani.

The survey was carried out during 1964. The land in this area was classified into nine land types. The land types were then classified into three main land classes according to their suitability for agricultural development. The survey like the rest of the terrain classification work used the available information e.g. maps and air photographs, to obtain a general indication of land variability in the area. Physical aspects played an important role to delimit the land types. They are also considered the main character in limiting the land and soils of the region from the point of view of agricultural potential.

However, the land classification of this survey was used as a basis for agricultural potential within these two Wadis of Jordan. Further suggestions for development have been given (Willimott et al ,1965). These are discussed under the following headings:

1. The prudent siting of dams.
2. Improved cultivation techniques.
3. A proper cropping policy.

6.3.3 A survey of Soil and Agricultural potential in the Trucial States.

The survey was carried out during October 1966 and January 1967.

The criteria which have been used for the reconnaissance survey of soil and agriculture potential are the soil, hyrdrology, accessibility and socio-economic phenomena.

For the detailed survey of the Trucial states, two areas have been chosen. These are the Tawi Mileiha on the Gharif plain and Tawi Hammraniyah on the Jiri plain.

Maps and air photographs were used in the preparation of the soil and land capability maps. Soil classification is based on information obtained both in the field and in the laboratory. The soil texture, the presence of gravel horizons, pH, salinity and the erosion hazard were the most important criteria in determining the land capability classes of the mentioned areas. Slope and the nature of the terrain surface are considered the two major topographic characteristics affecting the land for potential agricultural development of the survey areas. Bowen-Jones and Stevens (1967) pointed out that "Levelling by the water resources survey has shown that slopes within both survey area are uniform and very gentle. Slope, thus, does not provide any hindrance to agricultural development" (p.17). The socio-economic and blowing sand factors are the major contributors to the overall nature of the terrain surface.

An example of the effect of the nature of terrain surface on the land to be utilized for agriculture has been given in the Trucial States survey. For instance, the cost associated with development of some small and isolated areas which suffer from blowing sand do not make them attractive propositions for agricultural development. Therefore, they are classified as having no arable potential. An interesting point has been drawn to attention in this survey. This point is that the "... hillocks occur frequently and attain a height of 75cms with a diameter of up to 150cms" (p.17). The importance of this point appears in the removal of these hillocks which involve extra expenditure in the establishment of irrigated agriculture and hence the abundance and size of hillocks must be taken into account when determining capability" (p.18). Similar landforms to these hillocks are found in the study area (see 3.4.2.). Irrigation water and drainage are also two important matters concerning the agricultural development in these areas.

The survey team recommended that flood protection measures will need to be taken.

6.3.4 Some land problems of West Pakistan.

Aridity of West Pakistan has been discussed in the Unesco literature (see, for example, Unesco, 1953). Arid conditions of West Pakistan like any other arid areas in the world have an important effect upon any development.

Despite the aridity problem, it has been argued that West Pakistan has a great potentiality because of the water availability, the soils, which are mostly alluvial, potential markets and the rising standard of living. This potentiality on the one hand and the indication of commercialising the agriculture on the other have put the country a step forward towards development (Nir, 1974).

A case study of the land use classification has been made for parts of West Pakistan. This includes the Punjab plain and the western bordering mountains, widening out in the hilly lobe of north-east Baluchistan. This part of West Pakistan is the so-called semi arid land.

The physiography, soils, climate and water supply were considered the major determinants of the land use classification. The land is thus classified into eight land use classes (Ahmad, 1964).

However, it has been observed that irrigation not only has a great importance for agriculture but also in creating different types of land use e.g. perennially canal-irrigated cropland, seasonally canal-irrigated cropland, seasonally flooded cropland etc. (Asghar, 1962).

West Pakistan is also concerned about the salinity problem like most other arid areas. Fortunately, the quantity of salts in the river water of this region is not great, but the fact that the land has been irrigated for a long time (the last three-quarters of a century) and with little free drainage may raise the possibility that the salts may have remained in the soil formation, thus also increasing the concentration and affecting the crops (Ahmad, 1961).

Increasing salinity in West Pakistan has called for suitable action to be taken to free the problem. Some suggestions have been put foward to counteract this situation (Ahmad, 1961). Although neither the irrigation type nor the soil materials are similar in West Pakistan and al.Zubair area, the problem of salinity is still the focus of much attention. The following suggestions to counteract the salinity in West Pakistan may also be considered a valuable one for the study area.

"1. To counteract salinity, we need large volumes of water to wash down the soluble salts.

2. Water charged with a large amount of soluble salts must be drained away, but the formation of the punjab is such that there is very little natural sub-soil flow; it is mostly blocked by clay lenses.

3. Areas where subsoil flow is completely blocked by clay lenses have water unsuitable for irrigation and if this is pumped out there will be a possibility of its replace-

ment by fresh water from the present sources of infiltration

4. Subsoil brackish water does not possess as large an amount of salts as the surface accumulation, which is sometimes more than 0.2 per cent of the dry soil. Washing soil heavily charged with salts by saline water can reduce the salt percentage considerably and can make the soil fit for crops.

5. Where the water table is high, say within 10 feet of the surface, ordinary certifugal pumps have effectively been used to pump water, the pumps being located within 3-5 feet of the spring level. Such wells, with strainers 50-70 feet long and with a 10-16 h.p. motor, have yielded 1.0 to 2.0 cusecs of discharge" (Ahmad 1961, p.122).

Salinity in the Iraqi soils and irrigation water is concerning the Iraqi authorities at the present time. Solution of the problem requires a hydrologist rather than geomorphologist. The hydrology in general and salinity of the study area has been studied recently by Haddad (1978).

6.3.5 Implications and general comments.

It seems that there is a general agreement that all the surveys use for their terrain classification the available literature, maps and aerial photographs as a preliminary stage followed by fieldwork and laboratory analysis.

Furthermore, and for the practical purposes, it seems that converting these terrain classifications into terrain suitability/or capability classifications is seen as an important aspect of these surveys.

Since the environment of the areas and the purpose of the surveys differ, the criteria which have been taken to delimit the terrain suitability classification differ accordingly. Some of these surveys used, for instance, the soil properties, whilst others used the slopes.

In attempting terrain suitability classification of the study area for agricultural and grazing purposes similar criteria to those used in the surveys of Wadi Ziqlab (Jordan) and Trucial states (Section 6.3) are adopted. The criteria which have been used in these surveys i.e. soil properties and slope angles, are taken to be the criteria to delimit the terrain suitability classification for agriculture purposes of the study area.

Other purposes of terrain capability classification for example, building foundations as given in the Bahrain survey are not possible here due to a lack of data. Such a terrain suitability assessment could form the basis for further work (see 7.2).

6.4 TERRAIN SUITABILITY CLASSIFICATION.

6.4.1 Introduction.

It is believed for the present study that the terrain suitability classes should be restricted to two purposes. These are the agriculture and grazing. Other land use purposes for example industrial building and road building would require field and laboratory information not available for the present study (see 7.2).

6.4.2 Terrain suitability classification for agricultural purposes.

6.4.2.1 Introduction.

A framework for land suitability assessment has been outlined by the F.A.O. (1976). This has been discussed within the context of the Malawi study area by Young and Goldsmith (1977). Other examples of land capability have been given with these surveys as already discussed in section 6.3. The following table is a simplification of the F.A.O. land suitability classification and is to be used here.

Order	Class	
S suitable	S1	Highly suitable
	S2	Moderately suitable
	S3	Marginally suitable
N not suitable	N1	Currently not suitable
	N2	Permanently not suitable

Table 6.1: A SIMPLIFIED VERSION OF FAO LAND SUITABILITY CLASSIFICATION.

6.4.2.2 Criteria delimiting the terrain suitability classes for agricultural purposes.

In estimating suitability classes of the detailed study area, slope and soil factors are taken as the most important criteria limiting the land use potential for agriculture purposes.

Table 6.2 summarises the criteria used to delimit terrain suitability for agriculture.

CLASS	FACET	SLOPE	SOIL	0-15cm	15-30cm	LIMITATIONS
N2	1a	0°-0.90	Dull Yellow Brown			Seasonal flooding,very severe salini
			Soil texture class	II	II	
			organic matter class	III	III	
			calcium carbonate class	I	I	
			alkalinity and salinity class	3C	3C	
N2	1b	0°-1°	Dull Yellowish Brown			Seasonal flooding severe salini
			soil texture class	II	II	
			organic matter class	III	III	
			clacium carbonate class	II	II	
			alkalinity and salinity class	2C	2C	
N2	1c	0.30°-1.50°	Dull Yellowish Brown to Dull Yellow Orange			Seasonal flooding, severe salini
			soil texture class	II	II	
			organic matter class	II	II	
			clacium carbonate class	I	I	
			alkalinity and salinity class	2C	2C	
N2	2	0.30°-1.50°	Dull Yellow Orange			margin seasonal flooding
			soil texture class	II	II	
			organic matter class	II	I	
			calcium carbonate class	II	I	
			alkalinity and salinity class	2C	2C	
N1	3a	0.50°-2.5°	Dull Yellow Orange			coarse material, land levellin
			soil texture class	I	I	
			organic matter class	I	I	
			calcium carbonate class	II	II	
			alkalinity and salinity class	2B	2B	
S3	3b	-	Dull Yellow Orange			Moderate salinity
			soil texture class	I	I	
			organic matter class	II	III	
			calcium carbonate class	II	II	
			alkalinity and salinity class	2B	2B	
N1	4a	0.5°-2.5°	Bright Yellow Orange			coarse material land levellin
			soil texture class	I	I	
			organic matter class	I	I	
			calcium carbonate class	I	I	
			alkalinity and salinity class	2B	3B	
S3	4b	-	Dull Yellow Orange to dull orange			moderate salinity
			soil texture class	I	I	
			organic matter class	III	III	
			calcium carbonate class	II	I	
			alkalinity and salinity class	2B	2B	

S1	5	$0.5^{\circ}-1.5^{\circ}$	Dull Yellow Orange to Dull orange			low salinity, wind erosion
			soil texture class	I	I	
			organic matter class	II	II	
			calcium carbonate class	II	II	
			alkalinity and salinity class	3A	3A	
S2	6	$0.5^{\circ}-1.5^{\circ}$	Dull Yellow Brown			moderate salinity
			soil texture class	II	II	wind erosion
			organic matter class	II	II	
			calcium carbonate class	II	II	
			alkalinity and salinity class	3B	3A	
S2	7	$0^{\circ}-0.5^{\circ}$	Dull Yellowish Orange			moderate salinity
			soil texture class	I	I	wind erosion
			organic matter class	III	II	
			calcium carbonate class	II	II	
			alkalinity and salinity class	3B	3B	
S2	8	$0.5^{\circ}-1.5^{\circ}$	Dull Yellow Orange			moderate salinity
			soil texture class	I	I	wind erosion
			organic matter class	III	II	
			calcium carbonate class	II	II	
			alkalinity and salinity class	3B	3B	
S2	9	$0.5^{\circ}-1.5^{\circ}$	Dull Brown			moderate salinity
			soil texture class	I	I	wind erosion
			organic matter class	III	II	
			calcium carbonate class	II	II	
			alkalinity and salinity class	3B	3B	
-	included facet 10	-	-----	-	-	Restricted area
N2	11	$0.5^{\circ}-7.5^{\circ}$	Dull Yellow Orange			coarse material
			soil texture class	I	I	water erosion
			organic matter class	II	II	& wind erosion
			calcium carbonate class	II	II	
			alkalinity and salinity class	2A	2A	
N2	12	$0.5^{\circ}-14^{\circ}$	Dull Brown			same status as facet 11
			soil texture class	I	I	
			organic matter class	II	II	
			calcium carbonate class	III	III	
			alkalinity and salinity class	2A	2A	

N1	13a	$0.5-2.5^{o}$	Light Yellow orange to			coarse materia
			Dull orange			land levelling
			soil texture class	I	I	
			organic matter class	II	II	
			clacium carbonate class	I	I	
			alkalinity and salinity class	1B	1B	
N1	13b	-	Dull Yellow Orange			wind & water
			soil texture class	I	I	erosion
			organic matter class	III	III	
			clacium carbonate class	II	II	
			alkalinity and salinity class	2A	2A	

Table 6.2: CRITERIA USED TO DELIMIT THE TERRAIN SUITABILITY OF CLASSE OF THE STUDY AREA FOR AGRICULTURAL PURPOSES.

The classes adopted here, as they relate to the present study are largely modifications of some of the FAO classes. The terrain suitability classification of the detailed study area is shown in figure 6.9. A definition of this classification is given in section 6.4.4.

6.4.3 Terrain suitability classification for grazing purposes.

6.4.3.1 Criteria delimiting the terrain suitability classes for grazing purposes.

The criteria which has been adopted for the terrain suitability classes for grazing purposes is based on the percentage native vegetation cover and the quality of this vegetation.

The classes read as follows:

G1 very good

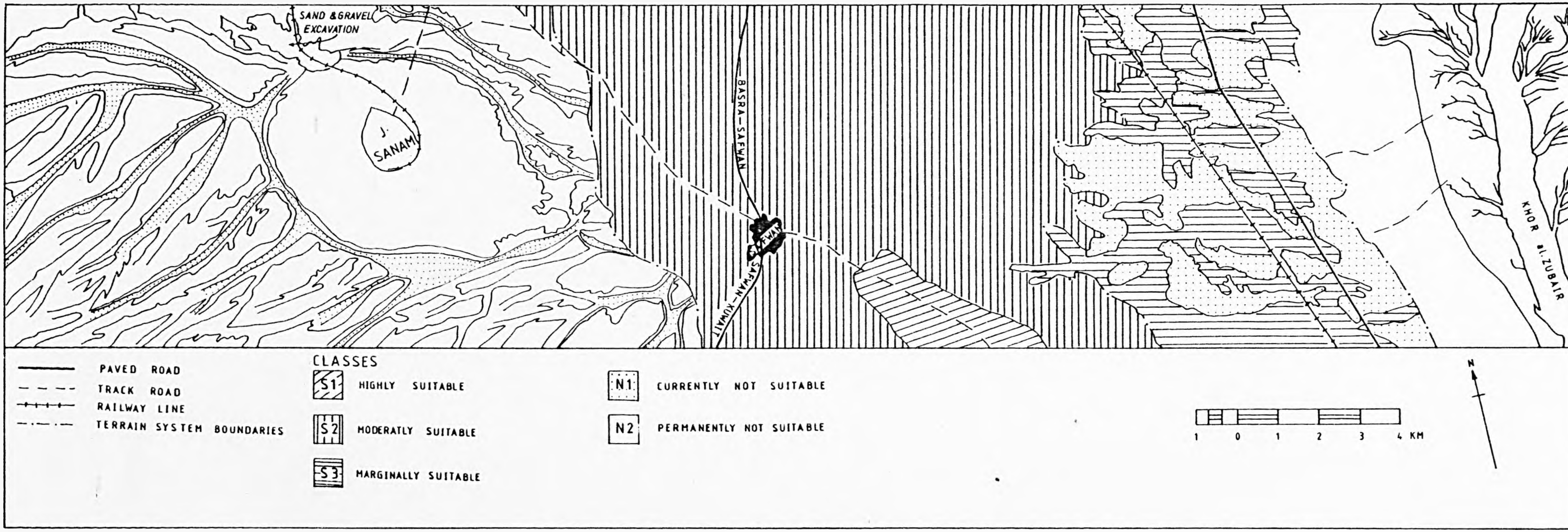
G2 good

G3 moderately good

P1 poor

P2 very poor.

These classes are quite similar to the FAO land suitability classification.



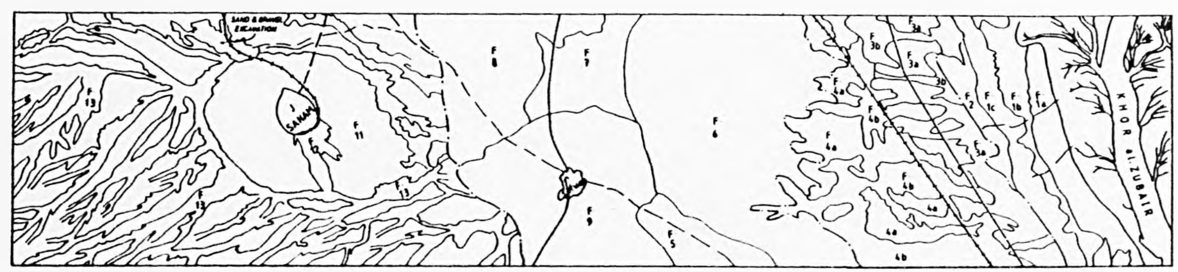


FIG.6.9: TERRAIN SUITABILITY CLASSES OF THE DETAILED STUDY AREA FOR AGRICULTURAL PURPOSES. (SMALLER SCALE MAP SHOWS TERRAIN FACETS FOR REFERENCE PURPOSES).

The following table thus summarises the criteria used to delimit the terrain suitability of the detailed study area for grazing purposes.

Class	Facet	% native vegetation cover	limitations
P2	1a	20-60	seasonal flooding, severe
P2	1b	20-60	" " salinity
P2	1c	20-60	" " "
P2	2	0-40	" " "
P1	3a	0-20	annual shrub
G3	3b	20-60	mixed perennial & annual
P1	4a	0-20	annual
G3	4b	20-60	mixed
G2	5	40-60	low rainfall - wind erosion
G3	6	20-40	" " " "
G2	7	40-60	" " " "
G1	8	40-60	" " " "
G2	9	40-60	mixed vegetation
-	10	-	restricted area
P1	11	0-40	limited rainfall, water and wind erosion
P1	12	0-40	" " " "
G3	13a	0-20	" " " "
G2	13b	20-60	" " " "

Table 6.3: CRITERIA USED TO DELIMIT THE TERRAIN SUITABILITY CLASSES OF THE STUDY AREA FOR GRAZING PURPOSES.

6.4.4 Definition of the terrain suitability classes.

(i) For Agricultural purposes (Fig.6.9).

Class S1. Terrain that is highly suitable for agriculture. The underground water is the only form of irrigation in this area since rainfall is limited. Terrain of this class consists of very gentle slopes (not exceeding 1.5^{o}). The soils are sandy and coarse textured with moderate percentages of organic matter. Accumulation of soluble salts in soils of this class is low. Both soils and topographic factors are encouraging for terrain development. This terrain comprises only a small part of the study area (al.Quabat area, facet 5).

Class S2. Terrain of moderate suitability for agriculture. The salinity in soils of this class is higher than that for class S1. Thus lifting the underground water for irrigation to be used for agriculture is far more costly than class S1. This class comprises almost all of the agricultural area included in the Government's land use development plan. This terrain presents no topographic problems being dominated by very gentle slopes. Terrain types of this class may encourage extensive cultivation, but care should be taken especially with limiting factors, for example saline underground water and wind erosion. Thus a standard for management must be adopted before any development.

Class S3. Terrain that is marginally suitable for cultivation. Topographic characteristics of this class are acceptable for agricultural development as the area is flat. Soils have no great restriction except that of moderate salinity which needs the proper management suggested for Class S2.

Class N1. Possesses the following limitations: (i) coarse surface material, (ii) topographic irregularity requires some levelling, (iii) water and wind erosion. Thus the terrain is included as being currently unsuitable for agricultural development. The class comprises two separate areas. The first includes the hill slopes of Muwailhat al.Janubiya terrain system and the second includes the Wadis of Sanam terrain system.

The surface material becomes as an important limiting factor to the agricultural development especially when the machinery used in this area is simple. Water erosion affects the agricultural development by producing small erosional gullies which present a similar problem to that found in the Mileiha area, Trucial States (Bowen-Jones, 1967, p.20).

In some areas like those of the Trucial states (see, for example, Bowen-Jones, 1967, p.47), slopes of less than 3^{o} do not form a limiting problem for agriculture, but in this area this degree of slope is a limiting factor for agriculture due to the need for an irrigation system where ground water is utilised.

However, for both areas (namely the hill slopes of Muwailhat al.Janubiya and the Wadi slopes of Sanam) a great risk may be involved if farming is established at the present time. Thus it can be stated here that, at least, a high standard of management concerning the above mentioned limitations must be attained before any cultivation is undertaken.

Class N2. The terrain in this class includes those considered permanently not suitable because of severe salinity, seasonal flooding limitation, coarse textured surface materials, water and wind erosion and topographic irregularity limitations. Severe salinity and flooding problems are found in Khor al. Zubair terrain system, while the latter limitations are found in the Sanam terrain system. Under such existing conditions, the potential value for agricultural purposes is very low. The extreme salinity in the soil of Khor al.Zubair combined with the bad drainage and the flat topographic character makes the undertaking of development often very costly if not impossible. The salinity problem in relation to the land capability is observed in other arid areas like Bahrain and West Pakistan (see, for example, Brunsden et al., 1979, Ahmad, 1961). The topography of this class as in Sanam area is one of the limiting factors for agricultural development being generally more than 3^o in slope. The dissected nature (some times deeply dissected e.g. slopes in the gullies may be as steep as 14^o) and coarse material of the surface, makes it difficult to see how major levelling operations and construction can be economically justified. Some emphasis of the slope importance has been noticed in other areas. For instance, in Wadi Ziqlab, Jordan, "Where the slope becomes steeper and more limiting, and where susceptibility to erosion hence increases, more emphasis has been placed on slope as a class determinant" (Fisher et al, 1966, p.50). Wind erosion is another important factor which limits the development of agriculture and gives the terrain the class N2. Small gullies are usually produced by water erosion as explained previously in class N1, whilst wind erosion frequently accumulates the small sand dunes around the vegetaion as well as transporting the soil material. The existence of these features restricts and adds to the cost of any form of development.

(ii) For grazing purposes (Fig.6.10)

Class G1. Terrain of this class is only restricted on the small area (facet 8). It is of very good suitability for grazing having a relatively high percentage cover of native vegetation cover and consisting of a perennial shrubs of high grazing value (e.g. Arfaj shrub). Aridity limits the terrain suitability for grazing.

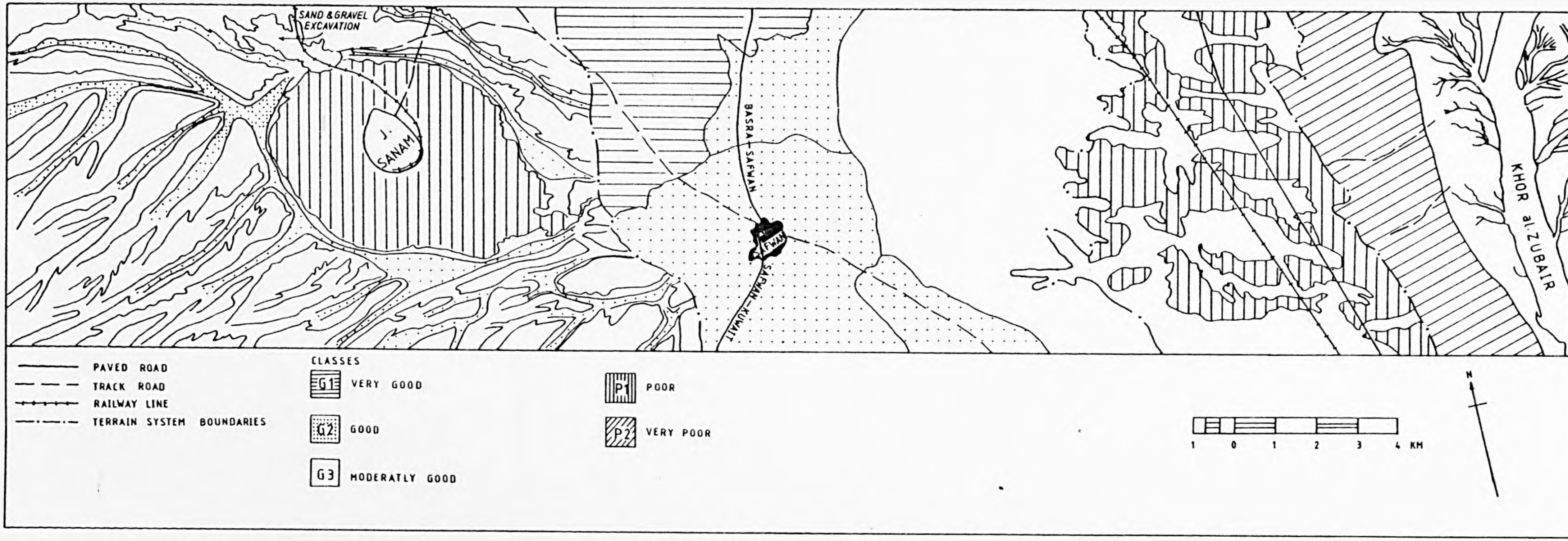
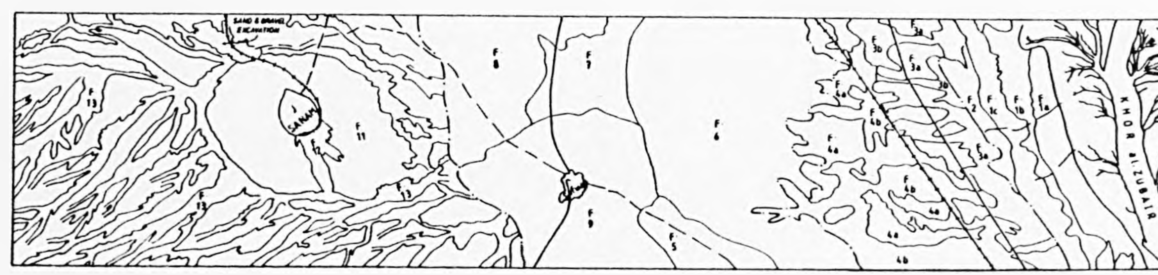


FIG.6.10: TERRAIN SUITABILITY CLASSES OF THE DETAILED STUDY AREA FOR GRAZING PURPOSES. (SMALLER SCALE MAP SHOWS TERRAIN FACETS FOR REFERENCE PURPOSES).



Class G2. Terrain of good suitability for grazing. Although it has a relatively high percentage cover of native vegetation cover, because of the limitations that exist here the terrain is classed as G2. These limiting factors are the low rainfall on one hand and the type of vegetation which consists of a vegetation of limited value for grazing, for example, chidad shrub.

Class G3. Terrain of moderately good suitability for grazing. The terrain is flat in some parts of this class (e.g. facets 4b and 6). This terrain is moderately vegetated but the wind erosion plays its part as a limiting factor. Wadi slopes yield a very low percentage cover of vegetation cover, and because of the quality of the vegetation, the terrain has a character of class G3.

Class P1. Terrain of poor suitability for grazing, because of the low percentage vegetation cover, sandy gravel soils and poor quality of vegetation type especially for sheep, for example, Ardah shrub. Wind erosion and water erosion are other limiting factors in producing a terrain of class P1 for grazing purposes.

Class P2. Terrain here is not suitable for grazing. Although this terrain has a relatively high percentage vegetation cover, the vegetation quality (Halophytic communities) is considered unfavourable for animals in this area, thus the terrain is classified as a class P2. Two other important factors also limit the grazing potential in this part of the study area.

These are the seasonal floods and the severe salinity.

6.5 COMPARISON OF TERRAIN SUITABILITY MAPS WITH GOVERNMENT PLAN.

At this stage it is important to compare the terrain suitability maps to the Government's land use development plan for this area. The Government's plan is shown in figure 6.11. In fact, generally there is no great difference between the maps of the terrain suitability and the Government's plan from the land use point of view. For instance, the Khor al.Zubair terrain system is classified as permanently not suitable for agriculture (class N2) and as a very poor area for grazing (class P2) and it appears as an industrial area in the Government's plan. Safwan area which is identified potentially as an agricultural area also appears so in the Government's plan. Other areas such as Muwailhat al.Janubiya and Sanam have potentially proved their value for agriculture and grazing in this study, though these areas are left as empty lands in the plan map of the Government.

The Government's land use plan shown in figure 6.11 is based on a superficial reconnaissance for this area without taking in account the terrain potential or assessing its limitations. For instance, Khor al.Zubair area has been chosen to be utilized for industrial buildings because of its location near Khor al.Zubair (river) where materials can be imported and exported easily. Similarly, the Safwan area is shown on the map as an agricultural area only because of the already existing farms.

