Analysis of relief, slopes and summits in the thaniyat turayf, n.w. Saudi Arabia.

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ANALYSIS OF RELIEF, SLOPES AND SUMMITS IN THE THANIYAT TURAYF, N.W. SAUDI ARABIA.

by

HODA SAAD AL MAZROOA

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To Abdallah , Hadeel
and Sarah

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CHAPTER 1

INTRODUCTION; ANALYSIS OF DESERT TOPOGRAPHY FROM CONTOUR MAPS; USE OF COMPUTER FOR ANALYSIS AND MAP PLOTTING

CHAPTER ONE

Introduction; analysis of desert topography from contour maps; use of computer for analysis and map plotting

1.1 General Remarks

Terrain analysis, in geomorphology, is the study of the variability in shape, pattern and orientation of landform. Geometric measurements and analysis are aimed at quantifying land surface characteristics to describe any type of terrain. Researchers and scientists have attempted different methods, ranging from manual to computer-aided techniques, for the collection and the analysis of terrain surface data and have derived many different quantitative descriptors as a measure of the variability in natural terrain surface.

Evans (1979) has contributed to this field of general geomorphometry by developing an integrated system of terrain analysis. Using digital altitude data, which is now often available through digital photogrammetric mapping, he uses computer processing to evaluate five basic properties of land form and to generate statistical summaries and graphic displays. The five basic land descriptors are the altitude and its derivatives gradient, aspect, profile convexity and plan convexity. Evans has emphasized that:

> The advantages of the present approach lie in its simplicity, directness and conceptual economy. It starts from the properties of points on the surface, and show how (excluding position) the properties of geomorphologic and human interest may be measured by derivatives of the surface. Without defining any elaborate indices or using indirect analysis such as variance spectra, areas may be characterized by moments of the frequency distributions of 'point' values, and by correlations between 'point' properties. In this way, the summarisation of areas has been coordinated with the mapping and interrelationship of the 'point' properties (Evans, 1979, p.121).

1.2 Study Objective

The primary objective of this study was to carry out terrain analysis of an area representative of the arid terrain in Saudi Arabia, by using computer-based techniques. As far as is known to the writer, computer methods for geomorphometric analysis of land form in Saudi Arabia have not been reported so far.

The Kingdom of Saudi Arabia offers a large variety in land form. Morphologically, Saudi Arabia is part of a tilted block of pre-Cambrian metamorphosed and highly deformed sediments intruded by masses of granites. Geological disturbances have resulted in accumulation of younger sedimentary rocks upon this block. Fisher (1978, p.462) describes it best as follows:

> "Tilting towards the north and east, and differential erosion acting upon layers of varying resistance, have given rise to a cuesta-like topography, with rather irregular ranges of hills in the form partly of arcs and cusps, partly in straight ranks, often presenting a scarp-face to the west or south, and a dip to the north and east. In quite a number of localities, however, strata are practically horizontal, and the landscape becomes tabular in character : flat massifs diversified by wadi-floors of various shapes and widths, and by blown sand deposits together with outwash features mostly but not entirely due to rainfall at an earlier geologic period."

The study area, which is more fully described in Chapter Two, captures some of this variety in landform. The topography includes rock outcrops and escarpments with steep slopes, alluvial fans, wadis, lowland and even sand dunes. A primary interest, therefore, was to ascertain how successfully can computer analysis be applied to such a terrain.

1.3 Scope of study

Different approaches are applied here for the geomorphometric analysis of the same study area.

Channels and ridges are elements of major morphological significance in the physical landscape. As rightly pointed out by Mark (1981) and Werner (1988 and 1972), although considerable progress has been achieved in the analysis of channel networks, the topologic and the geometric analysis of ridge line and ridge patterns has received much less attention.

Using the techniques of analytic topology and graph theory, Pfaltz (1976) promoted the concept of surface networks as a means for surface description which is particularly well suited for mathematical analysis and computer representation. Starting from peaks as points and using the graph theoretic approach, Mark (1981) demonstrated that 'minimum spanning trees' (MST), connecting peaks by straight lines with minimum total distance, matched the actual topology in most of several hundred sets of six peaks each. The match was most impressive in the homogenous topography of the Big Sandy Basin in Kentucky with considerable reduction in fit in the California Coast Range.

A different test in an earlier paper (Mark, 1979) was less convincing but did show resemblance between observed frequencies of the six possible graphs connecting six summits, and those from random simulations of points within ellipses of varying orientations. 'Chains' of six peaks were most common in each study area, followed by chains of five, with the sixth summit branching off at one end, and thirdly, with the sixth summit branching off in the middle. More compact graphs were much less common, even for circular areas.

In a purely topological approach, Werner (1988) has applied graph theoretic concepts to interlocking ridge and channel networks and provided definitions of several new terms such as 'bicorn', 'intermediate path' and 'drainage complex'. A drainage complex is bound by one ridge path and one channel path, joined by extending the two peripheral outer channel links up slope lines to the ridge junctions above.

Werner defines ridges initially in terms of a plan convexity threshold which, in simple fluvially-dissected topography provides a 'connected tree' topology which is trivalent, i.e. all junctions involve three links only. At least one ridge occurs between each pair of outer channel links.

Crucially, he later on eliminates all but one ridge link between any two outer channel links. The link retained is that which has least gradient and is attached to the ridge 'tree'. This reduced ridge network is termed the 'interlocking ridge network' which is a dual of the channel network: the alternating outer links establish a topologically symmetrical relationship.
Werner (1988) proceeds to test the independence of these dual networks in terms of the number of links in the channel path and the ridge path which together bound a drainage complex of a given magnitude. (Magnitude is defined by the number of outer channel links contained). The method by which a sample of drainage complexes is drawn is not stated. Not surprisingly, given the way the interlocking networks are defined, he rejects the notion of independence, even though the channel network or the ridge network considered alone is more or less topologically random. The combined channel plus ridge link length of the bounding path is considerably less varied than expected on the hypothesis of channel and ridge independence. This seems to reflect the operation of geometric constraints: for a very small or very large number of links to bound a given drainage complex would require excessive variations in either link length or angular relations, between links on the bounding path and those within. Such variation is very unlikely within topologically random networks.

Werner's test is only partial, but it does seem to be a test of the obvious. An important drawback of his approach is that it is unlikely to provide useful information about the ridge network, since the number of outer ridge links is determined purely by the number of outer channel links. The term 'divides' is more appropriate than 'ridges' for his interlocking network.

If ridges were defined consistently, it might be possible to learn how they relate to the independently-defined channel network. Presumably the closeness of this relationship would vary regionally, especially with structural and tectonic control, and with glaciation and complexity of denudation chronology.

As yet, the fruits of applying topological approaches to ridge networks have been limited. Geometric approaches are to be preferred. For example, the existence of summits on ridges guarantees that their profiles will have greater average gradients than intervening river channels. The analysis of mountain ranges bounded by valleys and low passes is appropriate for summits and for ridge networks, as is the analysis of drainage basins for channel networks. Werner's 'drainage complexes' seem to be an unhappy compromise between these two, useful only in providing neutrality as between ridges and channels.

A viewerlooking at two overlapping aerial photographic images of mountainous terrain pseudoscopically perceives the three dimensional model in reversed relief, i.e. the depressions and the drainage is elevated and the ridges are depressed. This dramatic appearance of the ridge pattern to be geometrically similar to the stream pattern led to the idea of analysing ridges by a technique which has been successfully used for the quantitative analysis of drainage patterns. In this approach, the streams are ordered starting from 1 and the numerical order increases as a stream meets another stream. This is usually a manual technique and involves the measurement of the total lengths of streams of different orders covering the study area. The results have been expressed in terms of stream densities per unit area and by bifurcation ratios.

The primary interest was to apply such analysis to the ridges in the study area. This was further extended to define the magnitude (relative height) of summits and to analyze the density and the distribution of summits. A summit, for this study, is defined as any terrain point which is enclosed by two or more contours. Terrain characteristics such as number of summits per linear length of ridge, average height of the summits, etc. were then evaluated as discussed in detail in Chapter Three.

Various attempts made in the use of computers for terrain analysis have differed in two major respects - in the way the terrain data has been collected and in defining the geomorphometric characteristics of the terrain. Mark (1975) has concluded that, for a given number of points, the 'surface-specific' terrain data results in a more accurate representation of the form, as compared with the surface-independent data for which the most common format is a uniform grid mesh.

In order to study the relief (altitude range) for grid squares at different sizes, altitude data were captured for the highest and lowest points in each 1 km x 1 km grid block for all the Thaniyat Turayf area. For subsequent analysis at 2 km grid intervals, the 1 km data were reprocessed for the larger aggregates. This analysis is presented in Chapter Four. In a more detailed grid-based approach, altitude data were captured for regular grid points for only part of the Thaniyat Turayf area. Evans (1979) has presented several convincing arguments in support of computer-assisted techniques for terrain analysis. This includes the use of digital ground models (DGM) which can be easily acquired from aerial photography or from good maps. It was decided to apply the integrated terrain analysis system developed by Evans to the selected area in Saudi Arabia.

The basic input data to this analysis is altitude at points over a uniform grid mesh covering the area; ideally it should be captured by photogrammetric processing of good-quality aerial photography of the area. However, in the absence of the availability of such a data base at the University of Durham, it was intended to use the existing topographic maps of the study area and to manually extract the digitized ground model data at a small grid interval compatible with the scale of the map. A grid mesh of 100 m was used, for 1:25,000 maps with photogrammetric contours at a 10 m vertical interval. The details of the procedure used and the results obtained are discussed in Chapter Five.

The primary interest was to demonstrate the application of these different methods of approach in facilitating interpretation of landforms in this part of Saudi Arabia, and providing quantitative measures of terrain properties which are often expressed qualitatively. The meaning of these various results is summarised in the concluding Chapter Six, and comments are made on the value of the different methods.

CHAPTER 2

THE THANIYAT TURAYF AREA; BACKGROUND AND GEOMORPHOLOGY

CHAPTER 2

The Thaniyat Turayf area; Background and geomorphology

2.1 General Remarks

This area was chosen for study because it is representative of the arid terrain in Saudi Arabia, and suitable for this type of analysis. Also, it is the only part of Saudi Arabia for which topographic maps were available in Durham. Another reason was the fact that no detailed study of this area exists, excepting the part covered by one of the 16 map sheets "Thaniyat Turayf Quadrangle" which area is known to contain large phosphate deposits. Since the discovery of the phosphorite in this area in 1965, several studies of this area have been made which include J.W. Mytton 1967, C.R. Meissner and A. Ankary, 1972, J.W. Berge and J.Jack, 1982, R.L. Walderich, 1969, V.J.Flanigan, 1969.

M.C. Mew 1980 p.172 states that:

> "Thaniyat lies to the southeast of Turayf and is 320-380 km from the Gulf of Aqaba and 210 km east of the Hejaz railway. The highest average phosphate values were found along a 10 km stretch near the centre of the line of cliffs named 'west Thaniyat'."

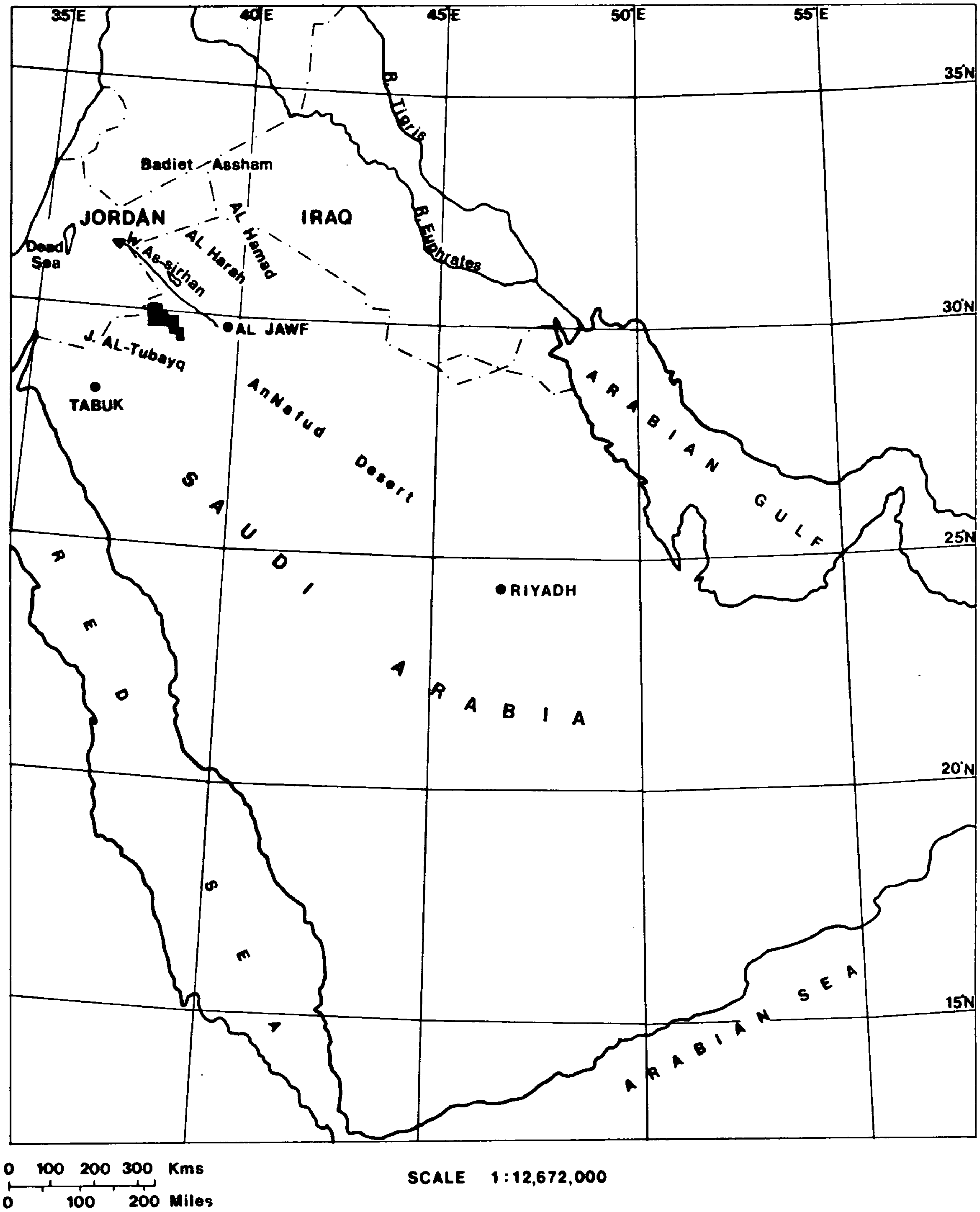
> "At the west Thaniyat the zone contains two beds of phosphate. Six core holes were drilled in a pattern behind the face of the outcrops and they range in depth from 30 m to 103 m. The results of the drilling indicate that the bed trends north-northwest in the subsurface from its outcrop for about 10 km and thins out to the east and west."
> C.R. Meissner, 1970 p.58.

2.2 Geographical location and position

The Thaniyat Turayf study area is located in the north western region of Saudi Arabia between 37°45' to 38°22' 33" East longitude and 29°22' 30" to 30°07' 30" North latitude, see Fig. 2.1. Its total area is about 2,500 sq.km. The scale of the maps used is 1:25000. This area is situated on the borderland between Saudi Arabia and Jordan.

Fig. 2.1

Location and position for Taniyat Turayf area in N.W. Saudi Arabia.



SCALE 1:12,672,000

In fact, the western part of Thaniyat Turayf area at one time used to belong to Jordan. In 1965, however, Jordan surrendered its sovereignty over this area to Saudi Arabia as part of a new border agreement.

The area is surrounded by many different types of topography. West of the Thaniyat Turayf area there are Jabal Al Tubeiq between Jordan and Saudi Arabia; to the east the Wadi As-Sirhan basin (300 km x 30 km) lies in the west of the northern hills of Saudi Arabia 600 m above sea level, the wadi As-Sirhan runs through it between Al Azrq in Jordan and Al Jawf in Saudi Arabia. The width of this 'wadi' is about 16 km. North east of Wadi As-Sirhan volcanic activity has produced an area of large basalt flows named Al Harah.

Between Al Harah and Wadi As-Sirhan is sabkhah Hazouza which has deposits of silt, clay and muddy sand, commonly saline. This sabkhah is fed by the short wadis flowing from Al Harah. Northeast of Al Harah is the Al Hamad basin which stretches from Saudi Arabia to Syria and Iraq.

The Nefud desert is south east of the Thaniyat Turayf area. This is the position for the study area in Saudi Arabia but outside of Saudi Arabia there are Badiet Esh Sham (Syrian Desert) at the far north, the Dead Sea at the west in Jordan and the Euphrates Lowland in Iraq to the east (Fig. 2.1).

2.3 Physical Characteristics of the Study Area

2.3.1 Climate

The climate of the area is dry and very hot in the summer, and moderate in the winter. Temperature conditions are typical of the hot desert type with wide variations from summer to winter and from day

Fig. 2.2 Mean annual maximum temperatures (°C) in Northern Saudi Arabia

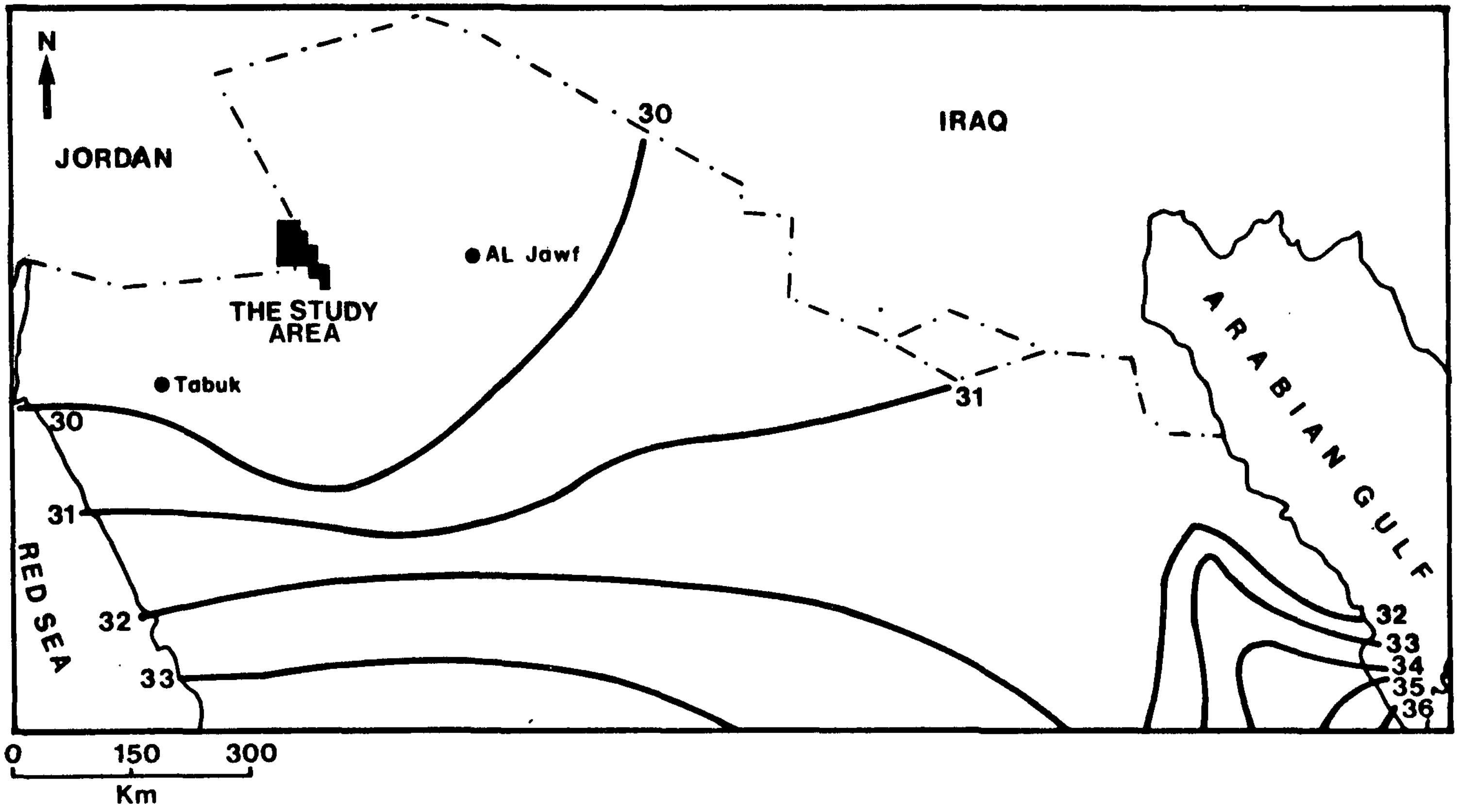
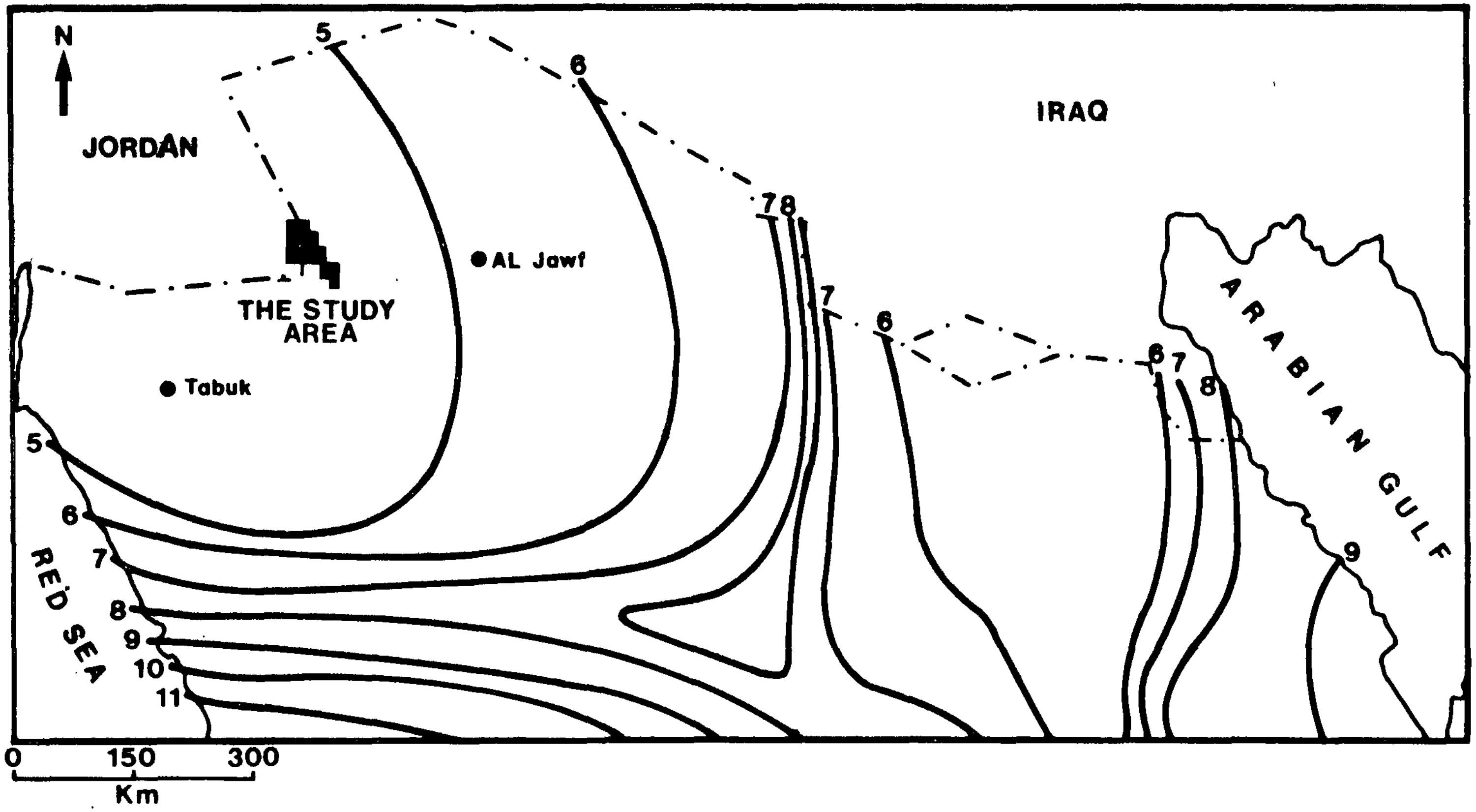


Fig.2.3 Mean annual temperatures of the coldest month (°C) in Northern Saudi Arabia.



to night. These result from a clear sky, high insolation, aridity and low vegetation. The daily variation in temperature is about 15°C and the coldest months in this area are December, January and February. Due to the absence of cloud cover during the winter, frosts are common and the temperature on many occasions falls below 0 °C. Figs. 2.2 and 2.3 show the temperature distribution in the northern S.A.

Table 2.1 shows the temperature and rainfall in Tabuk which is located south west of the Thaniyat Turayf area at 36°35' East longitude and 28°24 North latitude.

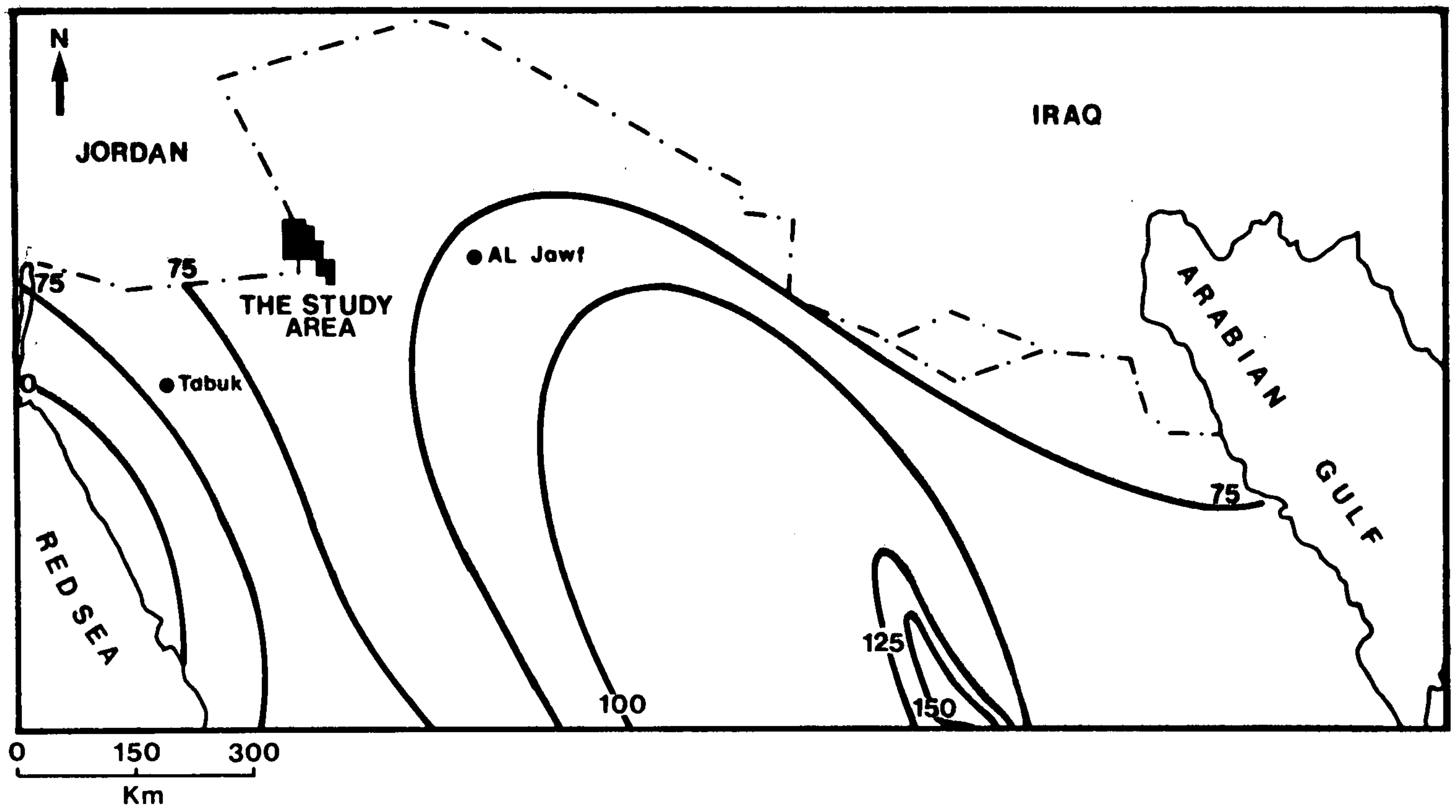
Table 2.1 Temperature and rainfall in Tabuk, N.W. Saudi Arabia

	Jan.	Feb.	Mar	Apr.	May	Ju.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Mean Min. Temp.°C	-1.1	0.0	2.7	4.8	11.7	16.8	18.2	19.2	15.5	8.9	5.1	1.8	
Mean daily Temp.°C	12.2	14.1	17.7	20.5	25.5	28.0	29.6	31.0	28.0	22.2	17.5	14.5	
Mean Max. Temp.°C	25.6	28.7	32.7	36.3	39.2	41.0	42.7	42.3	40.5	35.4	29.9	27.1	
Total amount of rainfall (mm)	15.7	0.2	10.2	1.1	8.8	0.0	0.0	8.2	6.6	1.9	18.4	5.0	76.1

From Takahashi and Arakawa 1981

For most of Saudi Arabia "the rainfall generally lower than 100 mm is accompanied by intense summer heat giving very high evapotranspiration rates." (H.Bowen-Jones and R. Dutton, 1983, p.18). The rainfall in this area usually occurs at the beginning of the winter season and has a low average because it lies on a transition zone at the junction between the Mediterranean, winter rainfall type and the Monsoon, summer rainfall variety. Rainfall is between30&50 mm per annum and part of it falls as heavy rain during thunderstorms. Fig. 2.4 shows the average annual rainfall in north Saudi Arabia. Sometimes this type of rainfall causes damage for people and soil as "in 1969, 400 km of a newly constructed highway in Central Arabia were washed away by one night of rainfall, and in 1945 Damascus (annual average 240 mm) received 100 mm in a single morning." Fisher 1978, p. 66. The relative humidity in Thaniyat Turayf area is low throughout the year, but especially in the summer. An important climatic feature is the Shamal winds which blow over the northern and middle parts of Saudi Arabia. "Twice a year, in December-January and May-June, the Shamal season of north west winds occurs. The length of the Shamal season varies from year to year but may range from a few days to 50 or more." D.A. Holm , 1960, p.1370. "The windy season in northern Saudi Arabia extends from late fall to late spring." J. Whitney et al.1983, p.5. The wind generally blows from the southwest or northwest, sometimes causing severe dust storms.

Fig. 2.4 Average annual rainfall (in mm) in Northern Saudi Arabia.



Sand storms are whipped up very strongly from March to May in this area reducing visibility to zero. The following statement about the climate of Kuwait applies also to northern Saudi Arabia :

> "The dry and hot north-westerly winds (Simoon) that prevail in the early summer, due to the effect of the monsoonal low pressure system, are mostly associated with dust-storms." Khalaf, Gharib and Hashah, 1984, p.13.

There is also some "cyclone" activity in the spring and summer.

2.3.2 Vegetation and soils

The rain, which falls mostly at the beginning and end of the winter season, is quite inadequate to support agriculture. Only scattered bushes and grass cover some parts of this area after heavy rain and the agriculture is entirely dependent on well water.

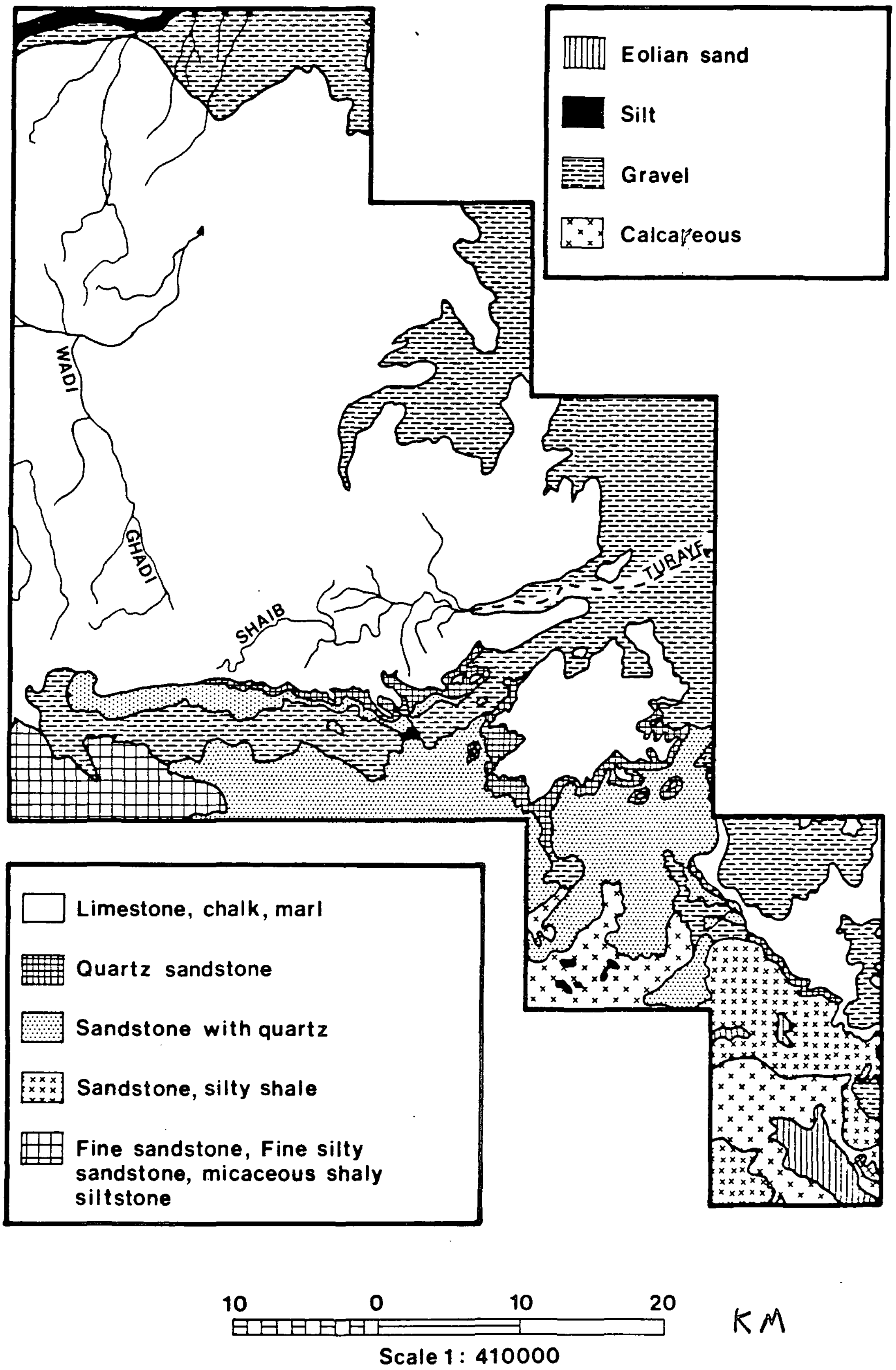
The stable dunes of the sandy part of this area support a variety of shrubs, grasses and herbs. "The most common dune grasses are Panicumm turgidum, stipag Rostis obtuea and Astenatherum forsskalu. The common perennial plants are Calligonum comosum, Artemesia monosperma, Artemesia abyssinica, Monsomia rivea, Ephedra alata, Cornulaca monocantha, Haloxylon salicornicum and Scrophularea deserti." Vesey-Fitzgerald, 1957; E.S. Schulz, written commun.1982 in J.W. Whitney, p.27 1983.

At present the land under agriculture is limited, but there are many fertile areas which can be cultivated with water supply. There is vast potential agricultural land in the valley floors.

Wadis are partially filled by alluvial and aeolian deposits, forming thick layers of silt and sand. Soil erosion in this region

Fig. 2.5

Geology of the Taniyat Turayf area. N.W. Saudi Arabia



as in most of Saudi Arabia is very high because of the powerful flash floods and strong winds.

2.3.3 Geology

Most of northern Saudi Arabia is formed of different sedimentary rocks; from the geologic map of this area (Fig. 2.5) we can see nine kinds of rock. We may divide the study area into two geologic areas, Turayf and Fajr. Most of the Turayf area is a plateau of limestone, chalk and marl. Northeast of this plateau are the Al Busayta plains of gravel, primarily coloured tan to brown and cream to white. In the far north at Al Ghinah wadi there are some silt and associated fine sediments, as well as in the south of Turayf wadi. South of Turayf there is some quartz sand stone at the Jibal Al Howsa footslope, and below this is a gravel piedmont, narrower than the plains to the northeast. In the Fajr area there are limestone, chalk, marl and gravel in the northeast, sandstone and calcareous duricrust in the northwest. In the southwest of Fajr there is some silt at Ashshibliyat, quartz, sandstone and silty shale in the middle and sandy limestone or calcareous duricrust in the south. Eolian sand in the south eastern part of the Fajr area is mostly mobile and forms the northwestern end of the Al Nefud Al Kabiar desert.

2.3.4 Topography

The topography of this area is quite similar to the adjacent topography. This area is part of two different types of topography, Wadi As Sirhan and the Great Nefud desert.

The study area is part of the group of the west wadis which collect in wadi As-Sirhan. "The Sirhan-Turayf basin in the northwest corner of Saudi Arabia developed either as a sag in a structurally flat area or as a result of the growth of the Hail arch to the east. The southwest flank of the Sirhan-Turayf basin may be a half graben controlling the present course of wadi As-Sirhan, a broad elongate trough." (Powers and others, 1966).

The topography of the southeastern part of this study area is similar to the Great Nefud desert where wind action is clearly visible by the sand dunes. "The Nefud desert of the north is almost as inhospitable and from it extend great lobes of sand dunes." (Bowen-Jones and Dutton, 1983, p.19) "... Violent winds in the Nefud, which spring up and die down with equal rapidity. Owing to the local character of these winds, sand dunes in many parts take on the barchan form, but because of extreme local variability and strength of the wind, the dunes are aligned in many directions." (Fisher, 1978, p.496, 497)

Sixteen map sheets covering the Thaniyat Turayf area have been photographed and reduced to 50% size (1/50 000 scale) and 25% size (1/100 000 scale). Photos at a scale of 1/100 000 were cut and joined together on one sheet for all the study area. From this sheet they were rephotographed for printing at different scales. These are reproduced here at 1/400,000 scale for the whole study area (Fig. 2.6), and at 1/148 000 scale in five sheets (Figs. 2.7 a,b,c,d, and e). The geomorphologic map was drawn from a print at 1/200 000 scale and reduced to 1/400 000 for Fig. 2.8.

The summit levels are between 1,045 m in the south west and 690 m in the northeast. The highest summit is Al Qasimah (1048 m) at the headwaters in Qasimah wadi, at the south west corner of the Thaniyat Turayf area. The heights of the lowland and valley floors are between 627 m in the northeast and 998 m in the southwest.