Despite the general agreement however, between the Government's land use plan and the terrain suitability classification,

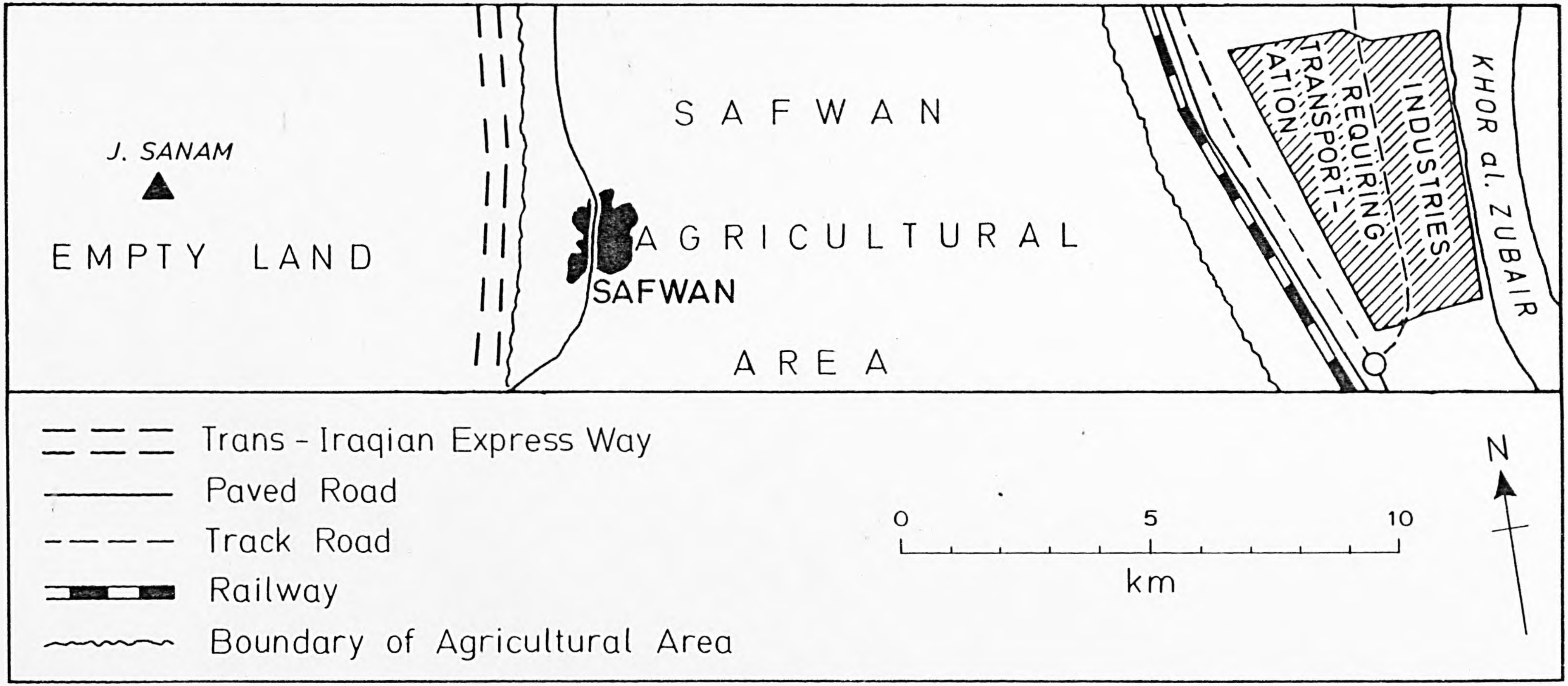


FIG.6.11: THE GOVERNMENT'S LAND USE DEVELOPMENT PLAN OF THE DETAILED STUDY AREA.

it is believed that the potential capability ought to be taken into account for any planning of this area, as it has been classified and mapped here, especially for agricultural and grazing purposes. Moreover, for the other purposes of utilization e.g. industrial building and road building, further work is needed as is recommended in section 7.2.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS.

From this study a number of conclusions can be drawn. These conclusions relate to the methodology of survey, the findings of the survey of terrain conditions, and the recommendations for terrain suitability.

7.1.1 Conclusions concerning methodology of survey.

7.1.1.1 It has been found most useful to utilize aerial photographic interpretation. This made it possible to outline the landforms of the study area on the basis of the available information. Generalization in field sampling was possible since the landforms existing in the area are not complicated. For instance, there is no need to check all these outlined landforms on the ground e.g. all the hill slopes and the flat of Muwailhat al.Janubiya or Wadi slopes and Wadi floor of Sanam.

The field measurements and soil analysis results acted as a support for the preliminary work which included the outline of landforms from the aerial photos and field checking (see also, section 7.1.1.3) These field measurements and soil analysis results also exposed some essential quantitative information which could be used as a base for more detailed work.

7.1.1.2 It has been found that due to the differences of the scale of the aerial photographs which is at 1:35000 and the maps which are at 1:500000 and 1:1000000 and the printing years of the aerial photos (1962) and the maps (1930, 1945), that it was necessary to rely on the aerial photographs in the interpretive approach more than the map data.

7.1.1.3 Due to the general flatness of some parts of the landscape the boundaries between one landform type and another are not clear on the aerial photographs e.g. Muwailhat al. Janubiya and Safwan landform features. Without knowing the topographic background information from ground surveys it is very difficult for the classifier to see these boundaries. Thus in order to define and recognize these landform types and then formulate the terrain elements and facets extra field work was required.

7.1.1.4 Due to the aridity it was very difficult to distinguish and carry out the field vegetation measurements according to association. Thus it was easier to achieve the total percentage vegetation cover measurements for all species.

7.1.1.5 Direct measurement of the percentage of vegetation cover from the available aerial photographs proved to be impossible. This was largely due to the fact that the photographs utilised were taken in summer.

7.1.1.6 It has been found that the extrapolation of the applied methodology used in the detailed study area enabled a terrain classification for the whole of al.Zubair desert in general. Terrain facet maps were not however, produced on this basis for the whole area and in order to do so needs more field work to be carried out.

7.1.1.7 It was found that the C.S.I.R.O. and M.E.X.E. approach to terrain classification were not entirely valid for this study (see Chapter 4).

7.1.2 Conclusions concerning the findings of terrain conditions.

7.1.2.1 It was found that fine material predominates in the top layers of the soil profiles with the coarser material being generally confined to the lower zones. This is considered to be due to aeolian processes. Wind transports the fine material both within the study area and from areas outside the area e.g. the Western Desert of Iraq or north east of Saudi Arabia, and deposits it as cover material over existing soil profiles.

7.1.2.2 The result from the analyses of selected soil properties are not strictly quantitative enough to be used in statistical tests in an effort to quantify the differences or similarities within or between the terrain facets and elements of the study area.

7.1.3 Conclusions concerning the terrain suitability analysis.

7.1.3.1 At present the farming area comprises the largest part of the detailed study area. This part includes terrain of high to moderate quality classes. They are mapped as classes S1 and S2. Other considerations e.g. quality and depth of the groundwater, should be borne in mind before any extensive utilization of the area is planned.

7.1.3.2 Extension of cultivation may be possible in terrain classes S3 and N1 of Muwailhat al.Janubiya providing adjustments are made e.g. land leveling.

7.1.3.3 Terrain of Khor al.Zubair system seems not to be suitable for either agriculture or grazing (reasons are given in Chapter 6).

7.1.3.4 It has been found that precise prediction of terrain suitability within each of the terrain facets is difficult. However it should be remembered that: soil samples have been obtained from accessible areas only, poor map data was available and there were severe time restrictions.

These samples were taken from predetermined specific areas. They are thus considered as only generalised examples (from which they were taken) of the landform types of the detail study area, and not as accurate representatives. Further soil samples need to be taken according to a specific pattern to overcome this problem.

7.1.3.5 Most of the study area is potentially suitable for grazing purposes apart from Khor al.Zubair area, but the native vegetation (perennial and annual) is not sufficient at the present. Recommendations from the grazing point of view are given in section 7.2.

7.1.3.6 It has been found that due to the lack of necessary information, it has been impossible to produce a terrain suitability map for engineering purposes e.g. road construction and building foundations. Further work in relation to the engineering problems is recommended (see 7.2).

7.2 RECOMMENDATIONS FOR FUTURE WORK.

The sampling sites of this study were limited to parts of al.Zubair desert which contained the detailed study area.

A large number of sampling sites would be needed to represent the whole study area with particular attention being given to those areas of potential agricultural value e.g. Safwan, and around Zubair town. Further study would be better to include all al.Zubair area. Increased sampling will give more accuracy, and allow a sufficient quantitative data base to be obtained for the terrain classification (facets and systems). This would enable more sophisticated statistical analysis. The quantitative data should relate to soil properties, slope angles and vegetation cover measurements. Other soil properties like soil strength and permeability would also help from the hydrological aspect, agricultural potential and enginerring construction.

The maximum soil depth which has been sampled in this study is 60cm. Taking more soil samples from further depths e.g. 2m probably will be more significant to an engineering interest. Available equipment, finance and time once again were major constraints in the present study. Related problems, for example erodibility characteristics, potential hazard to building foundations and concrete disintegration need far more attention and consideration, especially in relation to agricultural and engineering practice and potential.

Information concerning vegetation cover, organic matter, particle size analysis, quantitative estimation of wind speed and duration, amount and intensity of rainfall and slope characteristics are important for the study of the erodability problem. It has been suggested that the permeability, shear strength, particle size analysis, soil texture, particularly the amount and type of clay, the range of moisture content that the soil is likely to experience and consolidation are probably the most significant soil properties to the engineers (see, for example, Beaven, 1966 and Hove, 1971). Salt attack is a well known phenomenon in the arid areas of the Middle East (see, for example, Fookes and Collis, 1975 a & b and 1976, Fookes and French, 1977, Beaumont, 1968, Brunsden et al, 1979). This attack could seriously damage the buildings especially in the areas which suffer from severe salinity e.g. Khor al.Zubair area. Thus a special attention should be paid in the future work to this problem.

From the finding of conclusion number 7.1.1.5 it can be recommended that grazing stations need to be set up in the study area. Such stations are found in the other areas of the Western Desert of Iraq (Fig.7.1). It can be suggested that such stations will help both the Bedouin to settle and the farmers to foster livestock instead of depending on crops only. Furthermore, data on these grazing stations need to be checked from one period to another to prove the validity of these stations, and of the terrain suitability classification.

Geomorphological mapping is essential for studies of this type (see, for example, Bahrain survey). This lack of such a map in the present study thus provides a valuable opportunity for future work. An example of such a map is given in an extract shown in figure 7.2. Of course a detailed geomorphological mapping programme will require considerable time to be devoted to surveying, field mapping, and verification. An important pre-requisite for such a geomorphological base is complete air photo coverage at medium scale at least.

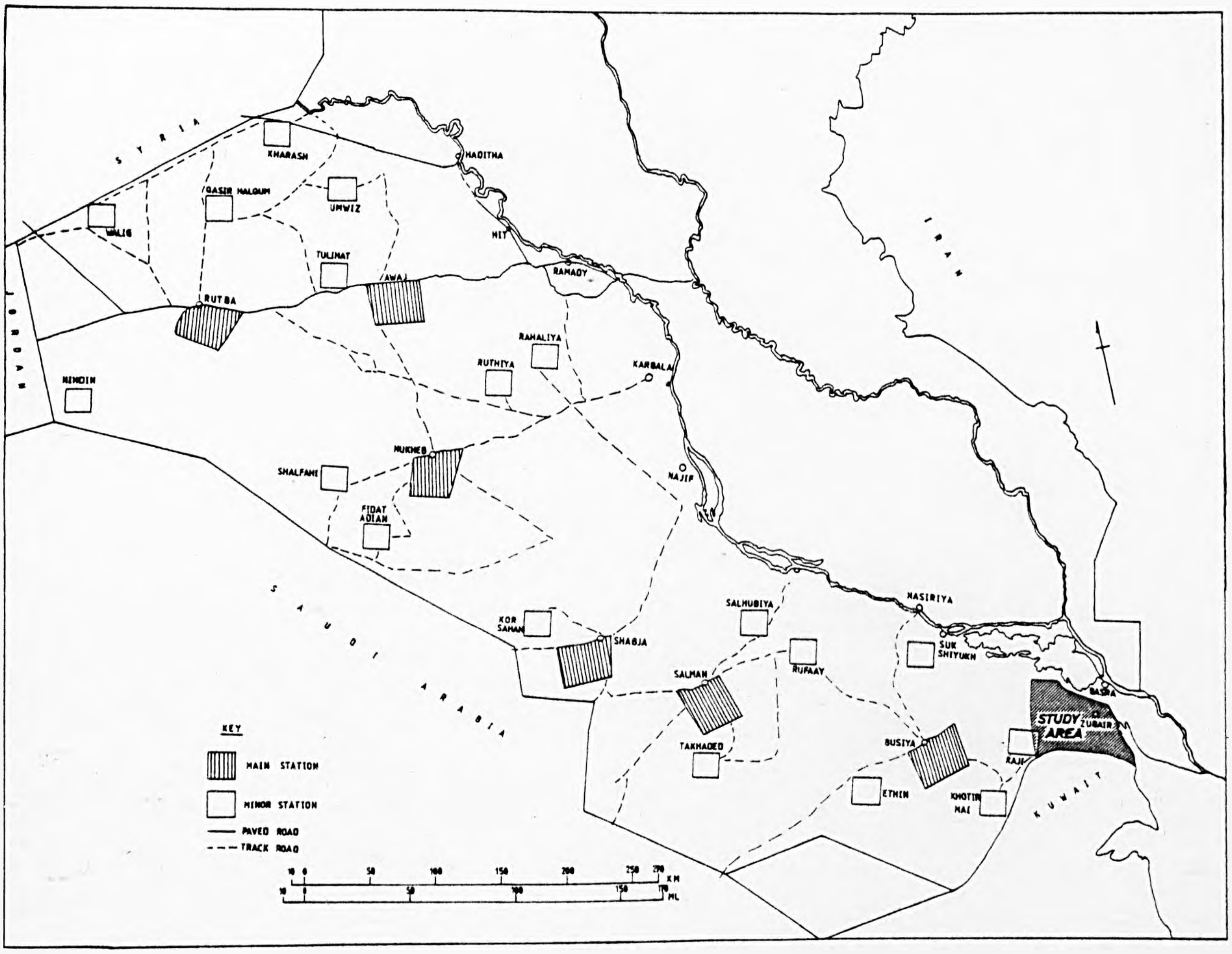


FIG. 7.1 GRAZING STATIONS OF THE WESTERN DESERT OF IRAQ.

FIG. 7.2: Extract of a 1:10,000 geomorphological map to illustrate the detailed legend required to portray successfully the complex landscape.

(after Brunsden et al ,1979)

The present study has collected a large amount of data in an area for which hitherto relatively little information was available. Further work is needed to provide a more complete inventory of terrain resource both in greater detail in the present study area and in general throughout the less settled parts of Iraq.

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APPENDIX 1

MAPS

MAPS

During the war of 1914-1918 the survey of India Department carried out fieldwork on which all Iraqi maps have been based. In the early stages of the war, large-scale surveys were made of the Basra region. By the end of the war about 117,300 square miles had been surveyed in Mesopotamia and west and north-west Persia on a scale of half an inch to a mile or larger. The first maps in colour were published on the quarter-inch scale by the survey of Inida at Calcutta. By 1924, the whole of Iraq, except the Western and Southern Deserts, the mountain region and parts of the marsh area in southern Iraq, was covered by accurate maps.

The survey Directorate of Iraq at that time was engaged on large-scale surveys for land settlement and irrigation, neglecting other developments such as the new roads and the railways. As a result, these older maps have lost much in accuracy and clarity.

The Iraqi map sheet index was published by the survey Directorate in 1943. Each sheet covers a degree of latitude and longitude and is given its international number (Fig.A.1.1). However, many series of maps of Iraq exist at scales ranging from 1:1000,000 (1 km: 1 mm or 16 miles to the inch) to 1:25,000 (0.4 miles to the inch) for parts of the country, but they are out of date.

One million scale maps.

For more than thirty years this scale was represented by international map of the world series, scale 1:1000,000 of which three sheets covered nearly the whole of Iraq (N.H.-38

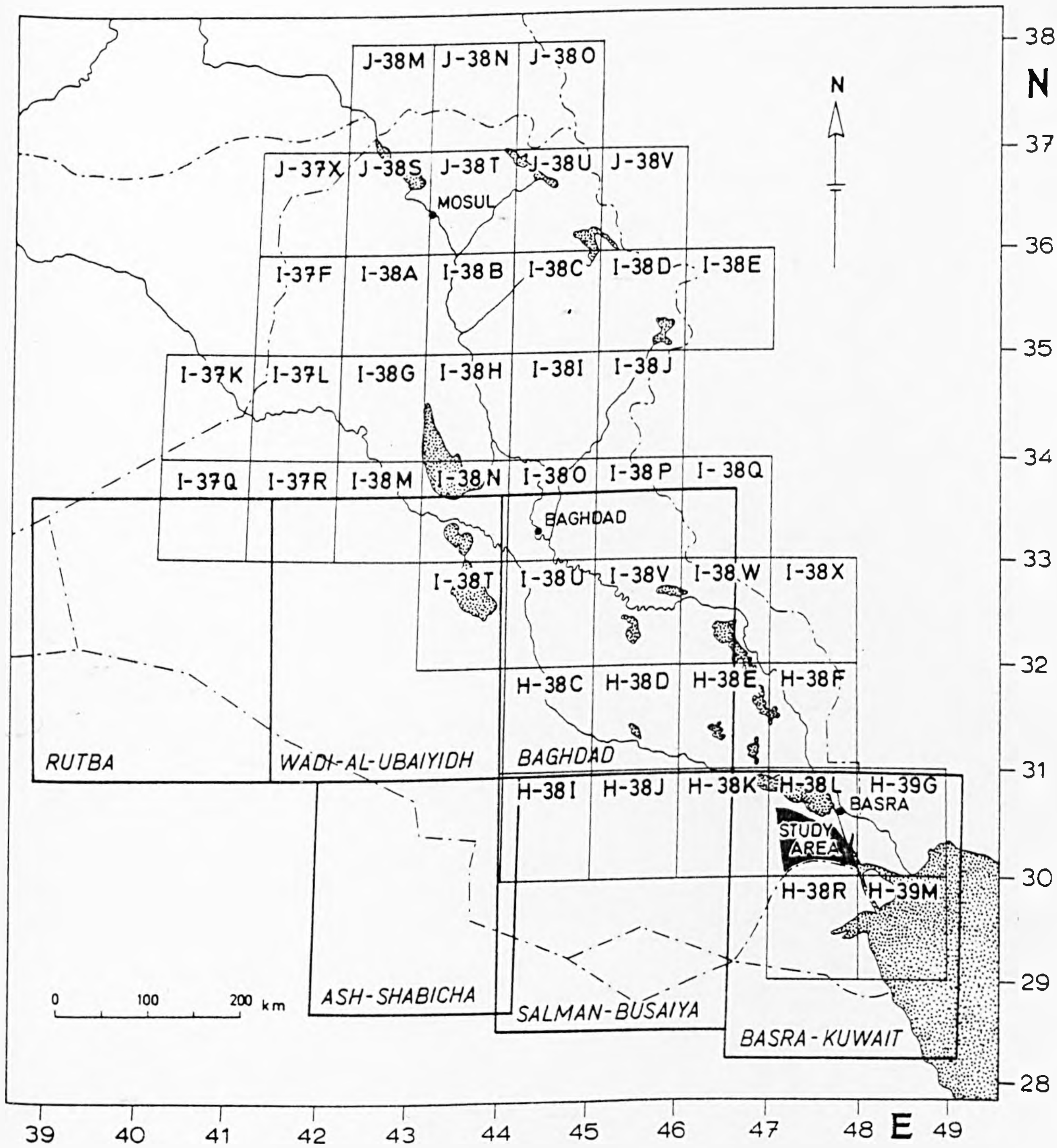

FIG.A.1.1: MAP INDEX OF IRAQ.

Basra, 1927 and 1938 editions; N.I-38 Baghdad: editions of 1928 and 1935; and N.J-38 Tabriz: 1930 and 1931 editions). Parts of the extreme Western Desert districts bordering on the Saudi, Jordanian and Syrian frontiers, were not covered by the above three sheets. New editions of maps have been printed and the title "World 1:1000,000" has been substituted for the original title of the series (International Map of the World). The reference number of the latest edition of the al.Basra sheet is, Basra: GSGS 4646, Sheet NH-38 (edition 8).

Half million scale maps.

Fifteen sheets of this map series were recently published under the title "World 1:5000,000" covering the whole of Iraq. Besides these two series there are degree sheets or $\frac{1}{4}$ inch maps of Iraq.

The "Iraq Desert Maps" sheet (scale 1:500,000) is now restricted, and it is no longer available for sale to the general public. However, it is still available for reference within Iraq. The five sheets of Iraq desert maps (reference GSGS 3954) are invaluable to anyone making a detailed study of the flora of the Southern and Western Deserts. One of these five sheets is the Basra - Kuwait (1940) sheet (Evans, 1966).

APPENDIX 2

SLOPE ANGLE MEASUREMENTS

Appendix 2: Slope angle measurements.

Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degree)
1	15	0.80	2	15	0.90	3	15	0.80
	15	0.60		15	0.50		15	0.70
	15	0.50		15	0.40		15	0.60
	15	0.30		15	0.30		15	0.50
	15	0.30		15	0.30		15	0.30
	15	0.30		15	0.30		15	0.30
4	15	1.0	5	15	1.0	6	15	1.0
	15	0.60		15	0.50		15	0.50
	15	0.50		15	0.40		15	0.50
	15	0.30		15	0.30		15	0.40
	15	0.30		15	0.30		15	0.30
							15	0.30
7	15	1.50	8	15	1.40	9	15	1.50
	15	1.30		15	1.30		15	1.10
	15	1.10		15	0.60		15	1.0
	15	0.60		15	0.30		15	0.60
	15	0.30		15	0.30		15	0.30
	15	0.30						

Slope angles and measured length of random slope profile sites, representing the Alluvial flood plain landform type.

Appendix 2 continued

Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)
10	3	18.20	11	3	18.10	12	3	18.30
	3	1.10		3	6.30		3	0.90
	3	0.20		3	2.40		3	0.60
	3	0.60		3	1.40		3	0.50
	3	0.50		3	0.50		3	
	3	0.50		3	0.60			
				3	0.50			
13	3	16.30						
	3	4.40						
	3	1.40						
	3	0.50						
	3	0.50						

Slope angles and measured lengths of random slope profile sites, representing the man made slopes (Earth works). These are within the Alluvial flood plain landform type. These are unvegetated.

Appendix 2 continued.

Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)
14	15	2.5	15	15	2.5	17	15	2.0
	15	1.5		15	1.5		15	1.5
	15	1.0		15	1.0		15	1.0
	15	0.5		15	0.5		15	0.5
	15	0.5		15	0.5			
	15	0.5						
	15	0.5						
	15	1.0						
	15	1.0						
	15	0.5						
16	15	2.5	18	15	1.5	21	15	2.0
	15	1.0		15	1.0		15	1.5
	15	0.5		15	0.5		15	1.0
	15	0.5						
19	5	11.0	20	3	14.5	22	5	6.0
	5	8.0		3	12.5		5	3.5
	5	1.0		3	3.5		5	2.5
				3	1.5		5	2.5
				3	1.0		5	1.0
23	5	16.0	24	3	15.0			
	5	1.0		3	10.0			
				3	1.0			

Slope angles and measured lengths of random slope profile sites, representing Muwailhat al-Janubiya landform types.

Appendix 2 continued.

Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees)
25	5	1.5	26	3	0.5	27	3	1.5
	5	1.5		3	0.5		3	1.0
	5	1.5		3	0.5		3	0.5
	5	1.5		3	0.5		3	0.5
	5	0.5		3	0.5		3	0.5
	5	0.5						
	5	0.5						
	5	0.5						
28	3	1.5	29	5	1.5	30	15	1.5
	3	0.5		5	1.0		15	1.0
	3	0.5		4	0.5		15	1.0
	3	0.5					15	0.5

Slope angles and measured lengths of random slope profile sites, representing Safwan landform types.

Appendix 2 continued.

Profile	Length (m)	Angles (degrees)	Profile	Length (m.)	Angles (degrees)	Profile	Length (m)	Angles (degrees)
31	15	6.50	32	15	3.5	33	15	2.90
	15	7.20		15	2.60		15	2.60
	15	2.50		15	2.40		15	2.50
	15	2.50		15	2.10		15	2.30
	15	4.60		15	1.30		15	2.20
	15	4.30		15	1.30		15	2.0
	15	4.60		15	1.60		15	1.60
	15	2.20		15	1.40		15	1.40
	15	2.20		15	1.40		15	1.30
	15	2.30		15	1.30		15	1.10
	15	2.30		15	1.20		15	1.10
	15	2.20		15	1.10		15	0.50
	15	2.50		15	1.0		15	0.50
	15	1.10		15	0.50			
	15	3.30		15	0.50			
	15	2.60		15	0.50			
	15	2.10						
	15	1.5						
41	3	14.0	42	3	14.0	43	3	5.5
	3	11.0		3	12.0		3	2.5
	3	4.50		3	3.50		3	2.5
	3	2.20		3	1.50		3	1.10
	3	1.0		3	1.0		3	0.5

Slope angles and measured lengths of random slope profile sites, representing the plateau of Sanam and the Gullies. Profiles 31,32 and 33 represent the Plateau. Profiles 41,42 and 43 represent the Gullies.

Appendix 2 continued.

Profile	Length (m)	Angles (degrees)	Profile	Length (m)	Angles (degrees	Profile	Length (m)	Angles (degrees)
34	5	2.50	35	15	2.60	36	15	2.40
	5	2.10		15	2.40		15	2.30
	5	1.60		15	1.50		15	1.60
	5	0.50		15	1.20		15	1.40
	5	0.50		15	0.50		15	1.30
							15	1.0
37	15	2.60	38	15	2.40	39	15	2.40
	15	2.50		15	1.30		15	1.30
	15	1.20		15	1.10		15	1.10
	15	1.10		15	1.0		15	1.0
	15	1.0					15	0.5
40	15	2.60						
	15	2.50						
	15	2.50						
	15	1.10						
	15	0.5						

Slope angles and measured length of random slope profile sites, representing the Wadis landform types.

APPENDIX 3

AVERAGE PERCENTAGE NATIVE VEGETATION COVER MEASUREMENTS

Appendix 3: Average percentage vegetation cover measurements.

	Site 1				Site 2			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	50	75	75	50	30	80	90	95
2	25	50	80	25	85	60	80	50
3	10	25	75	25	0	25	75	50
4	0	50	50	50	0	90	50	50
5	75	25	50	75	25	90	80	0
6	50	100	80	20	75	75	50	25
7	40	10	50	90	95	25	25	0
8	25	50	25	75	50	25	80	5
9	50	100	75	95	90	10	75	0
10	90	100	0	0	100	50	90	0
11	0	25	25	20	90	100	0	50
12	0	80	25	25	25	90	0	50
13	10	90	25	50	25	80	0	50
14	90	100	10	75	50	75	0	25
15	80	75	25	75	95	75	0	0
16	0	25	10	0	10	10	5	0
17	70	10	95	100	0	0	10	0
18	5	50	0	100	0	25	10	25
19	80	25	0	100	10	75	10	75
20	50	25	80	5	90	5	0	50
21	5	75	80	70	20	10	0	0
22	75	50	75	100	75	75	0	0
23	95	50	75	25	0	80	50	0
24	70	0	50	50	0	95	50	5
25	50	0	100	25	50	0	50	10
Average percentage	39.8	50.6	49.4	56.0	43.6	53.0	35.2	24.0

Average percentage vegetation cover of all species (using the quadrat method); Alluvial flood plain system, facet 1a.

Appendix 3 continued.

	Site 3				Site 4			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	25	50	25	75	50	5	90	0
2	25	50	75	50	25	10	50	100
3	50	85	20	25	25	50	75	90
4	50	25	90	25	5	5	100	0
5	75	75	75	50	50	25	50	0
6	75	10	50	50	50	50	75	90
7	75	50	10	25	25	0	25	90
8	50	75	90	75	50	25	25	80
9	80	25	5	10	5	25	25	75
10	90	75	50	10	50	100	0	75
11	90	50	25	0	100	0	5	25
12	50	25	0	75	10	0	5	50
13	25	25	5	75	0	10	50	25
14	10	75	10	50	50	25	5	5
15	10	50	25	0	0	50	50	5
16	80	50	25	10	100	75	0	25
17	25	75	25	25	100	5	0	50
18	100	50	50	25	0	5	50	100
19	50	50	0	50	25	25	0	0
20	50	10	0	75	0	50	0	5
21	10	25	0	50	25	0	100	50
22	0	50	5	75	10	20	80	75
23	25	75	25	25	10	0	0	10
24	5	75	20	50	25	0	0	25
25	15	50	50	50	0	50	0	5
Average Percentage	45.6	50.2	30.2	41.2	31.6	24.4	34.4	42.2

Average percentage vegetation cover of all species (using the quadrat method); Alluvial flood plain system, facet 1b.

Appendix 3 continued.

Square No.	Site 5 Sample 1	Site 5 Sample 2	Site 5 Sample 3	Site 5 Sample 4	Site 6 Sample 1	Site 6 Sample 2	Site 6 Sample 3	Site 6 Sample 4
1	50	25	5	50	50	75	25	75
2	25	25	5	75	50	25	75	50
3	10	0	0	50	50	0	10	90
4	5	0	0	25	75	0	10	90
5	0	5	0	25	75	90	75	10
6	0	90	25	75	50	90	75	25
7	10	95	75	75	25	75	50	25
8	75	100	50	50	25	50	50	75
9	80	100	25	0	10	50	50	75
10	70	25	50	0	10	25	25	50
11	10	0	0	25	25	10	25	25
12	0	0	0	50	10	10	90	50
13	5	5	0	50	75	0	90	50
14	5	5	10	75	50	50	50	75
15	5	10	10	50	50	75	50	90
16	75	5	100	50	25	90	75	75
17	80	5	10	25	75	25	75	75
18	10	75	0	10	90	75	25	90
19	0	95	0	0	90	50	25	75
20	0	10	5	75	75	25	0	25
21	50	0	0	90	25	50	10	25
22	10	5	0	75	50	90	25	10
23	0	0	75	75	50	25	50	50
24	0	75	95	50	75	75	25	50
25	0	25	50	50	25	50	75	75
Average percentage	23.0	31.2	23.6	47.0	48.4	44.2	45.4	56.2

Average percentage vegetation cover of all species (using the quadrat method); Alluvial flood plain system, facet 1c.