FIG. 2.6

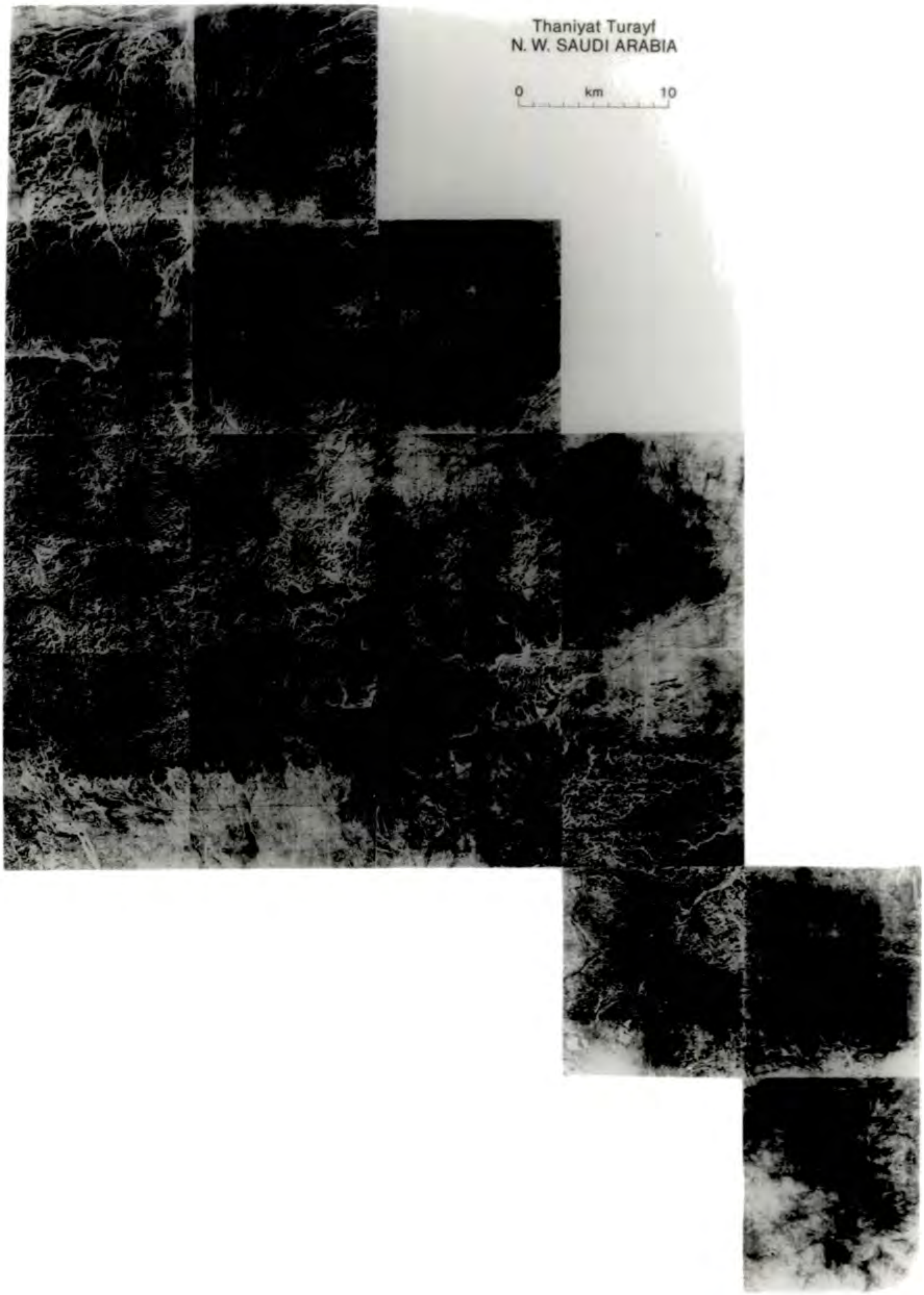


Fig. 2.7.a

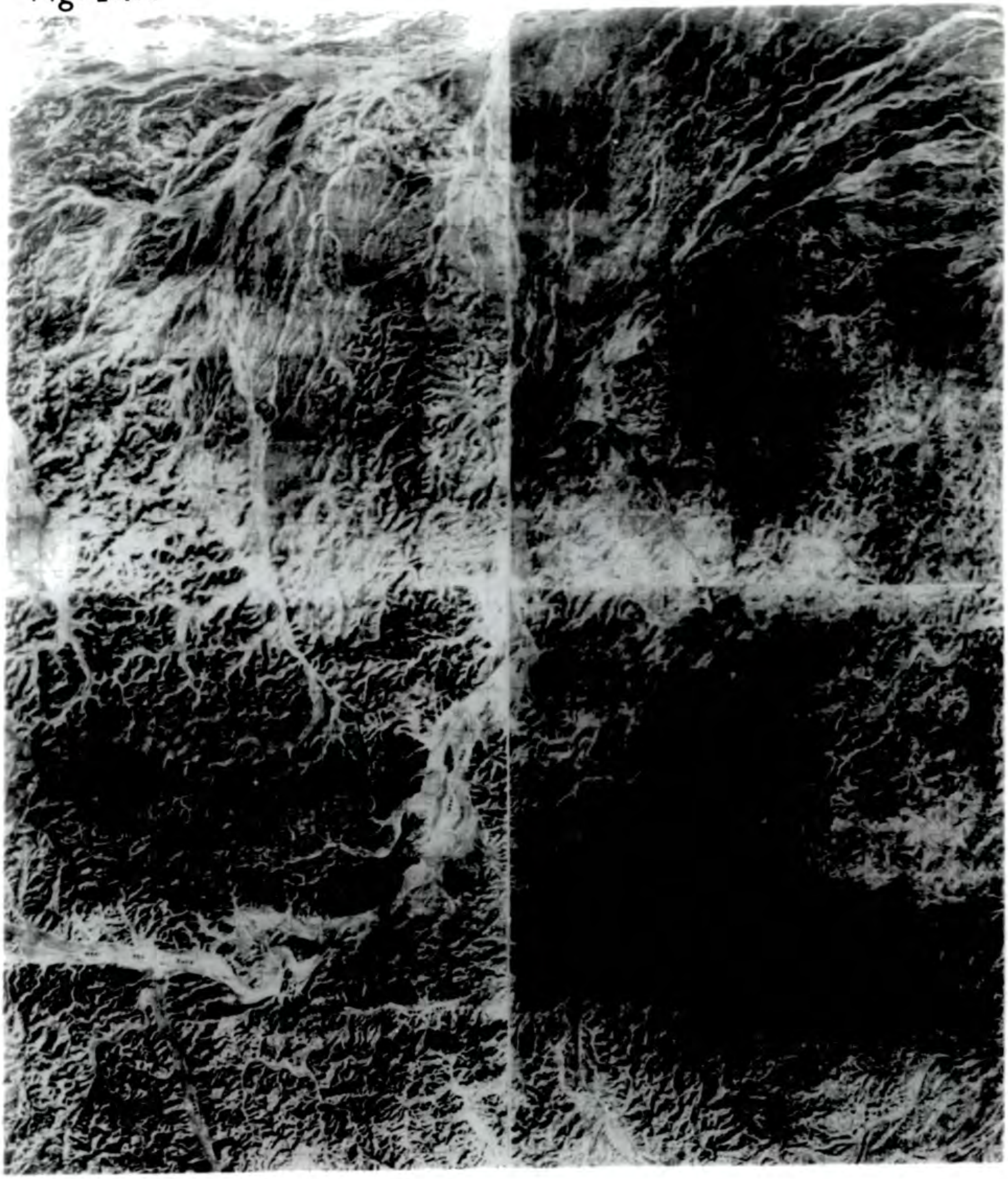


Fig. 2.7.b

Thaniyat Turayf
N. W. SAUDI ARABIA

0 km 10

Fig.2.7.c

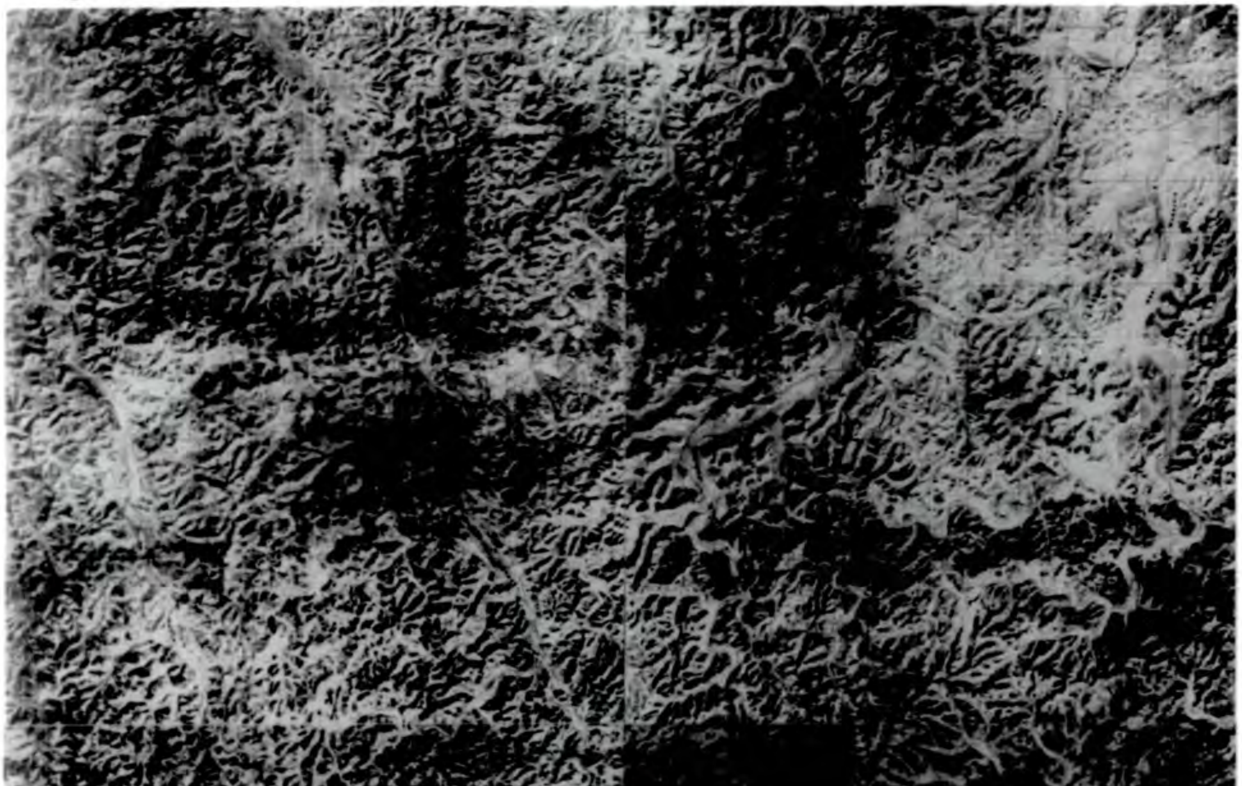
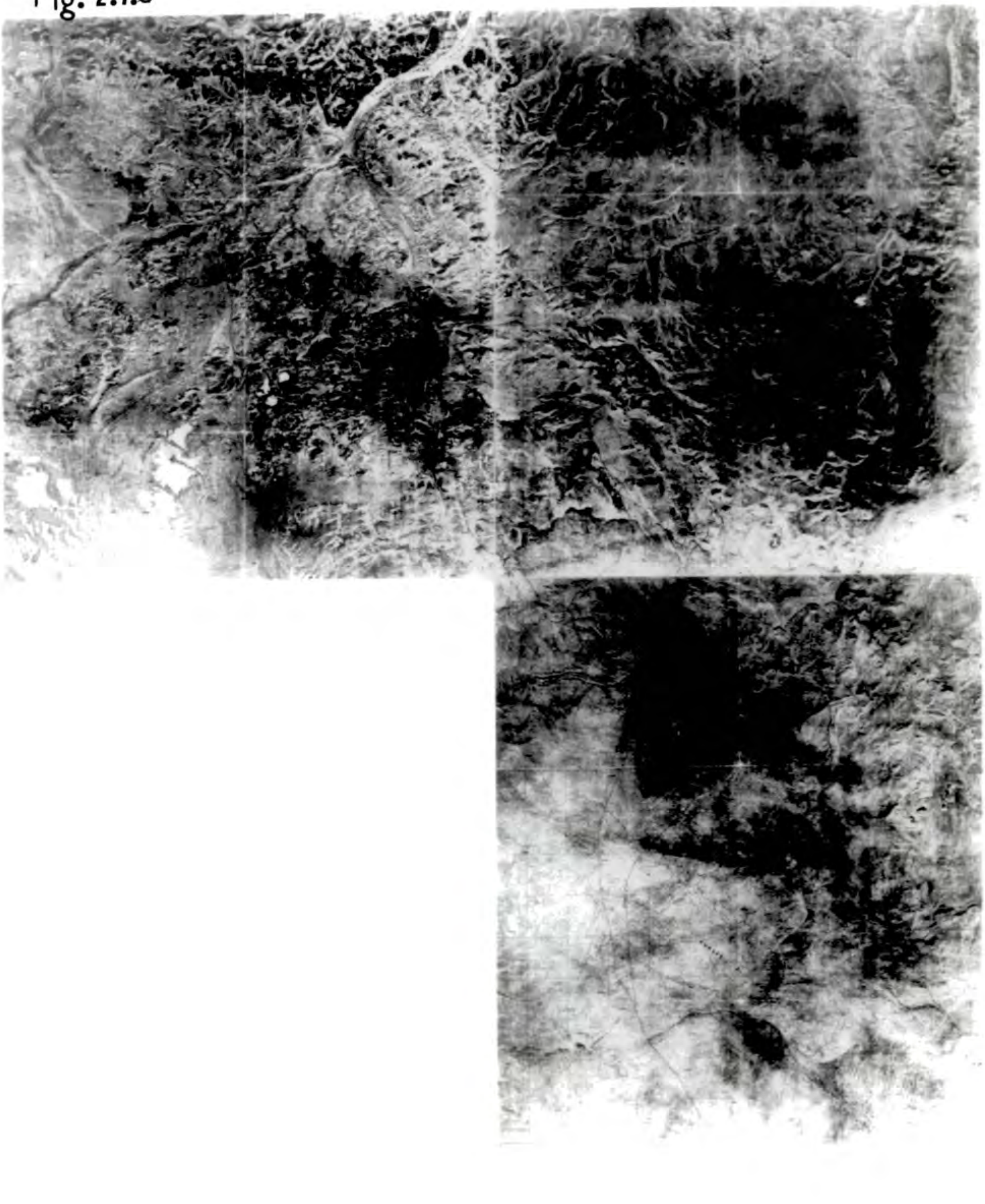
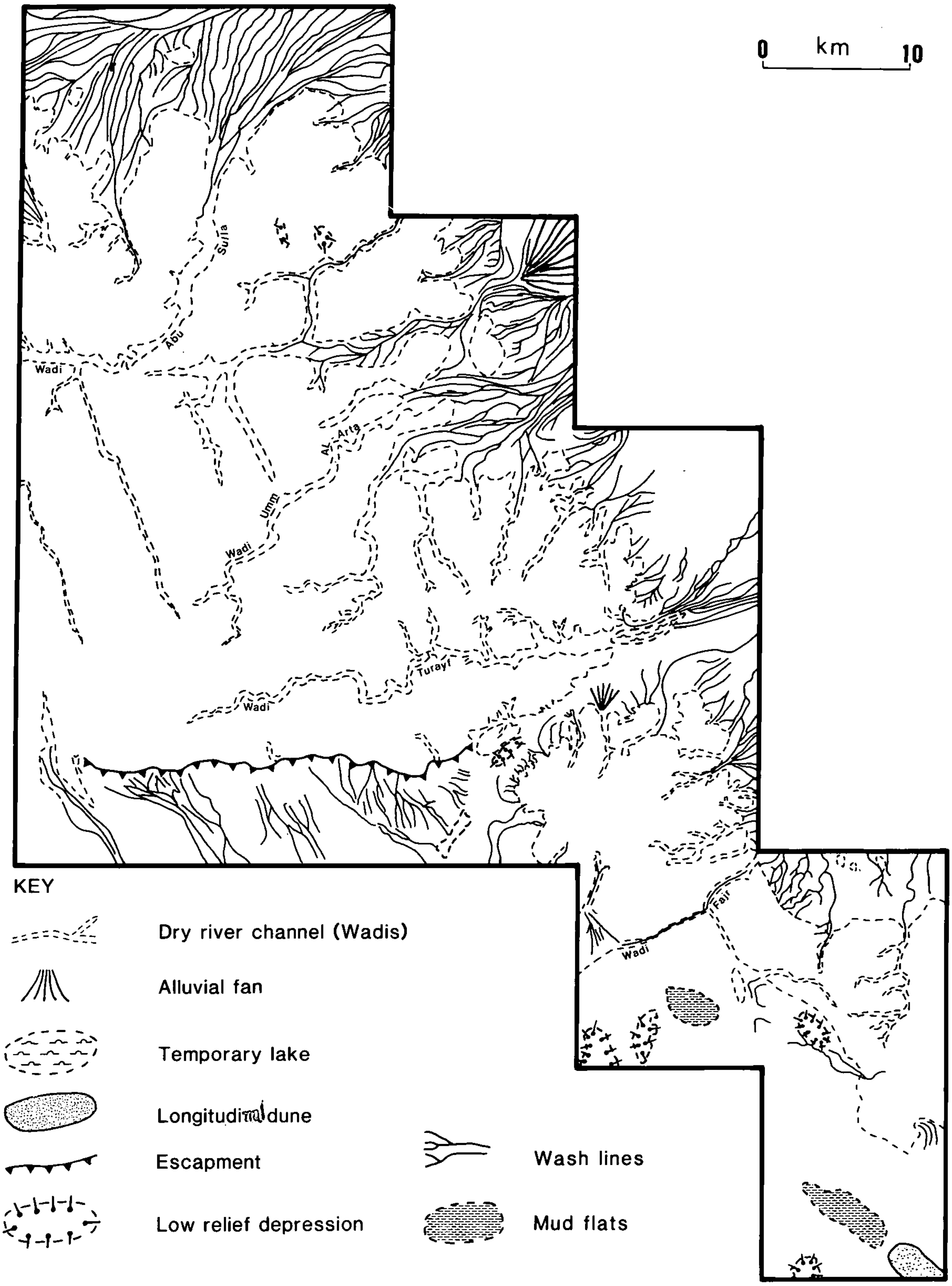


Fig. 2.7.d

Fig. 2.7.e



FIG·2·8 Geomorphologic map of Taniyat Turayf area N.W. Saudia Arabia



The geomorphologic map of Thaniyat Turayf area (Fig. 2.8) shows the drainage, e.g. Wadi Fajr, mainly flows to the northeast but wadi Turayf flows from west to east. Wadis Umm Alarta and Al Mudaysis initially flow northward, but then curve toward the north east. Al Ghinah wadi flows northward and then curves toward the east. Wadi Abu Sulla flows eastward but then curves toward the north and then to the northeast.

The geologic map shows that the main escarpment facing south is formed by three types of rocks, a resistant formation of quartz and sandstone below, then less resistant, poorly consolidated quartz and sandstone, and in the top a resistant rock of hard, chalky, nummilitic limestone. The scarp's height rises from 130 m in the east to 190 m in the west. It is linear, but dissected by valleys up to 4 km long, such as wadi Abu Tulayhah in the east. At the western edge of the study area wadi al Qāsimah has a much longer valley trending south.

Most of the plateau is well dissected by valleys, but in the northwest part of the plateau is undissected. In the south, below the escarpment, there are deposits of silt and gravel washed down by the wadis. "Alluvial fans are deposits with surfaces that are segments of cones radiating downslope from points which are usually where streams leave mountains, but which may be some distance within the mountain valleys." (Cooke and Warren 1973, p.174). But the alluvial fans tend to be concave in profile (I.S. Evans, personnel communication) Alluvial fans are found in the south below the escarpment, and in the east. The orthophoto maps show 'wash lines' formed by occasional flood discharges in wadis and where they flow onto the plains. These are common in the north and east of this area, as well as in the

south. Some temporary lakes form in the wadis after rain, for example at the end of Wadi Turayf. Low relief depressions occur in many parts of this area especially in the southeast corner. Longitudinal sand dunes reach the southeast of this study area, at the northwestern end of the Nefud. Hence in this part of the study area the topography changes from steep slopes to flat plain and the ridges are gentle.
To give an impression of the landforms in this region of Saudi Arabia, some photographs of the Al Harah area (near Thaniyat Turayf) were taken for me by the Ministry of Agriculture and Water. (Figs. 2.9 - 2.18).

Fig. 2.9 Typical limestone formation merging with sand and gravel plain.

Fig.2.10 Representative of flat plains and gentle ridges topography of the area.


Fig.2.11 Eolian sand and gravel plain.


Fig.2.12 Typical sandy gravel plain coloured cream to brown.

Fig.2.13 Arid desert topography showing mostly north-easterly steep slopes

Fig.2.14 Typical sandstone escarpment showing depressions filled with silty shale.

Fig.2.15 Sedimentary sandstone formation.

Fig. 2.16 Sedimentary sandstone and calcareous duricrust.

Fig.2.17 Typical saddle formation in sandstone ridges.

Fig.2.18 Sandy sandstone formation rising from a silt and gravel plain.

CHAPTER 3

THE THANIYAT TURAYF AREA; MAPPING AND ANALYSING SUMMITS, RIDGES AND COLS.

CHAPTER 3

The Thaniyat Turayf area : mapping and analysing summits, ridges and cols.

3.1 Introduction

Summit mapping is a method for studying the topography of almost any area and land surface and is meaningful in comparing areas of the same structure. Previous work by Evans (1972b,unpublished) concentrated on glaciated mountains in British Columbia and in Britain.. The objective here is to test whether his method can usefully be applied to a very different topography of a dissected plateau in the Saudi Arabian desert.

3.2 Definition of summits, ridges and cols:

A summit is defined as a point from which the surface slopes downward in all directions. To make the definition operational, we include only those summits defined by two or more closed contours, so the threshold summit magnitude relates to the contour interval. Ridges are the water divide lines which joint summits to summits, and the lowest part between two summits on the same ridge is a col.

The measurement of summit height by altitude above sea level is not satisfactory, since the height should be defined in relation to the adjacent parts of the land surface; hence it is more useful to measure summit magnitude. Summit magnitude is the height of any summit relative to the height of a col on the same ridge, and the magnitude of a summit is measured by the number of closed contours.

A summit and ridge map has been drawn from the orthophoto topographic maps of Thaniyat Turayf area; see Figure 3.1. Summits have been located for every 2 closed contours of 10 m contour interval, and the intermediate 5 m contours shown in some of the maps have been ignored.

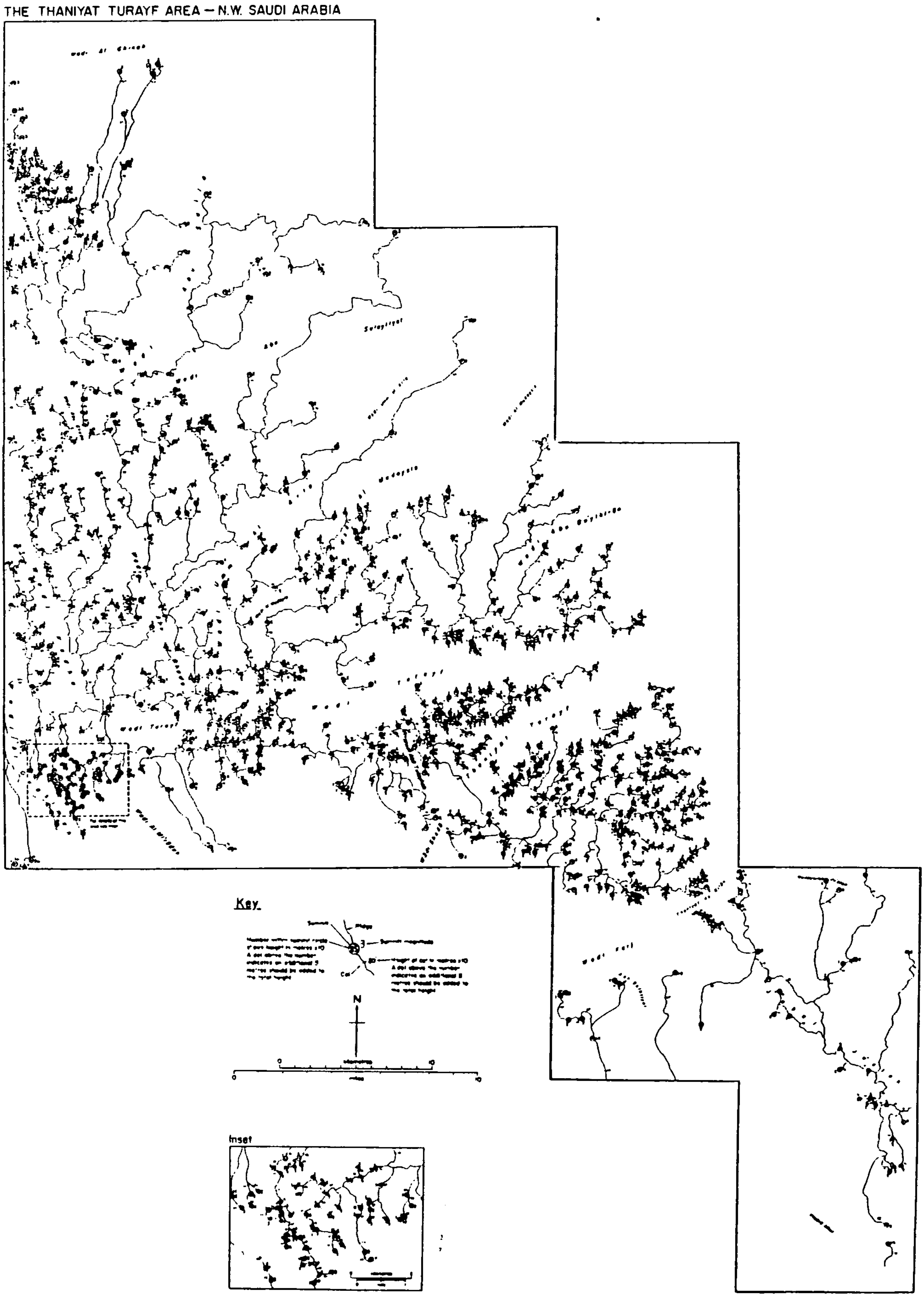
Ridges were drawn along the water divide lines to join summits together. Some ridges in the northeastern part are very long with slight undulations and low summit density because this part forms a plateau. The lowest part between two summits on ridges was located to calculate the magnitude for each summit.

Some summits on the fringe of this study area are difficult to define by ridges and cols because the maps adjoining the study area are not available. This affects especially the southern and western edges of the study area. Hence some difficulty was experienced in determining the summit magnitude for the highest summit in some mountain blocks, such as Al Howsa, Al Ghinah and Jabal Jualah. In the southwest corner of Jabal Al Howsa, the summits are very close to each other. This made it difficult to indicate some cols and ridges on the 1:50,000 scale map, and due to this reason it was necessary to double the scale for this area.

3.3 Distribution of summits, ridges and cols in the Thaniyat Turayf area

The topography is primarily a dissected plateau and in many cases the summits are about the same height, and not much higher than the cols which separate them. It was found that in 648 cases, the summit magnitude is defined by only two closed contours (about 20 m, or between 10 m and 30 m, if the contours are accurate). In the south, there is an abrupt escarpment terminating the Jabal Al Howsa with a cluster of summits in the southwest, together with some isolated

Fig. 3.1



(See the map at the end of the thesis)

summits. Here, around the headwaters of Wadi Turayf, the plateau is further dissected into separate summits and both the density and the magnitude of summits are generally greater. The method, developed by Evans (1972b)from the concepts of Cayley and Maxwell, works well in the dissected plateau but encounters some difficulty in the plains fringing the southern and northeastern margins where the magnitude as well as the density of summits are lower. Some of the ridge lines which link isolated summits to the main ridges cross pediments or bahadas; these are poorly defined and probably unstable over time, a single flood could change the pattern of wash lines and hence of ridge lines.

To calculate the summit density and the summit intensity for mountain blocks, the number of summits or the number of contour closures have been divided, respectively, by the length of the ridges as shown in Table 3.1, where in Evans (1972b)it has been divided by the area for every mountain block. This is because the length of ridge is clearly defined whereas for area measurement the limits of a mountain block may be difficult to establish in the surrounding plains. Summit density for any area is the number of summits divided by the total ridge length in the same area. The average summit height (magnitude) is (number of contour closures x contour interval)/number of summits.

There are four mountain blocks. Al Howsa Block is the largest, and was subdivided into four areas, A, B, C and D. The average summit height for Thaniyat Turayf area is almost similar in pattern to the summit density for the same mountain blocks (Table3.1), with the highest density in the Jabal Wailah (.990) as well as the greatest average summit height (26.95); the lowest summit density is in Jabal Jualah mountain block (.361) which also has the lowest average summit height (22.34).

Table 3.1 Measures of summit intensity for Thaniyat Turayf area

Mountain block	Ridge length km	Number of summits	Total* summit magnitude (m)	Summit density (per km)	Average summit height (m)	Closure intensity (m/km)
Al Ghinah	148.7	86	2080	0.578	24.18	13.98
Al Howsa:						
Block A	264.2	164	3760	0.620	22.92	14.21
" B	214.65	81	1830	0.377	22.59	8.52
" C	223.8	181	4560	0.808	25.19	20.35
" D	164.65	153	4000	0.929	26.14	24.28
Jabal Wailah	201.95	200	5390	0.990	26.95	26.68
Jabal Jualah	130.1	47	1050	0.361	22.34	8.07
Total Al Howsa	867.3	579	14150	0.668	24.43	16.32
Total for Thaniyat Turayf area	1348.05	912	22670	0.67653	24.85	16.80

* Number of contour closures x contour interval

Single-closure summits have been excluded. The resulting counts and parameters are presented in Table 3.2 which shows that the great majority of summits have a summit magnitude of two (or two contour closures). In the Thaniyat Turayf area there are 648 such summits, of which 417 are in Al Howsa mountain block. The frequency distribution is very skewed, with very few high-magnitude summits. The geographical distribution of summits in the Thaniyat Turayf area shows that the highest summit magnitude (16) is in Jabal Wailah mountain block. The Jabal Jualah mountain block has the lowest summit magnitude, with only 47 summits having magnitudes between 2 and 4. In the Al Ghinah mountain block, there are 86 summits with magnitudes between 2 and 7.

Figure 3.2 and Table 3.1 shows the closure intensity for this area. Jabal Wailah has the highest closure intensity (26.68m/km of ridge) followed by total Al Howsa mountain block. Jabal Jualah has the lowest closure intensity (8.07 m/km).

Some comparison is possible with similar work by Evans (1972b. unpublished) in the glaciated mountains of British Columbia in Canada using 100-foot (30.48m) contours. This has different landforms such as glacial troughs and cirques, which cut the ridges into series of prominent summits. The relief there, in the western Cordillera of America, is considerably greater than in northern Saudi Arabia.

Another glaciated area studied by Evans was Gwynedd in north-west Wales. This is lower than the British Columbia area and less strongly glaciated, but it is higher than Thaniyat Turayf area. It has the highest summit in England and Wales.

To compare the Thaniyat Turayf area with British Columbia and Gwynedd it was necessary to make the contour interval equivalent, at 30m. Table 3.3 for the summit distributions for all the three areas shows that Gwynedd has more summits (1534) than Thaniyat Turayf and

Fig. 3.2

Closure intensity in Thaniyat Turayf area — N.W. Saudi Arabia

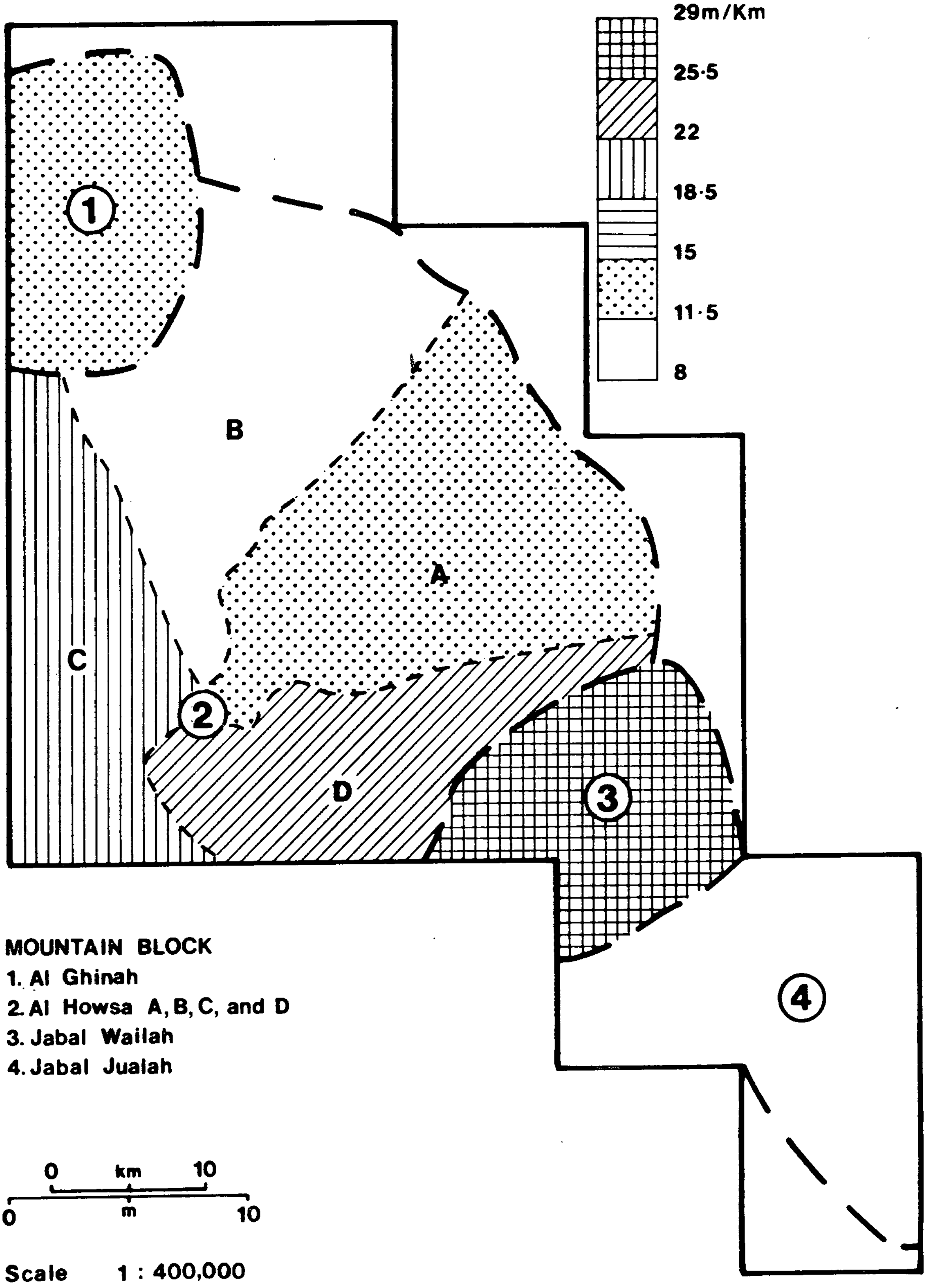


Table 3.2 Summit magnitude distributions for Thaniyat Turayf area

Mountain Block	Magnitude									$\sum_{2}^{\infty}$
	2	3	4	5	6	7	8	9	16	
Al Ghinah	65	12	6	1	1	1				86
Al Howsa:										
Block A	128	25	10	1						164
" B	65	12	3	1						81
" C	127	38	7*	3	3	1	1	1		181
" D	97	39	7	6	1	1		2		153
Jabal Wailah	129	41	13	10	2	4			1	200
Jabal Jualah	37	9	1							47
Total Al Howsa	417	114	27	11	4	2	1	3		579
Total Thaniyat Turayf area	648	176	47	22	7	7	1	3	1	912

* The highest point in the study area, Al Qasimah, has a magnitude of at least 4 (i.e. 104-100), but probably more. Maps to the west are required to determine this more precisely.

TABLE 3.3. SUMMIT MAGNITUDE DISTRIBUTIONS FOR THANIYAT TURAYF AREA, BRITISH COLUMBIA AND GWYNEDD

Metres	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480	510	540	570	600	630	660	690	720	750		
Closures (30m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	above 25	area km²
Total Thaniyat Turayf area	871	36	4	0	1																						250
Total Gwynedd area	1314	104	43	19	9	10	7	7	3	4	-	3	1	2	1	1	-	1	1	1	1	-	-	-	1	1 (33)	313
White Cap - Truax-Mission	179	63	30	19	13	12	9	6	3	-	1	-	-	1	1	2	1	-	-	1	-	-	-	-	-	2 (41+ 49)	
Mount Birch	101	18	14	8	6	3	4	2	1	-	-	-	1	-	1	1	-	-	-	-	1	-	-	-	-		
Rex - Shulaps - Bigdog	148	43	32	14	9	6	2	1	4	3	-	2	-	1	2	2	-	-	-	1	-	-	-	-	-	1 (44)	
Red Mountain	122	24	21	4	-	1	1	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1		
Yalakom-Ninemile	141	53	19	8	8	2	1	2	1	-	1	-	1	-	-	-	2	-	-	-	-	1	-	-	-		
Tyax -Gun	49	10	7	5	5	7	3	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1 (30)	
Black Dome	104	28	10	9	5	1	1	4	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-		
Total British Columbia area	844	239	133	67	46	32	21	15	9	4	3	3	3	2	4	6	3	-	-	2	2	1	-	-	1	4	454

B.C. Data is revised from 1986 except magnitude 1 for all Mountain Blocks, and Tyax-Gun, which are from Evans 1972b unpublished

British Columbia. Although the Thaniyat Turayf area has no summit magnitudes greater than 160 m, its summit distribution is similar to Gwynedd's, with the great majority of summits around 30 m, with a rapid decrease in number for greater magnitudes.

In British Columbia summits of considerable magnitude occur. In the Bendor Range the topography is high and as shown it has the greatest summit, at 1350 m. The Black Dome area in British Columbia is more similar to the Thaniyat Turayf area.

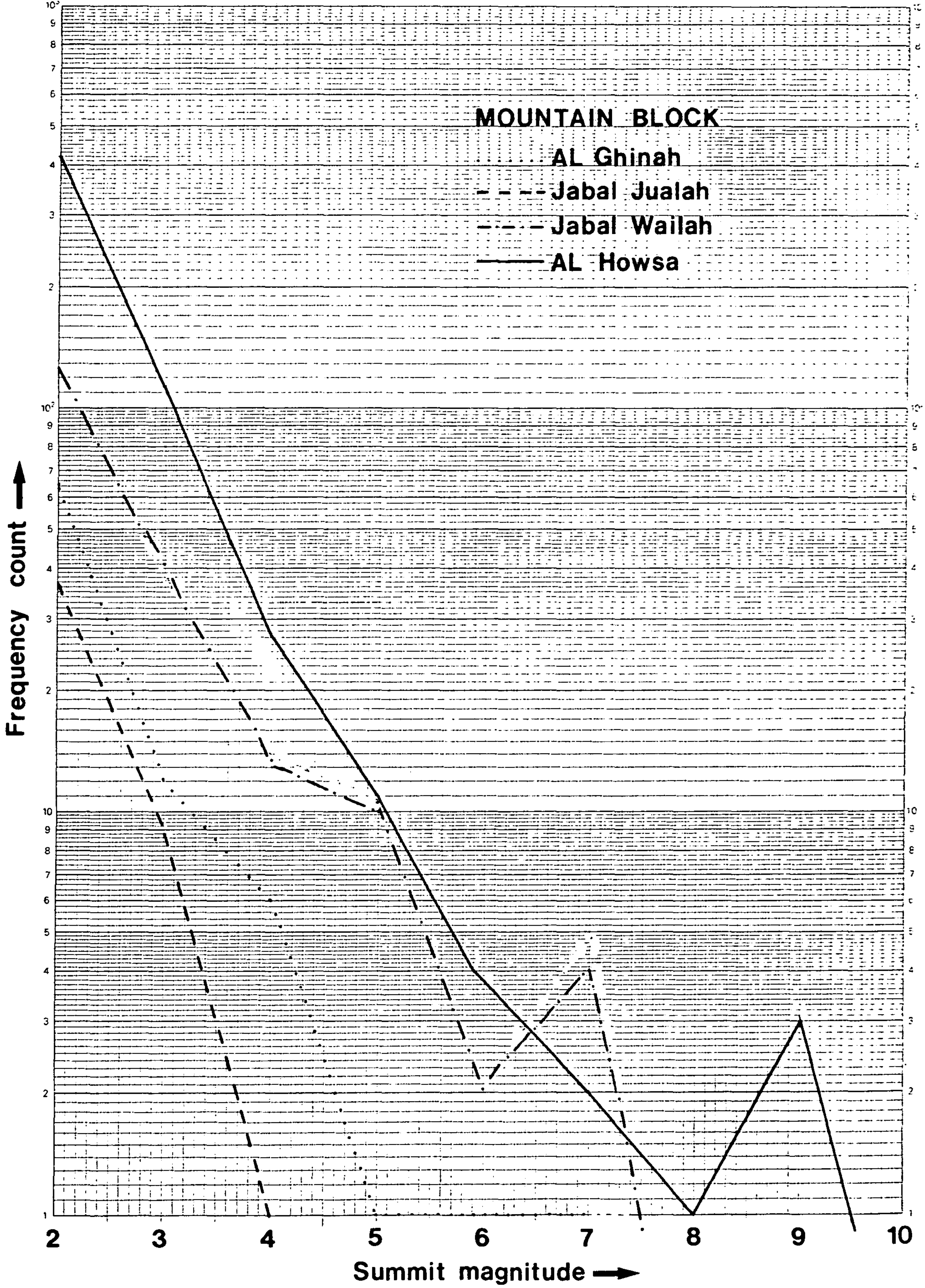
The logarithmic plots(Figures 3.3, 3.4, 3.5) for Thaniyat Turayf are linear perhaps because the area is fluvially eroded, but Jabal Wailah has a concave shape because it has a high value summit of 160m magnitude.

For the Bendor Range, Shulaps - Big Dog, which suffered intensive cirque and valley glaciation, the logarithmic plots Figures 3.6 and 3.7 are definitely convex. Mission and Tyax-Gun, less heavily glaciated but with numerous cirques, show convex tendencies, but Black Dome and Mount Birch, with only a few scattered cirques, provide straight plots, as does Gwynedd (Figure 3.8). As a provisional interpretation then, the convexity of most British Columbia plots may be due to glaciation. The Thaniyat Turayf area, more representative of fluvial terrain despite its desert location, provides the simpler logarithmic summit rank-size plot.

3.4 Ridge order

Ridge lengths for all mountain blocks in the Thaniyat Turayf area were measured and ordered as in Table 3.4. Starting from a terminal summit, a ridge remains a first order ridge until it meets another first order ridge. Where two first order ridges meet they form a

Fig.3.3


MOUNTAIN BLOCK
...... AL Ghinah
- - - - Jabal Jualah
-·-·- Jabal Wailah
—— AL Howsa
Frequency count
Summit magnitude
10³
10²
10
1
2
3
4
5
6
7
8
9
10

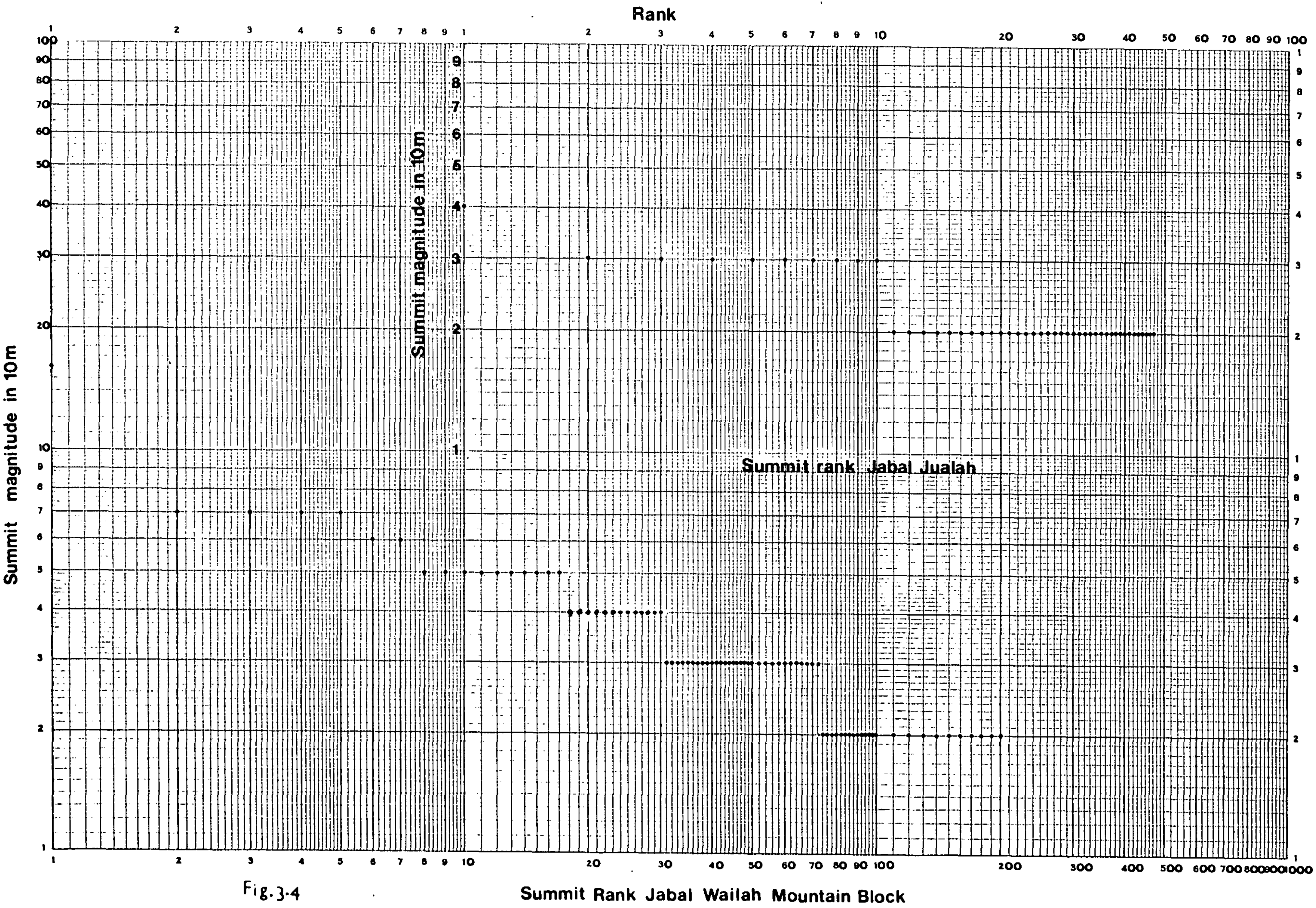

Rank
1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100
Summit magnitude in 10m
100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
9 8 7 6 5 4 3 2 1
Summit magnitude in 10m
1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1
Summit rank Jabal Jualah
1 2 3 4 5 6 7 8 9 10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800 900 1000
Summit Rank Jabal Wailah Mountain Block

Fig.3·4

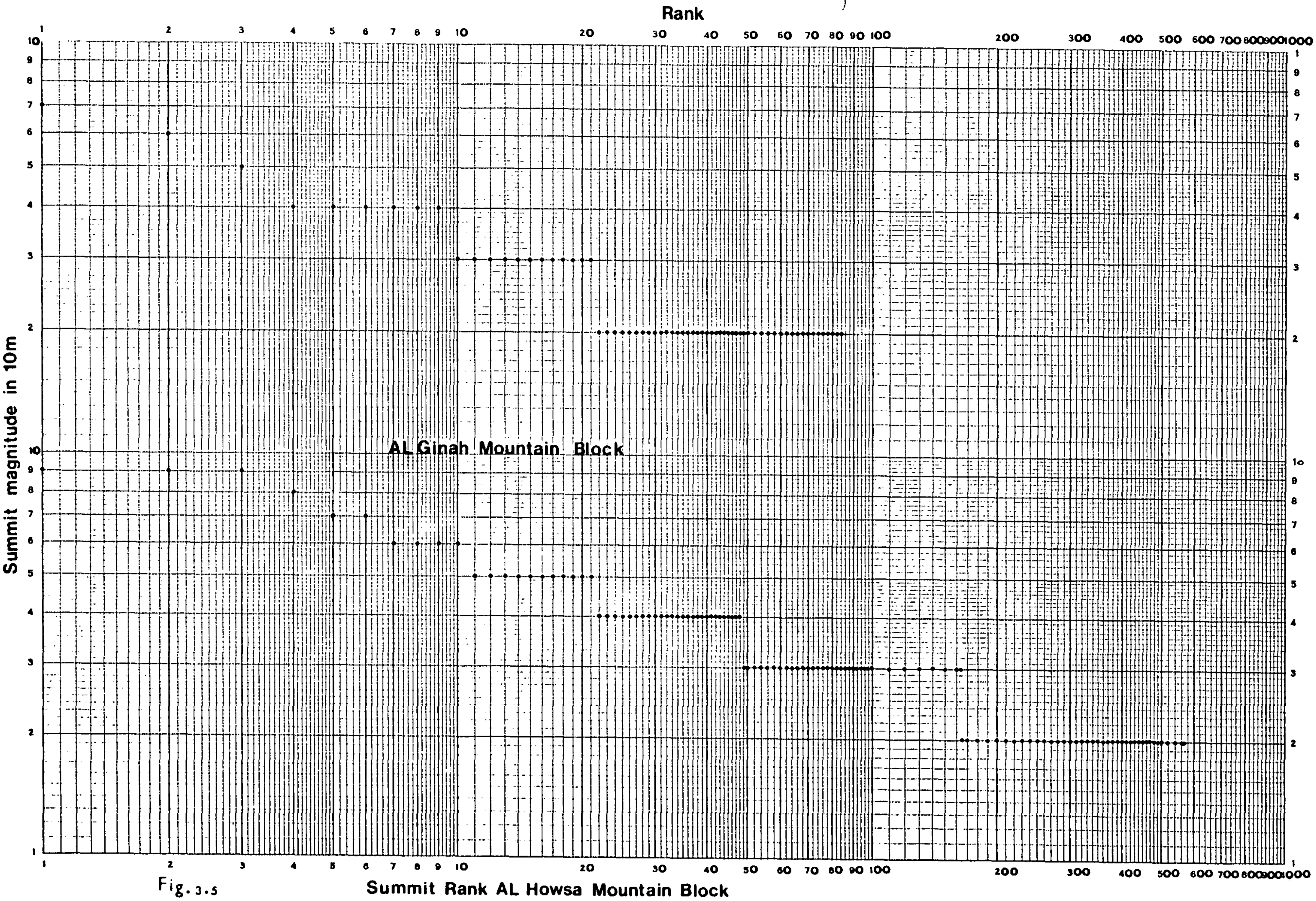

Rank
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
Summit magnitude in 10m
AL Ginah Mountain Block
Summit Rank AL Howsa Mountain Block

Fig. 3.5

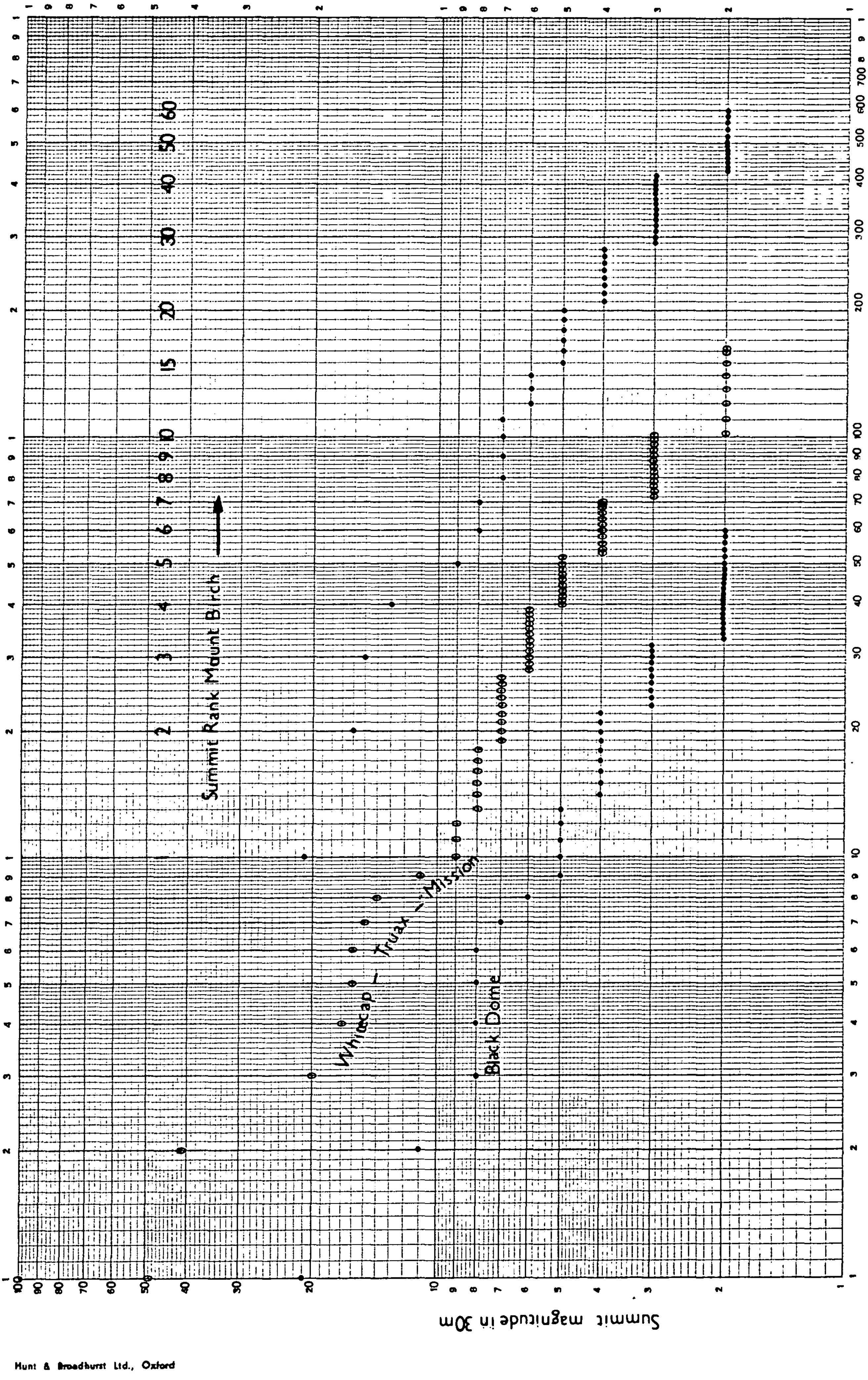

Summit Rank Mount Birch
Summit Rank Whitecap_Truax_Mission and Black Dome
Summit magnitude in 30m
Whitecap - Truax - Mission
Black Dome
2
3
4
5
6
7
8
9
10
15
20
30
40
50
60
100
200
300
400
500
600
700

Fig. 3.6

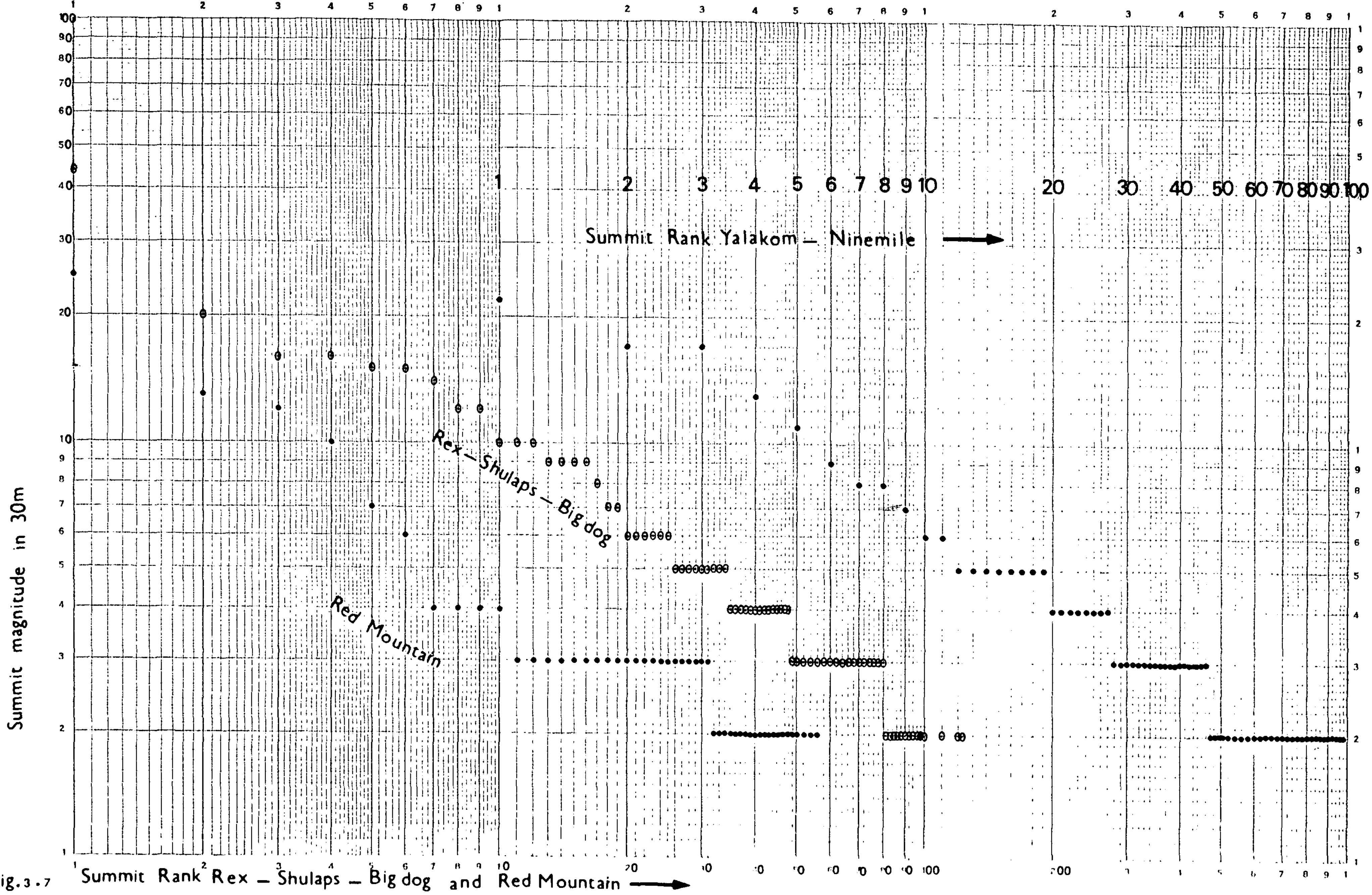

Summit magnitude in 30m
Summit Rank Yalakom – Ninemile
Summit Rank Rex – Shulaps – Big dog and Red Mountain
Rex – Shulaps – Big dog
Red Mountain
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200

Fig.3.7

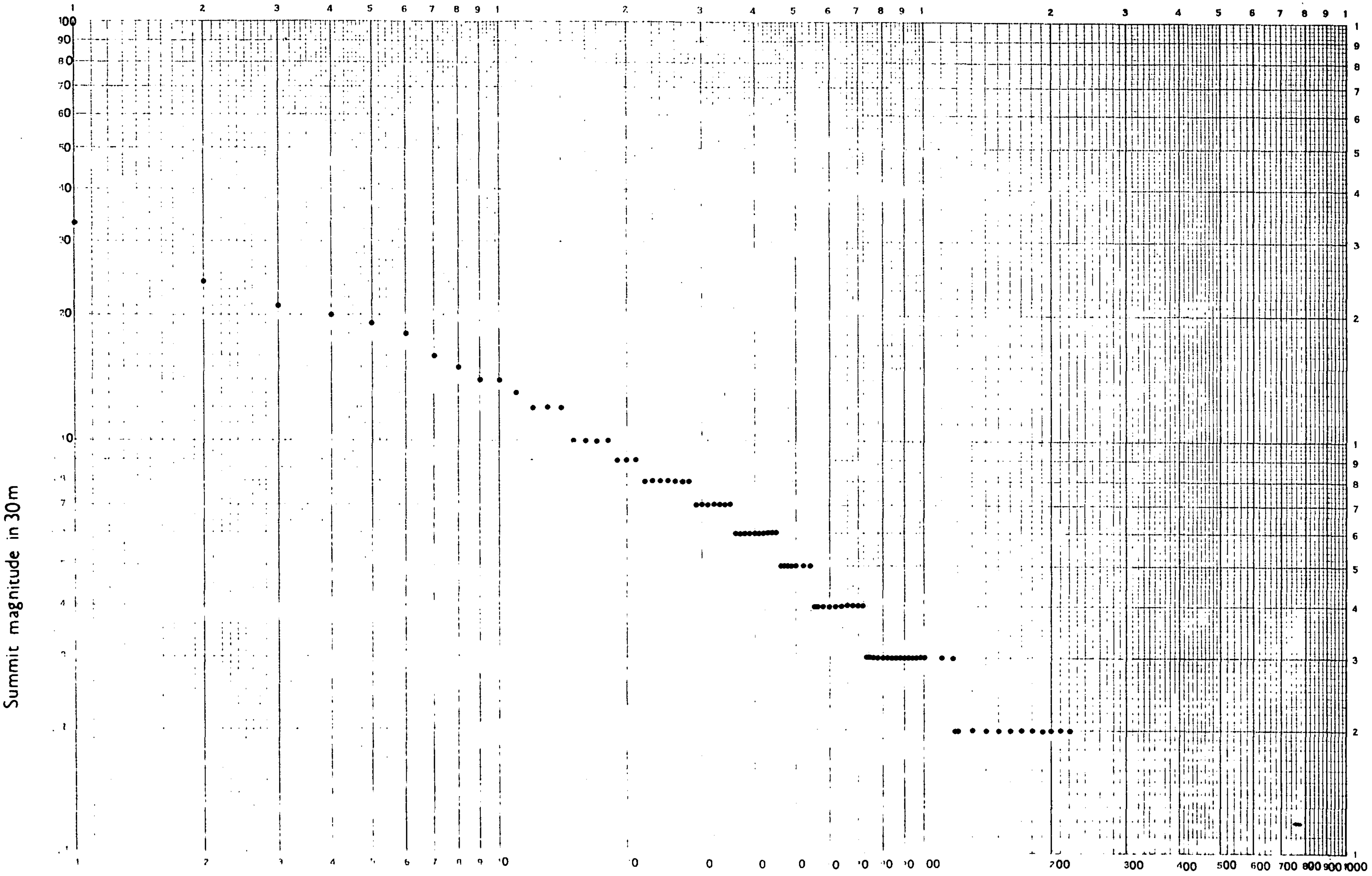

Summit magnitude in 30m
Summit Rank Gwynedd →
100
90
80
70
60
50
40
30
20
10
7
4
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000

Fig. 3.8

second order ridge, where two second order ridges meet they form a third order ridge, and when two third order ridges meet they form a fourth order ridge. A summit on a first order ridge is a first order summit and that on a second order ridge is a second order summit and so on. The number of first order ridges divided by the number of second order ridges defines a 'bifurcation ratio'. Evans suggests that the ordering of ridges may serve to reveal terrain regularities and variations.

In British Columbia and Gwynedd the results are quite similar to those of river system ordering, except that the bifurcation ratios are unusually high, see Table 3.5 (Evans 1972b. unpublished).

For all the Thaniyat Turayf area ridges defined by summits of magnitude two and more have been ordered as in Table 3.4. Figure 3.9 shows ridge orders from the second order to the fifth order. It shows also the main ridges which in Al Howsa and Wailah mountain blocks surround Wadi Turayf, the main topographic feature in this study area. The Jualah mountain block has only three ridge orders. The ridge bifurcation ratios are high, above (4.0) for most of mountain blocks.

It is not necessary to find the highest summit on the highest ridge order, as in Al Howsa mountain block the highest summit is 1048m and it is on a first order ridge.

Table 3.4 Ridge order in the Thaniyat Turayf area

A.