Appendix 3 continued.

	Site 7				Site 8			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	20	0	0	10	0	5	10	20
2	5	0	10	10	0	5	5	10
3	10	50	25	50	0	25	20	5
4	5	0	25	0	0	5	5	0
5	10	0	5	25	5	5	5	0
6	50	10	0	0	5	25	5	0
7	5	5	0	0	10	25	0	0
8	5	0	50	25	20	10	20	20
9	0	0	10	90	0	10	25	30
10	5	50	0	5	0	0	50	10
11	90	100	5	0	0	5	5	15
12	25	90	5	0	25	15	0	5
13	75	10	5	25	50	100	0	0
14	75	0	0	10	0	90	10	0
15	50	0	0	0	25	15	0	20
16	0	0	10	0	5	15	5	25
17	0	90	15	50	0	10	50	10
18	0	5	15	90	50	0	25	10
19	10	0	0	90	0	10	0	20
20	25	25	0	95	0	0	25	50
21	0	10	0	0	75	0	0	0
22	5	0	5	0	20	0	5	0
23	0	10	25	25	0	10	5	5
24	0	5	50	0	50	15	0	10
25	0	0	75	5	50	0	0	25
Average Percentage	18.8	18.4	13.4	24.2	15.6	16.0	11.0	11.6

Average percentage vegetation cover of all species (using the quadrat method); Alluvial flood plain system, facet 2.

Appendix 3 continued.

Square No.	Site 9 Sample 1	Site 9 Sample 2	Site 9 Sample 3	Site 9 Sample 4	Site 10 Sample 1	Site 10 Sample 2	Site 10 Sample 3	Site 10 Sample 4
1	50	25	75	0	5	5	10	90
2	10	50	70	40	5	0	75	15
3	25	95	20	30	5	0	50	5
4	25	15	10	80	10	5	20	5
5	80	5	0	0	50	5	15	5
6	25	10	5	50	5	15	10	30
7	5	0	0	95	5	10	5	80
8	10	0	0	100	20	0	20	20
9	5	50	0	100	10	5	5	0
10	0	25	10	50	5	25	5	25
11	10	25	10	80	90	5	10	0
12	25	20	0	95	20	5	0	5
13	95	5	15	95	80	0	0	0
14	80	90	100	95	40	0	0	0
15	20	80	25	75	5	15	15	5
16	25	25	90	45	0	0	0	80
17	90	25	90	5	0	0	0	10
18	80	80	80	0	0	0	0	10
19	25	75	75	5	0	0	0	0
20	0	25	0	50	0	0	0	0
21	10	95	30	10	0	0	0	15
22	15	10	0	0	0	10	0	0
23	100	0	0	0	0	0	0	10
24	100	0	0	90	0	0	0	0
25	75	0	75	80	0	0	0	0
Average Percentage	39.4	33.2	31.2	50.8	14.2	4.2	9.6	16.4

Average percentage vegetation cover of all species (using the quadrat method);

Muwaîlhat al-Janubiya terrain system, facet 3.

Site 9 represents Base of slope.

Site 10 represents Slope surface.

Appendix 3 continued.

	Site 11				Site 12			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	100	50	5	100	95	15	5	10
2	100	50	95	95	95	15	80	55
3	80	25	90	100	30	80	15	80
4	10	40	95	100	80	75	100	50
5	50	0	95	100	75	80	100	60
6	100	100	95	0	25	75	20	10
7	100	100	90	20	25	50	80	90
8	100	95	50	50	15	0	50	100
9	90	50	25	85	10	0	10	95
10	50	0	0	95	5	10	10	80
11	100	50	100	25	5	10	0	90
12	100	75	95	0	15	5	10	80
13	100	25	0	20	5	80	10	75
14	95	0	10	95	10	10	75	50
15	95	0	25	75	5	5	100	75
16	15	0	25	95	75	10	80	10
17	95	0	0	10	80	75	0	0
18	95	0	0	0	10	5	0	10
19	15	0	80	75	0	0	0	90
20	0	0	75	100	0	0	10	95
21	0	0	95	95	5	0	90	0
22	5	0	90	25	15	0	40	0
23	0	0	90	0	5	0	0	0
24	0	0	100	0	0	0	0	0
25	0	0	100	25	0	0	0	0
Average Percentage	56.4	26.4	64.6	67.2	27.2	23.6	35.6	48.2

Average percentage vegetation cover of all species (using the quadrat method); Muwailhat al-Janubiya terrain system, facet 3. Sites 11 and 12 represent the flat element.

Appendix 3 continued.

	Site 13				Site 14			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	5	60	50	0	0	10	10	10
2	10	100	10	0	50	15	10	5
3	75	100	75	0	5	5	10	0
4	100	25	0	5	5	10	5	0
5	80	5	0	5	75	5	0	5
6	0	75	75	0	5	15	5	5
7	0	100	50	5	50	15	75	25
8	30	100	25	80	5	0	50	10
9	20	80	0	5	5	10	10	5
10	5	0	50	25	0	10	15	5
11	0	5	20	80	5	5	5	0
12	0	10	75	100	0	0	0	0
13	10	0	50	95	0	5	0	5
14	95	25	10	80	0	5	0	0
15	15	0	50	90	0	10	5	0
16	0	0	0	100	5	15	5	0
17	5	5	0	100	5	0	5	0
18	10	0	50	100	0	0	5	0
19	85	0	50	50	0	10	0	0
20	90	0	75	0	15	5	0	0
21	0	0	0	50	10	90	0	0
22	0	0	5	75	50	10	0	0
23	10	0	50	25	5	5	0	0
24	40	0	0	25	75	10	0	0
25	35	5	10	20	20	5	0	0
Average percentage	28.4	27.8	31.2	44.6	15.6	11.4	8.6	3.0

Average percentage vegetation cover of all species (using the quadrat method); Muwailhat al-Janubiya terrain system, facet 4. Site 13: represent base of slope element. Site 14: represent slope surface element.

Appendix 3 continued.

	Site 15				Site 16			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	5	75	0	0	75	25	100	25
2	50	75	10	30	50	10	50	25
3	0	5	5	0	0	100	50	95
4	75	100	15	10	0	75	25	50
5	50	75	10	0	90	75	75	100
6	10	100	15	5	75	90	100	0
7	75	75	0	0	10	5	50	0
8	10	10	10	0	25	75	50	5
9	10	100	40	0	5	50	75	100
10	5	50	100	0	75	0	50	90
11	50	50	95	10	0	75	75	75
12	0	90	5	5	50	0	0	90
13	0	50	0	0	90	50	90	50
14	90	50	15	15	5	0	5	50
15	5	0	5	15	75	25	75	0
16	0	75	0	40	100	90	90	50
17	5	100	0	95	90	0	75	100
18	0	25	5	80	0	90	10	0
19	0	0	15	100	50	0	25	90
20	5	0	10	70	90	50	75	100
21	100	50	0	5	0	100	50	50
22	75	50	0	10	0	0	75	50
23	50	0	5	75	50	50	100	0
24	10	90	90	90	0	50	90	75
25	50	50	80	75	50	50	50	50
Average percentage	29.2	53.8	21.2	29.2	33.4	45.4	60.4	52.8

Average percentage vegetation cover of all species (using the quadrat method); Muwailhat al-Janubîya terrain system, facet 4. Sites 15 and 16 represent the flat element.

Appendix 3 continued.

Square No.	Site 17 Sample 1	Site 17 Sample 2	Site 17 Sample 3	Site 17 Sample 4	Site 18 Sample 1	Site 18 Sample 2	Site 18 Sample 3	Site 18 Sample 4
1	10	0	5	75	15	90	75	80
2	20	10	25	15	10	85	10	75
3	20	25	75	100	5	30	20	70
4	10	25	95	95	75	5	5	90
5	5	10	10	5	10	0	10	25
6	90	0	80	0	5	25	75	5
7	100	80	100	100	20	95	5	15
8	100	80	100	90	50	10	10	80
9	90	75	25	5	50	10	20	70
10	80	60	0	75	10	5	80	85
11	75	10	10	0	70	10	40	0
12	75	20	90	5	25	50	5	5
13	30	10	90	15	10	5	10	0
14	25	5	5	10	25	5	5	5
15	20	60	5	90	90	80	20	30
16	100	15	0	50	75	20	50	5
17	95	90	0	0	5	50	0	5
18	5	100	10	75	5	15	0	0
19	5	80	10	50	15	80	50	5
20	0	10	20	0	10	85	25	0
21	25	20	0	0	0	5	10	0
22	90	100	0	50	0	0	0	0
23	30	95	75	90	50	0	70	0
24	0	90	80	10	0	5	95	0
25	70	5	90	0	50	5	10	5
Average Percentage	46.8	43.0	40.0	42.2	25.8	30.8	28.0	26.2

Average percentage vegetation cover of all species (using the quadrat method); Safwan terrain system, facets 5 and 6. Site 17 represents al-Quabat facet. Site 18 represents Safwan-East facet.

Appendix 3 continued.

	Site 19				Site 20			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1.	50	75	0	95	0	10	10	90
2	50	25	75	75	50	25	10	75
3	25	10	0	90	75	0	75	90
4	5	5	15	75	10	50	0	50
5	75	25	75	75	5	0	25	50
6	0	50	25	95	75	50	0	90
7	100	25	50	100	50	75	50	90
8	50	50	75	100	10	0	90	75
9	0	25	25	75	75	50	25	90
10	10	75	25	50	90	5	25	75
11	50	90	75	50	75	25	50	25
12	0	75	0	10	90	100	0	50
13	5	25	25	25	90	0	50	25
14	25	50	75	0	25	0	90	50
15	50	50	50	10	0	10	0	50
16	50	50	90	5	50	50	100	75
17	75	75	5	5	50	75	90	0
18	90	0	5	10	75	0	50	0
19	25	50	0	5	0	100	0	50
20	100	10	75	0	100	25	25	75
21	25	75	50	10	0	0	75	5
22	25	25	75	75	25	50	75	5
23	75	0	75	0	10	0	0	75
24	75	0	10	25	50	90	100	10
25	25	50	75	50	50	10	25	0
Average percentage	42.4	39.6	41.8	44.4	45.2	50.0	41.6	50.8

Average percentage vegetation cover of all species (using the quadrat method); Safwan terrain system, facets 7 and 8. Site 19 represents Safwan-north facet (7). Site 20 represents al-Jufin facet (8).

Appendix 3 continued.

Square No.	Sample 1	Sample 2	Sample 3	Sample 4
	Site 21			
1	90	50	95	90
2	75	75	95	90
3	75	25	95	75
4	75	90	90	5
5	5	90	0	75
6	10	0	90	25
7	75	0	75	0
8	75	10	90	10
9	90	25	100	10
10	90	90	50	90
11	75	100	0	75
12	100	25	0	5
13	90	25	5	90
14	50	75	0	75
15	75	0	0	0
16	0	75	75	0
17	0	90	0	75
18	0	90	50	75
19	0	75	0	5
20	50	50	0	75
21	50	10	90	5
22	0	25	0	70
23	100	25	50	70
24	0	0	0	50
25	0	50	0	90
Average Percentage	50.0	46.8	42.0	49.2

Average percentage vegetation cover of all species (using the quadrat method); Safwan terrain system, facet 9. Site 21 represents Safwan-south.

Appendix 3 continued.

	Site 22				Site 23			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	75	50	50	90	75	90	25	10
2	50	25	50	90	25	80	50	25
3	25	50	25	25	50	75	90	95
4	75	50	0	50	25	50	20	25
5	50	75	25	0	25	25	25	50
6	90	100	15	0	10	5	0	25
7	50	80	25	20	0	100	75	75
8	5	5	5	0	50	25	100	95
9	5	10	25	50	90	0	95	80
10	50	0	40	0	90	25	5	5
11	25	0	20	0	10	10	100	20
12	0	10	75	0	15	10	75	30
13	25	0	0	0	75	50	25	25
14	25	20	0	0	100	30	0	0
15	0	0	15	50	100	5	0	50
16	0	0	5	0	0	0	0	5
17	25	0	0	0	0	0	20	0
18	75	0	0	25	0	0	5	0
19	100	0	10	95	50	0	0	0
20	100	0	0	100	25	25	0	20
21	10	5	5	0	0	5	0	30
22	0	0	0	0	0	25	50	0
23	0	0	0	0	0	50	0	0
24	0	10	0	0	30	25	10	25
25	0	20	10	25	95	0	30	0
Average Percentage	34.4	20.4	16.0	24.8	37.6	28.4	32.0	27.6

Average percentage vegetation cover of all species (using the quadrat method); representing plateau of Sanam, facet 11.

Appendix 3 continued.

	Site 24				Site 25			
Square No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
1	25	10	0	5	10	0	25	50
2	5	10	5	0	25	10	25	0
3	5	5	5	0	90	90	25	0
4	0	10	5	25	10	5	0	0
5	0	10	0	5	5	5	5	25
6	5	0	5	5	5	10	0	50
7	10	25	5	10	10	25	5	0
8	5	5	10	25	10	25	0	0
9	0	15	15	0	25	75	10	25
10	10	0	5	10	25	10	0	0
11	25	10	0	25	50	25	5	0
12	10	0	0	5	25	75	10	0
13	10	0	0	0	75	50	15	90
14	5	0	0	0	0	50	10	10
15	0	10	5	10	90	0	50	75
16	50	0	75	25	10	20	15	0
17	0	10	0	50	5	10	50	0
18	0	0	0	25	5	0	0	15
19	0	90	75	0	0	0	25	25
20	0	10	25	0	50	0	25	75
21	0	0	0	0	50	50	75	0
22	0	0	70	25	0	25	75	0
23	5	0	30	10	25	0	75	0
24	10	30	0	10	50	0	25	50
25	10	25	0	25	0	50	0	50
Average Percentage	7.9	10.8	13.4	12.0	26.0	24.4	22.0	21.6

Average percentage vegetation cover of all species (using the quadrat method), facet 12. Site 24 represents Gully slope surface element; Site 25 represents Gully floor element.

Appendix 3 continued.

Square No.	Site 26 Sample 1	Site 26 Sample 2	Site 26 Sample 3	Site 26 Sample 4	Site 27 Sample 1	Site 27 Sample 2	Site 27 Sample 3	Site 27 Sample 4	Site 28 Sample 1	Site 28 Sample 2	Site 28 Sample 3	Site 28 Sample 4
1	0	0	5	5	5	10	15	15	75	10	30	10
2	5	5	10	15	25	15	80	10	10	5	20	20
3	10	10	0	20	25	50	10	50	10	5	40	25
4	20	10	0	10	0	25	75	20	5	0	10	15
5	50	75	0	15	10	75	50	20	10	10	25	10
6	0	0	5	5	80	50	25	10	5	10	50	100
7	0	0	0	0	75	25	5	25	5	0	5	80
8	5	5	0	10	50	50	10	20	20	10	20	10
9	95	90	0	15	10	25	15	5	20	10	10	0
10	25	25	0	5	15	10	10	15	15	15	10	0
11	0	0	10	0	5	5	0	5	10	5	5	25
12	5	0	5	5	15	25	0	10	0	0	10	10
13	5	5	0	0	5	25	0	20	5	0	5	10
14	90	95	0	0	0	10	0	15	0	20	10	5
15	10	15	0	0	10	5	10	10	25	50	5	5
16	0	0	95	0	0	0	10	0	10	0	0	10
17	15	20	90	5	0	75	0	0	5	10	0	0
18	20	10	0	0	0	90	25	0	0	5	10	0
19	20	10	0	10	5	10	0	50	10	5	15	0
20	0	0	0	5	0	0	0	100	20	10	10	50
21	0	0	80	5	10	0	5	10	50	80	0	5
22	10	10	50	5	75	0	0	10	50	90	10	0
23	10	10	0	0	0	5	0	0	5	10	10	0
24	10	10	0	5	0	0	5	0	0	0	20	5
25	0	0	0	5	10	0	0	0	5	25	0	0
Average percentage	16.20	16.40	14.0	5.80	17.20	23.40	14.0	16.80	14.80	15.40	13.0	15.80

Average percentage vegetation cover of all species (using the quadrat method), facet 13, Wadi slope surface.

Square No.	Site 29 Sample 1	Site 29 Sample 2	Site 29 Sample 3	Site 29 Sample 4	Site 30 Sample 1	Site 30 Sample 2	Site 30 Sample 3	Site 30 Sample 4	Site 31 Sample 1	Site 31 Sample 2	Site 31 Sample 3	Site 31 Sample 4
1	25	80	10	25	100	100	25	50	5	10	75	50
2	95	75	50	25	100	90	75	10	10	10	90	25
3	90	20	25	10	100	80	75	50	50	10	10	75
4	50	15	50	10	100	25	25	5	50	25	75	80
5	50	20	10	25	100	10	50	25	75	0	90	50
6	25	10	25	0	90	100	0	50	75	50	50	100
7	50	50	25	50	80	10	15	50	25	50	25	100
8	0	10	10	75	100	20	90	5	100	25	0	50
9	5	40	50	75	80	75	25	75	100	25	80	75
10	10	10	10	0	80	90	10	100	75	50	80	0
11	15	5	5	0	50	90	5	10	0	75	25	100
12	5	95	90	0	50	20	5	25	25	100	75	100
13	0	10	25	5	70	10	10	50	75	80	25	100
14	5	95	75	10	50	25	100	25	75	25	0	100
15	20	20	75	10	20	25	100	0	75	25	75	50
16	10	5	10	90	10	100	20	20	0	100	25	50
17	10	0	25	25	20	100	0	10	0	100	75	90
18	95	40	75	10	0	90	75	0	0	100	25	100
19	100	20	90	75	20	25	50	0	25	100	0	75
20	100	10	75	75	0	10	50	10	75	50	0	10
21	10	10	10	25	0	10	75	75	0	0	0	0
22	90	5	10	50	0	80	25	25	50	0	0	0
23	50	5	5	75	50	50	25	0	0	25	25	0
24	10	0	10	25	50	0	90	0	20	100	50	25
25	50	5	10	50	70	0	75	75	20	100	50	0
Average percentage	38.80	26.80	33.80	32.8	51.6	49.4	43.8	29.8	40.2	49.4	41.0	56.2

Average percentage vegetation cover of all species (using the quadrat method), facet 13, Wadi floor.

APPENDIX 4

LABORATORY METHODS

1. Size, shape and surface texture of sedimentary particles.

For practical reasons, the larger particles (pebbles and cobbles) were measured in the field, using the method described in chapter 4.

Sand grade material was studied in the laboratory. A small amount of the coarse and medium sand grades of each sample was cleaned by boiling for half an hour (95°C) in citric acid* followed by washing in distilled water and oven drying. Thirty grains from each grade from each sample were then randomly selected. These selected grains were then viewed using optical and scanning electron microscopes to determine their shapes and surface texture. Five or six of the grains were selected for study using the scanning electron microscope. The sample preparation method used has been summarised by Shackely (1975).

The dry sieving method which has been used for the particle size analysis is described by the British Standards Institution (1377, 1975) Test 7 (B). The computed percentages of clay, silt and sand contents were derived by using the method for fine grained soils (hydrometer method). This method is explained in the British Standards Institution (1377, 1975) Test 7 (D).

2. Organic Matter Content.

The method used to determine the organic matter content of the studied samples was loss on ignition. This method is explained by Briggs (1977). The soil is dried overnight in the oven at 105°C, cooled in a desiccator, weighed in a crucible

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* The citric acid has been prepared by mixing 1g of citric acid powder with 10ml. of distilled water.

and the weight recorded as W_1. Approximately (25g.) of the soil is then weighed in a crucible, the weight of crucible plus soil being W_2. The crucible is then left in the furnace for two hours at $800^{o}C$, cooled in a desiccator, and weighed (crucible plus contents being recorded as W_3). Percentages organic matter is then calculated as:

$$\text{Percentage of Organic Matter} = \frac{W_2 - W_3}{W_2 - W_1} \text{ X } 100$$

3. Soil reaction.

The method of determining soil pH is widely used and is a standard method (British Standards Institute 1377, 1975, Test 11; Soil Survey Laboratory Methods, 1974 and Briggs, 1977). About 10g. of dry soil is used, placed in a beaker and 25-50ml. of distilled water added. It is stirred and left to stand, before the electrical pH meter probe is inserted and the pH value read to the nearest 0.1 pH units.

4. Calcium Carbonate Determination.

Determination of calcium carbonate determination using the Bascomb calcimeter is given by the soil survey (1974) and Bascomb (1961). The method depends on measuring the amount of CO_2 gas evolved during the reaction of the sample (less than 2mm fraction) with HCl. From this and the known mass of the sample the amount of carbonate originally can be calculated. The calculation (including constants plus correction factors) is as follows:

$$\% \; CaCO_3 = \frac{\text{Vol. of } CO_2 \text{ (ml.)}}{\text{wt. of sample (g)}} \text{ X } \frac{\text{Barametric pressure (mm.Hg.)}}{\text{Temperature } (^{o}C+273)} \text{ X K}$$

$$\text{where K} = \left[\frac{273 \times 100}{760 \times 224}\right] = 0.1604$$

5. Identification of clay minerals by x-ray diffraction.

The sample preparation technique for x-ray identification of clay minerals is now standardized (e.g. Soil Survey, 1974, Birkeland and Janda, 1971). This method has been summarized as follows (Derbyshire, 1967).

"A representative portion of each sample was roughly ground in a mortar and pestle and sieved to .02 mm mesh. A little of the fine fraction($\sim$1gm.) was added to $\sim$10ml. distilled water in a 50ml. beaker and the solution subjected to ultrasonic vibration, to disperse the clay fraction evenly. When necessary, a few drops of "calgon" were added to the solution to assist dispersal. After a completely dis-aggregating the sample the beaker was removed from the ultrasonic tank and allowed to stand for a few seconds (not longer than 30 secs.) This gives a suspension with a particle size range of up to 50μ. Some of the suspension was drawn up with a dropper and transferred to three $1\frac{1}{4}$" x $1\frac{1}{4}$" glass slides, carefully dropped so that about half the slide surface was covered. The slide was allowed to air-dry slowly. One slide was then scanned untreated, a second was heated in a electric furnace at 550$\pm$ 10^{o}C for 2 hours, then scanned, and the third was suspended in glycol vapour for 1 hour at 80^{o}C and then scanned. Length of scans was from 3-30^{o}2$\emptyset$". (Appendix 111).

6. Soluble Salts determination.

A simple method was recommended by the Geology Department, University of Keele for the preparation of samples in order to determine the Na, K, Mg and Ca elements of soluble salts of the samples of the study area.

The procedure is summarized as follows. A 100g sample of fine grade material (0.25mm in diameter) was transferred to 400ml and 350ml. of distilled water added. The contents were then stirred for 30-60 mins. using a rotary shaker. The suspended sample was filtered and 100ml. of the filtrate was collected in a clean dry plastic bottle. Soluble salt determination was then affected using flame emission (for Na and K) and atomic absorption (for Ca and Mg).

APPENDIX 5

SHAPE MEASUREMENTS OF PEBBLES AND THEIR DISTRIBUTION ON ZINGG's DIAGRAM.

Appendix 5a: Shape measurements of pebbles - sites 1 and 13 - facet 3 - top of the slope element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 1	1	4.1	2.6	0.9	0.3	0.6			x	
	2	3.8	2.4	1.3	0.5	0.6			x	
	3	2.9	1.7	1.3	0.7	0.5				x
	4	3.1	2.0	1.9	0.9	0.6				x
	5	2.1	1.7	1.2	0.7	0.8	x			
	6	2.3	2.2	1.8	0.8	0.9	x			
	7	3.5	1.5	1.0	0.6	0.4			x	
	8	2.0	1.8	0.9	0.5	0.9		x		
	9	3.1	1.8	1.0	0.5	0.5			x	
	10	2.8	1.5	0.4	0.2	0.5			x	
	11	3.2	1.6	1.0	0.6	0.5			x	
	12	1.9	1.4	1.0	0.7	0.7	x			
	13	1.8	1.6	1.1	0.6	0.8		x		
	14	2.5	1.5	1.2	0.8	0.6				x
	15	2.1	1.4	1.4	1.0	0.6				x
	16	2.5	1.9	0.8	0.4	0.7		x		
	17	1.9	1.7	0.7	0.4	0.8		x		
	18	1.7	1.0	0.7	0.7	0.5				x
	19	1.7	1.5	1.0	0.6	0.8		x		
	20	1.7	0.9	0.7	0.7	0.5				x
	21	2.1	1.3	0.8	0.6	0.6			x	
	22	1.6	1.1	1.0	0.9	0.6				x
	23	1.9	1.5	0.9	0.6	0.7		x		
	24	1.2	1.1	0.7	0.6	0.9		x		
	25	1.5	1.2	1.0	0.8	0.6				x
Site 13	1	4.9	2.9	1.8	0.6	0.5			x	
	2	4.7	2.9	1.6	0.5	0.6			x	
	3	3.8	2.6	1.5	0.5	0.6			x	
	4	2.9	1.4	0.8	0.5	0.4			x	
	5	2.4	1.9	0.9	0.4	0.7		x		
	6	4.1	2.1	1.4	0.6	0.5			x	
	7	3.4	1.7	1.5	0.8	0.4				x
	8	2.2	1.4	0.9	0.6	0.6			x	
	9	2.8	2.5	1.8	0.7	0.8	x			
	10	5.1	2.7	2.4	0.8	0.5				x
	11	4.3	2.5	2.1	0.8	0.5				x
	12	2.0	1.8	1.5	0.8	0.9	x			
	13	2.8	2.1	1.5	0.7	0.7	x			
	14	3.1	2.8	0.9	0.3	0.9		x		
	15	2.9	2.0	1.6	0.8	0.6				x
	16	3.2	2.7	2.2	0.8	0.8	x			
	17	3.2	2.9	1.7	0.5	0.9		x		
	18	3.3	2.2	1.7	0.7	0.6				x
	19	4.8	2.6	2.3	0.8	0.5				x
	20	2.0	1.7	1.4	0.8	0.8	x			
	21	3.7	2.0	1.0	0.5	0.5			x	
	22	3.7	2.3	1.4	0.6	0.6			x	
	23	3.1	2.0	1.1	0.5	0.6			x	
	24	2.8	2.1	1.6	0.7	0.7	x			
	25	3.2	2.5	1.1	0.4	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - Sites 4 and 14 - facet 3 - middle of the slope element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 4	1	3.8	2.7	1.5	0.5	0.7		x		
	2	3.4	2.1	1.7	0.8	0.6				x
	3	3.4	1.7	1.3	0.7	0.5				x
	4	2.9	2.4	1.3	0.5	0.8		x		
	5	3.0	1.9	1.1	0.5	0.6			x	
	6	3.1	2.7	1.7	0.6	0.8		x		
	7	3.3	2.2	1.4	0.6	0.6			x	
	8	3.4	2.7	0.8	0.2	0.7		x		
	9	3.8	2.8	0.8	0.2	0.7		x		
	10	4.1	3.1	1.9	0.6	0.7		x		
	11	6.5	2.0	1.8	0.9	0.3				x
	12	3.6	2.5	2.0	0.8	0.6				x
	13	2.7	2.2	1.5	0.6	0.8		x		
	14	2.7	1.6	1.0	0.6	0.5			x	
	15	2.9	2.6	1.7	0.6	0.8		x		
	16	3.1	2.2	1.5	0.6	0.7		x		
	17	3.6	2.6	1.7	0.6	0.7		x		
	18	3.6	2.5	1.3	0.5	0.6			x	
	19	3.0	2.2	0.7	0.3	0.7		x		
	20	3.5	2.6	1.0	0.3	0.7		x		
	21	2.5	2.2	1.4	0.6	0.8		x		
	22	3.0	2.3	1.4	0.6	0.7		x		
	23	2.6	2.1	1.4	0.6	0.8		x		
	24	2.0	1.8	1.3	0.7	0.6				x
	25	2.9	2.1	1.4	0.6	0.7		x		
Site 14	1	3.7	2.3	1.8	0.7	0.6				x
	2	4.1	3.5	2.0	0.5	0.8		x		
	3	5.3	3.9	2.1	0.5	0.7		x		
	4	2.9	2.4	2.2	0.9	0.8	x			
	5	3.1	1.9	1.6	0.8	0.6				x
	6	3.2	2.2	2.0	0.9	0.6				x
	7	2.7	2.4	1.7	0.7	0.8	x			
	8	4.8	2.5	1.5	0.6	0.5			x	
	9	3.8	3.1	1.9	0.6	0.8		x		
	10	3.5	2.9	1.6	0.5	0.8		x		
	11	2.5	1.5	1.3	0.8	0.6				x
	12	2.8	1.6	1.4	0.8	0.5				x
	13	3.4	1.4	0.9	0.6	0.4			x	
	14	2.8	2.4	1.5	0.6	0.8		x		
	15	4.4	2.7	1.6	0.5	0.6			x	
	16	2.3	1.9	1.5	0.7	0.8	x			
	17	3.6	2.8	2.0	0.7	0.7	x			
	18	2.2	1.4	0.9	0.6	0.4			x	
	19	2.1	1.6	1.2	0.7	0.7	x			
	20	3.5	2.0	1.6	0.8	0.5				x
	21	2.1	1.5	1.1	0.7	0.7	x			
	22	4.2	2.8	2.2	0.7	0.6				x
	23	2.9	2.5	1.6	0.6	0.8		x		
	24	3.4	2.2	1.8	0.8	0.6				x
	25	1.5	1.1	0.9	0.8	0.7	x			