	Number of Ridges of order					Ratios			
	1	2	3	4	5	1/2	2/3	3/4	4/5
Al Ghinah	47	13	4	2	1	3.6	3.3	2.0	2.0
Al Howsa	271	62	14	3*	1	4.4	4.4	(4.7)	(3.0)
Wailah	88	21	5	1*	-	4.2	4.2	(5.0)	-
Jualah	24	8	1	-	-	3.0	8.0	-	-
Total	430	104	24	5	2	4.1	4.3	4.8	2.5

B.

	Number of summits on ridges of order					Averages per ridge				
	1	2	3	4	5	1	2	3	4	5
Al Ghinah	62	16	6	1	1	1.3	1.2	1.5	0.5	1.0
Al Howsa	380	99	56	39	5	1.4	1.6	4.0	(13.0)	5.0
Wailah	124	55	12	9	-	1.4	2.6	2.4	(9.0)	-
Jualah	35	7	5	-	-	1.5	0.9	5.0	-	-
Total	601	177	79	49	6	1.4	1.7	3.3	9.8	3.0

Table 3.5 Ridge order in British Columbia and Gwynedd

A.

	Number of Ridges of order				Ratios		
	1	2	3	4	1/2	2/3	3/4
Camelsfoot-Black Dome-Shulaps-Rex	45	10	2	1*	4.5	5	(2)
Tyax-Gun	23	4	1*		5.75	(4)	
Bendor-Mission	48	13	4	1*	3.69	3.25	(4)
Gwynedd	64	14	3	1	4.6	4.7	3.0

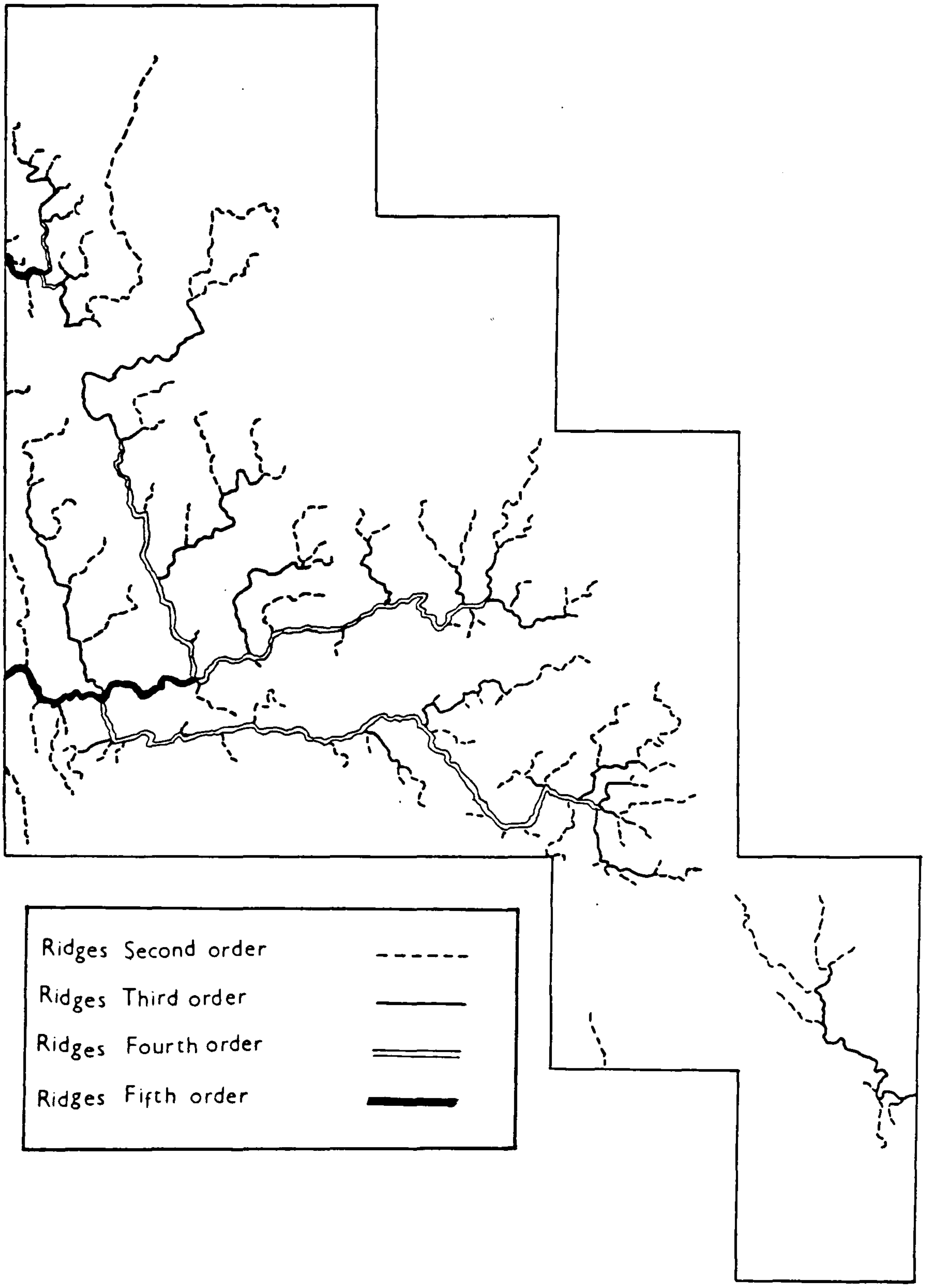
B.

	Number of summits on ridges of order				Averages per ridge			
	1	2	3	4	1	2	3	4
Camelsfoot-Black Dome-Shulaps-Rex	77	19	15	12	1.71	1.90	7.5	(12)
Tyax-Gun	38	12	4	-	1.65	3.00	(4.00)	
Bendor-Mission	88	32	27	17	1.83	2.46	6.75	(17)
Gwynedd	87	23	27	9	1.4	1.6	9.0	9.0

*Truncated at edge of mountain Block : Ridge continues with same order

Fig. 3.9

Map of the Ridge order in Thaniyat Turayf area



CHAPTER 4

RELIEF ANALYSIS OF THANIYAT TURAYF AREA.

CHAPTER 4

4. Relief Analysis of Thaniyat Turayf area

4.1 Relief

Although a relief map usually means a map showing the elevations and depressions of the terrain surface, the term relief, in this study, does not imply the absolute altitude above sea-level, but is defined as the difference in elevation between the highest and the lowest points within a specified area. This is what Smith (1935) regards as the "local relief" or the "relative relief" of an area.

Several studies of terrain analysis based on this concept of relief have been carried out and they differ mainly in the choice of the area over which the elevation data for the highest point and the lowest points are collected. Evans (1972a) used a 1 sq. km areal interval, Chen (1947) also started from 1 sq. km area, Smith (1935) used a 25 sq. km areal unit, while to cover the whole U.S.A. Hammond (1964) used the large area of 90 sq. km.

The choice of an appropriate areal unit over which the relief data are collected is important and should conform to the topography of the terrain under study. In general, hilly areas require a small area to correctly capture the surface characteristics, while a larger area may be satisfactory for plain areas.

The major objective here is to analyse the relief of the same area in Saudi Arabia by using different areal units for collecting the relief data.

4.2 Relief Data Collection

Topographic maps of the Thaniyat Turayf area at 1:25,000 scale and showing contours at 5 or 10 metre intervals were used for collecting the relief data. These maps were photogrammetrically produced by the U.S. Geological Survey in cooperation with the Ministry of Petroleum and Mineral Resources of the Saudi Arabian Government.

Data for the highest and the lowest altitude points were collected using 1 square kilometre areal units, which are represented by a 4 x 4 cm grid at this map scale. This was accomplished manually by superimposing a 4 cm grid mesh over the map and by reading the highest and the lowest altitude to the nearest metre value in each grid square, based on visual interpolation between contours and aided by the spot elevation information wherever available. Although necessary care was exercised in extracting the interpolated altitude values, this procedure cannot be regarded free from inadvertent human errors.

4.3 Relief Data Processing

The processing of the relief data was carried out, as in chapter 5, using the computer programs My9 (untransformed data) and My17 (transformed data) developed by Evans and Young for terrain analysis based on altitude matrices. It should be pointed out that the highest and the lowest altitude points can occur anywhere within each 1 km square grid and, therefore, the data do not truly represent altitude matrices. For this analysis, however, the altitude values are treated as if they corresponded to a regular 1 km mesh. The resulting histograms and computer maps essentially provide a generalised view of the topography and should be interpreted in this light.

From the above highest and the lowest point data, a second data set was derived based on a 2 x 2 km square grid for interpolation of the highest and the lowest altitude values using computer processing. The successive 2 x 2 km square areas were obtained by stepping only 1 km in each cardinal direction, resulting in a 50 per cent overlap between successive grid areas. Using this approach, although the highest and the lowest altitude values are aggregated over a 4 sq. km area (2 km in each direction), these values again represent a 1 km mesh for computer processing by the My9 and My17 programs. The total altitude data values of 2127 thus obtained are only slightly less than the original 2265 altitude data points, which helps in comparing the results obtained from the two data sets.

The computer processing resulted in the following four separate outputs:

- analysis of the high points only
- analysis of the low points only
- analysis of the relief for 1 x 1 km squares
- analysis of the relief for 2 x 2 squares

The results are presented and discussed in the following section.

4.4 Altitude Results

The processing carried out separately for the matrices of the low points and the high points shows that the lowest altitude varies from 632 m to 1000 m with mean value of 751 m and standard deviation of 77 m (Table 4.1). The highest altitude ranges between 639 m and 1039 m, has a mean value of 790 m and standard deviation of 91 m (Table 4.2). This indicates somewhat larger variation in the summit heights as compared with the valley heights. For the low points, the skewness is 0.98 and the kurtosis positive at 0.42, while for the high points the skewness

Table 4.1

LOWEST POINTS PER 1 x 1 KM2, THANIYAT TURAYF
No OF ROWS = 83

STATISTICS FOR 2265 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	750.912	0.604	-0.003	0.262
SDEV	76.981	0.440	0.060	7.843
SKEW	0.982	3.481	0.564	1.520
KURT	0.419	19.860	24.510	203.628
MAX	999.444	4.779	0.579	147.756
MIN	631.667	0.021	-0.530	-168.688

VECTOR MEAN ASPECT ANGLE 55.461
VECTOR STRENGTH (PROPORTION) 0.530
GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE 68.044
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION) 0.415

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT	1.000	0.405	0.194	0.059
GRADIENT	0.405	1.000	-0.064	0.028
PROFC	0.194	-0.064	1.000	0.133
PLANC	0.059	0.028	0.133	1.000

LOW TURAYF + FAJR, SAUDI ARABIA NO OF ROWS = 83
CURVATURES PROFC = 2/PI* ARCTAN (PROFC * 22.0) PLANC = 2/PI*ARCTAN (PLANC*0.1370)

GRADIENT TRANSFORMED TO SQUARE ROOT OF SINE OF GRADIENT
STATISTICS FOR 2265 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	750.912	0.098	-0.052	0.006
SDEV	76.981	0.031	0.354	0.299
SKEW	0.982	1.318	0.342	0.186
KURT	0.419	4.556	0.169	0.143
MAX	999.444	0.289	0.950	0.969
MIN	631.667	0.019	-0.945	-0.972

VECTOR MEANS MODULO	360	180	90
VECTOR MEAN ASPECT ANGLE	55.461	39.483	47.292
VECTOR STRENGTH (PROPORTION)	0.530	0.315	0.118
GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE	68.044	30.564	50.412
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION)	0.415	0.297	0.082

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT	1.000	0.452	0.193	0.064
GRADIENT	0.452	1.000	-0.050	0.091
PROFC	0.193	-0.050	1.000	0.267
PLANC	0.064	0.091	0.267	1.000
CORREL OF GRADIENT WITH ABS CURV			0.494	-0.171

Table 4.2

HIGH POINTS PER KM2, TURAYFF + FAJR
No OF ROWS = 83

STATISTICS FOR 2265 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	789.578	0.831	-0.001	-0.257
SDEV	91.202	0.676	0.108	11.137
SKEW	0.678	2.657	0.376	-11.015
KURT	-0.275	10.442	8.066	289.888
MAX	1038.555	5.445	0.723	96.256
MIN	639.000	0.014	-0.700	-309.392

VECTOR MEAN ASPECT ANGLE	55.135
VECTOR STRENGTH (PROPORTION)	0.473
GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE	70.576
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION)	0.360

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT	1.000	0.188	0.222	0.056
GRADIENT	0.188	1.000	-0.008	0.050
PROFC	0.222	-0.008	1.000	0.083
PLANC	0.056	0.050	0.083	1.000

TURAYF + FAJR, SAUDI ARABIA, HIGHEST POINTS PER 1 x 1 km square
CURVATURES PROFC = 2/PI* ARCTAN (PROFC *7.8450) PLANC = 2/PI*ARCTAN (PLANC*0.1270)
No of ROWS = 83
GRADIENT TRANSFORMED TO SQUARE ROOT OF SINE OF GRADIENT
STATISTICS FOR 2265 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	789.578	0.113	-0.006	0.005
SDEV	91.202	0.042	0.327	0.335
SKEW	0.678	1.104	0.066	-0.139
KURT	-0.275	2.297	-0.000	0.000
MAX	1038.555	0.308	0.889	0.948
MIN	639.000	0.015	-0.885	-0.984

VECTOR MEANS MODULO	360	180	90
VECTOR MEAN ASPECT ANGLE	55.135	37.116	47.815
VECTOR STRENGTH (PROPORTION)	0.473	0.339	0.091
GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE	70.576	27.241	64.671
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION)	0.360	0.321	0.037

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT	1.000	0.214	0.229	0.097
GRADIENT	0.214	1.000	-0.015	0.062
PROFC	0.229	-0.015	1.000	0.212
PLANC	0.097	0.062	0.212	1.000
CORREL OF GRADIENT WITH ABS CURV			0.532	-0.296

and kurtosis are 0.68 and -0.28, respectively. An inspection of the map of the highest points (Figure 4.1) and that of the lowest points (Figure 4.2) shows remarkable similarity in the visual information conveyed about the topography of the area.

The term gradient in this case no longer represents the usual concept of the terrain surface slope, but is the rate of change in the successive values for the highest and the lowest altitudes. For the low points, the gradient varies from 0.02° to 4.78° with a mean of 0.60° and standard deviation of 0.44°. Similar variation in the gradient for high points is from 0.01° to 5.44°, a mean value of 0.83° and standard deviation of 0.68°. Such a similarity in the gradient values is to be expected for a regularly sloping terrain. Compared with the mean value of the gradient, the corresponding standard deviation appears to be high. This is perhaps partly due to the fact that the gradient values are being computed by assuming a regular grid interval of 1 km between data points, while actually the highest and the lowest points occur at variable spacing.

The skewness in gradient of 3.48 for low points and 2.66 for high points is due to tails of high gradient values in both cases, and consequently is reflected in high positive kurtosis of 19.86 and 10.44. The high gradient values were checked and found to be real, occurring near the western end of the escarpment located south of Wadi Turayf. The scatter plots show that for both the lowest and the highest points, the steepest slopes face south, though most slopes face north-east.

Profile and plan convexity both have very high kurtosis (long tails of very high and very low values) and it is best to consider the results after arctangent transformation. The arbitrary k value in

Fig. 4.1

TURAYF + FAJR, SAUDI ARABIA . HIGHEST POINTS PER 1x1 km square
CALC.HT. IN METRES

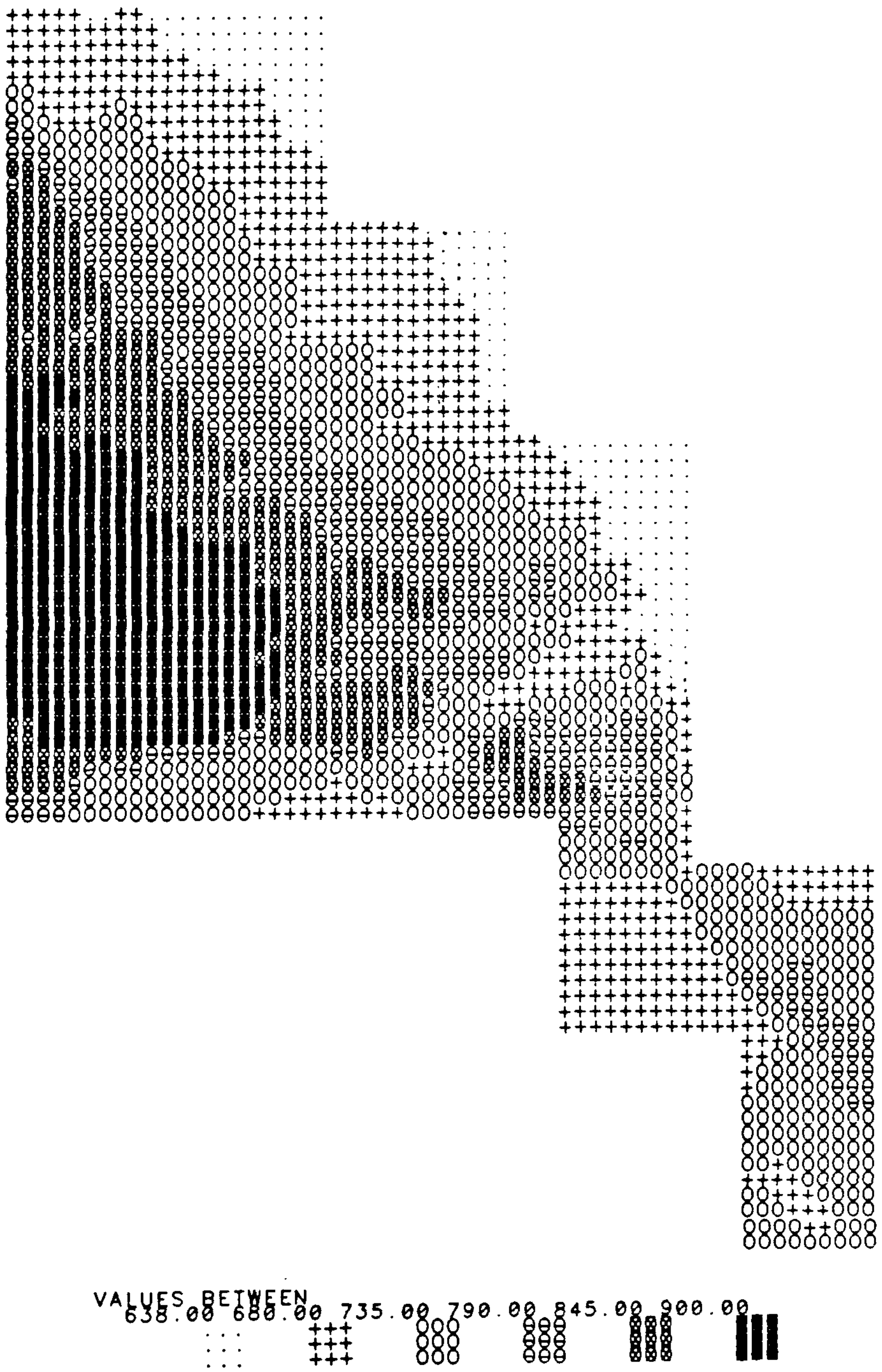
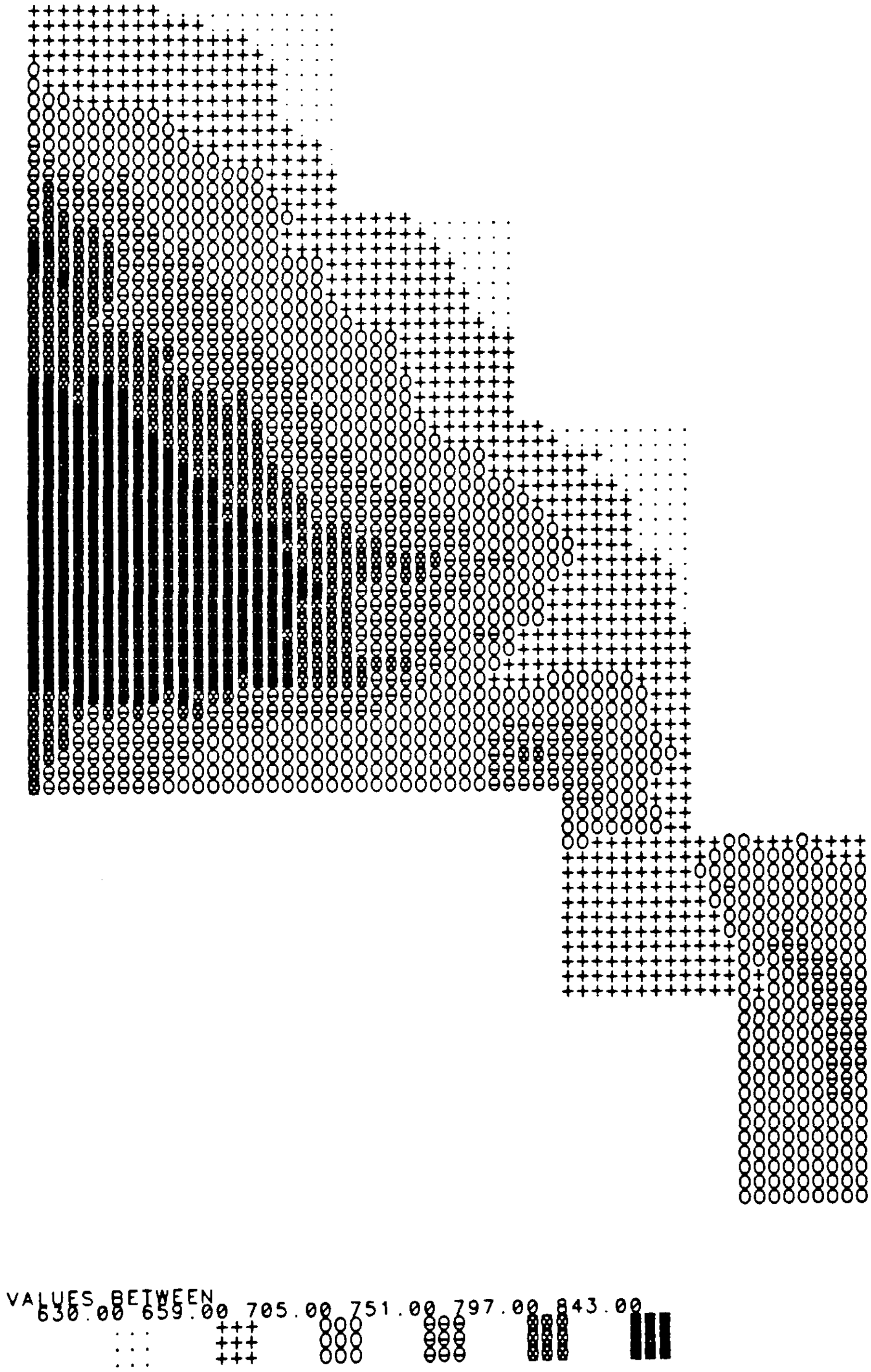


Fig. 4.2

LOWEST POINTS PER 1x1 KM2, THANIYAT TURAYF
CALC.HT. IN METRES



this transformation was iterated to produce near-zero kurtosis. This succeeded in producing symmetrical distributions, which were similar for high points and for low points. On the transformed scale their standard deviations are 0.35 and 0.33 for profile convexity for the low and the high points, respectively.. The corresponding standard deviations of plan convexity are 0.30 and 0.34. The profile and plan convexity are skewed to +0.34 and +0.19, respectively for the low points. The skewness values in the profile and plan convexity for the high points are +0.07 and -0.14 respectively. Table 4.3 shows that profile convexity obtained for Thaniyat Turayf low points has more concavity than convexity. In the range 0.01 to 1.00 there are 1331 concavities compared with 868 convexities. This trend applies even for other ranges and for the range 0.01 to 0.71, there are 1283 concavities and 794 convexities, and for the range 0.01 to 0.31, the corresponding numbers are 846 and 521 respectively. The profile convexity results for the high points display greater balance between the concavities and the convexities which number 1165 and 1015 respectively for the range from 0.01 to 1.00. The corresponding figures for the range 0.01 to 0.71 are 1128 and 973 and, for the range 0.01 to 0.31, the numbers are 801 to 635 respectively.

In plan convexity, there is a more consistent balance between total convexity and concavity for both low and high point data for Thaniyat Turayf. For the range 0.01 to 0.31, the concavities number 845 to 707 convexities for the low points and 667 concavities to 768 convexities for the high points. The corresponding numbers for the range from 0.01 to 0.71 are 1114 to 1033 for the low points and 990 to 1124 for the high points.

Table 4.3

	Range	+ Profile	Convexity-	+ Plan	Convexity-
Low	0.91 to 1.00	9	10	3	2
	0.81 0.91	32	16	10	3
	0.71 0.81	32	22	20	13
	0.61 0.71	46	63	33	21
	0.51 0.61	40	107	57	48
	0.41 0.51	84	118	89	79
	0.31 0.41	103	149	147	121
	0.21 0.31	116	219	157	217
	0.11 0.21	143	318	270	322
	0.01 0.11	262	309	280	306
		868	1331	1066	1132
	+0.01 to -0.01	66		67	
	over all total	2265		2265	
High	0.91 1.00	0	0	4	0
	0.81 0.91	15	10	9	20
	0.71 0.81	27	27	29	26
	0.61 0.71	40	59	40	51
	0.51 0.61	76	64	58	72
	0.41 0.51	86	90	118	78
	0.31 0.41	136	114	140	122
	0.21 0.31	156	181	194	159
	0.11 0.21	211	256	249	261
	0.01 0.11	268	364	325	247
		1015	1165	1166	1042
	+0.01 to -0.01	85		57	
	over all total	2265		2265	

4.5 Discussion of results of Relief

Relief, measured as the difference between the highest and the lowest points falling in 1 x 1 km square areas for the Thaniyat Turayf study area, is shown in Figure 4.3. The value of the relief ranges from a minimum of 0.1 m to 201.9 m, with mean relief value of 38.7 m and standard deviation of 26.0 m (Table 4.4 and Figure 4.7). The lowest relief ranging from 0 to 7 m occurs in the northeast and south of the escarpment located south of Wadi Turayf. The highest relief values exceeding 71 m fall around Wadi Turayf, Jabal Wailah and around Wadi Al Ginah. Jabal Al Howsa located in the middle of the study area has moderate relief.