Appendix 5a continued. Shape measurements of pebbles - sites 3 and 5 - facet 3 - base of the slope element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 3	1	5.0	2.4	1.7	0.7	0.4				x
	2	2.8	2.0	1.6	0.8	0.7	x			
	3	3.6	2.7	2.0	0.7	0.7	x			
	4	3.2	1.2	0.5	0.4	0.3			x	
	5	4.6	1.9	1.2	0.6	0.4			x	
	6	3.1	2.5	0.5	0.2	0.8		x		
	7	2.2	1.9	1.7	0.8	0.8	x			
	8	4.1	2.5	0.8	0.3	0.6			x	
	9	2.4	1.5	1.2	0.8	0.6				x
	10	2.3	1.7	1.5	0.8	0.7	x			
	11	2.3	1.0	0.8	0.8	0.4				x
	12	1.9	0.7	0.7	1.0	0.3				x
	13	1.8	1.3	0.7	0.5	0.7		x		
	14	4.1	1.8	1.4	0.7	0.4				x
	15	3.3	2.7	1.6	0.5	0.8		x		
	16	2.6	1.2	0.8	0.6	0.4			x	
	17	1.8	1.4	0.6	0.4	0.7		x		
	18	2.6	2.0	0.9	0.4	0.7		x		
	19	2.1	1.1	0.6	0.5	0.5			x	
	20	1.9	0.8	0.7	0.8	0.4				x
	21	2.8	1.7	1.6	0.9	0.6				x
	22	2.9	2.3	1.7	0.7	0.7	x			
	23	2.2	1.2	0.9	0.7	0.5				x
	24	3.3	1.7	0.7	0.4	0.5			x	
	25	2.0	1.5	0.9	0.6	0.7		x		
Site 5	1	3.4	1.8	0.9	0.5	0.5			x	
	2	3.5	1.6	1.3	0.8	0.4				x
	3	2.6	1.4	1.1	0.7	0.5				x
	4	2.5	2.0	1.0	0.5	0.8		x		
	5	2.5	1.5	1.3	0.8	0.6				x
	6	2.7	1.7	1.2	0.7	0.6				x
	7	3.3	1.6	1.2	0.7	0.4				x
	8	4.0	2.1	1.5	0.7	0.5				x
	9	2.3	2.2	1.3	0.5	0.9		x		
	10	4.1	1.9	1.0	0.5	0.4			x	
	11	2.6	1.9	1.4	0.7	0.7	x			
	12	2.2	1.6	0.9	0.5	0.7		x		
	13	2.1	1.3	1.1	0.8	0.6				x
	14	2.3	1.7	1.4	0.8	0.7	x			
	15	2.6	1.7	1.2	0.7	0.6				x
	16	3.5	2.2	1.6	0.7	0.6				x
	17	2.6	1.3	1.0	0.7	0.5				x
	18	2.7	1.6	1.4	0.8	0.5				x
	19	3.3	2.3	1.4	0.6	0.6			x	
	20	2.6	1.6	0.9	0.5	0.6			x	
	21	3.4	1.9	1.1	0.5	0.5			x	
	22	3.3	1.7	0.9	0.5	0.5			x	
	23	2.9	1.7	1.3	0.7	0.5				x
	24	2.5	2.3	0.6	0.2	0.9		x		
	25	2.6	1.5	1.1	0.7	0.5				x

Appendix 5a continued. Shape measurement of pebbles - sites 2 and 6 - facet 3 - flat element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 2	1	3.8	1.7	1.6	0.9	0.4				x
	2	3.3	2.3	0.7	0.3	0.6			x	
	3	3.4	1.8	1.0	0.5	0.5			x	
	4	3.3	1.8	1.2	0.6	0.5			x	
	5	3.3	2.0	1.0	0.5	0.6			x	
	6	2.9	2.0	1.2	0.6	0.6			x	
	7	2.2	1.9	1.3	0.6	0.8		x		
	8	2.6	2.1	1.4	0.6	0.8		x		
	9	3.6	2.0	1.0	0.5	0.5			x	
	10	2.8	1.3	0.8	0.6	0.4			x	
	11	2.8	1.9	1.5	0.7	0.6				x
	12	2.0	1.4	0.8	0.5	0.7		x		
	13	2.0	1.7	1.2	0.7	0.8	x			
	14	2.7	2.2	0.8	0.3	0.8		x		
	15	3.3	2.0	1.3	0.6	0.6			x	
	16	2.8	2.3	1.4	0.6	0.8		x		
	17	2.1	1.6	0.6	0.3	0.7		x		
	18	2.2	1.5	1.3	0.8	0.6				x
	19	2.6	1.4	1.2	0.8	0.5				x
	20	2.5	1.7	1.3	0.7	0.6				x
	21	2.1	1.5	1.0	0.6	0.7		x		
	22	2.4	1.5	1.3	0.8	0.6				x
	23	2.0	1.2	1.0	0.8	0.6				x
	24	2.7	2.5	1.3	0.5	0.9		x		
	25	1.8	1.5	1.0	0.6	0.8		x		
Site 6	1	4.2	3.6	2.0	0.5	0.8		x		
	2	2.3	2.0	1.6	0.8	0.8	x			
	3	2.2	1.5	1.2	0.8	0.6				x
	4	3.2	2.1	1.7	0.8	0.6				x
	5	2.9	2.2	1.1	0.5	0.7		x		
	6	3.9	2.1	1.3	0.6	0.5			x	
	7	3.1	2.8	1.5	0.5	0.9		x		
	8	3.2	2.1	1.3	0.6	0.6			x	
	9	3.5	2.5	0.8	0.3	0.7		x		
	10	3.9	2.5	0.7	0.2	0.6			x	
	11	4.0	3.1	1.7	0.5	0.7		x		
	12	2.6	2.1	1.1	0.5	0.8		x		
	13	2.8	2.3	1.4	0.6	0.8		x		
	14	3.4	2.3	1.3	0.5	0.6			x	
	15	2.3	1.7	1.3	0.7	0.7	x			
	16	2.8	2.3	0.9	0.3	0.8		x		
	17	4.6	3.1	1.8	0.5	0.6			x	
	18	2.8	2.7	1.7	0.6	0.9		x		
	19	3.3	2.3	1.0	0.4	0.6			x	
	20	3.1	2.0	1.1	0.5	0.6			x	
	21	3.2	3.0	1.4	0.4	0.9		x		
	22	2.8	2.2	1.1	0.5	0.7		x		
	23	4.2	2.6	1.0	0.3	0.6			x	
	24	3.3	2.5	1.9	0.7	0.7	x			
	25	2.5	1.6	1.3	0.8	0.6				x

Appendix 5a continued. Shape measurements of pebbles - sites 7 and 10 - facet 4 - top of the slope element.

Site	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 7	1	4.1	2.7	2.2	0.8	0.6				x
	2	4.3	3.6	1.1	0.3	0.8		x		
	3	3.2	2.0	1.9	0.9	0.6				x
	4	4.6	3.0	1.6	0.5	0.6			x	
	5	3.0	2.7	2.6	0.9	0.9	x			
	6	2.9	2.2	1.3	0.5	0.7		x		
	7	3.5	2.2	1.6	0.7	0.6				x
	8	3.6	2.5	1.6	0.6	0.6			x	
	9	3.5	2.3	1.7	0.7	0.6				x
	10	3.4	2.2	0.6	0.2	0.6			x	
	11	2.5	2.0	1.4	0.7	0.8	x			
	12	2.5	1.9	1.6	0.8	0.7	x			
	13	2.2	2.0	1.3	0.6	0.9		x		
	14	3.9	2.7	1.3	0.4	0.6			x	
	15	2.9	2.4	1.1	0.4	0.8		x		
	16	2.3	1.3	1.3	1.0	0.5				x
	17	2.6	1.6	1.2	0.7	0.6				x
	18	2.0	1.7	1.6	0.9	0.8	x			
	19	2.5	1.8	0.8	0.4	0.7		x		
	20	2.8	2.7	1.3	0.4	0.9		x		
	21	3.5	1.9	1.4	0.7	0.5				x
	22	2.6	1.4	1.2	0.8	0.5				x
	23	2.1	2.0	1.4	0.7	0.9	x			
	24	2.4	1.7	1.0	0.5	0.7		x		
	25	3.1	2.2	1.0	0.4	0.7		x		
Site 10	1	7.0	4.7	1.6	0.3	0.6			x	
	2	3.7	2.5	2.0	0.8	0.6				x
	3	3.7	3.2	1.6	0.5	0.8		x		
	4	3.7	2.7	1.7	0.6	0.7		x		
	5	2.4	1.6	1.2	0.7	0.6				x
	6	4.1	2.0	1.5	0.7	0.4				x
	7	4.0	2.5	1.6	0.6	0.6			x	
	8	3.3	2.3	1.9	0.8	0.6				x
	9	2.7	2.1	1.8	0.8	0.7	x			
	10	3.8	3.0	1.3	0.4	0.7		x		
	11	3.6	2.6	1.2	0.4	0.7		x		
	12	2.5	1.9	1.0	0.5	0.7		x		
	13	3.4	2.7	2.0	0.7	0.7	x			
	14	3.8	1.6	1.3	0.8	0.4				x
	15	3.3	1.9	1.6	0.8	0.5				x
	16	2.2	1.4	1.0	0.7	0.6				x
	17	2.8	2.1	1.2	0.5	0.7		x		
	18	2.7	1.2	0.8	0.6	0.4			x	
	19	3.3	2.2	1.4	0.6	0.6			x	
	20	2.7	1.7	1.5	0.8	0.6				x
	21	2.4	1.8	0.8	0.4	0.7		x		
	22	3.7	2.5	1.5	0.6	0.6			x	
	23	2.4	2.2	1.0	0.4	0.9		x		
	24	2.8	2.5	1.5	0.6	0.8		x		
	25	2.4	1.6	1.5	0.9	0.6				x

Appendix 5a continued. Shape measurements of pebbles - sites 8 and 11 - facet 4 - middle of the slope element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 8	1	2.7	1.6	1.4	0.8	0.5				x
	2	3.5	2.7	2.5	0.7	0.7	x			
	3	6.7	3.4	2.0	0.5	0.5			x	
	4	2.9	1.8	1.4	0.7	0.6				x
	5	2.2	1.7	1.7	1.0	0.7	x			
	6	2.3	1.5	1.1	0.7	0.6				x
	7	3.6	2.1	1.6	0.7	0.5				x
	8	2.9	1.9	1.6	0.8	0.6				x
	9	2.5	2.1	1.5	0.7	0.8	x			
	10	2.5	1.5	1.5	1.0	0.6				x
	11	3.3	1.8	1.5	0.8	0.5				x
	12	2.6	2.3	1.2	0.5	0.8		x		
	13	4.3	3.5	2.1	0.6	0.8		x		
	14	2.9	2.0	1.6	0.8	0.6				x
	15	2.4	2.2	1.6	0.7	0.9	x			
	16	2.5	1.8	1.4	0.7	0.7	x			
	17	2.2	2.1	1.8	0.8	0.9	x			
	18	2.3	1.7	1.5	0.8	0.7	x			
	19	2.9	1.5	0.9	0.6	0.5			x	
	20	3.7	1.1	0.9	0.8	0.2				x
	21	3.3	1.8	1.0	0.5	0.5			x	
	22	2.6	1.6	0.7	0.4	0.6			x	
	23	2.2	1.4	1.2	0.8	0.6				x
	24	3.1	2.0	1.2	0.6	0.6			x	
	25	2.3	1.6	1.5	0.9	0.6				x
Site 11	1	3.6	1.8	1.6	0.8	0.5				x
	2	2.9	2.1	1.6	0.7	0.7	x			
	3	3.4	2.1	1.4	0.6	0.6			x	
	4	2.7	1.7	1.1	0.6	0.6			x	
	5	2.8	2.2	0.6	0.2	0.7		x		
	6	2.2	1.8	1.6	0.8	0.8	x			
	7	2.8	1.1	0.9	0.8	0.3				x
	8	2.6	1.7	1.1	0.6	0.6			x	
	9	3.2	1.9	1.2	0.6	0.5			x	
	10	2.3	1.9	1.0	0.5	0.8		x		
	11	3.0	2.1	0.8	0.3	0.7		x		
	12	2.4	1.8	1.1	0.6	0.7		x		
	13	2.6	1.1	0.8	0.7	0.4				x
	14	2.9	1.6	1.5	0.9	0.5				x
	15	2.6	2.1	1.2	0.5	0.8		x		
	16	2.2	1.6	0.7	0.4	0.7		x		
	17	2.1	1.7	1.2	0.7	0.8	x			
	18	2.2	1.5	1.3	0.8	0.6				x
	19	2.5	1.3	1.0	0.7	0.5				x
	20	2.1	1.6	1.2	0.7	0.7	x			
	21	3.3	2.7	2.3	0.8	0.8	x			
	22	2.8	1.6	1.5	0.9	0.5				x
	23	3.4	1.6	1.4	0.8	0.4				x
	24	2.3	1.7	1.3	0.7	0.7	x			
	25	3.2	2.4	1.3	0.5	0.7		x		

Appendix 5a continued. Shape of measurements of pebbles - sites 9 and 12 - facet 4 - base of the slope element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 9	1	4.0	2.8	1.8	0.6	0.7		x		
	2	3.1	1.9	1.5	0.7	0.6				x
	3	2.8	1.3	1.2	0.9	0.4				x
	4	3.3	2.5	1.8	0.7	0.7	x			
	5	3.2	2.5	1.4	0.5	0.7		x		
	6	1.7	1.1	0.9	0.8	0.6				x
	7	3.5	2.7	1.3	0.4	0.7		x		
	8	2.0	1.8	1.3	0.7	0.9	x			
	9	2.0	1.8	1.5	0.8	0.9	x			
	10	2.4	1.7	1.1	0.6	0.7		x		
	11	2.4	1.9	1.2	0.6	0.7		x		
	12	3.0	2.0	1.4	0.7	0.6				x
	13	3.2	2.5	1.6	0.6	0.7		x		
	14	2.9	2.0	1.1	0.5	0.6			x	
	15	1.8	1.6	1.1	0.6	0.8		x		
	16	2.2	1.4	1.2	0.8	0.6				x
	17	1.9	1.7	1.0	0.5	0.8		x		
	18	1.8	1.5	1.3	0.8	0.8	x			
	19	1.9	1.6	1.2	0.7	0.8	x			
	20	4.9	3.1	1.2	0.3	0.6			x	
	21	2.1	1.7	1.6	0.9	0.8	x			
	22	2.0	1.2	0.9	0.7	0.6				x
	23	2.5	1.2	0.8	0.6	0.4			x	
	24	2.2	1.3	0.8	0.6	0.5			x	
	25	4.2	3.3	1.9	0.5	0.7		x		
Site 12	1	4.4	2.0	1.0	0.5	0.4			x	
	2	2.6	1.8	1.7	0.9	0.6				x
	3	2.5	2.2	2.0	0.9	0.8	x			
	4	1.9	1.2	1.0	0.8	0.6				x
	5	3.1	2.4	1.7	0.7	0.7	x			
	6	2.4	2.0	1.5	0.7	0.8	x			
	7	4.1	2.2	1.1	0.5	0.5			x	
	8	2.7	1.4	1.0	0.7	0.5				x
	9	4.6	1.5	1.2	0.8	0.3				x
	10	2.5	2.0	1.6	0.8	0.8	x			
	11	3.5	2.2	1.7	0.7	0.6				x
	12	4.8	2.1	0.9	0.4	0.4			x	
	13	4.3	1.7	1.5	0.8	0.3				x
	14	2.6	1.8	0.6	0.3	0.6			x	
	15	2.5	2.1	1.5	0.7	0.8	x			
	16	2.8	2.0	1.4	0.7	0.7	x			
	17	2.6	1.5	1.4	0.9	0.5				x
	18	2.1	1.9	1.5	0.7	0.9	x			
	19	3.0	1.7	1.2	0.7	0.5				x
	20	3.3	2.5	1.4	0.5	0.7		x		
	21	3.9	1.9	1.2	0.6	0.4			x	
	22	1.9	1.6	1.1	0.6	0.8		x		
	23	1.8	1.3	1.2	0.9	0.7	x			
	24	2.1	1.9	1.4	0.7	0.9	x			
	25	2.5	2.0	1.1	0.5	0.8		x		

Appendix 5a continued. Shape measurement of pebbles - sites 15 and 16 - facet 4 - flat element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 15	1	4.2	2.9	1.9	0.6	0.6			x	
	2	2.5	2.2	0.7	0.3	0.8		x		
	3	2.6	1.7	1.4	0.8	0.6				x
	4	2.4	2.1	1.7	0.8	0.8	x			
	5	4.9	3.9	0.9	0.2	0.7		x		
	6	4.3	2.4	1.1	0.4	0.5			x	
	7	4.1	2.4	1.2	0.5	0.5			x	
	8	4.3	2.5	0.6	0.2	0.5			x	
	9	3.0	2.4	1.7	0.7	0.8	x			
	10	2.8	2.5	1.5	0.6	0.8		x		
	11	3.3	2.8	1.9	0.6	0.8		x		
	12	3.4	1.5	1.3	0.8	0.4				x
	13	2.9	1.8	1.0	0.5	0.6			x	
	14	1.9	1.5	0.9	0.6	0.7		x		
	15	2.0	1.8	1.1	0.6	0.9		x		
	16	2.9	2.0	1.1	0.5	0.6			x	
	17	3.0	2.0	0.9	0.4	0.6			x	
	18	4.2	1.4	1.2	0.8	0.3				x
	19	3.0	1.5	1.1	0.7	0.5				x
	20	3.3	1.2	0.6	0.2	0.6			x	
	21	3.7	2.3	1.2	0.5	0.6			x	
	22	2.0	1.7	0.9	0.5	0.8		x		
	23	2.5	2.3	1.1	0.4	0.9		x		
	24	2.7	2.2	1.3	0.5	0.8		x		
	25	2.9	1.6	1.2	0.7	0.5				x
Site 16	1	3.4	1.7	1.2	0.7	0.5				x
	2	4.7	3.6	2.2	0.6	0.7		x		
	3	3.7	2.6	1.6	0.6	0.7		x		
	4	2.7	1.9	1.5	0.7	0.7	x			
	5	2.7	1.9	0.8	0.4	0.7		x		
	6	2.2	1.7	1.1	0.6	0.7		x		
	7	2.7	1.7	1.1	0.6	0.6			x	
	8	2.7	1.6	0.7	0.4	0.5			x	
	9	2.6	1.7	1.2	0.7	0.6				x
	10	3.4	2.2	1.4	0.6	0.6			x	
	11	3.0	1.4	1.2	0.8	0.4				x
	12	2.5	1.9	0.7	0.3	0.7		x		
	13	2.8	1.9	1.3	0.6	0.6			x	
	14	2.2	1.7	1.0	0.5	0.7		x		
	15	2.9	1.9	1.0	0.5	0.6			x	
	16	2.8	1.8	1.4	0.7	0.6				x
	17	2.8	1.7	1.4	0.8	0.6				x
	18	2.7	2.2	0.4	0.1	0.8		x		
	19	2.2	1.7	1.2	0.7	0.7	x			
	20	2.6	2.1	1.6	0.7	0.8	x			
	21	2.3	1.7	1.0	0.5	0.7		x		
	22	2.4	2.0	1.2	0.6	0.8		x		
	23	3.2	2.3	1.7	0.7	0.7	x			
	24	3.2	1.4	1.3	0.9	0.4				x
	25	2.4	1.3	1.0	0.7	0.5				x

Appendix 5a continued. Shape measurements of pebbles - sites 18 and 21 - facet 5. al-Quabat.

Site	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 18	1	5.0	2.7	1.7	0.6	0.5			x	
	2	5.1	4.4	3.1	0.7	0.8	x			
	3	2.9	2.3	1.4	0.6	0.7		x		
	4	4.9	3.1	2.1	0.6	0.6			x	
	5	2.4	1.8	1.4	0.7	0.7	x			
	6	3.7	2.4	1.5	0.6	0.6			x	
	7	3.7	2.6	1.9	0.7	0.6				x
	8	3.6	2.6	1.6	0.6	0.7		x		
	9	4.0	2.9	2.4	0.8	0.7	x			
	10	2.8	1.9	1.5	0.7	0.6				x
	11	2.2	1.9	1.0	0.5	0.8		x		
	12	2.2	1.9	1.2	0.6	0.8		x		
	13	2.0	1.7	1.0	0.5	0.8		x		
	14	3.8	1.5	1.2	0.8	0.3				x
	15	3.3	2.4	1.4	0.5	0.7		x		
	16	4.6	2.9	2.6	0.8	0.6				x
	17	3.8	2.6	1.4	0.5	0.6			x	
	18	3.0	2.1	1.7	0.8	0.7				x
	19	4.2	3.6	2.6	0.7	0.8	x			
	20	2.9	2.2	1.1	0.5	0.7		x		
	21	1.8	1.3	0.9	0.6	0.7		x		
	22	2.4	1.8	1.1	0.6	0.7		x		
	23	2.6	2.0	1.7	0.8	0.7	x			
	24	2.3	1.9	1.2	0.6	0.8		x		
	25	2.4	0.9	0.8	0.8	0.3				x
Site 21	1	4.8	3.5	2.3	0.6	0.7		x		
	2	5.2	3.6	2.2	0.6	0.6			x	
	3	3.5	2.2	1.4	0.6	0.6			x	
	4	2.5	2.1	1.5	0.7	0.8	x			
	5	4.7	2.6	1.5	0.5	0.5			x	
	6	2.9	2.4	1.5	0.6	0.8		x		
	7	2.3	1.7	1.4	0.8	0.7	x			
	8	3.3	2.4	1.7	0.7	0.7	x			
	9	5.0	2.5	1.0	0.4	0.5			x	
	10	3.4	2.1	1.8	0.8	0.6				x
	11	3.2	2.1	1.4	0.6	0.6			x	
	12	2.4	1.9	1.2	0.6	0.7		x		
	13	2.4	2.0	1.1	0.5	0.8		x		
	14	5.1	2.7	1.4	0.5	0.5			x	
	15	1.9	1.4	0.9	0.6	0.7		x		
	16	2.1	1.6	1.1	0.6	0.7		x		
	17	2.6	1.7	0.9	0.5	0.6			x	
	18	2.8	2.0	1.4	0.7	0.7	x			
	19	3.5	2.5	1.8	0.7	0.7	x			
	20	2.4	1.8	1.3	0.7	0.7	x			
	21	2.8	2.5	2.3	0.9	0.8	x			
	22	3.1	2.9	2.0	0.6	0.9		x		
	23	1.7	1.5	1.3	0.8	0.8	x			
	24	3.2	2.2	1.8	0.8	0.6				x
	25	3.5	2.6	1.2	0.4	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - sites 23 and 25 - facet 6 - Safwan east.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 23	1	3.6	2.6	0.7	0.2	0.7		x		
	2	2.9	2.7	1.1	0.4	0.9		x		
	3	3.5	2.7	0.7	0.2	0.7		x		
	4	4.9	3.3	1.9	0.5	0.6			x	
	5	3.0	2.4	2.0	0.8	0.8	x			
	6	3.5	2.6	1.6	0.6	0.7		x		
	7	3.0	1.3	1.1	0.8	0.4				x
	8	3.3	2.0	1.1	0.5	0.6			x	
	9	2.6	2.0	1.9	0.9	0.7	x			
	10	3.8	2.1	1.8	0.8	0.5				x
	11	1.9	1.8	1.0	0.5	0.9		x		
	12	3.1	1.1	0.6	0.5	0.3			x	
	13	2.2	1.9	1.0	0.5	0.8		x		
	14	3.2	2.8	1.8	0.6	0.8		x		
	15	3.9	1.9	0.9	0.4	0.4			x	
	16	3.5	2.5	1.9	0.7	0.7	x			
	17	3.6	2.3	1.6	0.6	0.6			x	
	18	2.5	1.7	1.3	0.7	0.6				x
	19	4.0	2.7	1.7	0.6	0.6			x	
	20	3.0	2.6	1.1	0.4	0.8		x		
	21	2.6	2.0	0.8	0.4	0.7		x		
	22	1.5	1.4	0.9	0.6	0.9		x		
	23	1.5	1.1	0.9	0.8	0.7	x			
	24	1.4	1.1	0.7	0.6	0.7		x		
	25	2.3	1.9	1.7	0.8	0.8	x			
Site 25	1	5.1	3.9	2.8	0.7	0.7	x			
	2	7.9	3.8	2.3	0.6	0.4			x	
	3	4.4	2.9	2.1	0.7	0.6				x
	4	4.3	2.4	1.7	0.7	0.5				x
	5	3.0	1.7	0.6	0.3	0.5			x	
	6	2.5	1.9	1.4	0.7	0.7	x			
	7	2.9	2.8	1.6	0.5	0.9		x		
	8	2.3	1.5	1.1	0.7	0.6				x
	9	2.7	1.8	1.0	0.5	0.6			x	
	10	5.6	3.5	2.5	0.7	0.6				x
	11	2.3	2.0	1.1	0.5	0.8		x		
	12	2.7	1.9	1.1	0.5	0.4			x	
	13	4.5	2.0	2.0	1.0	0.4				x
	14	2.8	2.7	0.9	0.3	0.9		x		
	15	2.9	1.9	0.5	0.2	0.6			x	
	16	2.9	2.0	0.8	0.4	0.6			x	
	17	3.0	2.5	1.5	0.6	0.3			x	
	18	3.7	2.6	0.9	0.3	0.7		x		
	19	2.5	1.8	1.3	0.7	0.7	x			
	20	4.3	2.2	1.4	0.6	0.5			x	
	21	3.8	3.3	1.9	0.5	0.8		x		
	22	4.0	2.9	1.2	0.4	0.7		x		
	23	2.9	1.9	1.2	0.6	0.6			x	
	24	3.4	1.2	1.0	0.8	0.3				x
	25	1.8	1.6	1.0	0.6	0.8		x		

Appendix 5a continued. Shape measurements of pebbles - sites 17 and 24 - facet 7 - Safwan north.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 17	1	7.2	6.1	3.6	0.5	0.8		x		
	2	8.1	2.1	1.5	0.7	0.2				x
	3	3.9	2.5	1.8	0.7	0.6				x
	4	4.3	4.1	1.1	0.2	0.9		x		
	5	3.3	2.5	2.5	1.0	0.7	x			
	6	3.5	2.7	2.0	0.7	0.7	x			
	7	7.9	3.4	2.8	0.8	0.4				x
	8	3.4	2.5	1.6	0.6	0.7		x		
	9	5.5	5.4	1.6	0.2	0.9		x		
	10	4.1	3.2	1.9	0.5	0.7		x		
	11	4.7	3.6	2.1	0.5	0.7		x		
	12	4.9	3.1	1.4	0.4	0.6			x	
	13	3.0	2.6	1.6	0.6	0.8		x		
	14	3.0	2.6	1.2	0.4	0.8		x		
	15	3.3	1.9	1.6	0.8	0.5				x
	16	4.5	3.9	2.1	0.5	0.8		x		
	17	6.0	3.6	2.4	0.6	0.6			x	
	18	3.7	2.2	1.5	0.6	0.5			x	
	19	2.9	2.8	1.5	0.5	0.9		x		
	20	3.6	2.1	1.7	0.8	0.5				x
	21	4.2	3.1	1.4	0.4	0.7		x		
	22	3.6	2.2	1.4	0.6	0.6			x	
	23	3.5	2.5	1.5	0.6	0.7		x		
	24	5.3	3.7	2.8	0.7	0.6				x
	25	2.8	2.4	1.7	0.7	0.8	x			
Site 24	1	4.8	3.2	1.7	0.5	0.6			x	
	2	3.9	3.4	0.8	0.2	0.8		x		
	3	4.7	3.3	1.4	0.4	0.7		x		
	4	3.2	2.4	1.3	0.5	0.7		x		
	5	3.9	1.7	1.2	0.7	0.4				x
	6	5.9	2.6	1.7	0.6	0.4			x	
	7	2.9	2.2	1.8	0.8	0.7	x			
	8	3.2	2.3	1.9	0.8	0.7	x			
	9	2.7	1.9	1.6	0.8	0.7	x			
	10	3.4	2.2	1.9	0.8	0.6				x
	11	3.5	2.7	1.8	0.6	0.7		x		
	12	2.8	2.3	1.8	0.7	0.8	x			
	13	3.6	2.8	1.7	0.6	0.7		x		
	14	2.9	2.4	1.2	0.5	0.8		x		
	15	3.1	2.0	1.4	0.7	0.6				x
	16	5.1	2.1	1.4	0.6	0.4			x	
	17	4.4	3.1	1.9	0.6	0.7		x		
	18	4.9	2.5	1.0	0.4	0.5			x	
	19	3.5	2.3	1.0	0.4	0.6			x	
	20	2.1	2.0	0.7	0.3	0.9		x		
	21	2.7	2.0	1.5	0.7	0.7	x			
	22	2.6	1.8	1.1	0.6	0.6			x	
	23	2.8	2.0	1.1	0.5	0.7		x		
	24	2.6	1.8	1.4	0.7	0.6				x
	25	2.8	2.3	0.8	0.3	0.8		x		

Appendix 5a continued. Shape measurements of pebbles - sites 20, 22 and 26 - facet 8 - al.Jufin.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 20	1	5.9	4.1	3.1	0.7	0.6				x
	2	4.1	2.5	1.4	0.5	0.6			x	
	3	4.5	2.5	2.1	0.8	0.5				x
	4	6.3	4.6	3.0	0.6	0.7		x		
	5	3.8	3.0	1.8	0.6	0.7		x		
	6	4.5	1.9	0.9	0.4	0.4			x	
	7	3.6	2.3	1.6	0.6	0.6			x	
	8	2.9	2.7	1.6	0.5	0.9		x		
	9	3.2	2.8	2.4	0.8	0.8	x			
	10	3.1	2.1	2.0	0.9	0.6				x
	11	3.3	2.1	1.5	0.7	0.6				x
	12	2.9	1.8	1.3	0.7	0.6				x
	13	2.8	2.1	1.7	0.8	0.7	x			
	14	3.0	1.5	1.0	0.6	0.5			x	
	15	3.4	2.8	1.5	0.5	0.8		x		
	16	2.4	2.0	1.5	0.7	0.8	x			
	17	2.8	1.7	0.7	0.4	0.6			x	
	18	1.8	2.0	1.2	0.6	0.7		x		
	19	1.8	1.3	0.9	0.6	0.7		x		
	20	1.9	1.8	1.5	0.8	0.9	x			
	21	2.1	1.6	1.2	0.7	0.7	x			
	22	2.6	1.5	1.0	0.6	0.5			x	
	23	2.1	1.7	1.2	0.7	0.8	x			
	24	1.5	1.4	1.1	0.7	0.9	x			
	25	2.3	1.1	0.8	0.7	0.4				x
Site 22	1	4.1	3.6	2.6	0.7	0.8	x			
	2	4.8	4.1	3.5	0.8	0.8	x			
	3	4.5	3.9	2.5	0.6	0.8		x		
	4	3.9	2.4	1.9	0.7	0.6				x
	5	3.9	3.0	2.7	0.9	0.7	x			
	6	3.6	2.5	1.7	0.6	0.6			x	
	7	4.8	2.9	1.8	0.6	0.6			x	
	8	3.5	2.7	1.6	0.5	0.7		x		
	9	2.2	1.7	1.6	0.9	0.7	x			
	10	4.3	3.2	2.0	0.6	0.7		x		
	11	3.2	2.6	1.6	0.6	0.8		x		
	12	3.2	2.0	1.2	0.6	0.6			x	
	13	4.8	2.5	1.6	0.6	0.5			x	
	14	4.2	2.7	2.1	0.7	0.6				x
	15	3.1	2.5	1.3	0.5	0.8		x		
	16	2.7	2.1	1.5	0.7	0.7	x			
	17	4.5	3.1	1.6	0.5	0.6			x	
	18	3.3	1.8	1.2	0.6	0.5			x	
	19	2.9	1.8	1.7	0.9	0.6				x
	20	2.6	1.9	1.1	0.5	0.7		x		
	21	1.7	1.4	0.9	0.6	0.8		x		
	22	1.8	1.3	1.0	0.7	0.7	x			
	23	4.2	3.1	1.8	0.5	0.7		x		
	24	3.4	2.2	0.9	0.4	0.6			x	
	25	2.9	1.9	1.8	0.9	0.6				x

Site 26	1	3.8	2.6	2.4	0.9	0.6				x
	2	3.2	3.1	1.4	0.4	0.9		x		
	3	2.9	2.2	1.1	0.5	0.7		x		
	4	4.0	3.6	1.5	0.4	0.9		x		
	5	4.8	2.9	2.5	0.8	0.6				x
	6	3.9	1.4	1.2	0.8	0.3				x
	7	2.7	2.4	0.9	0.3	0.8		x		
	8	3.9	2.2	1.9	0.8	0.5				x
	9	2.6	1.4	0.7	0.5	0.5			x	
	10	1.7	1.5	1.3	0.8	0.8	x			
	11	3.1	2.3	1.4	0.6	0.7		x		
	12	3.6	1.8	1.5	0.8	0.5				x
	13	2.8	1.6	1.5	0.9	0.5				x
	14	3.4	3.1	2.2	0.7	0.9	x			
	15	3.2	1.8	1.0	0.5	0.5			x	
	16	3.1	2.7	1.7	0.6	0.8		x		
	17	3.7	2.5	1.6	0.6	0.6			x	
	18	5.9	3.3	2.7	0.8	0.5				x
	19	2.7	1.7	1.3	0.7	0.6				x
	20	3.6	2.2	1.8	0.8	0.6				x
	21	3.2	2.1	1.5	0.7	0.6				x
	22	2.9	1.8	1.4	0.7	0.6				x
	23	3.2	2.2	1.4	0.6	0.6			x	
	24	3.5	2.2	1.7	0.7	0.6				x
	25	2.6	1.9	1.4	0.7	0.7	x			

Appendix 5a continued. Shape measurements of pebbles - sites 19 and 27 - facet 9 - Safwan-south.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 19	1	8.5	5.1	3.2	0.6	0.6			x	
	2	7.1	4.1	2.4	0.5	0.5			x	
	3	4.3	2.5	1.7	0.6	0.5			x	
	4	4.7	2.5	1.2	0.4	0.5			x	
	5	3.8	3.0	2.3	0.7	0.7	x			
	6	3.1	2.6	2.1	0.8	0.8	x			
	7	3.9	2.7	1.9	0.7	0.6				x
	8	3.8	3.6	2.2	0.6	0.9		x		
	9	4.3	3.0	2.3	0.7	0.6				x
	10	4.1	2.2	1.2	0.5	0.5			x	
	11	2.8	2.6	2.1	0.8	0.9	x			
	12	3.8	1.9	1.4	0.7	0.5				x
	13	3.5	2.7	1.0	0.3	0.7		x		
	14	3.0	1.7	1.3	0.7	0.5				x
	15	4.0	2.2	1.6	0.7	0.5				x
	16	4.9	3.4	2.7	0.7	0.6				x
	17	3.4	2.7	1.9	0.7	0.7	x			
	18	4.1	2.5	1.3	0.5	0.6			x	
	19	3.2	2.1	1.4	0.6	0.6			x	
	20	2.6	1.8	1.4	0.7	0.6				x
	21	4.6	3.1	2.5	0.8	0.6				x
	22	3.8	2.5	1.4	0.5	0.6			x	
	23	3.5	2.0	0.7	0.3	0.5			x	
	24	4.2	2.6	2.1	0.8	0.6				x
	25	2.3	1.9	1.2	0.6	0.8		x		
Site 27	1	4.4	2.7	1.8	0.6	0.6			x	
	2	3.7	2.5	1.5	0.6	0.6			x	
	3	3.7	2.7	2.1	0.7	0.7	x			
	4	4.0	2.4	2.0	0.9	0.6				x
	5	4.6	2.1	1.2	0.5	0.5			x	
	6	4.9	2.3	1.6	0.6	0.4			x	
	7	2.1	1.1	0.9	0.8	0.5				x
	8	2.0	1.5	1.0	0.6	0.7		x		
	9	3.5	2.7	0.8	0.2	0.7		x		
	10	2.3	1.4	1.2	0.8	0.6				x
	11	2.6	1.7	1.2	0.7	0.6				x
	12	2.6	1.5	1.0	0.6	0.5			x	
	13	2.0	1.7	1.6	0.9	0.8	x			
	14	2.2	2.0	1.1	0.5	0.9		x		
	15	2.3	1.8	0.9	0.5	0.7		x		
	16	4.3	2.9	1.5	0.5	0.6			x	
	17	2.2	1.5	1.1	0.7	0.6				x
	18	4.1	2.0	1.6	0.8	0.4				x
	19	3.5	1.8	1.1	0.6	0.5			x	
	20	2.5	1.5	1.3	0.8	0.6				x
	21	2.6	1.9	0.8	0.4	0.7		x		
	22	2.2	1.8	1.2	0.6	0.8		x		
	23	2.9	2.0	1.4	0.7	0.6				x
	24	1.9	1.7	0.7	0.4	0.8		x		
	25	1.7	1.1	0.8	0.7	0.6				x

Appendix 5a continued. Shape measurements of pebbles - sites 33 and 34 - facet 11 - top of the plateau.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 33	1	6.0	3.7	3.5	0.9	0.6				x
	2	6.5	4.3	3.2	0.7	0.6				x
	3	5.9	3.7	3.6	0.9	0.6				x
	4	5.5	4.7	3.0	0.6	0.8		x		
	5	4.0	3.7	3.1	0.8	0.9	x			
	6	5.4	3.0	2.0	0.6	0.5			x	
	7	3.6	3.2	2.3	0.7	0.8	x			
	8	4.6	2.9	2.1	0.7	0.5				x
	9	3.5	2.8	1.9	0.6	0.8		x		
	10	3.5	3.2	2.8	0.8	0.9	x			
	11	4.0	2.5	1.5	0.6	0.6			x	
	12	5.7	2.8	2.2	0.7	0.4				x
	13	3.4	3.1	1.6	0.5	0.9		x		
	14	5.1	2.5	2.4	0.9	0.4				x
	15	5.0	4.1	3.1	0.7	0.8	x			
	16	4.3	3.1	2.4	0.7	0.7	x			
	17	3.1	2.2	1.7	0.7	0.7	x			
	18	3.6	2.1	1.5	0.7	0.5				x
	19	3.6	2.4	1.3	0.5	0.6			x	
	20	3.7	1.9	1.5	0.7	0.5				x
	21	2.6	2.0	1.2	0.6	0.7		x		
	22	3.1	2.2	1.7	0.7	0.7	x			
	23	4.1	2.7	2.0	0.7	0.6				x
	24	2.6	1.6	1.0	0.6	0.6			x	
	25	1.9	1.5	1.1	0.7	0.7	x			
Site 34	1	4.2	3.6	2.1	0.5	0.8		x		
	2	4.8	3.6	2.5	0.6	0.7		x		
	3	3.2	2.7	1.7	0.6	0.8		x		
	4	4.5	2.8	2.4	0.8	0.6				x
	5	3.5	2.4	1.7	0.7	0.6				x
	6	4.9	3.6	1.3	0.3	0.7		x		
	7	4.2	1.5	1.4	0.9	0.3				x
	8	3.1	1.9	1.6	0.8	0.6				x
	9	2.5	1.9	1.5	0.7	0.7	x			
	10	4.5	3.4	1.6	0.4	0.7		x		
	11	3.1	2.2	1.5	0.6	0.7		x		
	12	3.0	2.6	2.5	0.9	0.8	x			
	13	6.7	3.0	2.4	0.8	0.4				x
	14	3.6	2.0	0.9	0.4	0.5			x	
	15	2.7	2.2	1.8	0.8	0.8	x			
	16	4.5	3.2	2.2	0.6	0.7		x		
	17	2.5	2.4	1.6	0.6	0.9		x		
	18	5.1	3.0	2.0	0.6	0.5			x	
	19	3.6	3.1	1.8	0.5	0.8		x		
	20	3.1	2.2	1.5	0.6	0.7		x		
	21	3.5	2.8	1.3	0.4	0.8		x		
	22	4.0	3.0	2.1	0.7	0.7	x			
	23	3.5	2.5	0.9	0.3	0.7		x		
	24	3.3	2.7	1.3	0.4	0.8		x		
	25	3.6	1.8	1.3	0.7	0.6				x

Appendix 5a continued. Shape measurements of pebbles - sites 35, 36 and 37 - facet 11 - top of the plateau.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 35	1	4.8	4.6	1.4	0.3	0.9		x		
	2	4.6	3.5	1.7	0.4	0.7		x		
	3	3.2	1.7	0.7	0.4	0.5			x	
	4	3.0	2.2	0.5	0.2	0.7		x		
	5	2.9	2.2	1.4	0.6	0.7		x		
	6	2.1	1.6	1.2	0.7	0.7	x			
	7	2.9	2.5	1.2	0.4	0.8		x		
	8	3.1	2.3	1.8	0.7	0.7	x			
	9	2.8	2.4	1.4	0.5	0.8		x		
	10	2.4	1.8	1.2	0.6	0.7		x		
	11	5.0	3.9	1.4	0.3	0.7		x		
	12	3.5	2.7	1.1	0.4	0.7		x		
	13	3.1	2.2	2.0	0.9	0.7	x			
	14	3.5	2.2	1.0	0.4	0.6			x	
	15	2.7	2.1	1.7	0.8	0.7	x			
	16	3.6	2.0	1.4	0.7	0.5				x
	17	4.9	3.8	2.5	0.6	0.7		x		
	18	3.9	3.2	2.0	0.6	0.8		x		
	19	2.7	1.8	1.2	0.6	0.6			x	
	20	3.1	2.7	1.5	0.5	0.8		x		
	21	3.7	2.8	2.0	0.3	0.7		x		
	22	4.0	2.5	1.1	0.4	0.6			x	
	23	4.9	2.7	1.7	0.6	0.5			x	
	24	2.4	1.8	1.5	0.8	0.7	x			
	25	3.9	2.4	2.2	0.9	0.6				x
Site 36	1	5.0	2.7	2.5	0.9	0.5				x
	2	5.3	4.6	1.3	0.2	0.8		x		
	3	2.1	1.6	1.5	0.9	0.7	x			
	4	2.4	1.7	1.5	0.8	0.7	x			
	5	4.3	3.5	2.5	0.7	0.8	x			
	6	2.5	1.7	1.1	0.6	0.6			x	
	7	2.5	2.0	1.3	0.6	0.8		x		
	8	4.1	2.0	0.9	0.4	0.4			x	
	9	3.2	2.9	1.8	0.6	0.9		x		
	10	2.7	2.3	1.0	0.4	0.8		x		
	11	2.4	2.0	1.0	0.5	0.8		x		
	12	5.7	3.4	1.0	0.2	0.5		x		
	13	3.2	1.6	0.9	0.5	0.5			x	
	14	5.5	3.0	1.4	0.4	0.5			x	
	15	3.3	2.8	1.8	0.6	0.8		x		
	16	3.2	1.8	1.1	0.6	0.5			x	
	17	2.5	2.2	1.6	0.7	0.8	x			
	18	2.5	2.2	1.8	0.8	0.8	x			
	19	3.7	2.8	1.6	0.5	0.7		x		
	20	2.9	1.9	1.3	0.6	0.7		x		
	21	2.5	1.9	1.4	0.7	0.7	x			
	22	2.8	1.9	1.0	0.5	0.6			x	
	23	2.5	2.0	1.6	0.8	0.8	x			
	24	2.4	1.6	1.4	0.8	0.6				x
	25	2.0	1.8	1.2	0.6	0.9		x		

Site	1	2.9	2.0	1.6	0.8	0.6				x
37	2	3.3	2.3	1.7	0.7	0.6				x
	3	3.1	2.2	2.0	0.9	0.7	x			
	4	3.1	2.2	1.4	0.6	0.7		x		
	5	3.9	2.6	2.4	0.9	0.6				x
	6	3.1	2.7	1.6	0.5	0.8		x		
	7	3.9	2.8	2.2	0.7	0.7	x			
	8	4.5	2.9	2.0	0.6	0.6			x	
	9	4.1	3.1	1.4	0.4	0.7		x		
	10	4.2	3.3	1.9	0.5	0.7		x		
	11	2.5	2.1	1.7	0.8	0.8	x			
	12	2.0	1.9	1.8	0.9	0.9	x			
	13	4.1	1.3	0.9	0.6	0.3			x	
	14	3.1	2.0	1.8	0.9	0.6				x
	15	3.7	2.8	1.3	0.4	0.7		x		
	16	2.7	2.1	1.2	0.5	0.7		x		
	17	4.1	2.9	1.9	0.6	0.7		x		
	18	5.0	4.0	2.7	0.6	0.8		x		
	19	3.0	2.8	1.4	0.5	0.9		x		
	20	2.7	2.0	1.3	0.6	0.7		x		
	21	3.9	2.9	2.3	0.7	0.7	x			
	22	2.5	2.4	1.5	0.6	0.9		x		
	23	4.2	2.6	1.3	0.5	0.6			x	
	24	2.7	2.2	1.7	0.7	0.8	x			
	25	3.7	2.6	1.5	0.5	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - sites 28 and 29 - facet 11 - base of the plateau.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 28	1	7.8	4.8	3.1	0.6	0.6			x	
	2	8.4	6.5	3.5	0.5	0.7		x		
	3	6.9	4.5	3.9	0.8	0.6				x
	4	6.0	5.2	2.5	0.4	0.8		x		
	5	5.6	3.5	2.4	0.6	0.6			x	
	6	5.9	3.2	1.7	0.5	0.5			x	
	7	4.4	4.2	2.8	0.6	0.9		x		
	8	5.1	2.1	1.7	0.8	0.4				x
	9	3.9	3.5	2.5	0.7	0.7	x			
	10	2.9	2.6	1.8	0.6	0.8		x		
	11	3.5	2.9	1.4	0.4	0.8		x		
	12	3.4	2.7	2.0	0.7	0.7	x			
	13	3.6	2.4	1.5	0.6	0.6			x	
	14	3.2	2.8	1.7	0.6	0.8		x		
	15	2.0	1.6	1.2	0.7	0.8	x			
	16	3.2	2.1	0.7	0.3	0.6			x	
	17	3.4	1.9	1.4	0.7	0.5				x
	18	3.4	3.0	2.0	0.6	0.8		x		
	19	2.8	2.2	1.4	0.6	0.7		x		
	20	2.4	2.0	1.2	0.6	0.8		x		
	21	2.2	1.8	1.2	0.6	0.8		x		
	22	2.2	1.5	1.2	0.8	0.6				x
	23	2.5	1.6	0.7	0.4	0.6			x	
	24	3.5	3.0	1.5	0.5	0.8		x		
	25	3.2	2.4	1.2	0.5	0.7		x		
Site 29	1	4.1	2.2	1.6	0.7	0.5				x
	2	5.4	4.3	2.5	0.5	0.7		x		
	3	3.8	2.8	1.4	0.5	0.7		x		
	4	5.4	3.8	3.5	0.9	0.7	x			
	5	3.1	2.4	1.5	0.6	0.7		x		
	6	3.9	3.0	2.2	0.7	0.7	x			
	7	4.5	3.4	2.4	0.7	0.7	x			
	8	7.0	3.5	2.3	0.6	0.5			x	
	9	4.8	3.1	2.0	0.6	0.6			x	
	10	4.3	2.5	2.1	0.8	0.5				x
	11	4.1	4.0	2.3	0.5	0.9		x		
	12	4.7	3.3	1.7	0.5	0.7		x		
	13	4.4	3.2	1.0	0.3	0.7		x		
	14	2.7	2.2	1.9	0.8	0.8	x			
	15	2.9	2.4	1.7	0.7	0.8	x			
	16	2.1	1.5	1.3	0.8	0.7	x			
	17	3.0	1.6	0.8	0.5	0.5			x	
	18	3.5	1.9	1.0	0.5	0.5			x	
	19	2.7	1.7	1.4	0.8	0.6				x
	20	3.7	2.6	1.0	0.3	0.7		x		
	21	4.4	3.9	1.7	0.4	0.8		x		
	22	4.0	1.5	1.0	0.6	0.3			x	
	23	2.8	1.6	1.2	0.7	0.5				x
	24	2.5	1.2	1.0	0.8	0.4				x
	25	2.2	1.3	1.0	0.7	0.5				x

Appendix 5a continued. Shape measurements of pebbles - sites 30, 31 and 32 - facet 11 - base of the plateau.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 30	1	3.4	2.9	2.0	0.6	0.8		x		
	2	2.2	1.3	0.9	0.6	0.5			x	
	3	3.8	3.0	2.4	0.8	0.7	x			
	4	3.4	2.0	0.5	0.2	0.5			x	
	5	3.5	2.1	1.4	0.6	0.6			x	
	6	4.6	3.0	1.7	0.5	0.6			x	
	7	2.8	2.1	1.1	0.4	0.7		x		
	8	3.4	3.2	1.2	0.3	0.9		x		
	9	3.6	2.8	1.4	0.5	0.7		x		
	10	2.9	2.2	1.6	0.7	0.7	x			
	11	3.4	2.7	1.8	0.6	0.7		x		
	12	2.4	1.8	1.2	0.6	0.7		x		
	13	2.5	1.7	0.6	0.3	0.6			x	
	14	3.4	2.5	1.7	0.6	0.7		x		
	15	2.6	2.0	1.5	0.7	0.7	x			
	16	3.2	2.7	1.8	0.6	0.8		x		
	17	2.8	2.1	1.4	0.6	0.7		x		
	18	2.6	1.6	1.3	0.8	0.6				x
	19	2.2	1.8	1.2	0.6	0.8		x		
	20	3.8	2.6	2.0	0.3	0.2			x	
	21	3.4	2.7	1.9	0.7	0.7	x			
	22	2.7	2.0	1.4	0.7	0.7	x			
	23	2.8	1.8	1.6	0.8	0.6				x
	24	3.1	2.2	1.8	0.8	0.7	x			
	25	3.5	2.6	0.9	0.3	0.7		x		
Site 31	1	2.5	1.7	1.4	0.8	0.6				x
	2	3.6	2.1	1.4	0.6	0.5			x	
	3	2.9	2.3	1.5	0.6	0.7		x		
	4	4.9	3.7	1.2	0.3	0.7		x		
	5	2.0	1.7	1.3	0.7	0.8	x			
	6	2.8	2.5	2.0	0.8	0.8	x			
	7	2.3	2.0	1.4	0.7	0.8	x			
	8	3.0	2.1	1.4	0.6	0.7		x		
	9	2.8	1.6	1.3	0.8	0.5				x
	10	1.8	1.4	1.0	0.7	0.7	x			
	11	3.8	2.5	1.9	0.7	0.6				x
	12	3.0	2.0	1.5	0.7	0.6				x
	13	2.6	2.4	1.4	0.5	0.9		x		
	14	2.3	1.8	1.4	0.7	0.7	x			
	15	2.2	1.4	0.9	0.6	0.6			x	
	16	3.0	2.1	1.0	0.4	0.7		x		
	17	3.2	2.7	1.5	0.5	0.8		x		
	18	2.8	1.8	1.2	0.6	0.6			x	
	19	1.8	1.7	1.2	0.7	0.9	x			
	20	2.0	1.9	1.1	0.5	0.9		x		
	21	2.5	1.8	1.6	0.8	0.7	x			
	22	2.0	1.4	1.2	0.8	0.7	x			
	23	3.1	2.1	1.6	0.7	0.6				x
	24	2.7	2.1	1.4	0.6	0.7		x		
	25	2.4	2.1	1.1	0.5	0.8		x		

Site 32	1	2.1	1.9	1.4	0.7	0.9	x			
	2	3.0	2.2	1.7	0.7	0.7	x			
	3	3.5	2.2	1.4	0.6	0.6			x	
	4	3.3	2.6	2.1	0.8	0.7	x			
	5	2.9	2.3	1.1	0.4	0.7		x		
	6	3.3	2.7	0.6	0.2	0.8		x		
	7	3.2	2.4	1.4	0.5	0.7		x		
	8	2.6	1.6	1.2	0.7	0.6				x
	9	3.1	2.6	1.9	0.7	0.8	x			
	10	2.6	2.0	1.8	0.9	0.7	x			
	11	4.1	2.8	1.7	0.6	0.6			x	
	12	3.8	1.7	1.0	0.5	0.4			x	
	13	5.3	2.8	2.2	0.7	0.5				x
	14	3.2	2.5	0.8	0.3	0.7		x		
	15	3.8	2.4	1.8	0.7	0.6				x
	16	3.9	2.7	1.6	0.5	0.6			x	
	17	3.0	2.3	1.7	0.7	0.7	x			
	18	5.2	3.4	2.0	0.5	0.6			x	
	19	4.6	1.7	0.9	0.5	0.3			x	
	20	3.2	2.5	1.1	0.4	0.7		x		
	21	4.6	3.0	1.4	0.4	0.6			x	
	22	4.0	2.6	1.6	0.6	0.6			x	
	23	2.3	2.0	0.8	0.4	0.8		x		
	24	2.8	1.4	1.1	0.7	0.5				x
	25	2.2	2.0	1.5	0.7	0.9	x			

Appendix 5a continued. Shape measurements of pebbles - sites 40 and 41 - facet 12 - gully slope element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 40	1	4.1	3.3	3.1	0.9	0.8				x
	2	4.3	3.5	2.4	0.6	0.8		x		
	3	3.2	2.5	1.6	0.6	0.7		x		
	4	4.7	2.8	2.6	0.9	0.5				x
	5	2.7	2.5	1.3	0.5	0.9		x		
	6	3.5	2.7	1.6	0.5	0.7		x		
	7	3.5	2.4	1.4	0.5	0.6			x	
	8	3.7	3.1	1.0	0.3	0.8		x		
	9	4.1	2.5	1.6	0.6	0.6			x	
	10	3.0	2.9	1.0	0.3	0.9		x		
	11	2.1	1.7	1.5	0.8	0.8	x			
	12	2.1	1.8	1.4	0.7	0.8	x			
	13	2.6	2.0	1.7	0.8	0.7	x			
	14	2.8	2.5	0.7	0.2	0.8		x		
	15	2.7	2.1	0.8	0.3	0.7		x		
	16	2.1	1.7	1.2	0.7	0.8	x			
	17	2.5	2.0	0.5	0.2	0.8		x		
	18	2.7	1.6	1.4	0.8	0.5				x
	19	2.7	2.4	1.2	0.5	0.8		x		
	20	2.9	1.5	0.6	0.4	0.5			x	
	21	3.5	2.5	1.5	0.6	0.7			x	
	22	2.8	1.6	1.1	0.6	0.5			x	
	23	2.1	1.7	1.4	0.8	0.8	x			
	24	2.0	1.6	1.2	0.7	0.8	x			
	25	2.9	2.1	1.0	0.4	0.7		x		
Site 41	1	3.0	2.4	1.8	0.7	0.8	x			
	2	6.2	2.7	2.0	0.7	0.4				x
	3	6.5	2.4	1.9	0.7	0.3				x
	4	6.1	2.1	1.6	0.7	0.3				x
	5	3.8	3.0	1.1	0.3	0.7		x		
	6	3.7	3.2	1.8	0.5	0.8		x		
	7	4.5	3.4	1.1	0.3	0.7		x		
	8	3.2	2.5	1.7	0.6	0.7		x		
	9	4.4	3.0	1.0	0.3	0.6			x	
	10	3.5	2.4	1.6	0.6	0.6			x	
	11	5.8	2.2	1.5	0.6	0.3			x	
	12	3.4	1.8	1.2	0.6	0.5			x	
	13	2.2	1.3	1.1	0.8	0.5				x
	14	3.0	2.0	1.8	0.9	0.6				x
	15	4.3	3.1	1.5	0.4	0.7		x		
	16	3.5	3.0	1.9	0.6	0.8		x		
	17	3.7	2.9	1.0	0.3	0.7		x		
	18	2.8	2.1	0.9	0.4	0.7		x		
	19	2.7	1.7	1.6	0.9	0.6				x
	20	3.3	2.7	1.7	0.6	0.8		x		
	21	5.7	3.4	1.4	0.4	0.5			x	
	22	3.5	2.1	1.5	0.7	0.6				x
	23	2.9	2.2	1.1	0.5	0.7		x		
	24	3.8	3.2	1.8	0.5	0.8		x		
	25	2.5	2.2	1.3	0.5	0.8		x		