In general, the relief in the Thaniyat Turayf area is low with a mean value of 38.7 m. Although for such a generally low relief area, the standard deviation in relief of 26.0 m appears to be high, this result is to be expected when compared with the standard deviation of 91 m for the highest altitude points and 77 m for the lowest points. Visual comparison of the maps showing distribution of the highest points and the lowest points (Figs. 4.1 and 4.2) with the relief distribution in Figure 4.3 indicates that all three maps succeed in capturing similar topographic patterns in the study area. However, the numbers generated through the computer processing are most meaningful in the case of relief data.

The map of relief gradient for Thaniyat Turayf is shown in Figure 4.4 and its histogram in Figure 4.8. The gradient, in this case, represents the rate of change in relief, but is still expressed in degrees. The gradient varies from a maximum of 4.82° to the minimum of 0.01° with a mean value of 0.55° and standard deviation of 0.58°. These gradient figures represent a relief change of 84.3m, 0.2m, 9.6m

Fig. 4.3

THANIYAT TURAYF , SAUDI ARABIA , RELIEF PER 1x1 km square
CALC.HT. IN METRES

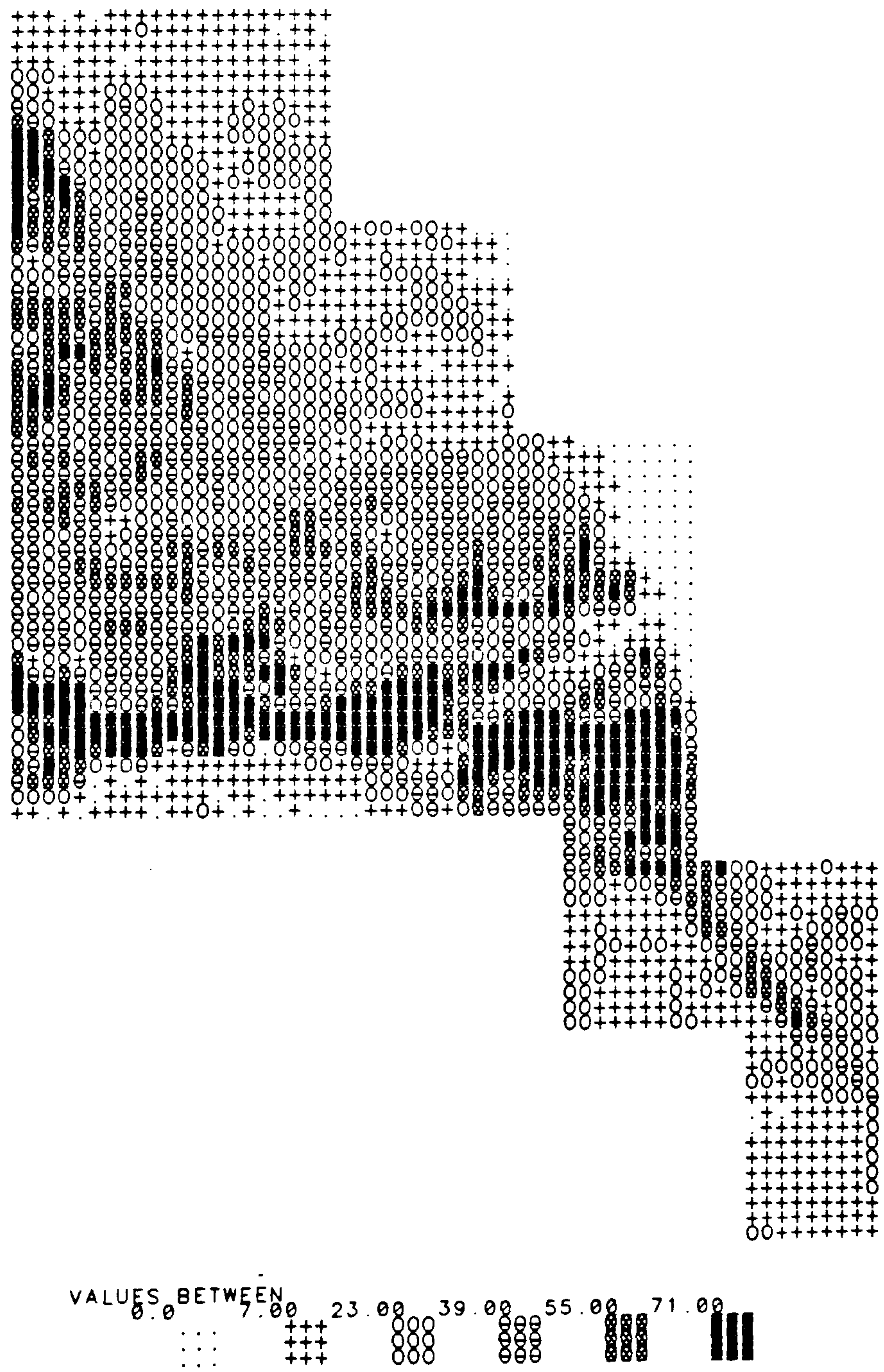


Table 4.4

RELIEF PER 1 x 1 KM2, TURAYFF + FAJR

NO OF ROWS = 83

STATISTICS FOR 2264 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	38.680	0.547	-0.005	0.687
SDEV	25.979	0.581	0.118	19.498
SKEW	1.520	2.842	1.231	3.720
KURT	4.307	11.294	13.673	82.138
MAX	201.889	4.821	1.178	325.990
MIN	0.111	0.010	-0.641	-213.799

VECTOR MEAN ASPECT ANGLE 60.126

VECTOR STRENGTH (PROPORTION) 0.106

GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE 6.465

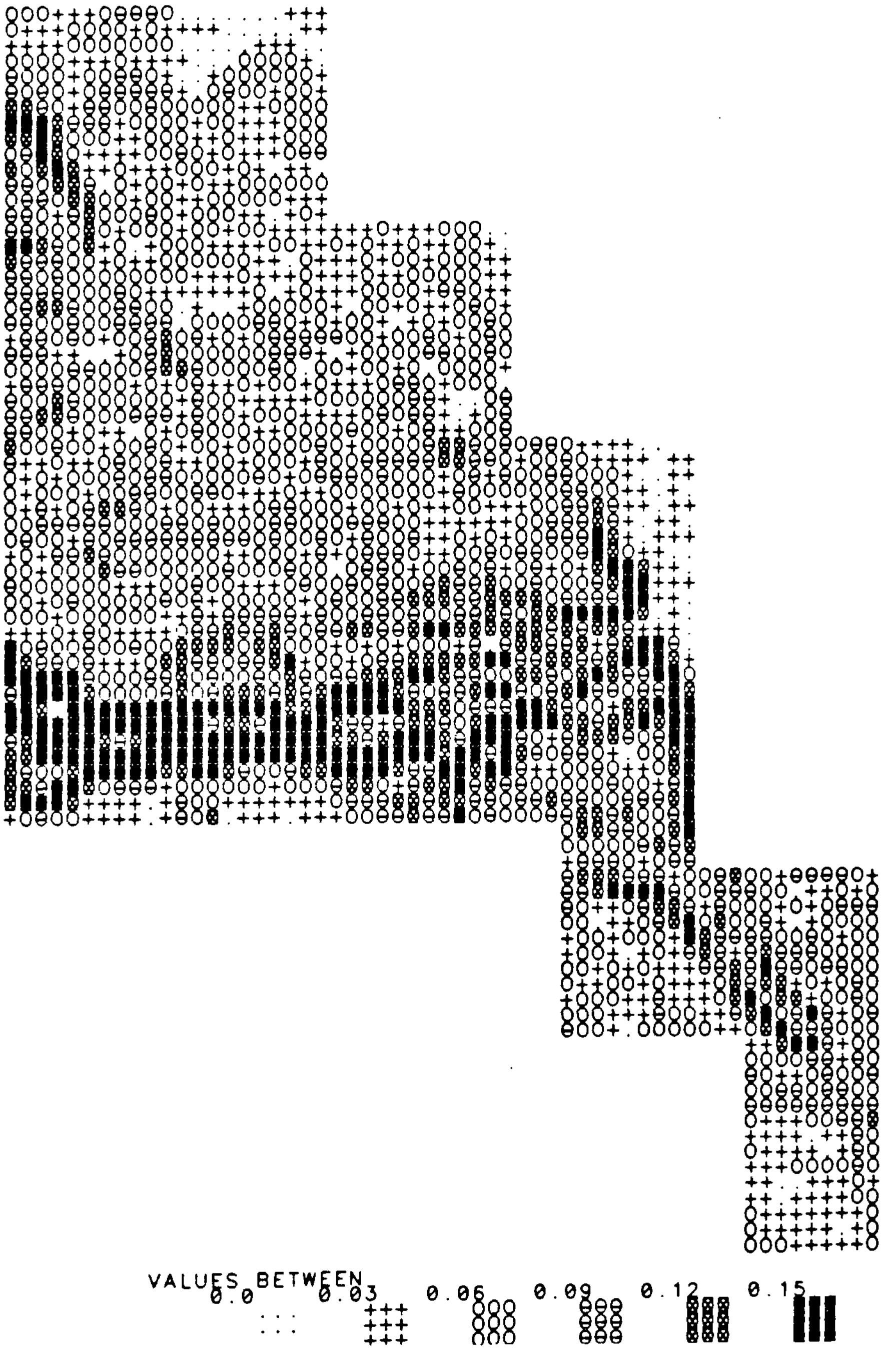
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION) 0.091

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT.	1.000	0.469	0.470	0.202
GRADIENT	0.469	1.000	-0.115	-0.001
PROFC	0.470	-0.115	1.000	0.098
PLANC	0.202	-0.001	0.098	1.000

Fig. 4.4

THANIYAT TURAYF SAUDI ARABIA , RELIEF PER 1x1 km square
SORT OF SIN OF GRADIENT



and 10.1m in a distance of 1 km respectively. It is seen that neither the maximum relief gradient of 84.3m per km nor the minimum gradient of 0.2m per km are representative of Thaniyat Turayf area. However, the average relief gradient of 9.6m per km is quite consistent with the average low relief of the area.

The standard deviation of 10.0m per km for the computed values of the relief gradient is even a bit higher than the average relief value of 9.6m per km. It should normally indicate a high level of terrain dissection, but for the study area, it results partly from the discontinuities in the terrain in the south-west. It is not clear whether the skewness and the kurtosis in the relief gradient convey any meaningful information about the terrain; they are perhaps relevant parameters for the comparison of relief of different areas.

The most concave zones (dots) on the map of profile convexity (Fig. 4.5) delineate the areas of greatest change in relief shaded dark in Fig. 4.4. Otherwise both this and the map of plan convexity (Fig. 4.6) emphasise local detail, giving a near-random pattern about which it is very difficult to generalise.

4.6 Relief Maps based on 2 x 2 km Data

Since relief is the difference between the highest and the lowest altitude over a given area, it is logical to expect that an increase in the unit area over which relief is determined would numerically increase the value of relief. This is borne out by the results of relief analysis of the same Thaniyat Turayf area when a 2 x 2 km square area is used for calculating relief.

The maximum relief value is 227.2m (Table 4.5) as compared with 201.9m for the earlier 1 x 1 km square case. The mean relief value increases markedly from 38.7 m for 1 km squares to 59.5 m for 2 km

Fig. 4.5

THANIYAT TURAYF, SAUDI ARABIA. RELIEF PER 1x1 km square
PROFILE CONVEXITY WITH ARCTAN TRANSFORMATION

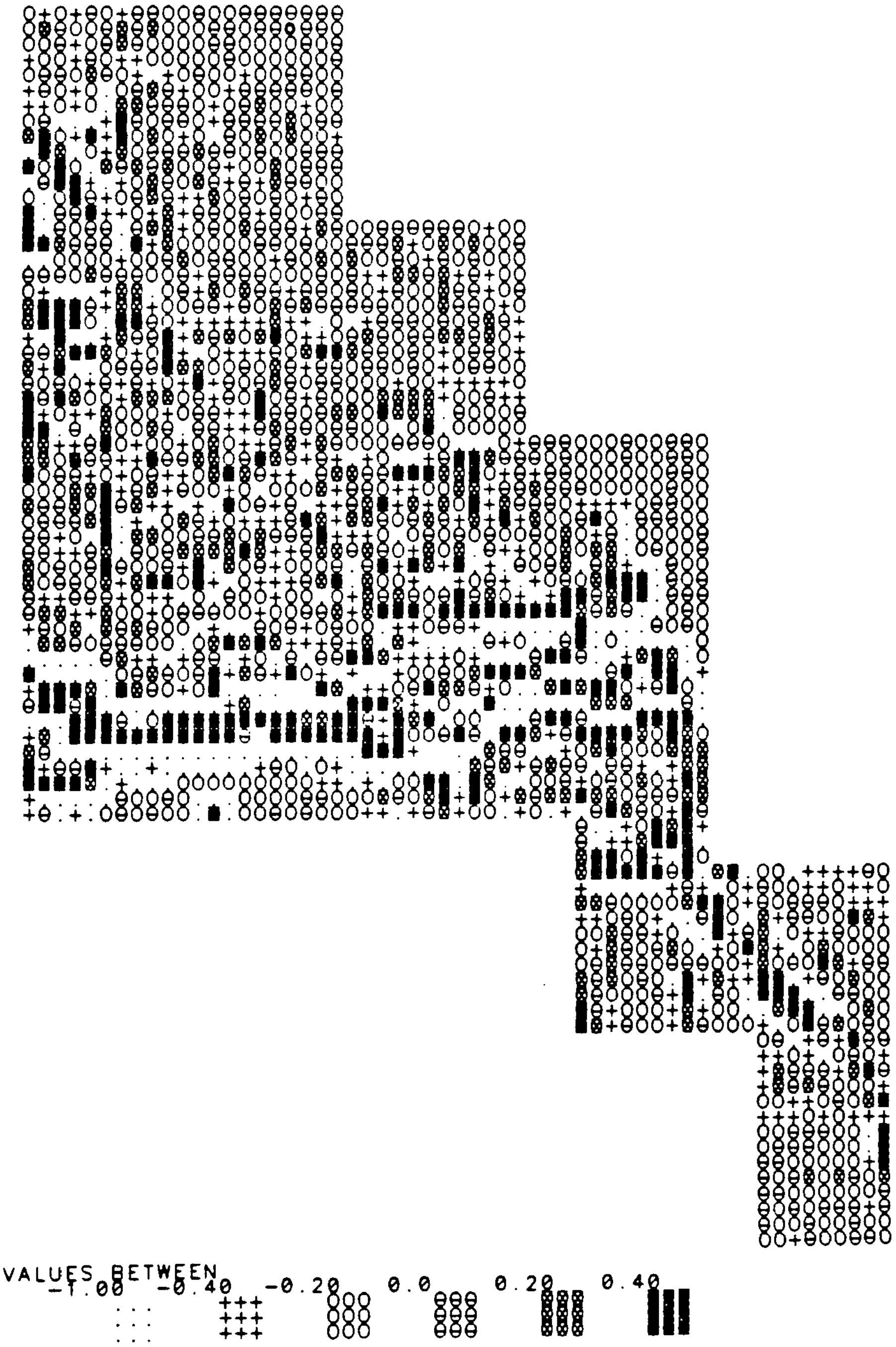


Fig. 4·6

THANIYAT TURAYF SAUDI ARABIA RELIEF PER 1x1 km square
PLAN CONVEXITY WITH ARCTAN TRANSFORMATION

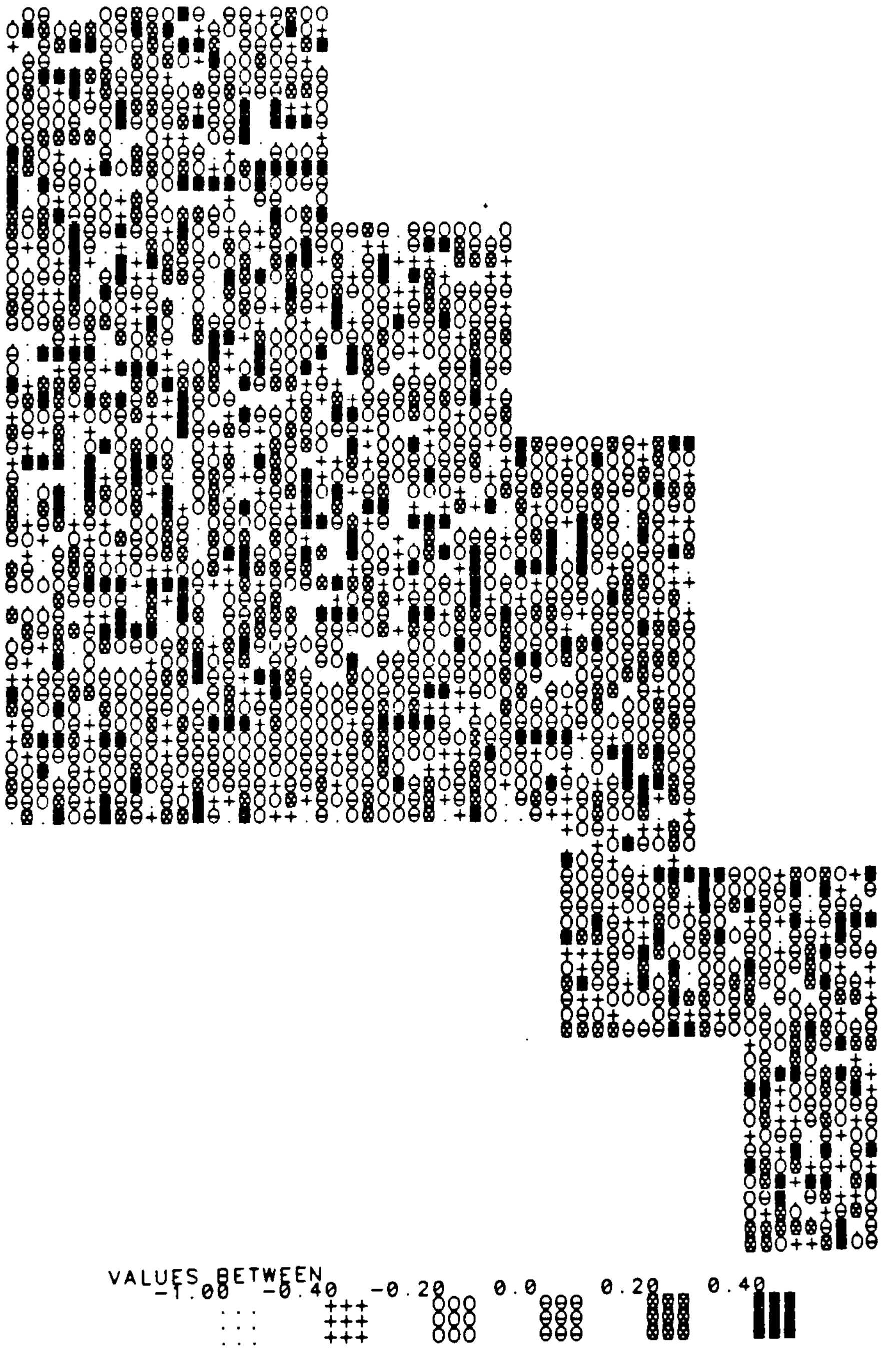


Table 4.5
RELIEF PER 2 x 2 KM2, TURAYFF + FAJR
NO OF ROWS = 82

STATISTICS FOR 2127 POINTS WITH NON ZERO GRADIENT

	EST.ALT	GRADIENT	PROFC	PLANC
MEAN	59.505	0.649	-0.003	0.593
SDEV	33.951	0.679	0.121	15.109
SKEW	1.340	2.681	0.461	3.501
KURT	3.127	9.409	8.686	70.514
MAX	227.222	5.377	0.778	276.732
MIN	3.667	0.010	-0.648	-145.129

VECTOR MEAN ASPECT ANGLE 41.022
VECTOR STRENGTH (PROPORTION) 0.120
GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE 82.543
GRADIENT WEIGHTED VECTOR STRENGTH (PROPORTION) 0.097

CORRELATION COEFFS

	EST.ALT	GRADIENT	PROFC	PLANC
EST.ALT	1.000	0.482	0.466	0.151
GRADIENT	0.482	1.000	0.004	-0.007
PROFC	0.466	0.004	1.000	0.096
PLANC	0.151	-0.007	0.096	1.000

```
THANIYAT TURAYF . SAUDI ARABIA . RELIEF PER 1x1 km square

 HISTOGRAM OF F  HEIGHT CALC. FROM QUADRATIC
  EACH • IS  1 POINTS  + IS 1 TO  0 POINTS        CLASS WIDTH =   2.00

COUNT  TOTAL%  MIDPOINT
    4    0.18     0.0    I••••
   10    0.62     2.00   I••••••••••
   41    2.43     4.00   I•••••••••••••••••••••••••••••••••••••••••
   54    4.81     6.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••
   89    8.75     8.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   68   11.75    10.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   63   14.53    12.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   69   17.58    14.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   79   21.07    16.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   58   23.63    18.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   73   26.86    20.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   86   30.65    22.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   72   33.83    24.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   74   37.10    26.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   69   40.15    28.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   60   42.80    30.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   88   46.69    32.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   70   49.78    34.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   81   53.36    36.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   69   56.40    38.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   58   58.97    40.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   78   62.41    42.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   84   66.12    44.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   64   68.95    46.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   67   71.91    48.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   62   74.65    50.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
   55   77.08    52.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••
   46   79.11    54.00   I••••••••••••••••••••••••••••••••••••••••••••••
   47   81.18    56.00   I•••••••••••••••••••••••••••••••••••••••••••••••
   41   82.99    58.00   I•••••••••••••••••••••••••••••••••••••••••
   36   84.58    60.00   I••••••••••••••••••••••••••••••••••••
   36   86.17    62.00   I••••••••••••••••••••••••••••••••••••
   30   87.50    64.00   I••••••••••••••••••••••••••••••
   21   88.43    66.00   I•••••••••••••••••••••
   28   89.66    68.00   I••••••••••••••••••••••••••••
   16   90.37    70.00   I••••••••••••••••
   21   91.30    72.00   I•••••••••••••••••••••
   22   92.27    74.00   I••••••••••••••••••••••
   19   93.11    76.00   I•••••••••••••••••••
   16   93.82    78.00   I••••••••••••••••
    5   94.04    80.00   I•••••
   13   94.61    82.00   I•••••••••••••
   16   95.32    84.00   I••••••••••••••••
    8   95.67    86.00   I••••••••
    6   95.94    88.00   I••••••
    9   96.33    90.00   I•••••••••
    7   96.64    92.00   I•••••••
    6   96.91    94.00   I••••••
    5   97.13    96.00   I•••••
    4   97.31    98.00   I••••
    2   97.39   100.00   I••
    3   97.53   102.00   I•••
    4   97.70   104.00   I••••
    3   97.84   106.00   I•••
    2   97.92   108.00   I••
    1   97.97   110.00   I•
    1   98.01   112.00   I•
    2   98.10   114.00   I••
    5   98.32   116.00   I•••••
    3   98.45   118.00   I•••
    2   98.54   120.00   I••
    0   98.54   122.00   I
    4   98.72   124.00   I••••
    1   98.76   126.00   I•
    2   98.85   128.00   I••
    3   98.98   130.00   I•••
    0   98.98   132.00   I
    3   99.12   134.00   I•••
    1   99.16   136.00   I•
    1   99.20   138.00   I•
    3   99.34   140.00   I•••
    2   99.43   142.00   I••
    2   99.51   144.00   I••
    1   99.56   146.00   I•
    0   99.56   148.00   I
    0   99.56   150.00   I
    0   99.56   152.00   I
    1   99.60   154.00   I•
    0   99.60   156.00   I
    0   99.60   158.00   I
    1   99.65   160.00   I•
    0   99.65   162.00   I
    2   99.73   164.00   I••
    1   99.78   166.00   I•
    1   99.82   168.00   I•
    0   99.82   170.00   I
    0   99.82   172.00   I
    0   99.82   174.00   I
    0   99.82   176.00   I
    0   99.82   178.00   I
    1   99.87   180.00   I•
    0   99.87   182.00   I
    0   99.87   184.00   I
    0   99.87   186.00   I
    0   99.87   188.00   I
    0   99.87   190.00   I
    0   99.87   192.00   I
    0   99.87   194.00   I
    2   99.96   196.00   I••
    0   99.96   198.00   I
    0   99.96   200.00   I
    1  100.00   202.00   I•

PLOTTED VALUES  2264
```

Fig. 4·8

```
THANIYAT TURAYF , SAUDI ARABIA , RELIEF PER 1x1 km square

 HISTOGRAM OF GRADIENT SQRT OF SIN OF GRADIENT
  EACH * IS  3 POINTS  + IS 1 T0  2 POINTS        CLASS WIDTH =   0.01

 COUNT  TOTAL%  MIDPOINT
     0    0.0      0.0     I
     1    0.04     0.01    I+
    43    1.94     0.02    I**************+
    99    6.32     0.03    I*********************************
   141   12.54     0.04    I***********************************************
   211   21.86     0.05    I**********************************************************************+
   214   31.32     0.06    I***********************************************************************+
   260   42.80     0.07    I**************************************************************************************+
   282   55.26     0.08    I**********************************************************************************************
   232   65.50     0.09    I*****************************************************************************+
   198   74.25     0.10    I******************************************************************
   128   79.90     0.11    I******************************************+
    97   84.19     0.12    I********************************+
    67   87.15     0.13    I**********************+
    61   89.84     0.14    I********************+
    53   92.18     0.15    I*****************+
    40   93.95     0.16    I*************+
    39   95.67     0.17    I*************
    17   96.42     0.18    I*****+
    18   97.22     0.19    I******
    18   98.01     0.20    I******
    12   98.54     0.21    I****
    11   99.03     0.22    I***+
     5   99.25     0.23    I*+
     5   99.47     0.24    I*+
     3   99.60     0.25    I*
     3   99.73     0.26    I*
     0   99.73     0.27    I
     3   99.87     0.28    I*
     3  100.00     0.29    I*
     0  100.00     0.30    I

PLOTTED VALUES  2264
```

squares, with a corresponding increase in the standard deviation from 26.0 m to 34.0 m. Since both sets of relief data pertain to the same terrain surface, they convincingly demonstrate that such a relief analysis is strongly dependent on the choice of the areal unit for determining relief.