Appendix 5a continued. Shape measurements of pebbles - sites 38 and 39 - facet 12 - gully floor element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 38	1	5.0	4.5	2.3	0.5	0.9		x		
	2	6.1	3.6	2.1	0.5	0.5		x		
	3	4.0	3.6	2.6	0.7	0.9	x			
	4	3.9	2.6	1.5	0.5	0.6			x	
	5	3.3	2.2	2.1	0.9	0.6				x
	6	4.8	3.5	1.2	0.3	0.7		x		
	7	4.3	2.6	2.0	0.7	0.6				x
	8	4.1	2.9	2.5	0.8	0.7	x			
	9	6.0	3.5	2.3	0.6	0.5			x	
	10	6.6	2.4	2.2	0.9	0.3				x
	11	4.1	3.3	1.5	0.4	0.8		x		
	12	3.0	2.7	1.7	0.6	0.9		x		
	13	7.4	4.3	2.3	0.5	0.5			x	
	14	4.0	3.1	2.1	0.6	0.7		x		
	15	4.1	3.0	1.4	0.4	0.7		x		
	16	3.2	2.6	1.7	0.6	0.8		x		
	17	3.0	1.8	0.9	0.5	0.6			x	
	18	2.8	1.8	0.8	0.4	0.6			x	
	19	5.2	3.8	3.3	0.8	0.7	x			
	20	2.5	2.4	1.7	0.7	0.9	x			
	21	2.9	2.2	1.3	0.5	0.7		x		
	22	4.0	2.6	1.3	0.5	0.6			x	
	23	2.6	2.1	1.6	0.7	0.8	x			
	24	3.1	2.4	1.7	0.7	0.7	x			
	25	2.4	1.5	1.3	0.8	0.6				x
Site 39	1	7.4	6.7	4.9	0.7	0.9	x			
	2	4.8	4.0	3.1	0.7	0.8	x			
	3	4.1	3.8	2.4	0.6	0.9		x		
	4	6.4	5.3	3.6	0.6	0.8		x		
	5	4.4	3.4	2.4	0.7	0.7	x			
	6	4.7	2.5	0.8	0.3	0.5			x	
	7	3.4	2.9	2.2	0.7	0.8	x			
	8	2.8	2.5	1.5	0.6	0.8		x		
	9	4.3	2.3	1.2	0.5	0.5			x	
	10	6.3	4.7	4.3	0.9	0.7	x			
	11	3.9	2.9	2.7	0.9	0.7	x			
	12	2.3	2.0	1.9	0.9	0.8	x			
	13	3.7	2.7	2.0	0.7	0.7	x			
	14	3.5	2.5	1.7	0.6	0.7		x		
	15	5.0	2.4	1.7	0.7	0.4				x
	16	5.5	4.2	3.3	0.7	0.7	x			
	17	2.6	2.1	1.0	0.4	0.8		x		
	18	5.3	2.7	1.1	0.4	0.5			x	
	19	4.3	3.2	1.7	0.5	0.7		x		
	20	3.0	1.4	1.1	0.7	0.4				x
	21	4.7	2.3	1.1	0.4	0.4			x	
	22	3.7	1.4	0.9	0.6	0.3			x	
	23	2.7	1.9	1.1	0.5	0.7		x		
	24	4.1	2.5	1.8	0.7	0.6				x
	25	2.8	2.2	1.4	0.6	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - sites 50, 51, 52 and 53 - facet 13 - wadi slope element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 50	1	4.6	3.6	2.7	0.7	0.7	x			
	2	1.9	1.7	1.5	0.8	0.8	x			
	3	3.0	2.2	2.0	0.9	0.7	x			
	4	2.6	1.9	1.3	0.6	0.7		x		
	5	4.0	3.1	1.5	0.4	0.7		x		
	6	3.9	3.2	1.9	0.5	0.8		x		
	7	3.2	3.0	1.7	0.5	0.9		x		
	8	3.4	2.3	1.3	0.5	0.6			x	
	9	2.6	1.8	1.4	0.7	0.6				x
	10	4.9	3.9	2.4	0.6	0.7		x		
	11	2.9	1.9	1.0	0.5	0.6			x	
	12	3.6	3.3	2.2	0.6	0.9		x		
	13	3.8	2.4	0.7	0.2	0.6			x	
	14	3.1	1.4	0.9	0.6	0.4			x	
	15	2.5	1.9	1.2	0.5	0.7		x		
	16	2.2	1.8	1.0	0.5	0.8		x		
	17	1.8	1.4	1.0	0.7	0.7	x			
	18	2.0	1.7	1.5	0.8	0.8	x			
	19	3.9	2.9	1.6	0.5	0.7		x		
	20	3.0	2.0	1.0	0.5	0.6			x	
	21	5.3	2.3	2.0	0.8	0.4				x
	22	1.7	1.5	0.9	0.6	0.8		x		
	23	2.5	2.1	1.7	0.8	0.8	x			
	24	2.5	2.1	1.4	0.6	0.8		x		
	25	1.9	1.6	1.0	0.6	0.8		x		
Site 51	1	8.5	4.1	2.8	0.6	0.4			x	
	2	4.8	3.2	2.1	0.6	0.6			x	
	3	5.9	3.8	1.9	0.5	0.6			x	
	4	3.7	3.0	1.7	0.5	0.8		x		
	5	2.6	1.8	1.4	0.7	0.6				x
	6	5.5	3.7	2.9	0.7	0.6				x
	7	3.8	2.3	1.0	0.4	0.6			x	
	8	3.3	2.4	1.8	0.7	0.7	x			
	9	4.0	3.0	2.3	0.7	0.7	x			
	10	4.4	2.5	1.6	0.4	0.5			x	
	11	5.3	4.1	1.1	0.2	0.7		x		
	12	3.5	2.4	1.6	0.6	0.6			x	
	13	2.8	2.5	1.0	0.4	0.8		x		
	14	2.6	2.3	1.5	0.6	0.8		x		
	15	3.9	2.9	1.1	0.3	0.7		x		
	16	3.8	2.7	1.1	0.4	0.7		x		
	17	2.6	2.4	1.2	0.5	0.9		x		
	18	4.1	3.1	2.0	0.6	0.7		x		
	19	3.7	2.5	2.2	0.8	0.6				x
	20	3.5	2.2	1.5	0.6	0.6			x	
	21	2.3	2.0	1.5	0.7	0.8	x			
	22	2.4	2.0	1.7	0.8	0.8	x			
	23	4.3	3.8	2.0	0.5	0.8		x		
	24	3.6	2.9	2.3	0.7	0.8	x			
	25	2.9	1.6	1.0	0.6	0.5			x	

Site 52	1	5.0	2.6	2.4	0.9	0.5				x
	2	3.5	2.3	1.3	0.5	0.6			x	
	3	2.5	2.2	1.5	0.6	0.8		x		
	4	3.1	2.9	1.2	0.4	0.9		x		
	5	3.3	3.0	2.0	0.6	0.9		x		
	6	3.3	2.5	1.6	0.6	0.7		x		
	7	3.3	2.3	1.2	0.5	0.6			x	
	8	3.5	3.0	2.0	0.6	0.8		x		
	9	2.7	2.4	1.7	0.7	0.8	x			
	10	2.5	1.7	0.9	0.5	0.6			x	
	11	3.1	2.2	1.2	0.5	0.7		x		
	12	3.0	1.8	0.9	0.5	0.6		x		
	13	2.2	1.3	1.2	0.9	0.5				x
	14	2.8	2.0	1.5	0.7	0.7	x			
	15	2.5	2.2	0.8	0.3	0.8		x		
	16	3.0	1.8	0.7	0.3	0.6			x	
	17	2.5	1.7	1.3	0.7	0.6				x
	18	2.3	2.2	1.3	0.5	0.9		x		
	19	2.4	1.8	1.1	0.6	0.7		x		
	20	2.2	1.7	1.5	0.8	0.7	x			
	21	1.7	1.5	1.0	0.6	0.8		x		
	22	1.7	1.4	1.1	0.7	0.8	x			
	23	1.9	1.3	1.0	0.7	0.6				x
	24	2.0	1.7	1.0	0.5	0.8		x		
	25	2.2	1.8	0.8	0.4	0.8		x		
Site 53	1	7.6	7.4	3.4	0.4	0.9		x		
	2	4.0	3.2	2.6	0.8	0.8	x			
	3	4.0	2.5	1.0	0.4	0.6			x	
	4	7.0	5.6	4.7	0.8	0.8	x			
	5	4.6	2.8	1.5	0.5	0.6			x	
	6	3.1	2.2	1.1	0.5	0.7		x		
	7	4.8	3.5	1.8	0.5	0.7		x		
	8	5.2	4.4	2.9	0.6	0.8		x		
	9	6.6	4.5	2.8	0.6	0.6			x	
	10	4.0	2.4	1.8	0.7	0.6				x
	11	4.1	3.5	2.2	0.6	0.8		x		
	12	3.7	2.1	1.8	0.8	0.5				x
	13	3.7	2.8	1.3	0.4	0.7		x		
	14	2.9	2.2	1.0	0.4	0.7		x		
	15	4.4	2.8	1.9	0.6	0.6			x	
	16	3.2	2.4	0.6	0.2	0.7		x		
	17	6.3	4.1	3.0	0.7	0.6				x
	18	2.9	2.4	1.7	0.7	0.8	x			
	19	3.2	2.5	1.5	0.6	0.7		x		
	20	3.0	1.7	0.7	0.4	0.5		x		
	21	2.8	2.1	1.3	0.6	0.7		x		
	22	2.8	1.7	1.5	0.8	0.6				x
	23	4.0	2.5	1.5	0.6	0.6			x	
	24	3.5	2.6	2.4	0.9	0.7	x			
	25	4.1	2.5	2.4	0.9	0.6				x

Appendix 5a continued. Shape measurements of pebbles - sites 54, 55, 56 and 57 - facet 13 - wadi slope element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 54	1	4.0	2.8	1.8	0.6	0.7		x		
	2	3.4	2.2	1.9	0.8	0.6				x
	3	4.2	2.7	1.8	0.6	0.6			x	
	4	4.6	2.8	2.4	0.8	0.6				x
	5	3.5	2.4	0.8	0.3	0.6			x	
	6	3.6	3.1	1.9	0.6	0.8		x		
	7	3.5	2.7	2.1	0.7	0.7	x			
	8	3.5	2.3	1.8	0.7	0.6				x
	9	2.5	2.1	1.7	0.8	0.8	x			
	10	4.1	2.2	1.7	0.7	0.5				x
	11	3.1	1.6	1.4	0.8	0.5				x
	12	3.1	2.3	1.7	0.7	0.7	x			
	13	2.9	2.4	1.6	0.6	0.8		x		
	14	2.5	2.0	1.5	0.7	0.8	x			
	15	3.0	2.1	1.4	0.6	0.7		x		
	16	3.8	2.3	1.9	0.8	0.2				x
	17	2.9	2.1	1.8	0.8	0.7	x			
	18	2.6	1.8	1.2	0.6	0.6			x	
	19	2.7	2.0	1.3	0.6	0.7		x		
	20	3.0	1.6	1.4	0.8	0.5				x
	21	2.8	1.7	0.9	0.5	0.6			x	
	22	3.2	2.0	1.1	0.5	0.6			x	
	23	2.5	2.2	1.8	0.8	0.8	x			
	24	2.6	1.9	1.1	0.5	0.7		x		
	25	2.1	1.4	1.2	0.8	0.6				x
Site 55	1	4.5	3.3	1.0	0.3	0.7		x		
	2	3.5	2.0	1.3	0.6	0.5			x	
	3	4.2	2.1	1.8	0.8	0.5				x
	4	3.3	1.8	1.3	0.7	0.5				x
	5	3.2	2.4	2.2	0.9	0.7	x			
	6	3.5	2.4	1.3	0.5	0.6			x	
	7	3.2	1.9	1.7	0.8	0.5				x
	8	3.7	1.5	1.2	0.8	0.4				x
	9	3.9	2.5	2.0	0.8	0.6				x
	10	3.0	2.1	1.6	0.7	0.7	x			
	11	4.1	2.7	1.4	0.5	0.6			x	
	12	3.4	2.5	1.6	0.6	0.7		x		
	13	2.2	1.4	1.0	0.7	0.6				x
	14	2.9	1.6	1.4	0.8	0.5				x
	15	4.0	2.0	1.7	0.8	0.5				x
	16	3.8	2.8	1.7	0.6	0.7		x		
	17	2.6	1.5	1.0	0.6	0.5			x	
	18	2.7	1.7	1.1	0.6	0.6			x	
	19	2.1	2.0	1.5	0.7	0.9	x			
	20	3.3	1.6	1.1	0.6	0.4			x	
	21	2.8	1.9	0.9	0.4	0.6			x	
	22	1.7	1.4	1.1	0.7	0.5				x
	23	1.7	1.5	1.2	0.8	0.8	x			
	24	1.8	1.6	0.8	0.5	0.8		x		
	25	2.9	2.0	0.8	0.4	0.6			x	

Site 56	1	4.3	3.1	2.2	0.7	0.7	x			
	2	3.1	2.8	1.8	0.6	0.9		x		
	3	2.6	1.9	1.8	0.9	0.7	x			
	4	2.7	2.3	0.9	0.3	0.8		x		
	5	3.3	2.0	1.9	0.9	0.6				x
	6	3.0	2.5	1.8	0.7	0.8	x			
	7	3.4	1.9	1.5	0.7	0.5				x
	8	2.9	2.5	1.6	0.6	0.8		x		
	9	2.0	1.5	0.8	0.5	0.7		x		
	10	3.2	2.4	1.3	0.5	0.7		x		
	11	4.0	1.9	1.5	0.7	0.4				x
	12	3.6	2.3	1.6	0.6	0.6			x	
	13	3.1	2.6	1.9	0.7	0.8	x			
	14	2.2	2.0	1.0	0.5	0.9		x		
	15	2.1	1.5	1.1	0.7	0.7	x			
	16	3.2	2.5	1.1	0.4	0.7		x		
	17	2.4	1.7	1.2	0.7	0.7	x			
	18	2.0	1.8	0.6	0.3	0.5			x	
	19	2.8	1.8	1.0	0.5	0.6			x	
	20	2.1	2.0	1.4	0.7	0.9	x			
	21	3.2	2.2	1.2	0.5	0.6			x	
	22	1.9	1.5	1.3	0.8	0.7	x			
	23	3.0	2.4	0.4	0.1	0.8	x			
	24	3.6	2.2	1.3	0.5	0.6			x	
	25	2.9	2.2	1.0	0.4	0.7		x		
Site 57	1	2.3	1.7	0.8	0.4	0.7		x		
	2	3.4	2.8	1.6	0.5	0.8		x		
	3	1.7	1.5	1.3	0.8	0.8	x			
	4	3.4	2.3	1.6	0.6	0.6			x	
	5	4.1	2.1	0.6	0.2	0.5			x	
	6	2.8	1.4	0.6	0.4	0.5			x	
	7	2.1	1.6	0.8	0.5	0.7		x		
	8	2.9	1.6	1.3	0.8	0.5				x
	9	3.0	2.1	0.8	0.3	0.7		x		
	10	2.3	1.5	1.3	0.8	0.6				x
	11	3.5	1.6	1.4	0.8	0.4				x
	12	3.8	2.8	1.6	0.5	0.7		x		
	13	4.0	3.3	1.4	0.4	0.8		x		
	14	3.1	2.1	1.0	0.4	0.6			x	
	15	2.6	1.7	1.5	0.8	0.6				x
	16	1.7	1.4	1.1	0.7	0.8	x			
	17	2.9	2.3	0.9	0.3	0.7		x		
	18	1.9	1.6	1.3	0.8	0.8	x			
	19	2.2	1.6	0.9	0.5	0.7		x		
	20	2.6	1.6	1.3	0.8	0.6				x
	21	3.3	2.6	1.3	0.5	0.7		x		
	22	4.6	2.3	1.3	0.5	0.5			x	
	23	3.5	2.0	1.7	0.8	0.5				x
	24	2.8	1.9	1.4	0.7	0.6				x
	25	3.6	2.0	1.4	0.7	0.5				x

Appendix 5a continued. Shape measurements of pebbles - sites 58 and 59 - facet 13 - wadi slope element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 58	1	3.1	1.6	1.2	0.7	0.5				x
	2	3.6	1.9	1.7	0.8	0.5				x
	3	3.8	2.6	2.2	0.8	0.6				x
	4	4.8	1.9	1.7	0.8	0.3				x
	5	3.5	2.1	1.2	0.5	0.6			x	
	6	3.6	2.5	1.3	0.5	0.6			x	
	7	3.5	2.9	2.0	0.6	0.8		x		
	8	3.9	2.7	1.5	0.5	0.8		x		
	9	4.6	3.2	2.7	0.8	0.6				x
	10	3.3	2.2	2.1	0.9	0.6				x
	11	3.0	2.6	2.0	0.7	0.8	x			
	12	2.4	1.7	0.9	0.5	0.7		x		
	13	4.2	2.7	2.5	0.9	0.4				x
	14	3.2	2.3	1.0	0.4	0.7		x		
	15	3.9	3.2	1.9	0.5	0.8		x		
	16	3.0	2.6	1.5	0.5	0.8		x		
	17	3.9	2.4	1.2	0.5	0.6			x	
	18	2.9	2.5	0.9	0.3	0.8		x		
	19	3.9	2.5	1.6	0.6	0.6			x	
	20	3.9	3.1	1.9	0.6	0.7		x		
	21	2.6	2.1	2.0	0.9	0.8	x			
	22	2.9	2.5	1.5	0.6	0.8		x		
	23	4.2	3.1	1.8	0.5	0.7		x		
	24	3.4	2.6	1.4	0.5	0.7		x		
	25	5.5	2.7	1.8	0.6	0.4			x	
Site 59	1	1.9	1.6	1.4	0.8	0.8	x			
	2	2.5	1.5	1.4	0.9	0.6				x
	3	2.9	2.3	0.9	0.4	0.7		x		
	4	2.8	2.4	1.8	0.7	0.8	x			
	5	3.5	2.1	1.4	0.6	0.6			x	
	6	3.4	2.6	1.7	0.6	0.7		x		
	7	3.3	2.2	1.7	0.7	0.6				x
	8	3.2	2.2	1.3	0.5	0.6			x	
	9	3.5	3.0	2.3	0.7	0.8	x			
	10	3.5	2.8	2.5	0.8	0.8	x			
	11	3.7	1.8	1.4	0.7	0.4				x
	12	2.5	2.0	1.3	0.6	0.8		x		
	13	2.8	2.1	1.0	0.4	0.7		x		
	14	2.5	1.8	1.2	0.5	0.7		x		
	15	2.4	2.0	0.6	0.3	0.8		x		
	16	3.1	2.5	1.5	0.6	0.8		x		
	17	2.9	1.9	0.9	0.4	0.6			x	
	18	2.4	1.6	1.0	0.6	0.6			x	
	19	3.2	2.4	2.0	0.8	0.7	x			
	20	3.0	2.1	1.2	0.5	0.7		x		
	21	2.8	2.2	1.6	0.7	0.7	x			
	22	4.4	2.7	1.4	0.5	0.6			x	
	23	4.9	2.2	1.3	0.5	0.4			x	
	24	3.7	2.7	1.9	0.7	0.7	x			
	25	2.6	1.9	0.7	0.3	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - sites 42, 43, 44 and 45 - facet 13 - wadi floor element.

	Pebble No.	A	B	C	C/B	B/A	Sphere	Disc	Blade	Rod
Site 42	1	3.9	3.0	2.0	0.6	0.7		x		
	2	3.4	2.9	1.9	0.6	0.8		x		
	3	4.2	3.5	2.1	0.6	0.8		x		
	4	4.3	3.4	2.0	0.5	0.7		x		
	5	7.8	3.7	1.5	0.4	0.4			x	
	6	2.8	2.4	1.6	0.6	0.8		x		
	7	2.9	2.5	2.1	0.8	0.8	x			
	8	3.1	2.3	1.8	0.7	0.7	x			
	9	2.3	1.8	1.7	0.9	0.7	x			
	10	3.1	2.7	1.6	0.5	0.8		x		
	11	4.9	2.8	1.6	0.5	0.5			x	
	12	3.7	2.7	1.7	0.6	0.7		x		
	13	3.5	1.5	1.3	0.8	0.4				x
	14	3.3	2.3	1.2	0.5	0.6			x	
	15	3.3	2.0	1.5	0.7	0.6				x
	16	3.5	2.5	1.9	0.7	0.7	x			
	17	3.9	2.3	1.2	0.5	0.5			x	
	18	2.3	1.9	1.3	0.6	0.8		x		
	19	2.9	2.2	1.1	0.5	0.7		x		
	20	6.0	3.2	1.9	0.5	0.5			x	
	21	3.0	1.8	1.6	0.8	0.6				x
	22	2.6	2.0	1.2	0.6	0.7		x		
	23	3.5	2.7	2.2	0.8	0.7	x			
	24	2.6	2.1	1.5	0.7	0.8	x			
	25	3.1	2.4	1.5	0.6	0.7		x		
Site 43	1	4.7	4.0	2.0	0.5	0.8		x		
	2	6.2	3.4	1.9	0.5	0.5			x	
	3	4.5	2.4	2.2	0.9	0.5				x
	4	4.8	3.3	0.9	0.2	0.6			x	
	5	2.7	1.5	0.6	0.4	0.5			x	
	6	3.4	1.6	1.4	0.8	0.4				x
	7	3.2	2.5	1.4	0.5	0.7		x		
	8	3.4	2.1	1.4	0.6	0.6			x	
	9	3.2	2.6	1.5	0.5	0.8		x		
	10	3.8	2.3	1.6	0.6	0.6			x	
	11	2.9	2.3	1.3	0.5	0.8		x		
	12	4.4	3.3	1.5	0.4	0.7		x		
	13	1.6	1.5	0.6	0.4	0.9		x		
	14	5.9	2.0	1.4	0.7	0.3				x
	15	5.0	3.0	1.0	0.3	0.4			x	
	16	2.7	2.6	1.4	0.5	0.9		x		
	17	3.2	2.0	1.4	0.7	0.6				x
	18	3.4	2.5	1.0	0.4	0.7			x	
	19	3.0	2.9	0.9	0.3	0.9		x		
	20	4.4	3.7	2.0	0.5	0.8		x		
	21	3.3	1.8	1.6	0.8	0.5				x
	22	4.3	2.4	2.2	0.9	0.5				x
	23	4.8	2.7	1.7	0.6	0.5			x	
	24	2.5	2.3	1.5	0.6	0.9		x		
	25	3.4	2.4	1.0	0.4	0.7		x		

Site 44	1	4.5	4.1	2.4	0.5	0.9		x		
	2	4.2	3.0	2.7	0.9	0.7	x			
	3	2.9	1.7	1.4	0.8	0.5				x
	4	1.8	1.5	1.1	0.7	0.8	x			
	5	4.7	2.9	2.8	0.9	0.6				x
	6	2.8	2.2	2.0	0.9	0.7	x			
	7	6.5	2.0	1.7	0.8	0.3				x
	8	3.3	1.7	0.9	0.5	0.5			x	
	9	3.9	1.8	1.4	0.7	0.4				x
	10	2.3	1.5	1.1	0.7	0.6				x
	11	3.3	1.9	1.7	0.8	0.5				x
	12	3.0	1.9	1.4	0.7	0.6				x
	13	3.3	2.1	1.9	0.9	0.6				x
	14	2.2	1.8	1.6	0.8	0.8	x			
	15	4.3	2.4	0.9	0.3	0.5			x	
	16	4.7	1.6	1.0	0.6	0.3			x	
	17	2.6	1.4	1.3	0.9	0.5				x
	18	2.6	1.4	1.1	0.7	0.5				x
	19	2.4	1.5	1.3	0.8	0.6				x
	20	2.5	1.9	1.1	0.5	0.7			x	
	21	4.2	2.6	1.0	0.3	0.6			x	
	22	3.6	3.3	1.7	0.5	0.9		x		
	23	3.7	2.4	2.2	0.9	0.6				x
	24	2.3	1.5	1.3	0.8	0.6				x
	25	2.1	1.8	1.2	0.6	0.8		x		

Site 45	1	4.6	4.1	1.9	0.4	0.8		x		
	2	3.3	2.1	1.5	0.7	0.6				x
	3	3.5	2.8	1.0	0.3	0.8		x		
	4	2.8	2.5	2.3	0.9	0.8	x			
	5	2.2	1.6	0.8	0.5	0.7		x		
	6	1.9	1.3	1.0	0.7	0.6				x
	7	2.8	2.0	1.4	0.7	0.7	x			
	8	3.4	2.8	2.3	0.8	0.8	x			
	9	4.1	2.7	2.0	0.7	0.6				x
	10	2.3	2.0	1.6	0.8	0.8	x			
	11	2.2	1.8	1.4	0.7	0.8	x			
	12	2.2	1.7	1.2	0.7	0.7	x			
	13	1.8	1.5	1.4	0.9	0.8	x			
	14	2.2	1.6	1.4	0.8	0.7	x			
	15	2.4	2.0	1.6	0.8	0.8	x			
	16	3.0	2.3	1.6	0.6	0.7		x		
	17	2.7	2.3	1.1	0.4	0.8		x		
	18	3.0	2.0	1.4	0.7	0.6				x
	19	2.5	2.3	0.9	0.3	0.9		x		
	20	2.0	1.6	1.5	0.9	0.8	x			
	21	4.0	3.6	1.5	0.4	0.9		x		
	22	2.5	2.3	1.2	0.5	0.4			x	
	23	2.2	1.5	0.9	0.6	0.6			x	
	24	1.9	1.6	1.3	0.8	0.8	x			
	25	3.1	2.3	1.0	0.4	0.7		x		

Appendix 5a continued. Shape measurements of pebbles - sites 46, 47, 48 and 49 - facet 13 - wadi floor element.

	Pebble No.	A	B	C	$\frac{C}{B}$	$\frac{B}{A}$	Sphere	Disc	Blade	Rod
Site 46	1	5.3	3.1	2.0	0.6	0.5			x	
	2	2.2	1.8	1.0	0.5	0.8		x		
	3	2.9	2.4	2.1	0.8	0.3				x
	4	2.6	2.1	1.2	0.5	0.8		x		
	5	2.5	1.4	1.0	0.7	0.5				x
	6	2.9	1.4	1.2	0.8	0.4				x
	7	4.9	2.7	1.4	0.5	0.5			x	
	8	2.0	1.5	0.9	0.6	0.7		x		
	9	4.2	2.0	0.9	0.4	0.4			x	
	10	2.0	1.2	1.0	0.8	0.6				x
	11	2.9	2.3	0.9	0.3	0.7		x		
	12	3.0	2.0	1.6	0.8	0.6				x
	13	3.6	1.5	1.3	0.8	0.4				x
	14	3.0	2.9	2.2	0.7	0.9	x			
	15	2.5	1.8	1.6	0.8	0.7	x			
	16	2.1	1.6	1.2	0.7	0.7	x			
	17	2.6	1.9	0.9	0.4	0.7		x		
	18	3.8	2.9	1.9	0.6	0.7		x		
	19	2.5	1.9	1.2	0.6	0.7		x		
	20	2.2	1.7	0.9	0.5	0.7		x		
	21	2.5	1.7	1.5	0.8	0.6				x
	22	2.6	1.4	1.2	0.8	0.5				x
	23	2.5	1.8	1.7	0.9	0.7	x			
	24	2.1	1.9	1.6	0.8	0.9	x			
	25	2.7	2.5	1.7	0.6	0.9		x		
Site 47	1	2.9	2.6	2.1	0.8	0.8	x			
	2	3.2	2.9	2.0	0.6	0.9		x		
	3	4.4	2.5	2.0	0.8	0.5				x
	4	4.1	2.1	1.9	0.9	0.5				x
	5	2.8	1.9	1.7	0.8	0.6				x
	6	2.6	1.9	1.1	0.5	0.7		x		
	7	2.4	1.5	1.0	0.6	0.6			x	
	8	4.7	3.3	1.7	0.5	0.7		x		
	9	3.9	2.2	1.7	0.7	0.5				x
	10	3.7	2.3	1.6	0.6	0.6			x	
	11	4.8	1.8	1.2	0.6	0.3			x	
	12	4.6	3.0	1.7	0.5	0.6			x	
	13	2.8	2.4	1.8	0.7	0.8	x			
	14	2.9	2.0	1.4	0.7	0.6				x
	15	2.6	2.2	1.0	0.4	0.7		x		
	16	3.0	2.2	1.4	0.6	0.7		x		
	17	4.1	3.6	2.5	0.6	0.8		x		
	18	4.2	3.2	1.4	0.4	0.7		x		
	19	3.3	2.7	1.8	0.6	0.8		x		
	20	4.5	2.9	1.7	0.5	0.6			x	
	21	1.8	1.2	0.9	0.7	0.6				x
	22	2.6	2.1	1.4	0.6	0.8		x		
	23	3.6	1.6	1.2	0.6	0.4			x	
	24	2.0	1.7	1.5	0.8	0.8	x			
	25	3.0	2.4	1.4	0.5	0.8		x		

Site 48	1	3.2	2.7	1.4	0.5	0.8		x		
	2	5.7	3.3	1.7	0.5	0.5			x	
	3	3.3	2.0	0.7	0.3	0.6			x	
	4	4.9	3.5	2.2	0.6	0.7		x		
	5	3.0	2.0	1.7	0.8	0.6				x
	6	1.8	1.4	1.2	0.8	0.7	x			
	7	4.2	3.0	2.0	0.6	0.7		x		
	8	2.7	2.4	1.2	0.5	0.8		x		
	9	2.3	1.9	1.7	0.8	0.8	x			
	10	2.9	2.1	1.8	0.8	0.7	x			
	11	4.0	3.7	2.0	0.5	0.9		x		
	12	3.3	2.2	1.3	0.5	0.6			x	
	13	2.5	2.3	1.5	0.6	0.9		x		
	14	3.1	1.8	1.4	0.7	0.5				x
	15	2.3	1.7	1.4	0.8	0.7	x			
	16	2.8	2.5	1.2	0.4	0.8		x		
	17	3.2	2.2	1.2	0.4	0.6			x	
	18	1.7	1.5	1.1	0.7	0.8	x			
	19	3.9	2.2	1.6	0.7	0.5				x
	20	2.7	2.1	1.5	0.7	0.7	x			
	21	2.7	1.9	1.6	0.8	0.7	x			
	22	2.5	1.5	0.9	0.6	0.6			x	
	23	4.5	2.9	1.4	0.4	0.6			x	
	24	2.7	2.0	1.3	0.6	0.7		x		
	25	2.6	2.1	1.0	0.4	0.8		x		
Site 49	1	2.7	1.6	1.4	0.8	0.5				x
	2	3.0	2.3	1.4	0.6	0.7		x		
	3	3.8	3.3	2.1	0.6	0.8		x		
	4	3.3	2.5	1.1	0.4	0.7		x		
	5	2.4	1.8	1.4	0.7	0.7	x			
	6	3.1	2.3	1.7	0.7	0.7	x			
	7	3.8	2.7	2.5	0.9	0.7	x			
	8	4.1	2.5	1.5	0.6	0.6			x	
	9	2.8	2.3	1.9	0.8	0.8	x			
	10	3.2	2.7	1.6	0.5	0.8		x		
	11	3.1	2.6	1.5	0.5	0.8		x		
	12	2.0	1.5	1.4	0.9	0.7	x			
	13	2.7	1.7	1.2	0.7	0.6				x
	14	3.3	2.6	2.0	0.7	0.7	x			
	15	1.9	1.4	1.3	0.9	0.7	x			
	16	2.7	2.0	1.4	0.7	0.7	x			
	17	2.9	2.0	1.5	0.7	0.6				x
	18	2.0	1.7	1.2	0.7	0.8	x			
	19	2.7	2.2	1.8	0.8	0.8	x			
	20	5.3	3.5	1.8	0.5	0.6			x	
	21	2.9	1.7	1.2	0.7	0.5				x
	22	2.4	2.0	1.0	0.5	0.8		x		
	23	4.0	2.5	1.0	0.4	0.6			x	
	24	3.5	3.0	1.6	0.5	0.8		x		
	25	5.7	3.2	2.1	0.6	0.5			x	

APPENDIX 5b

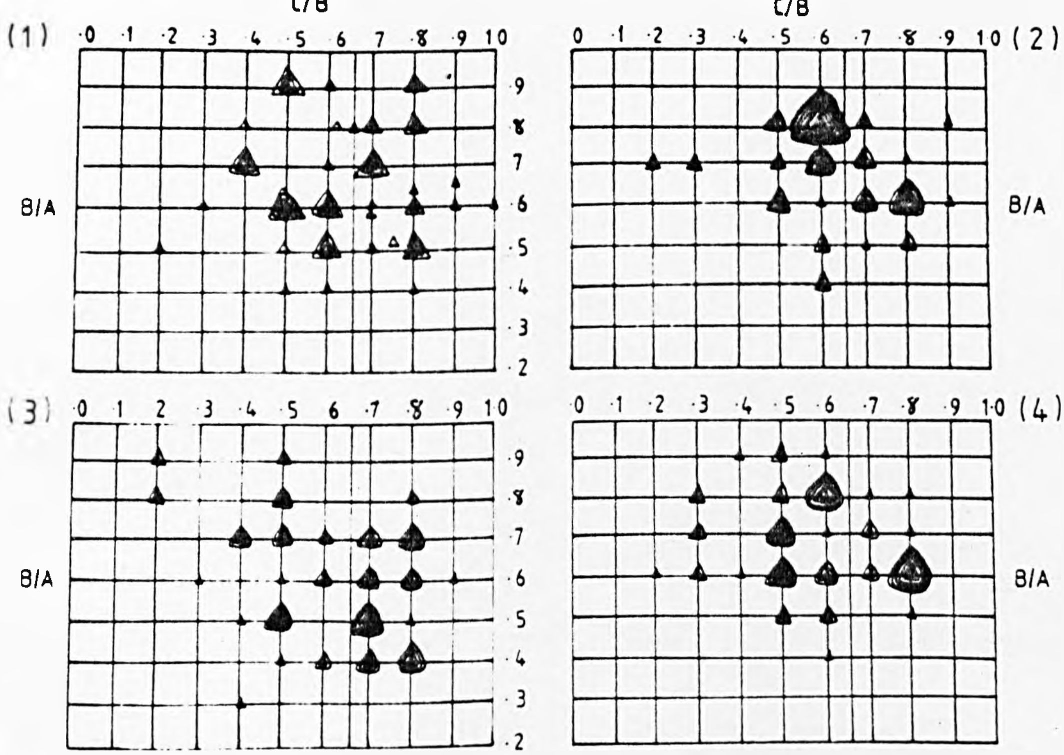


FIG.A.5b.1.
ZINGG'S DIAGRAM OF THE PEBBLE SHAPES OF MUWAILHAT al.JANUBIYA - FACET 3.
EACH CONCENTRIC TRIANGLE INDICATES ONE MEASURED PEBBLE.