A comparison of the 2 x 2 km relief map shown in Figure 4.9 with that in Figure 4.3 shows strong similarity, the major difference being in the numerical scale only. Therefore, although the numerical value for relief changes, the larger data collection interval captures the same attribute of land form.

In the same logical context, gradient should be expected to be less dependent on the data collection interval since the relief gradient is derived from the change in the relief (Fig. 4.10). A comparison of the results is made in Table 4.6 and supports this view.

The results of the relief data analysis for the Thaniyat Turayf area show that relief gradient is a relatively more stable terrain characteristic, as compared with relief. The relief gradient is dependent on and representative of the relief, as is indicated by the correlations of +0.47 for 1 km squares and +0.48 for 2 km squares.

Since relief is derived from the extreme values, it is necessarily tied to the definition of the area over which relief is measured. It is, therefore, not a stable geomorphological parameter. Evans (1972a) suggests that relief, defined as dispersion in altitude, should preferably be measured with the standard deviation in altitude which appears to be stable over large areas.

Even profile convexity, defined as the rate of change of relief gradient, demonstrates stability similar to the gradient when the area for relief is changed from 1 x 1 km square to 2 x 2 km square (see Table 4.6). The mean value for the profile convexity, however, is

Fig. 4·9

RELIEF PER 2x2 KM2, TURAYFF+FAJR
CALC.HT. IN METRES

Fig. 4·10

RELIEF PER 2x2 KM2. TURAYFF+FAJR
GRADIENT (degrees)

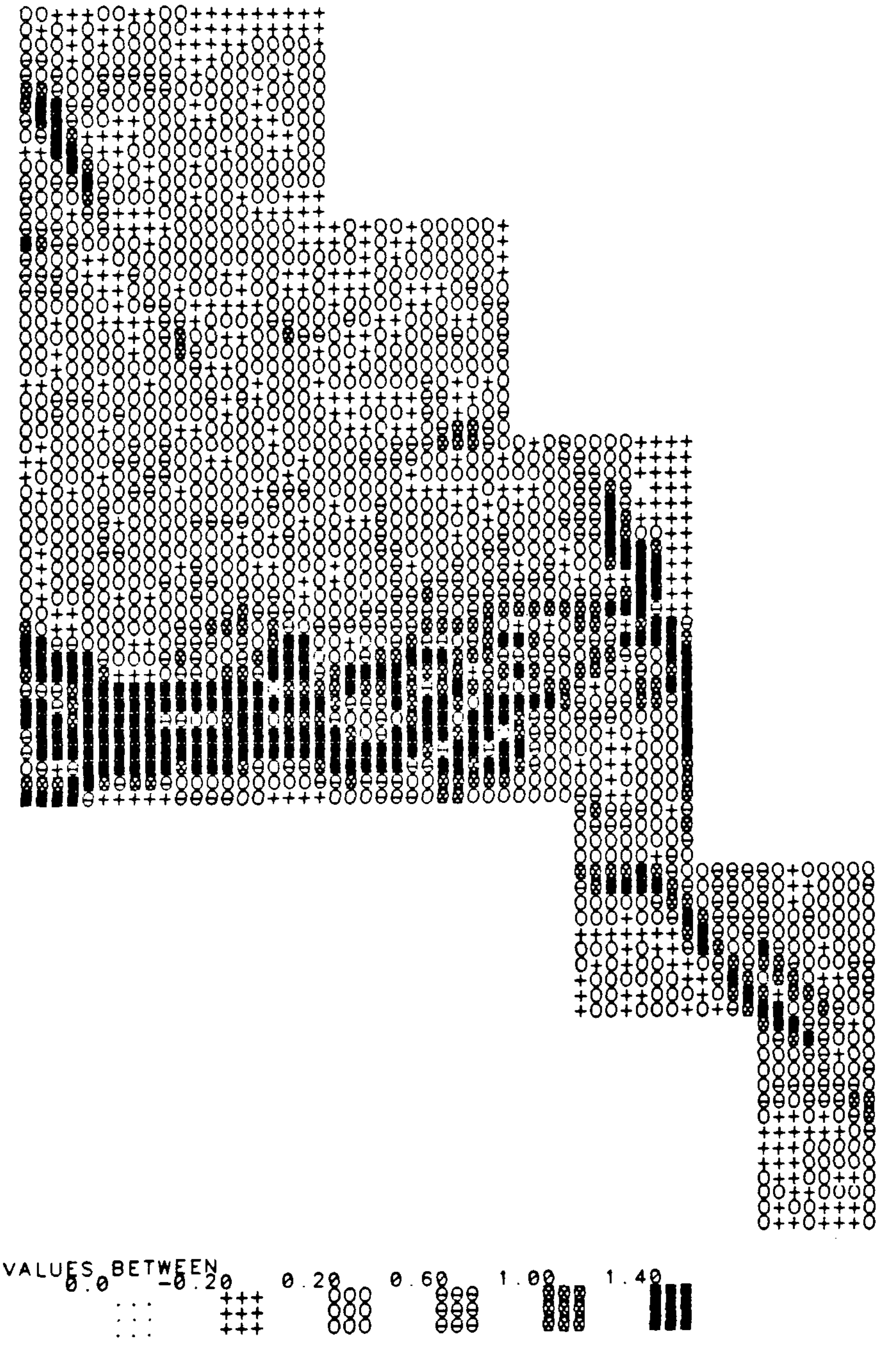


Table 4.6 Results of Relief Analysis

No.	Parameter	1 x 1 km^2	2 x 2 km^2
1.	Relief (m) :		
	Maximum	201.9	227.2
	Minimum	0.1	3.7
	Mean	38.7	59.5
	Standard Deviation	26.0	34.0
2.	Gradient (Degrees) :		
	Maximum	4.82	5.38
	Minimum	0.01	0.01
	Mean	0.55	0.65
	Standard Deviation	0.58	0.68
	Correlation with Relief	0.47	0.48
3.	Profile C :		
	Maximum	1.18	0.78
	Minimum	-0.64	- 0.65
	Mean	-0.005.	- 0.003
	Standard Deviation	0.12	0.12
	Correlation with Relief	0.47	0.47
4.	Plan C :		
	Maximum	326.0	276.7
	Minimum	-213.8	-145.1
	Mean	0.69	0.60
	Standard Deviation	19.5	15.1
	Correlation with Relief	0.20	0.15

approaching zero in either case, resulting from the significant generalisation that has taken place. Neither profile convexity nor plan convexity provide an easily interpretable measure for the relief of the area, in spite of the significantly strong correlation of the profile convexity with the relief.

CHAPTER 5

WADI UMM AL ARTA AUTOMATED MORPHOMETRIC ANALYSIS OF SLOPES AND CONVEXITIES

CHAPTER 5

Wadi Umm Alarta automated morphometric analysis of slopes and convexities

5. Integrated morphometric analysis of wadi Umm Alarta

5.1 Area location

Wadi Umm Alarta is situated in the middle of the Thaniyat Turayf area which lies near the north western corner of the Kingdom of Saudi Arabia. The study area is 10 km along each cardinal direction covering a longitude range from approximately 37°52'58" to 37°59'13" east and a latitude range from 29°45'10" to 29°50'36" north as shown in Figure 5.1.

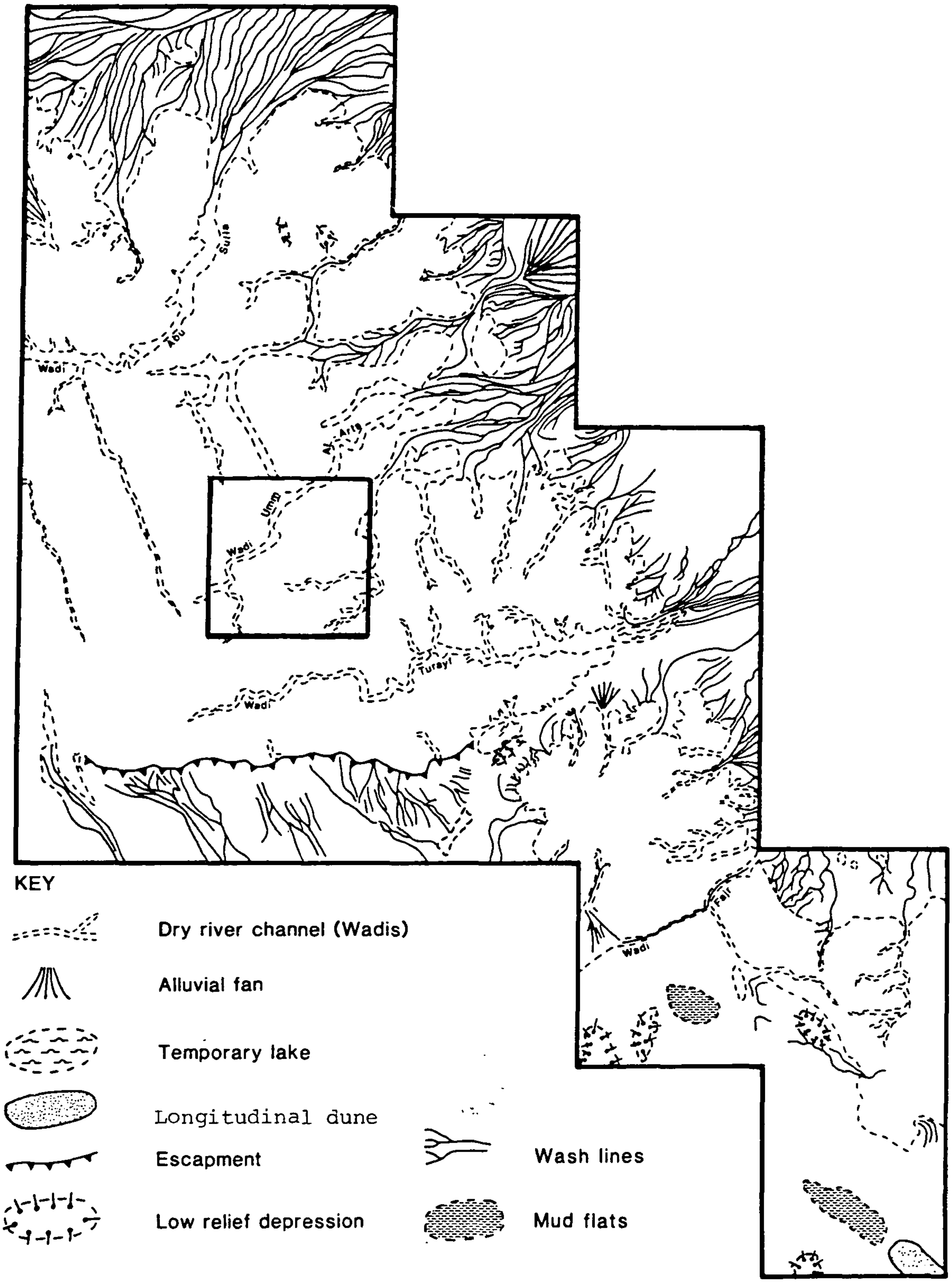
The major topographic features in this area include a high plateau in the south west corner, dissected by two wadis running in a northerly to north-easterly direction which is also the general direction of the terrain slopes. The larger of the two wadis is the wadi Umm Alarta after which the area has been named.

5.2 Altitude data collection

A topographic map of the area at 1:25,000 scale with 10 metres contour interval was available. This map sheet was prepared in 1969, using photogrammetric methods, from 1966 aerial photography by the U.S. Geological Survey under the sponsorship of the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia. Besides depicting the contours, the map was printed against an orthophoto background, thus highlighting the mountainous features and drainage lines.

Evans (1980) suggested that analysis of an altitude matrix of appropriate grid mesh might provide useful background information for most geomorphic field studies. A 100-metre grid mesh was chosen to collect altitude data in accordance with the map scale and the nature of the

Fig.5.1 Location of Umm Al arta



terrain. A 1-km grid lattice was first drawn over the map sheet by joining the U.T.M. grid ticks, 1000 metres apart, along the opposite edges. A 4 mm grid was then constructed on a transparent base and was used to read the altitude value at each 100 metre (4 mm on map scale) grid intersection, by linear interpolation to the nearest metre between the 10-metre contour lines. This process was quite tedious and was made even more difficult by the brown orthophoto background against which the brown contour lines had to be interpreted. In spite of exercising a lot of care in the reading and transcribing of the altitude data from the map sheet, the presence of errors or mistakes in this manual operation is quite possible.

5.3 Data Processing

The altitude data for 101 x 101 points was processed at the University of Durham Computer Centre using the integrated terrain analysis programs developed by Young (1978) and Evans (1979). Derivatives cannot be calculated for peripheral data points. Results for the remaining 9,801 points (none with zero gradient) were output in the form of statistical summaries, histograms and computer-generated graphic displays for computed altitude, gradient, aspect, profile convexity and plan convexity.

5.4 Discussion of results

5.4.1 Computed altitude

The altitude histogram (Fig. 5.2) shows a range from 756 to 959 metres, with a mean altitude of 855 m, 852 m as the median and a mode of 850 m. These values, combined with a lack of any significant skew, are indicative of a fairly regularly sloping terrain as seen in Figure 5.3. This map shows that the mountains are mainly located

Fig. 5.2

```
WADI UMM ALARTA. Saudi Arabia

 HISTOGRAM OF F  HEIGHT CALC. FROM QUADRATIC
  EACH • IS  3 POINTS  + IS 1 TO  2 POINTS          CLASS WIDTH =    2.00

 COUNT  TOTAL%  MIDPOINT
    0    0.0     754.00   I
    3    0.03    756.00   I•
   13    0.16    758.00   I••••+
   17    0.34    760.00   I•••••+
    6    0.40    762.00   I••
   19    0.59    764.00   I••••••+
   16    0.76    766.00   I•••••+
   21    0.97    768.00   I•••••••
   22    1.19    770.00   I•••••••+
   22    1.42    772.00   I•••••••+
   21    1 63    774.00   I•••••••
   39    2.03    776.00   I•••••••••••••
   41    2.45    778.00   I•••••••••••••+
   33    2.79    780.00   I•••••••••••
   30    3.09    782.00   I••••••••••
   46    3.56    784.00   I•••••••••••••••+
   52    4.09    786.00   I•••••••••••••••••+
   74    4 85    788.00   I••••••••••••••••••••••••+
   72    5.58    790.00   I••••••••••••••••••••••••
   73    6.33    792.00   I••••••••••••••••••••••••+
   65    6.99    794.00   I•••••••••••••••••••••+
   78    7.78    796.00   I••••••••••••••••••••••••••
   79    8.59    798.00   I••••••••••••••••••••••••••+
   75    9.36    800.00   I•••••••••••••••••••••••••
   93   10.31    802.00   I•••••••••••••••••••••••••••••••
   82   11.14    804.00   I•••••••••••••••••••••••••••+
   94   12.10    806.00   I•••••••••••••••••••••••••••••••+
  129   13.42    808.00   I•••••••••••••••••••••••••••••••••••••••••••
  128   14.72    810.00   I••••••••••••••••••••••••••••••••••••••••••+
  109   15.84    812.00   I••••••••••••••••••••••••••••••••••••+
  109   16.95    814 00   I••••••••••••••••••••••••••••••••••••+
  127   18.24    816.00   I••••••••••••••••••••••••••••••••••••••••••+
  142   19.69    818.00   I•••••••••••••••••••••••••••••••••••••••••••••••+
  141   21.13    820.00   I•••••••••••••••••••••••••••••••••••••••••••••••
  121   22.37    822.00   I••••••••••••••••••••••••••••••••••••••••+
  112   23.51    824.00   I•••••••••••••••••••••••••••••••••••••+
  131   24.84    826.00   I•••••••••••••••••••••••••••••••••••••••••••+
  154   26.42    828.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••+
  144   27.88    830 00   I••••••••••••••••••••••••••••••••••••••••••••••••
  147   29.38    832.00   I•••••••••••••••••••••••••••••••••••••••••••••••••
  119   30.60    834.00   I•••••••••••••••••••••••••••••••••••••••+
  151   32.14    836.00   I••••••••••••••••••••••••••••••••••••••••••••••••••+
  169   33.86    838.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  158   35.48    840.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••+
  191   37.42    842.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  157   39.03    844.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••+
  181   40.87    846.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  261   43.54    848.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  263   46.22    850.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  229   48.56    852.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  211   50.71    854.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  189   52.64    856.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  253   55.22    858.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  227   57.53    860.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  189   59.46    862.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  183   61.33    864.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  183   63.20    866 00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  188   65 12    868 00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  209   67.25    870 00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  139   68.67    872.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  148   70.18    874.00   I•••••••••••••••••••••••••••••••••••••••••••••••••+
  133   71.53    876.00   I••••••••••••••••••••••••••••••••••••••••••••+
  136   72.92    878.00   I•••••••••••••••••••••••••••••••••••••••••••••+
  109   74.03    880.00   I••••••••••••••••••••••••••••••••••••+
  105   75.10    882.00   I•••••••••••••••••••••••••••••••••••
  101   76.14    884.00   I•••••••••••••••••••••••••••••••••+
  108   77.24    886.00   I••••••••••••••••••••••••••••••••••••
  105   78.31    888.00   I•••••••••••••••••••••••••••••••••••
  123   79.56    890.00   I•••••••••••••••••••••••••••••••••••••••••
  111   80.70    892.00   I•••••••••••••••••••••••••••••••••••••
  111   81.83    894.00   I•••••••••••••••••••••••••••••••••••••
   98   82.83    896.00   I••••••••••••••••••••••••••••••••+
  128   84.13    898.00   I••••••••••••••••••••••••••••••••••••••••••+
  123   85.39    900.00   I•••••••••••••••••••••••••••••••••••••••••
  106   86.47    902.00   I•••••••••••••••••••••••••••••••••••+
   91   87.40    904.00   I••••••••••••••••••••••••••••••+
   95   88.37    906.00   I•••••••••••••••••••••••••••••••+
  103   89.42    908.00   I••••••••••••••••••••••••••••••••••+
  103   90.47    910.00   I••••••••••••••••••••••••••••••••••+
  107   91.56    912.00   I•••••••••••••••••••••••••••••••••••+
   78   92.36    914.00   I••••••••••••••••••••••••••
   74   93.11    916.00   I••••••••••••••••••••••••+
   92   94.05    918.00   I••••••••••••••••••••••••••••••+
   82   94.89    920.00   I•••••••••••••••••••••••••••+
   98   95.89    922.00   I••••••••••••••••••••••••••••••••+
   60   96.50    924.00   I••••••••••••••••••••
   61   97.12    926.00   I••••••••••••••••••••+
   49   97.62    928.00   I••••••••••••••••+
   50   98.13    930.00   I••••••••••••••••+
   40   98.54    932.00   I•••••••••••••+
   27   98.82    934.00   I•••••••••
   23   99.05    936.00   I•••••••+
   22   99.28    938.00   I•••••••+
   19   99.47    940.00   I••••••+
   10   99.57    942.00   I•••+
   11   99.68    944.00   I•••+
    8   99.77    946.00   I••+
    5   99.82    948.00   I•+
    5   99.87    950.00   I•+
    4   99.91    952.00   I•+
    3   99.94    954.00   I•
    2   99.96    956.00   I+
    3   99.99    958.00   I•
    1  100.00    960.00   I+

PLOTTED VALUES  9801
```

Fig. 5.3

VALUES BETWEEN
755.00 807.00 831.00 855.00 879.00 903.00

WADI UMM ALARIA, Saudi Arabia
CALC.HT. IN METRES

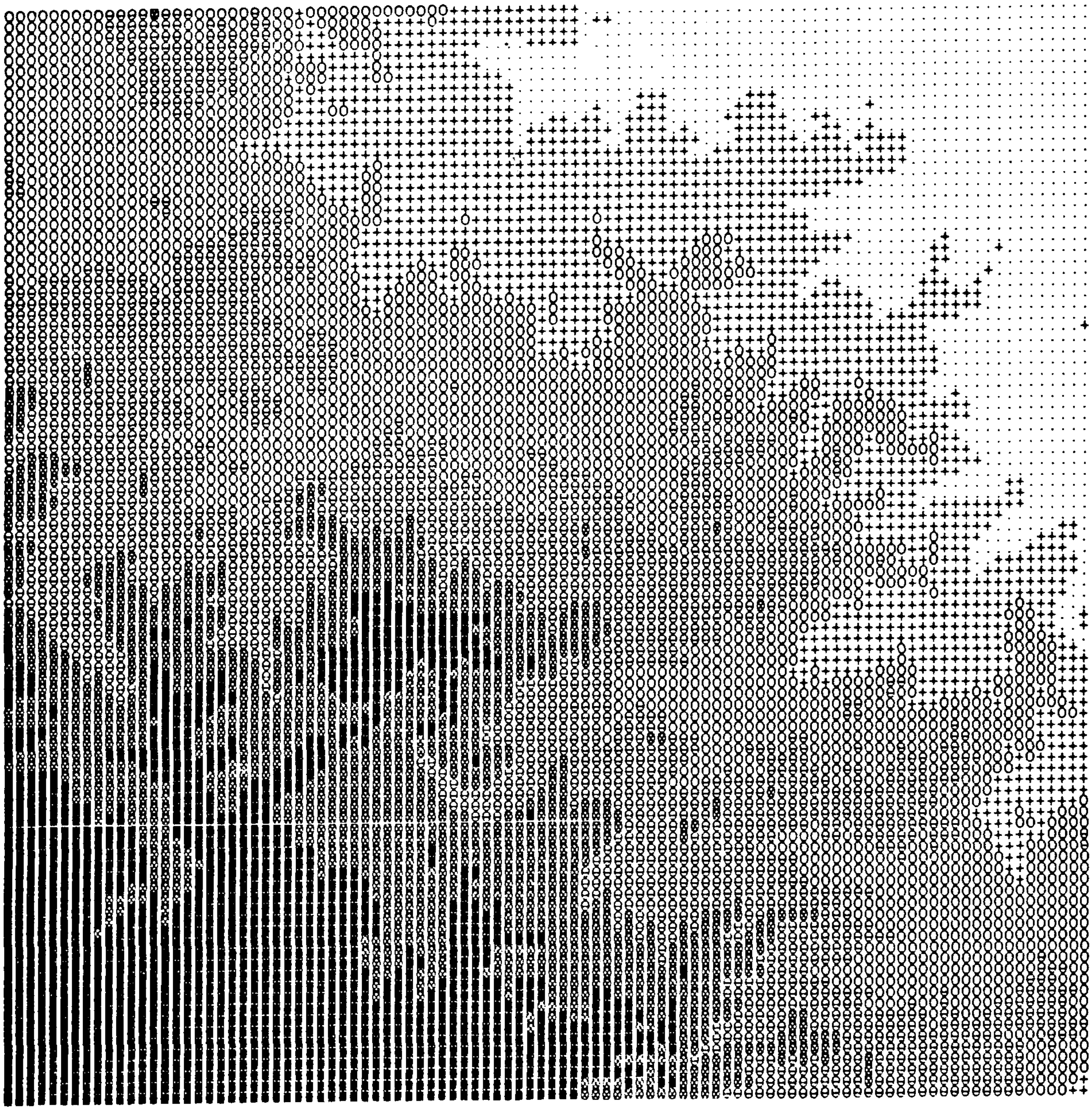
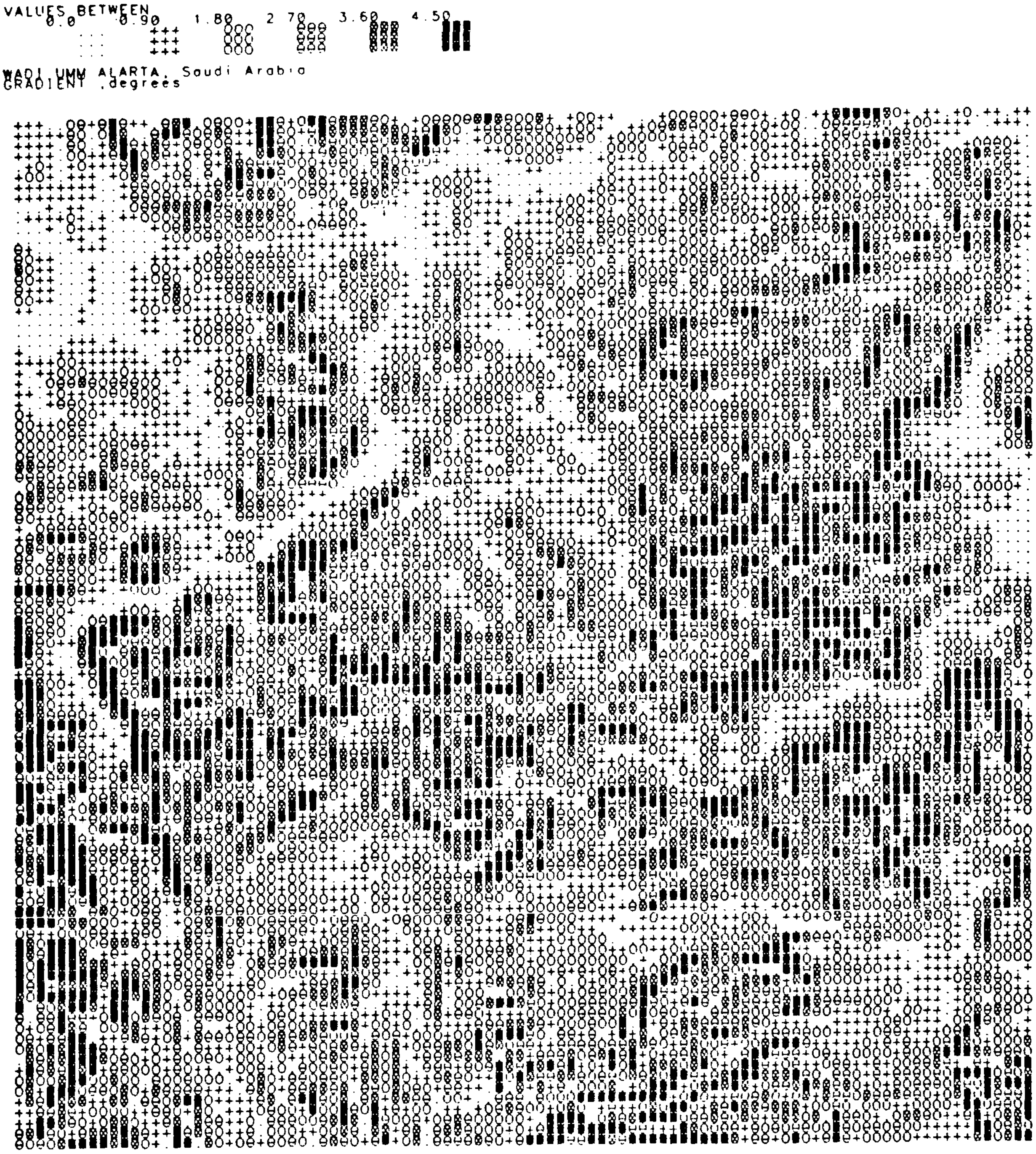