DIAGRAM NO.	SITES NO.	TERRAIN ELEMENT
1	1 & 13	TOP OF THE SLOPE
2	4 & 14	MIDDLE OF THE SLOPE
3	3 & 5	BASE OF THE SLOPE
4	2 & 6	FLAT

APPENDIX 5b

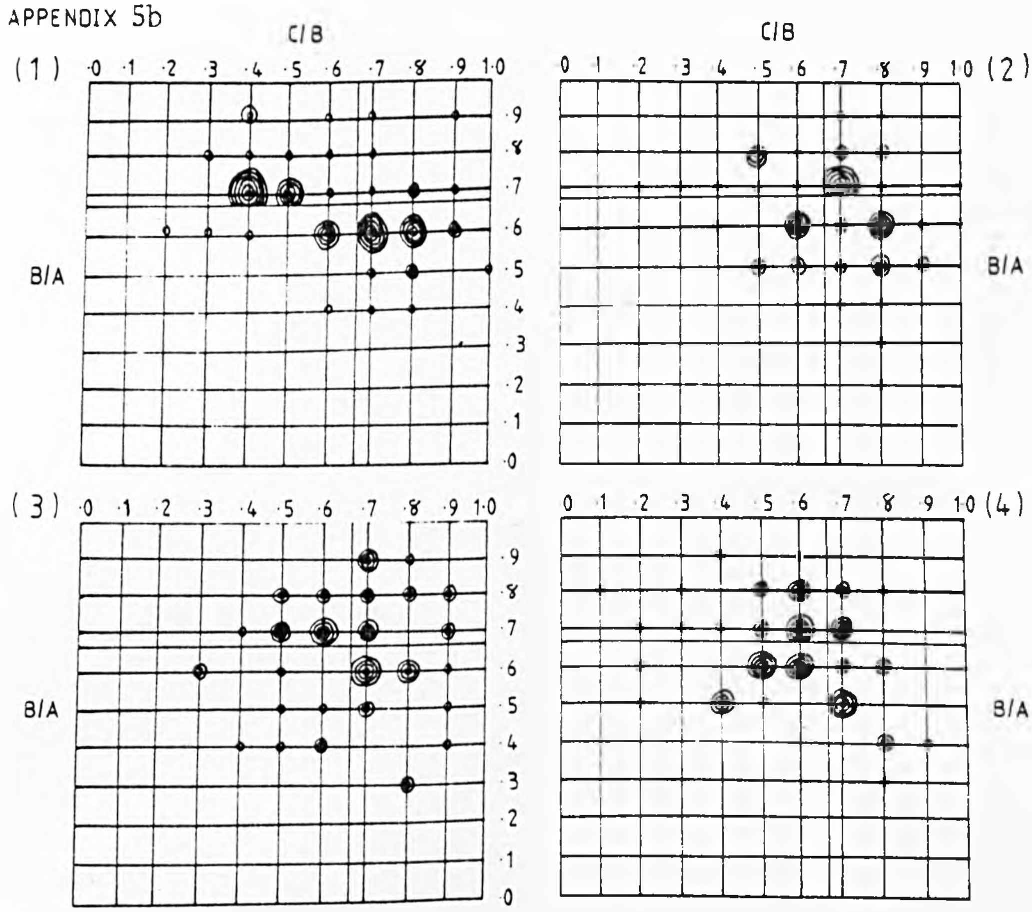


FIG.A.5b.2
ZINGG's DIAGRAM OF THE PEBBLE SHAPES OF THE MUWAILHAT al.JABUBIYA - FACET 4. EACH CONCENTRIC CIRCLE INDICATES ONE MEASURED PEBBLE.

DIAGRAM NO.	SITES NO.	TERRAIN ELEMENT
1	7 & 10	TOP OF THE SLOPE
2	8 & 11	MIDDLE OF THE SLOPE
3	9 & 12	BASE OF THE SLOPE
4	15 & 16	FLAT

APPENDIX 5b

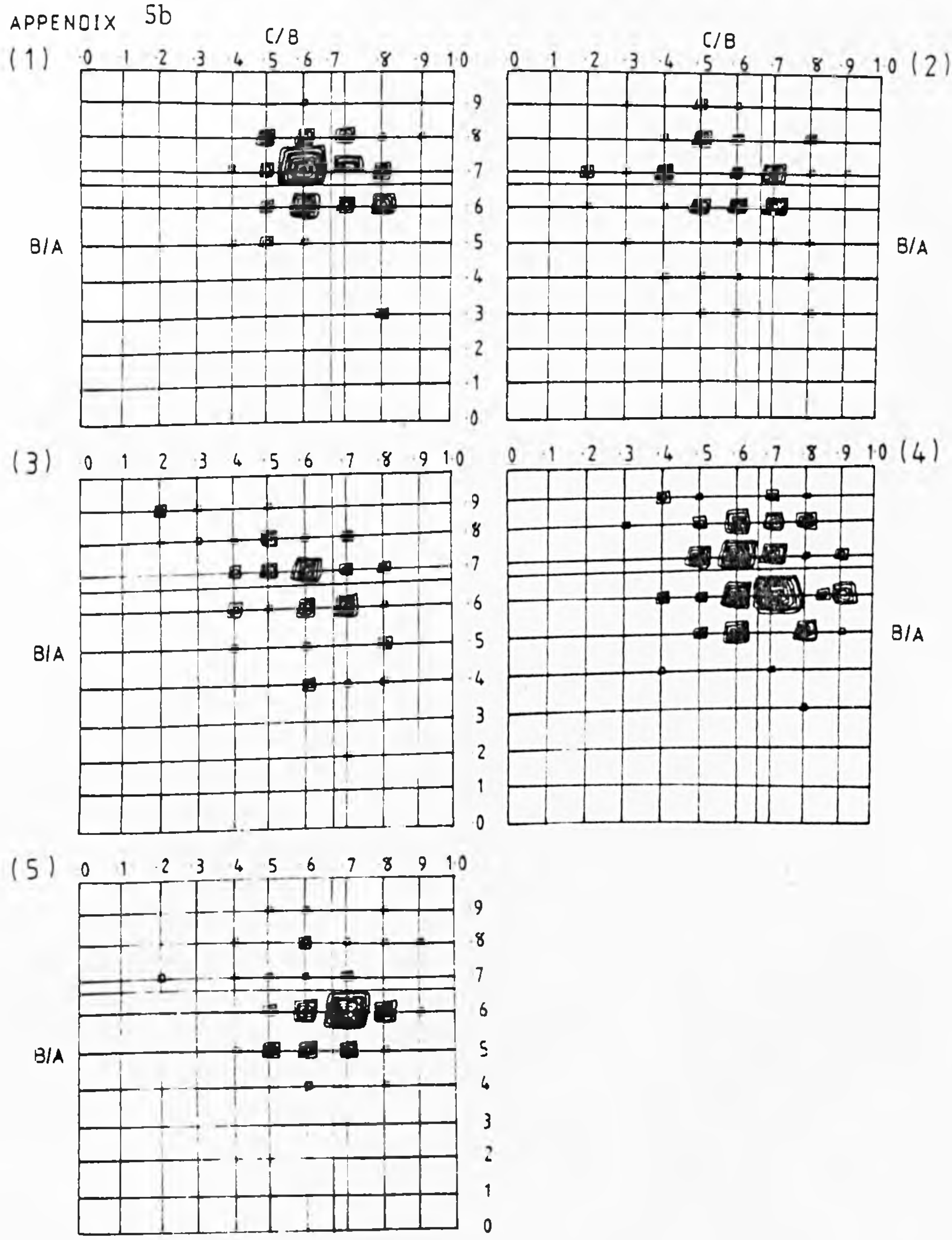


FIG.A.5b.3
ZINGG'S DIAGRAM OF THE PEBBLE SHAPE OF SAFWAN. EACH CONCENTRIC SQUARE INDICATES ONE MEASURED PEBBLE.

DIAGRAM NO.	SITES NO.	TERRAIN ELEMENT.
1	18 & 21	FACET 5
2	23 & 25	FACET 6
3	24 & 17	FACET 7
4	26, 20 & 22	FACET 8
5	27 & 29	FACET 9

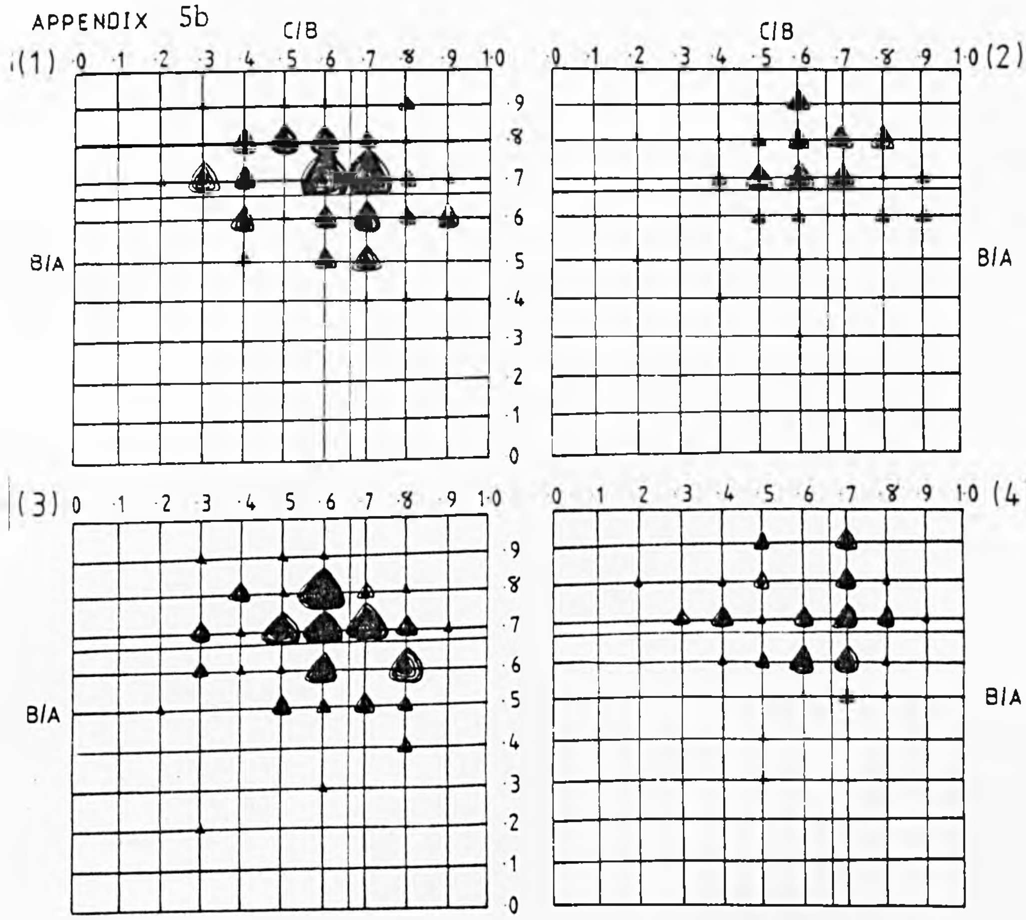


FIG.A.5b.4
Zingg's diagram of the pebble shapes of Sanam - facet 11.
Each concentric triangle indicates one measured pebble.

Diagram No.	Sites No.	Terrain element
1	33,34 & 35	Top of the plateau
2	36 & 37	Top of the plateau
3	31 & 32	Base of the plateau
4	28,28 & 30	Base of the plateau

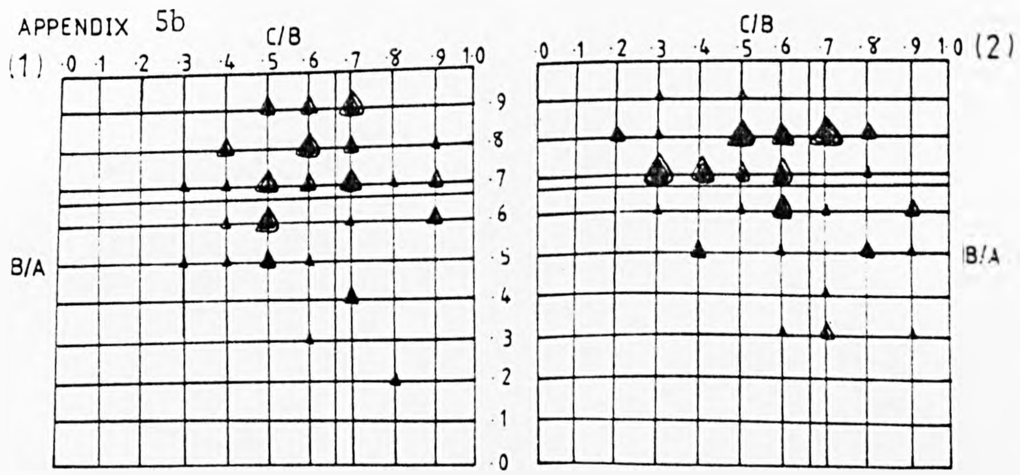


FIG.A.5b.5
Zingg's diagram of the pebble shapes of Sanam - facet 12.
Each concentric triangle indicates one measured pebble.

Diagram No.	Sites No.	Terrain element
1	38 & 39	Gully floor
2	40 & 41	Gully floor

APPENDIX 5b

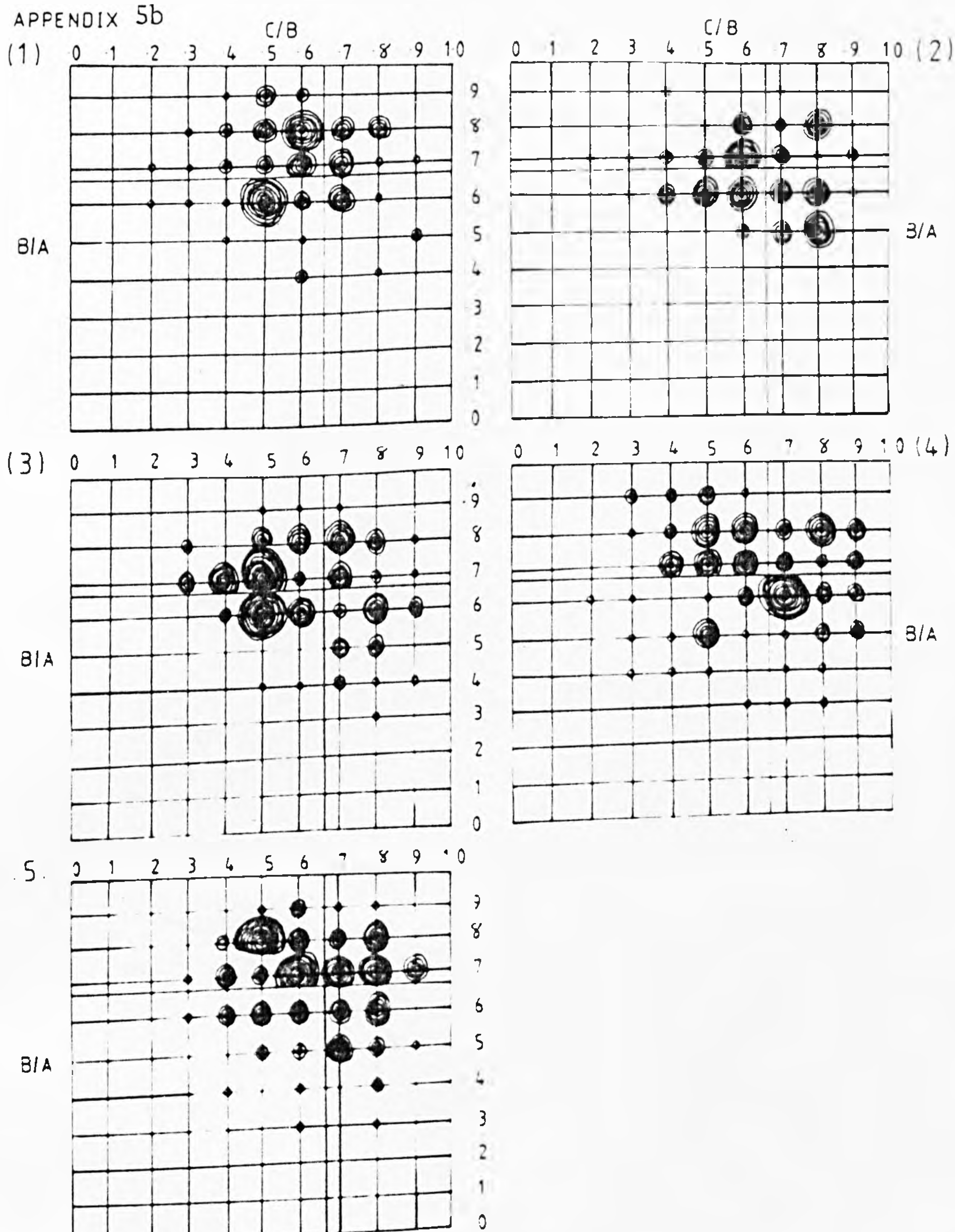


FIG.A.5b.6
Zingg's diagram of the pebble shapes of Sanam - facet 13.
Each concentric circle indicates one measured pebble.

Diagram No.	Sites No.	Terrain element
1	50,51 & 52	Wadi slope
2	53,54 & 55	Wadi slope
3	56,57,58 & 59	Wadi slope
4	42,43,44 & 45	Wadi floor
5	46,47,48 & 49	Wadi floor

APPENDIX 5c

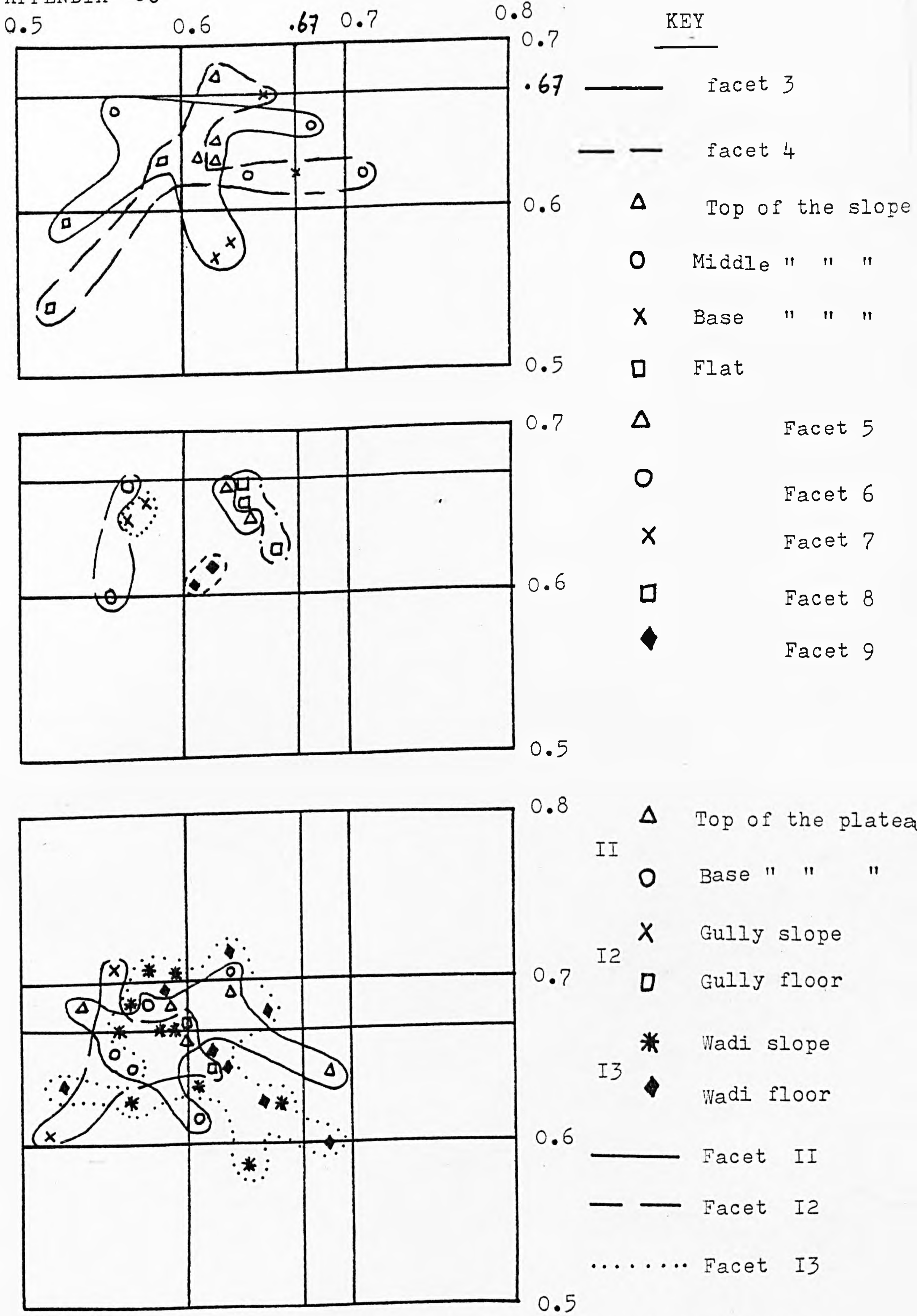


FIG.A.5c.1
Pebble shape distribution on the basis of their means (according to Zingg's diagram).

APPENDIX 6

ROUNDNESS, SURFACE TEXTURE AND SPHERICITY MICROSCOPIC EXAMINATION FOR THE SAND GRAINS

Sample No.	Size in diameter (mm)	Frequency of Roundness classes						Surface Texture		Sphericity											
		.4	.5	.6	.7	.8	.9	F.	V.	.97	.95	.93	.91	.89	.87	.85	.83	.81	.79	.77	.75
Khor al.Zubair																					
1	0.5	–	–	4	15	11	–	30	–			x		x	xx	x	x				
	0.25	–	8	17	5	–	–	30	–					x		x	xx	x		x	
2	0.5	–	5	3	12	9	1	30	–				x	xxx	xx						
	0.25	2	11	12	3	2	–	30	–								x	xx	x		xx
3	0.5	–	2	11	10	5	2	30	–		x	x	xxx	x							
	0.25	–	9	14	7	–	–	30	–					x	x				x		xxx
Muwailhat al.Janubiya																					
14	0.5	–	4	6	9	8	3	30	–	x	xx		xx	x							
	0.25	–	9	12	6	3	–	30	–						x		xx	x		x	x
19	0.5	–	3	3	12	11	1	30	–	x	x	x	xx	x							
	0.25	1	8	11	7	3	–	30	–							x	x	xx	xx		
7	0.5	–	2	3	11	11	3	29	1			xx	xxx				x				
	0.25	–	8	14	7	1	–	30	–				xx		xx		x		x		
16	0.5	–	1	7	9	9	4	29	1	xx			xx		x			x			
	0.25	1	3	12	10	4	–	30	–			x	xx		x	x		x			
15	0.5	–	–	2	13	14	1	30	–		x	xx	x		xx						
	0.25	–	8	15	6	1	–	30	–					x	x		x	xx			x
Safwan																					
9	0.5	–	5	7	11	7	–	30	–			x	xx	xx		x					
	0.25	–	3	13	11	3	–	30	–								xx	x	xxx		
6	0.5	–	2	4	10	9	5	30	–		xx		xx	x	x						
	0.25	–	7	13	8	2	–	30	–					x			xx		xxx		
8	0.5	–	–	6	11	9	4	30	–			x	xx	x	xx						
	0.25	–	3	14	8	5	–	29	1					x	x	x	xx	x			
13	0.5	–	2	4	10	10	4	29	1	x		x	xx		xx						
	0.25	2	4	11	8	5	0	30	–					xx		xx		xx			
12	0.5	–	2	5	10	9	4	30	–			xx	xxx	x							
	0.25	2	6	12	7	3	–	30	–				x				xx	xx			x
5a	0.5	–	–	5	12	13	0	30	–		xx	x	x	xx							
	0.25	–	8	15	4	3	–	30	–								xx	xx	xx		

Safwan continued																				
5b	0.5	-	-	6	10	11	3	30	-	x	x		x		xxx					
	0.25	-	9	13	6	2	-	30						x			x	xx	xx	
Sanam																				
20	0.5	2	6	13	3	6	-	25	5			xx			x			xx	x	
	0.25	-	5	11	8	6	-	25	5				xxx			x			x	x
17	0.5	-	5	6	13	6	0	29	1	x			xxx					xx		
	0.25	-	6	10	10	4	-	30	-			x	xxxx					x		
11	0.5	-	0	7	8	10	5	30	-			x			xx		xx	x		
	0.25	-	8	11	8	3	-	30	-			x		xx	x		x		x	
10	0.5	-	0	7	10	10	3	30	-				xx	x	xxx					
	0.25	-	10	12	5	3	-	29	1			x			x		x	x	xx	
18	0.5	-	0	9	9	10	2	28	2	x	x		x	x	xx					
	0.25	-	8	12	8	2	0	30	-					x	x	x	x	x	x	

F = Frosted V = Vitreous

Roundness-surface texture and sphericity of microscope examination for the sand grains (30 grains for roundness and 5-6 grains for sphericity) of the study area at depth 0-15 cm.

Based on Powers (1958) chart of roundness and Rittenhouse (1943) chart of sphericity.

Sample No.	Size in diameter (mm)	Frequency of Roundness classes .4	.5	.6	.7	.8	.9	Surface Texture F.	V.	Sphericity .97	.95	.93	.91	.89	.87	.85	.83	.81	.79	.77	.75
2	0.5	–	3	11	8	8	–	30	–		x		xx	xx	x						
	0.25	3	7	15	5	–	–	30	–							x		xx	xx	x	
3	0.5	–	3	10	8	6	3	29	1		xx		xx		x		x				
	0.25	2	9	11	7	1	–	30	–								xx	xx	x		x
14	0.5	–	3	14	8	5	–	30	–		x		xx	x	x						x
	0.25	–	6	13	9	2	–	30	–							x		xx	xx		x
19	0.5	–	2	5	10	12	1	30	–				xx	xx	xx						
	0.25	2	7	8	11	2	–	30	–							x		x	x	x	xx
7	0.5	–	–	4	12	13	1	29	1			xx	xx	xx							
	0.25	–	9	15	5	1	–	30	–			x	x				xx	x	x		
16	0.5	–	–	6	12	10	2	30	–			x	xxxx					x			
	0.25	–	4	10	9	6	1	30	–				x				xx	xxx			
9	0.5	–	0	6	12	10	2	30	–			x	xxx				xx				
	0.25	–	5	14	9	2	–	30	–						x		x	x		x	xx
6	0.5	–	0	7	10	8	5	30	–				x	xx	xxx						
	0.25	2	6	12	9	1	–	30	–								x	xx	xx		x
8	0.5	–	2	6	6	13	3	30	–	x	x		xx		xx						
	0.25	–	9	12	8	1	–	30	–					xx	x		xxx				
13	0.5	–	2	7	12	6	3	30	–			x	xx		x	x	x				
	0.25	3	12	10	5	–	–	29	1								x	xx	x		xx
12	0.5	–	4	9	7	7	3	30	–			x	xx	x		xx					
	0.25	3	9	12	4	2	–	30	–					x		x	xx	x			x
5a	0.5	–	5	5	10	8	2	29	1	x			xx	x	x		x				
	0.25	3	9	11	6	1	–	30	–								xx	xx	x	x	
5b	0.5	–	0	8	9	11	2	30	–			x	xx	x			x	x			
	0.25	2	10	9	7	2	–	30	–								xx		xx	x	x
20	0.5	2	2	8	9	5	4	30	–	x		xx	x	x		x					
	0.25	–	4	12	11	3	–	30	–				xxxx					xx			
17	0.5	–	5	8	13	1	3	30	–				xxxx					x			x
	0.25	2	3	9	10	6	0	29	1			xxx	x						x		x

11	0.5	-	-	7	12	9	2	30	-	x	xxx	x				x
	0.25	-	8	14	4	4	-	30	-		x				xxx	xx
10	0.5	-	0	3	10	13	4	30	-	x	xxx	xx				
	0.25	-	9	12	6	3	-	30	-		x		x	x		xxx
18	0.5	-	5	8	4	8	5	29	1	xx	xx	x	x			
	0.25	-	6	12	9	3	-	30	-			x	x	xx		xx

F = Frosted V = Vitreous

Roundness and surface texture of microscope examination for the sand grains of the study area at depth 15-30 cm; based on Powers (1958) chart of roundness and Rittenhouse (1943) chart of sphericity.

APPENDIX 7

PARTICLE SIZE DISTRIBUTION

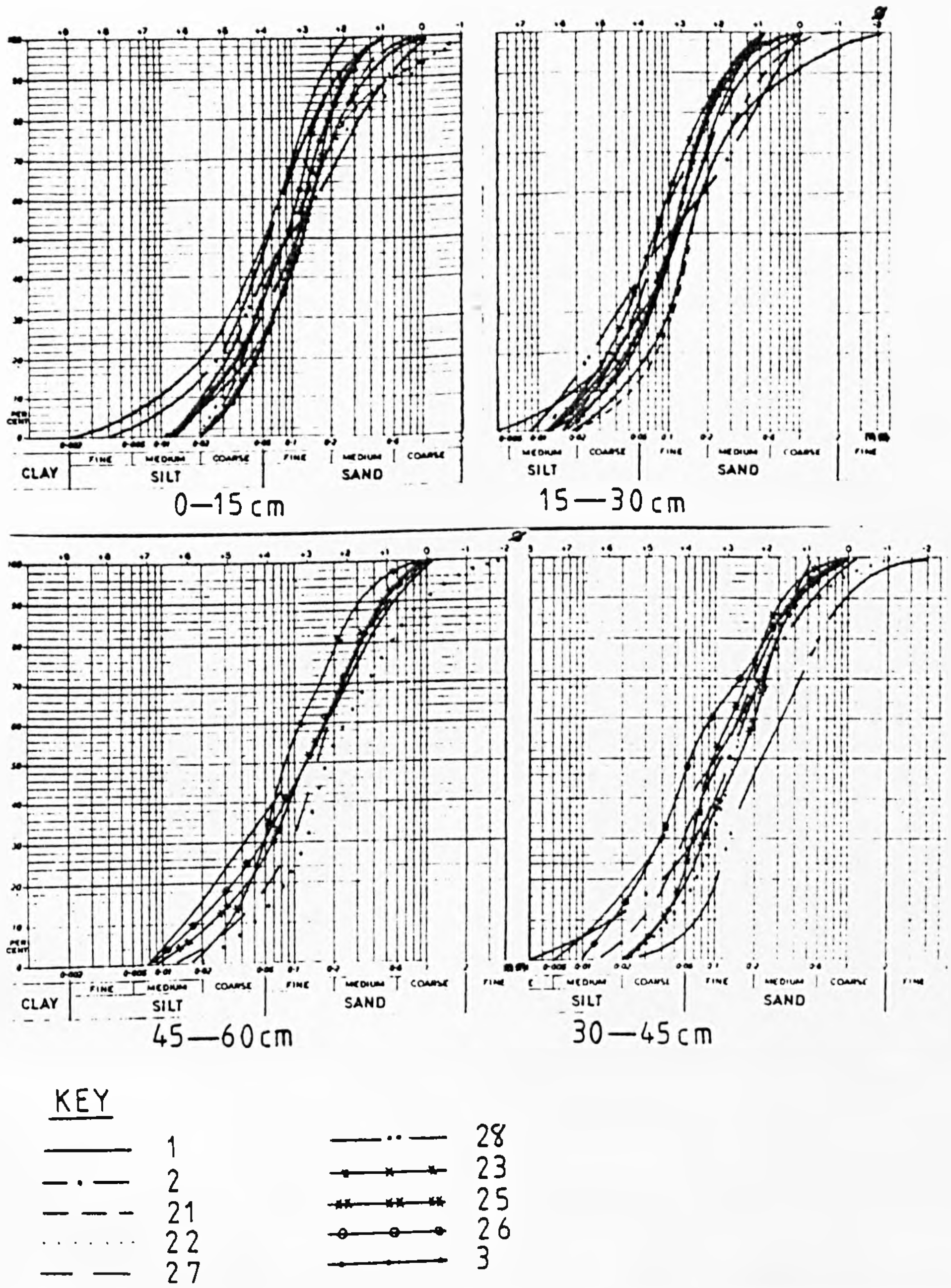
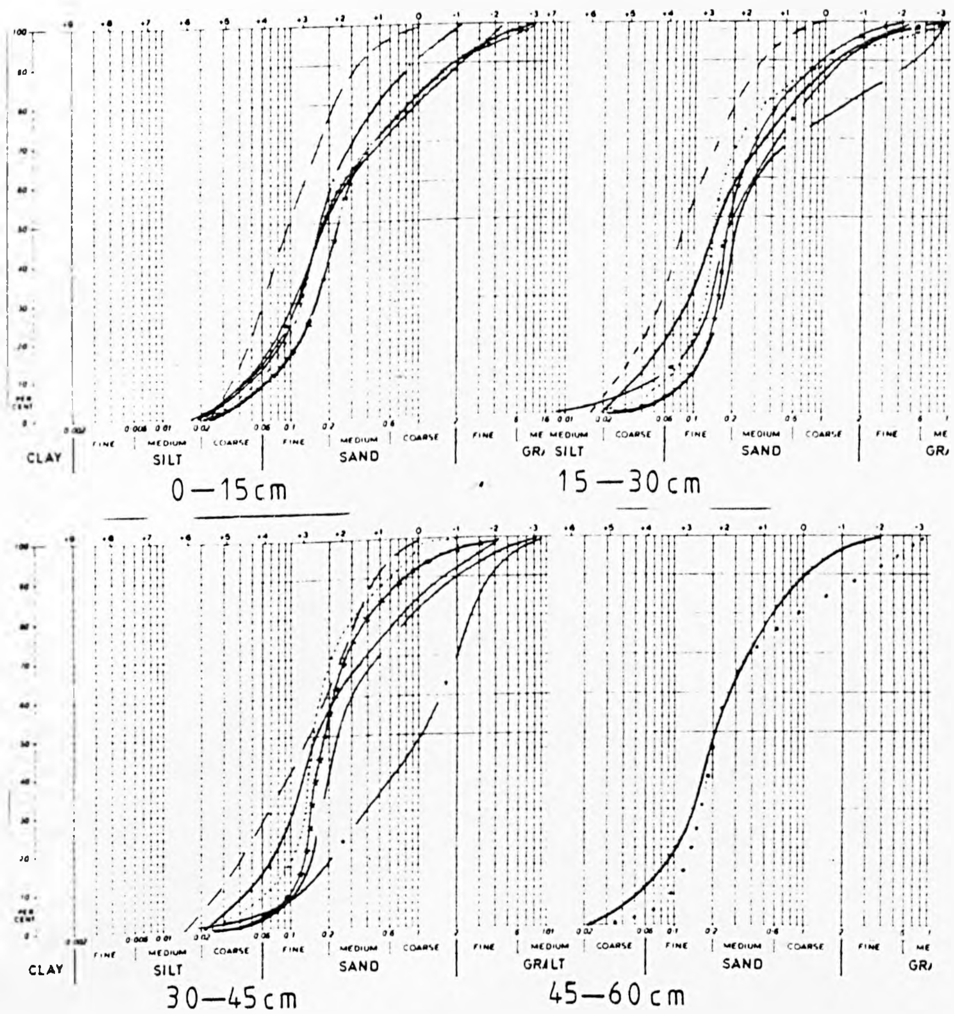


FIG.A.7.1 PARTICLE SIZE DISTRIBUTION OF KHOR al-ZUBAIR SAMPLES



KEY

- ——— 14
- —·— 19
- - - - - 24
- — — 7
- ······· 15
- —x—x— 16

FIG.A.7.2 PARTICLE SIZE DISTRIBUTION OF MUWAILHAT al.JANUBIYA SAMPLES.

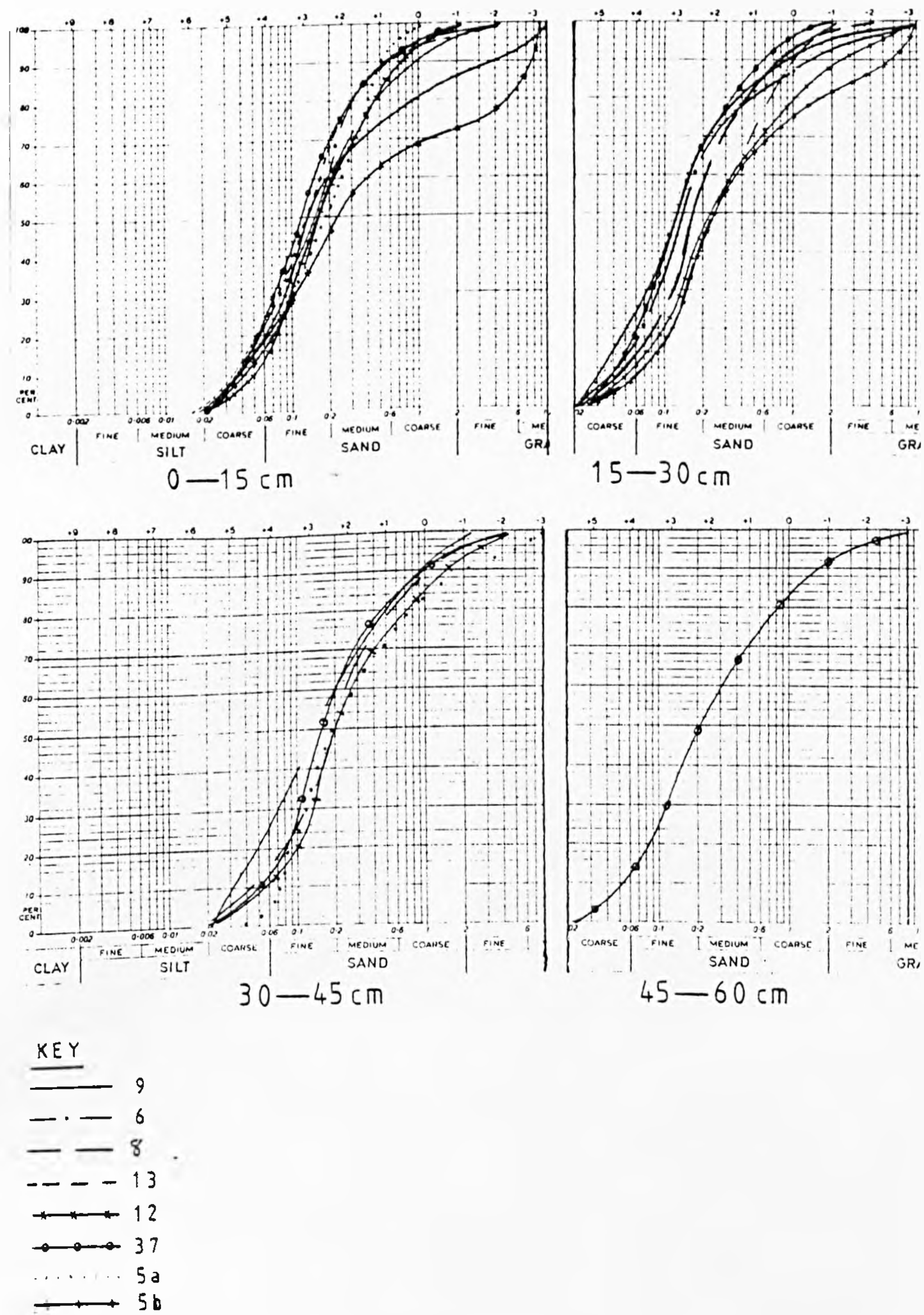


FIG.A.7.3 PARTICLE SIZE DISTRIBUTION OF SAFWAN SAMPLES.

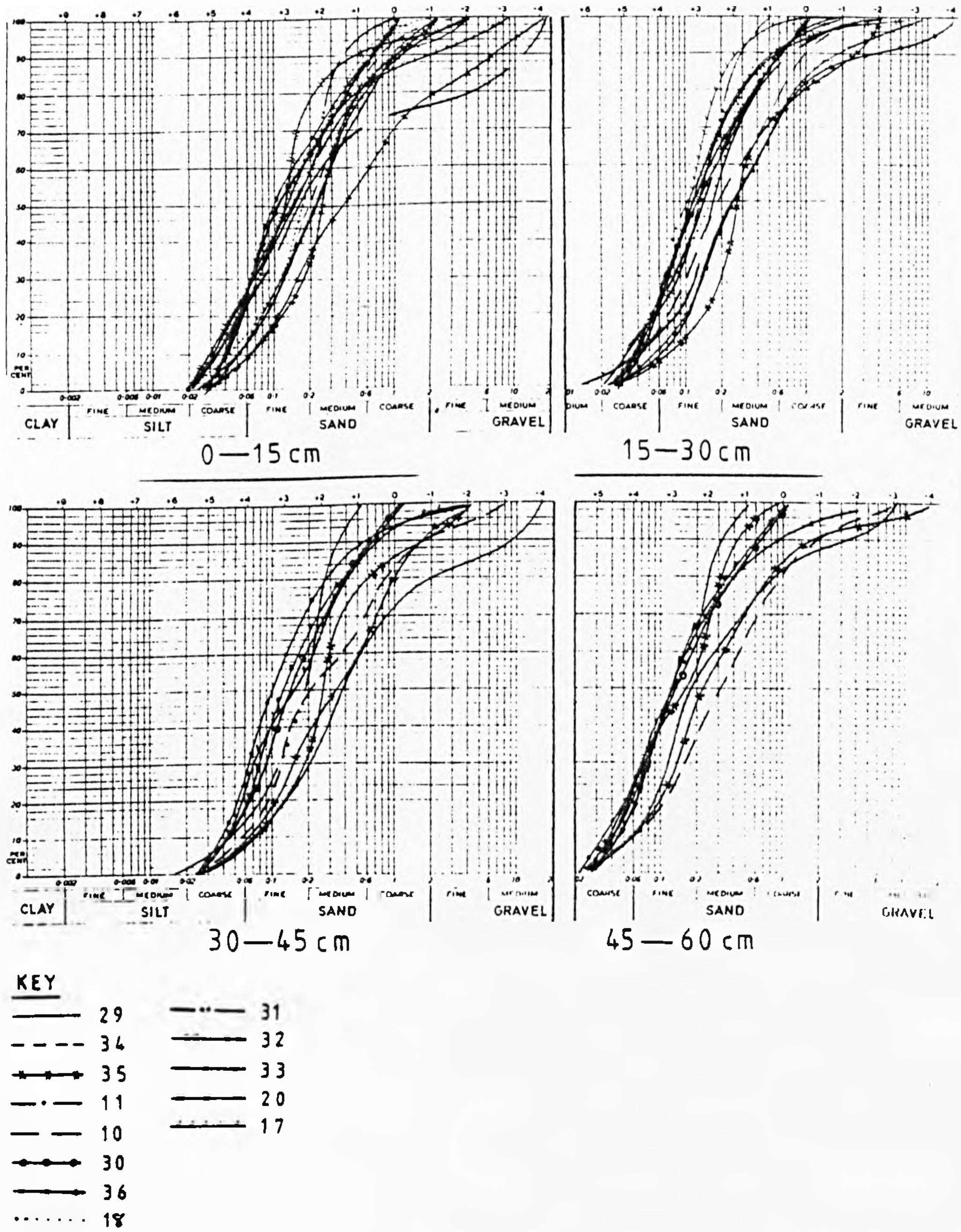


FIG. A.7.4 PARTICLE SIZE DISTRIBUTION OF SANAM SAMPLES.

APPENDIX 8

PARTICLE SIZE (phi VALUES) ACCORDING TO THE PERCENTILES OF THE SAMPLES OF THE STUDY AREA

Appendix 8

	Sample No.	percentiles 5	16	25	50	75	84	95
f.1a	1	7.4	6.0	5.2	4.0	3.2	2.9	2.4
	2	7.0	5.5	4.9	3.9	3.0	2.6	1.9
	21	5.4	4.8	4.5	3.5	2.4	1.9	1.3
f.1b	22	5.4	4.9	4.4	3.5	2.2	1.1	-0.1
	27	5.9	5.0	4.4	3.2	2.3	1.9	1.1
	28	6.0	5.2	4.8	3.5	2.0	1.5	0.5
f.1c	23	6.1	5.1	4.5	3.5	2.9	2.6	1.8
	25	5.2	4.4	4.1	3.1	2.5	2.3	1.8
	26	5.2	4.4	4.1	3.1	2.7	2.2	1.6
f.2	3	5.9	4.9	4.0	3.0	2.3	1.6	-0.2
f.3	14	5.1	4.2	3.5	2.5	0.6	-0.4	-1.6
	19	5.1	4.0	3.4	2.7	1.5	0.7	-0.4
	24	5.2	4.5	4.2	3.4	2.5	2.0	1.1
f.4	7	5.2	3.9	3.4	2.6	0.8	-0.2	-1.5
	16	4.6	3.5	3.0	2.1	0.8	-0.1	-2.1
	15	4.7	3.7	3.2	2.5	0.6	-0.4	-1.6
f.5	9	5.3	4.4	3.9	3.0	2.9	-0.4	-2.9
	6	5.3	4.5	3.9	2.8	2.0	1.5	0.2
f.6	8	5.2	4.3	3.6	2.7	1.6	0.8	-0.6
f.7	13	5.4	4.6	4.0	2.9	2.1	1.5	-0.3
f.8	12	5.3	4.4	3.7	2.2	-1.6	-2.6	-3.0
	37	5.3	4.5	4.1	3.1	2.1	1.5	0.2
f.9	5a	5.2	4.4	3.7	2.5	1.5	1.2	0.6
	5b	4.9	4.0	3.5	2.7	1.4	0.9	0.0
f.11	18	5.2	4.2	3.5	2.6	1.7	1.3	0.4
	31	4.9	4.4	4.1	2.9	2.0	1.9	1.1
	32	4.6	3.4	2.9	2.0	1.5	0.6	-0.7
	33	4.7	4.1	3.6	2.2	1.1	0.5	-0.7
f.12	20	5.4	4.8	4.2	3.0	2.6	1.9	-0.6
	17	5.3	4.7	4.2	2.9	1.8	0.5	-2.3
f.13	29	4.9	3.8	3.2	2.2	1.0	0.4	-1.3
	34	4.8	3.8	3.2	2.4	1.2	0.8	-0.2
	35	4.6	3.6	3.0	1.5	-0.4	-1.9	-3.4
	11	5.3	4.7	4.2	2.9	1.4	0.7	-0.3
	10	5.3	4.6	4.0	2.7	-0.2	-2.9	-3.9
	30	5.0	4.5	4.2	3.2	1.7	1.1	0.2
	36	4.9	4.5	4.3	3.4	1.9	1.1	0.3

a: Particle size (phi values) according to the percentiles of the sample of the study area at depth 0-15 cm.

(f = facet)

Appendix 8 continued.

	Sample No.	percentiles 5	16	25	50	75	84	95
f.1a	1	5.5	4.5	4.1	3.1	2.3	2.0	1.4
	2	6.7	5.2	4.4	3.2	2.5	2.3	1.5
	21	5.8	4.9	4.5	3.6	2.6	2.2	1.5
f.1b	22	4.9	3.9	3.5	2.8	1.9	1.2	0.6
	27	6.0	5.0	4.4	3.1	2.1	1.8	0.9
	28	6.3	5.5	4.9	3.2	1.5	1.0	0.3
f.1c	23	6.0	5.2	4.7	3.6	2.8	2.3	1.5
	25	5.4	4.6	4.2	3.2	2.5	2.1	1.2
	26	5.8	4.8	4.2	3.2	2.7	2.2	1.5
f.2	3	5.2	4.2	3.6	2.9	1.9	0.9	-0.5
f.3	14	5.3	4.4	3.7	2.9	1.2	0.4	-1.0
	19	5.3	3.6	3.0	2.4	0.8	0.2	-1.0
	24	5.6	4.8	4.4	3.5	2.5	2.0	1.2
f.4	7	3.9	3.0	2.7	2.1	0.1	-1.4	-2.8
	16	4.4	3.6	3.2	2.9	1.9	0.9	-1.4
	15	4.1	3.1	2.9	2.5	1.5	0.7	-0.5
f.5	9	5.7	4.7	4.2	3.1	1.9	1.0	-0.8
	6	5.2	4.2	3.7	2.9	1.6	0.5	-1.7
f.6	8	5.0	3.9	3.4	2.7	1.6	0.9	-0.2
f.7	13	4.5	3.4	2.9	2.1	0.9	0.4	-0.3
f.8	12	4.5	3.4	3.0	2.0	0.1	-1.5	-2.8
	37	5.0	4.2	3.9	3.0	1.9	1.3	0.3
f.9	5a	5.2	4.5	3.9	3.1	1.6	0.7	-1.2
	5b	4.7	3.7	3.1	2.2	0.4	-0.4	-2.2
f.11	18	5.5	4.7	4.0	2.7	1.9	1.6	0.9
	31	4.9	4.3	4.1	3.3	2.3	2.1	1.5
	32	4.5	3.2	2.6	2.0	0.9	-0.5	-1.6
	33	5.0	4.4	4.1	3.2	2.1	1.6	0.2
f.12	20	5.2	4.6	4.1	3.2	2.6	2.2	1.4
	17	5.5	4.6	3.9	2.9	2.3	1.7	0.0
f.13	29	4.5	3.5	3.0	2.0	0.8	0.1	-1.9
	34	5.0	4.1	3.6	2.5	0.9	0.5	-0.5
	35	4.8	3.6	3.0	1.9	0.7	-0.2	-3.5
	11	5.3	4.6	3.9	2.8	1.8	1.2	0.3
	10	5.3	4.0	3.3	2.6	1.7	1.1	-0.3
	30	5.0	4.4	4.0	3.0	1.5	1.1	0.4
	36	5.0	4.4	4.0	3.1	1.8	1.1	0.3

b: Particle size (phi values) according to the percentiles of the samples of the study area at depth 15–30 cm.

(f = facet)

Appendix 8 continued.

		percentiles						
	Sample No.	5	16	25	50	75	84	95
f.1a	1	-	-	-	-	-	-	-
	2	5.2	3.9	3.2	2.4	1.1	-0.1	-1.7
	21	5.8	4.9	4.5	3.3	2.3	1.9	1.1
f.1b	22	5.0	4.1	3.6	2.9	2.0	1.5	0.2
	27	6.8	5.8	5.1	3.4	1.9	1.5	0.6
	28	4.4	3.5	3.1	2.1	1.0	0.5	-0.2
f.1c	23	5.1	4.4	4.2	3.5	2.3	2.1	1.5
	25	5.2	4.3	3.9	2.8	2.0	1.8	1.1
	26	6.5	5.5	5.1	4.2	2.5	1.9	1.0
f.2	3	-	-	-	-	-	-	-
f.3	14	5.0	4.1	3.5	2.8	1.0	0.1	-1.3
	19	3.8	2.6	1.8	0.1	-1.1	-1.5	-2.2
	24	5.6	4.8	4.2	2.9	1.9	1.5	0.8
f.4	7	3.6	2.9	2.6	2.2	0.6	-0.2	-1.7
	16	3.7	3.1	2.9	2.5	1.8	1.1	-0.2
	15	4.6	3.5	3.0	2.9	2.1	1.4	0.3
f.5	9	-	-	-	-	-	-	-
	6	-	-	-	-	-	-	-
f.6	8	5.3	4.7	4.2	2.9	1.5	0.7	-0.5
f.7	13	5.2	4.2	3.4	2.5	1.3	0.5	-0.8
f.8	12	-	-	-	-	-	-	-
	37	4.9	3.9	3.5	2.8	1.4	0.8	-0.6
f.9	5a	3.9	3.6	3.3	2.4	0.8	-0.2	-2.4
	5b	4.9	3.7	3.2	2.4	0.9	0.2	-1.2
f.11	18	-	-	-	-	-	-	-
	31	4.9	4.3	4.1	2.8	2.1	1.9	1.4
	32	4.5	3.2	2.8	2.0	1.3	0.5	-1.6
	33	5.0	4.3	4.1	3.3	2.2	1.5	-0.1
f.12	20	-	-	-	-	-	-	-
	17	5.0	3.9	3.3	2.5	1.9	1.0	0.0
f.13	29	4.5	3.2	2.7	1.5	-0.1	-2.1	-3.7
	34	4.6	3.7	3.1	2.3	0.6	-0.1	-2.2
	35	4.5	3.5	3.0	1.5	0.3	-0.1	-1.2
	11	-	-	-	-	-	-	-
	10	-	-	-	-	-	-	-
	30	4.9	4.2	3.8	2.9	1.6	1.0	0.3
	36	4.8	4.2	3.9	3.0	1.8	1.0	0.3

c: Particle size (phi values) according to the percentiles of the samples of the study area at depth 30-45 cm.

(f = facet)

Appendix 8 continued.

	Sample No.	percentiles 5	16	25	50	75	84	95
f.1a	1	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-
	21	5.5	4.3	3.7	2.9	1.9	1.5	0.7
f.1b	22	4.9	3.8	3.3	2.5	1.1	0.7	-0.6
	27	6.6	5.8	5.0	3.2	1.8	1.3	0.5
	28	-	-	-	-	-	-	-
f.1c	23	5.4	4.5	4.3	3.6	2.5	2.1	1.3
	25	6.0	4.9	4.2	3.1	1.9	1.5	0.9
	26	6.3	5.2	4.5	3.0	1.8	1.4	0.9
f.2	3	-	-	-	-	-	-	-
f.3	14	4.7	3.7	3.2	2.4	1.2	0.6	-0.6
	19	-	-	-	-	-	-	-
	24	-	-	-	-	-	-	-
f.4	7	-	-	-	-	-	-	-
	16	-	-	-	-	-	-	-
	15	3.8	3.1	2.8	2.4	0.8	-0.4	-2.4
f.5	9	-	-	-	-	-	-	-
	6	-	-	-	-	-	-	-
f.6	8	-	-	-	-	-	-	-
f.7	13	-	-	-	-	-	-	-
f.8	12	-	-	-	-	-	-	-
	37	4.9	3.9	3.3	2.2	0.7	-1.1	-1.5
f.9	5a	-	-	-	-	-	-	-
	5b	-	-	-	-	-	-	-
f.11	18	-	-	-	-	-	-	-
	31	4.9	4.3	4.1	3.0	2.2	2.0	1.5
	32	4.9	4.4	4.2	2.8	1.9	1.6	1.1
	33	5.2	4.4	4.0	3.0	1.9	1.1	-0.2
f.12	20	-	-	-	-	-	-	-
	17	-	-	-	-	-	-	-
f.13	29	4.8	3.6	3.2	2.8	0.9	-0.1	-2.5
	34	4.7	3.5	3.0	1.6	0.5	-0.2	-1.8
	35	4.6	3.6	3.1	2.2	0.8	0.1	-2.7
	11	-	-	-	-	-	-	-
	10	-	-	-	-	-	-	-
	30	5.0	4.3	3.9	3.0	1.6	1.0	0.3
	36	4.8	4.2	3.9	3.0	1.9	1.2	0.4

d: Particle size (phi values) according to the percentiles of the samples of the study area at depth 45-60 cm.

(f = facet)