Fig. 5.4

```
<HISTO VAR=3 INTERVAL=(0.)/.25>

HISTOGRAM

MIDPOINT     COUNT FOR 3.GRAD  (EACH X= 7)

 0.              8 +XX
 .25000        109 +XXXXXXXXXXXXXXXX
 .50000        353 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 .75000        479 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.0000        562 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.2500        584 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.5000        668 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.7500        679 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.0000        677 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.2500        656 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.5000        658 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.7500        613 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.0000        523 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.2500        491 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.5000        425 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 3.7500        382 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.0000        329 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.2500        258 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.5000        231 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 4.7500        206 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 5.0000        191 +XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 5.2500        144 +XXXXXXXXXXXXXXXXXXXXX
 5.5000        118 +XXXXXXXXXXXXXXXXX
 5.7500         82 +XXXXXXXXXXXX
 6.0000         72 +XXXXXXXXXXX
 6.2500         67 +XXXXXXXXXX
 6.5000         39 +XXXXXX
 6.7500         44 +XXXXXXX
 7.0000         36 +XXXXXX
 7.2500         26 +XXXX
 7.5000         21 +XXX
 7.7500         16 +XXX
 8.0000         12 +XX
 8.2500          9 +XX
 8.5000          8 +XX
 8.7500          9 +XX
 9.0000          3 +X
 9.2500          3 +X
 9.5000          1 +X
 9.7500          3 +X
 10.000          0 +
 10.250          1 +X
 10.500          0 +
 10.750          2 +X
 11.000          0 +
 11.250          1 +X
 11.500          0 +
 11.750          0 +
 12.000          0 +
 12.250          1 +X
 12.500          0 +
 12.750          0 +
 13.000          1 +X

 TOTAL        9801  (INTERVAL WIDTH=  .25000)
```

```
HISTOGRAM OF GRADIENT SORT OF SIN OF GRADIENT
 EACH • IS  7 POINTS  + IS 1 TO  6 POINTS        CLASS WIDTH =   0.01

COUNT  TOTAL%  MIDPOINT
    0    0.0     0.0     I
    0    0.0     0.01    I
    0    0.0     0.02    I
    0    0.0     0.03    I
    8    0.08    0.04    I•+
    4    0.12    0.05    I+
   25    0.38    0.06    I•••+
   52    0.91    0.07    I•••••••+
   82    1.74    0.08    I•••••••••••+
  137    3.14    0.09    I•••••••••••••••••••+
  162    4.80    0.10    I•••••••••••••••••••••••+
  217    7.01    0.11    I•••••••••••••••••••••••••••••••
  310   10.17    0.12    I••••••••••••••••••••••••••••••••••••••••••••+
  321   13.45    0.13    I•••••••••••••••••••••••••••••••••••••••••••••+
  342   16.94    0.14    I••••••••••••••••••••••••••••••••••••••••••••••••+
  435   21.38    0.15    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  523   26.71    0.16    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  510   31.92    0.17    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  543   37.46    0.18    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  582   43.39    0.19    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  606   49.58    0.20    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  634   56.05    0.21    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  610   62.27    0.22    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  540   67.78    0.23    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  535   73.24    0.24    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  504   78.38    0.25    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  404   82.50    0.26    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  334   85.91    0.27    I•••••••••••••••••••••••••••••••••••••••••••••••+
  283   88.80    0.28    I••••••••••••••••••••••••••••••••••••••••+
  278   91.63    0.29    I•••••••••••••••••••••••••••••••••••••••+
  227   93.95    0.30    I••••••••••••••••••••••••••••••••+
  152   95.50    0.31    I•••••••••••••••••••••+
  119   96.71    0.32    I•••••••••••••••••
   95   97.68    0.33    I•••••••••••••+
   63   98.33    0.34    I•••••••••
   62   98.96    0.35    I••••••••+
   33   99.30    0.36    I••••+
   26   99.56    0.37    I•••+
   17   99.73    0.38    I••+
   12   99.86    0.39    I•+
    5   99.91    0.40    I+
    3   99.94    0.41    I+
    1   99.95    0.42    I+
    2   99.97    0.43    I+
    1   99.98    0.44    I+
    0   99.98    0.45    I
    1   99.99    0.46    I+
    1  100.00    0.47    I+
    0  100.00    0.48    I
    0  100.00    0.49    I
    0  100.00    0.50    I

PLOTTED VALUES  9801
```

Fig. 5.5



WADI UMM ALARTA, Saudi Arabia
GRADIENT, degrees

in the southwest and the lowlands in the northeast. The standard deviation is 39.5m and kurtosis -0.55.

5.4.2 Gradient

Gradient is the maximum rate of change of altitude in degrees and ranges between 0.0 and 90°. For Alarta, the untransformed values of gradient range from a minimum of 0.1° to a maximum of 12.9°, with a mean of 2.67° and standard deviation of 1.55°. The skewness of the gradient is +0.99 and the kurtosis is 1.37.

The histogram of the gradient (Fig.5.4) has a skewed shape because most of the gradients in Wadi Umm Alarta are low, but a few gradients are moderately steep. The square root of sine transformation reduces the skewness to +0.18, which is quite expected as the gradient values are much closer to the lower limit of zero than to the upper limit of 90 degrees.

The map shown in Figure 5.5 provides a visual display of the gradient distribution and shows that the gradients are steepest in the southeast, in the west and along the sides of the valleys. This correlates well with the orthophotographic background of the topographic map sheet. Both the main wadis, and particularly the Wadi Umm Alarta, are easily distinguishable in Figure 5.5. The strongest correlation in Table 5.1 is between gradient and altitude, but it is only 0.22.

For comparison, some measurements were made directly from the map. The greatest fall in 100 m is 35 m, giving a slope of arctan (0.35) = 19.3°. This is compatible with the matrix results, since the quadratics fitted to the matrix provide some smoothing.

Table 5.1

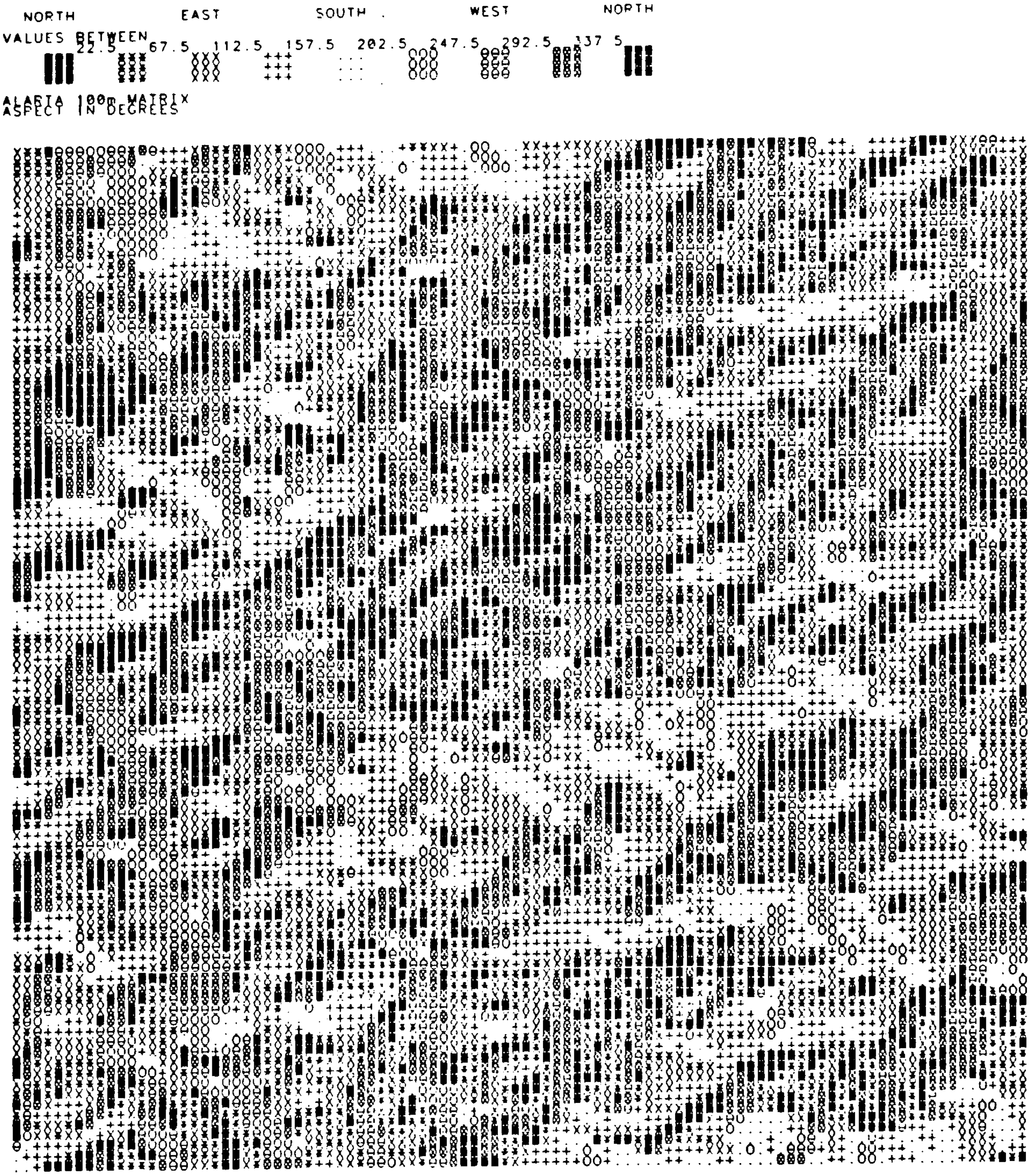
```
WADI UMM ALARTA, Saudi Arabia
 NO. OF ROWS=  101

 STATISTICS FOR       9801  POINTS WITH NON ZERO GRADIENT

               EST.ALT.      GRADIENT         PROFC          PLANC

MEAN            854.971         2.669        -0.306          1.047

SDEV             39.479         1.550         2.987        127.054

SKEW              0.006         0.987         0.696          0.375

KURT             -0.547         1.367         2.874         32.465

 MAX            959.000        12.914        20.894       1916.621

 MIN            756.000         0.095       -14.788      -1924.413

 VECTOR MEAN ASPECT ANGLE           49.858
 VECTOR STRENGTH(PROPORTION)         0.295
 GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE      44.656
 GRADIENT WEIGHTED VECTOR STRENGTH(PROPORTION)    0.270

CORRELATION COEFFS

             EST.ALT.    GRADIENT      PROFC       PLANC

EST.ALT.        1.000       0.206       0.126       0.073

GRADIENT        0.206       1.000      -0.082       0.070

PROFC           0.126      -0.082       1.000       0.184

PLANC           0.073       0.070       0.184       1.000


STATISTICS INCLUDING ZERO GRADIENT POINTS
EST ALT AND GRADIENT FOR ALL       9801    POINTS
PROFC AND PLANC FOR       9801   NON ZERO AND PLAIN POINTS
WHERE PLANC IS TAKEN AS 0.0 FOR PLAIN POINTS

               EST.ALT.      GRADIENT         PROFC          PLANC

MEAN            854.971         2.669        -0.306          1.047

SDEV             39.479         1.550         2.987        127.054

SKEW              0.006         0.987         0.696          0.375

KURT             -0.547         1.367         2.874         32.465
```

```
ALARTA 100m MATRIX
 NO. OF ROWS=  101
 CURVATURES   PROFC=2/PI•ARCTAN(PROFC•0.1872) PLANC=2/PI•ARCTAN(PLANC•0.008
GRADIENT TRANSFORMED TO SQUARE ROOT OF SINE OF GRADIENT

 STATISTICS FOR       9801  POINTS WITH NON ZERO GRADIENT

               EST.ALT.      GRADIENT         PROFC          PLANC

MEAN            854.971         0.206        -0.038          0.005

SDEV             39.479         0.062         0.275          0.335

SKEW              0.006         0.177         0.382         -0.054

KURT             -0.547        -0.193         0.000         -0.001

 MAX            959.000         0.473         0.841          0.959

 MIN            756.000         0.041        -0.779         -0.959

   VECTOR MEANS MODULO                                  360     180      90
 VECTOR MEAN ASPECT ANGLE                            40.143  24.197  48.063
 VECTOR STRENGTH(PROPORTION)                          0.295   0.004   0.025
 GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE          45.344 135.611  53.837
 GRADIENT WEIGHTED VECTOR STRENGTH(PROPORTION)        0.270   0.026   0.033

CORRELATION COEFFS

             EST.ALT.    GRADIENT      PROFC       PLANC

EST.ALT.        1.000       0.215       0.128       0.094

GRADIENT        0.215       1.000      -0.072       0.131

PROFC           0.128      -0.072       1.000       0.244

PLANC           0.094       0.131       0.244       1.000

CORREL OF GRADIENT WITH ABS CURV            0.249      -0.372

STATISTICS INCLUDING ZERO GRADIENT POINTS
EST ALT AND GRADIENT FOR ALL       9801    POINTS
PROFC AND PLANC FOR       9801   NON ZERO AND PLAIN POINTS
WHERE PLANC IS TAKEN AS 0.0 FOR PLAIN POINTS

               EST.ALT.      GRADIENT         PROFC          PLANC

MEAN            854.971         0.206        -0.038          0.005

SDEV             39.479         0.062         0.275          0.335

SKEW              0.006         0.177         0.382         -0.054

KURT             -0.547        -0.193         0.000         -0.001
```

Fig. 5.6

```
ALARTA 100m MATRIX

 HISTOGRAM OF THETD ASPECT OF MAX SLOPE IN DEG
  EACH • IS  3 POINTS  + IS 1 T0  2 POINTS          CLASS WIDTH =    5.00

 COUNT  TOTAL%  MIDPOINT
   43    0.44     0.0    I••••••••••••••+
  171    2.18     5.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  195    4.17    10.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  201    6.22    15.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  219    8.46    20.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  208   10.58    25.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  226   12.89    30.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  217   15.10    35.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  244   17.59    40.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  246   20.10    45.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  224   22.39    50.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  227   24.70    55.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  223   26.98    60.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  224   29.26    65.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  210   31.40    70.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  196   33.40    75.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  201   35.46    80.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  188   37.37    85.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  165   39.06    90.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••
  146   40.55    95.00   I••••••••••••••••••••••••••••••••••••••••••••••••+
  160   42.18   100.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••+
  162   43.83   105.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••
  145   45.31   110.00   I••••••••••••••••••••••••••••••••••••••••••••••••+
  163   46.97   115.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  140   48.40   120.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  136   49.79   125.00   I•••••••••••••••••••••••••••••••••••••••••••••+
  139   51.21   130.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  150   52.74   135.00   I••••••••••••••••••••••••••••••••••••••••••••••••••
  139   54.16   140.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  129   55.47   145.00   I•••••••••••••••••••••••••••••••••••••••••••
  100   56.49   150.00   I•••••••••••••••••••••••••••••••••+
  114   57.66   155.00   I••••••••••••••••••••••••••••••••••••••
  103   58.71   160.00   I••••••••••••••••••••••••••••••••••+
   80   59.52   165.00   I••••••••••••••••••••••••••+
  103   60.58   170.00   I••••••••••••••••••••••••••••••••••+
   80   61.39   175.00   I••••••••••••••••••••••••••+
   85   62.26   180.00   I••••••••••••••••••••••••••••+
   69   62.96   185.00   I•••••••••••••••••••••••
   63   63.61   190.00   I•••••••••••••••••••••
   60   64.22   195.00   I••••••••••••••••••••
   58   64.81   200.00   I•••••••••••••••••••+
   61   65.43   205.00   I••••••••••••••••••••+
   46   65.90   210.00   I•••••••••••••••+
   52   66.43   215.00   I•••••••••••••••••+
   62   67.06   220.00   I••••••••••••••••••••+
   57   67.65   225.00   I•••••••••••••••••••
   43   68.08   230.00   I••••••••••••••+
   49   68.58   235.00   I••••••••••••••••+
   70   69.30   240.00   I•••••••••••••••••••••••+
   60   69.91   245.00   I••••••••••••••••••••
   56   70.48   250.00   I••••••••••••••••••+
   80   71.30   255.00   I••••••••••••••••••••••••••+
   53   71.84   260.00   I•••••••••••••••••+
   67   72.52   265.00   I••••••••••••••••••••••+
  118   73.73   270.00   I•••••••••••••••••••••••••••••••••••••••+
   77   74.51   275.00   I•••••••••••••••••••••••••+
   93   75.46   280.00   I•••••••••••••••••••••••••••••••
  106   76.54   285.00   I•••••••••••••••••••••••••••••••••••+
  127   77.84   290.00   I••••••••••••••••••••••••••••••••••••••••••+
  138   79.25   295.00   I••••••••••••••••••••••••••••••••••••••••••••••
  121   80.48   300.00   I••••••••••••••••••••••••••••••••••••••••+
  139   81.90   305.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  135   83.28   310.00   I•••••••••••••••••••••••••••••••••••••••••••••
  157   84.88   315.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••+
  140   86.31   320.00   I••••••••••••••••••••••••••••••••••••••••••••••+
  143   87.77   325.00   I•••••••••••••••••••••••••••••••••••••••••••••••+
  147   89.27   330.00   I•••••••••••••••••••••••••••••••••••••••••••••••••
  196   91.27   335.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  166   92.96   340.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••+
  171   94.70   345.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  183   96.57   350.00   I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  162   98.22   355.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••
  174  100.00   360.00   I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••

PLOTTED VALUES  9801
```

Fig. 5.7


NORTH
EAST
SOUTH
WEST
NORTH
VALUES BETWEEN
22.5
67.5
112.5
157.5
202.5
247.5
292.5
337 5
ALARIA 100m MATRIX
ASPECT IN DEGREES

5.4.3 Aspect

Aspect is the compass direction of maximum gradient and ranges between 0.0 and 360°. The histogram of aspect (Fig.5.6) indicates that the slopes are mainly facing in northerly and northeasterly directions, and few slopes face southwest. This conforms to the direction of flow of the wadis. The map in Figure 5.7 also shows a pattern of topography where the ridges and valleys trend toward the northeast, with a predominance of north easterly slopes. When seen together with the gradient map (Fig. 5.5), it is also apparent that the steepest slopes face east-northeast (0 71°).

Vector analysis shows a resultant of 27-29% to the northeast, with no lineation or tendency to four equal-spaced modes (Table 5.1).

5.4.4 Profile convexity

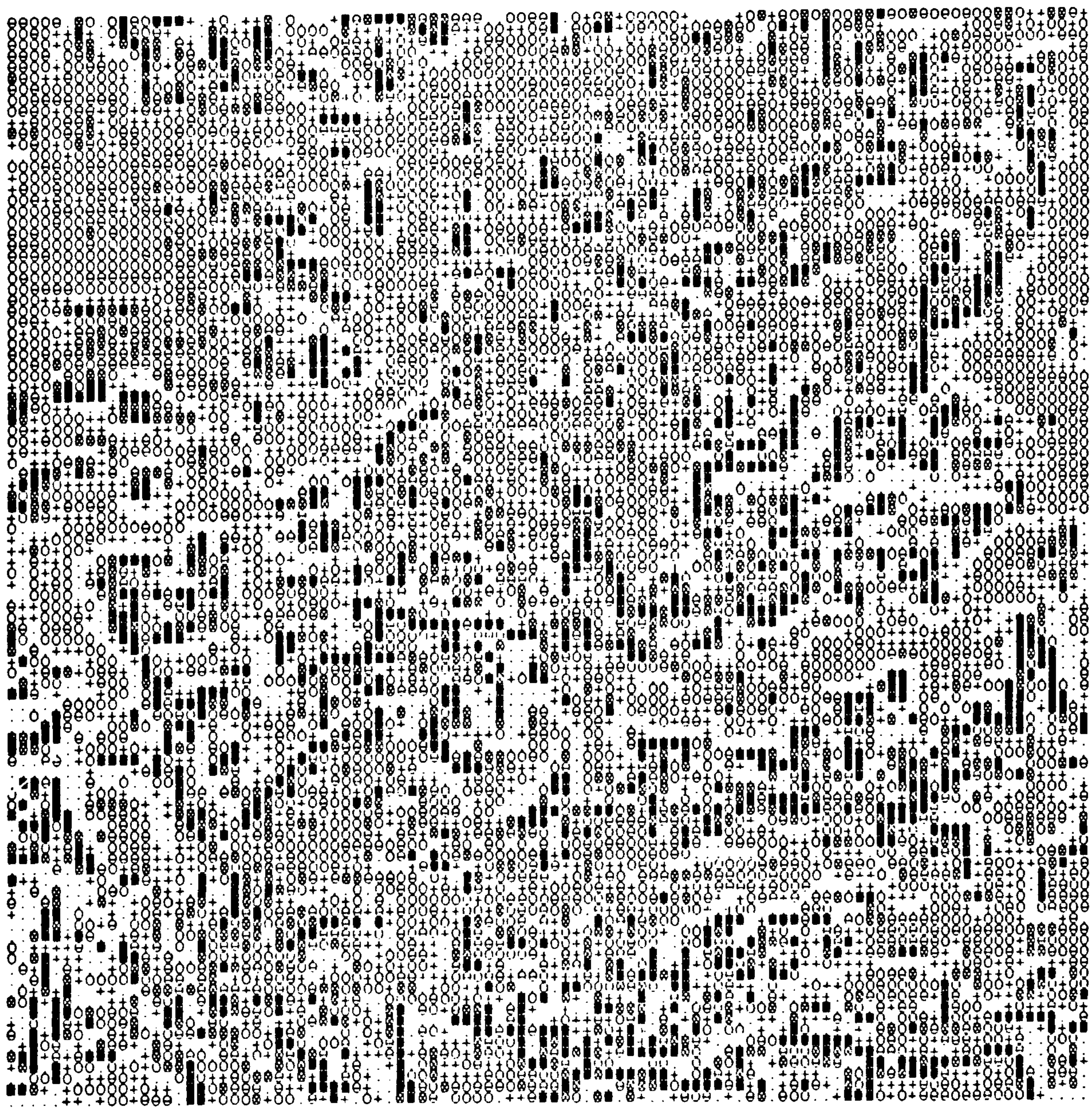
The results of profile convexity lie between 20.9 maximum and -14.8 minimum degrees/100 metres, with a negative mean of -0.31 /100m. The standard deviation is 2.99°/100m and skewness is 0.70. A maximum of 0.84 and -0.78 minimum after transformation are accompanied by a mean of -0.04, standard deviation +0.28 and skewness +0.38. The histogram of profile convexity has a symmetrical shape (Fig.5.8). Table 5.2 shows that between the range of 0.01 to 0.61 the concavities are more numerous than the convexities, with 5,676 and 3,528 respectively. That means the area has much gentle concavity. 182 convexity values are in the range of 0.61 to 0.91, compared with 76 concavities. This suggests a surface largely concave in profile, with some sharper convexities.

Fig. 5·8

```
ALARTA 100m MATRIX

 HISTOGRAM OF PROFC   ARCTAN TRANSFORM PROFC
  EACH * IS  4 POINTS  + IS 1 TO  3 POINTS        CLASS WIDTH =    0.02

 COUNT  TOTAL%  MIDPOINT
     0    0.0     -1.00    I
     0    0.0     -0.98    I
     0    0.0     -0.96    I
     0    0.0     -0.94    I
     0    0.0     -0.92    I
     0    0.0     -0.90    I
     0    0.0     -0.88    I
     0    0.0     -0.86    I
     0    0.0     -0.84    I
     0    0.0     -0.82    I
     0    0.0     -0.80    I
     1    0.01    -0.78    I+
     1    0.02    -0.76    I+
     4    0.06    -0.74    I*
     5    0.11    -0.72    I*+
     3    0.14    -0.70    I+
    17    0.32    -0.68    I****+
     9    0.41    -0.66    I**+
    20    0.61    -0.64    I*****
    34    0.96    -0.62    I********+
    36    1.33    -0.60    I*********
    51    1.85    -0.58    I************+
    52    2.38    -0.56    I*************
    49    2.88    -0.54    I************+
    75    3.64    -0.52    I******************+
    70    4.36    -0.50    I*****************+
    87    5.24    -0.48    I*********************+
    96    6.22    -0.46    I************************
   109    7.34    -0.44    I***************************+
   119    8.55    -0.42    I*****************************+
   131    9.89    -0.40    I********************************+
   134   11.25    -0.38    I*********************************+
   147   12.75    -0.36    I************************************+
   174   14.53    -0.34    I*******************************************+
   179   16.36    -0.32    I********************************************+
   205   18.45    -0.30    I***************************************************+
   178   20.26    -0.28    I********************************************+
   208   22.39    -0.26    I****************************************************
   217   24.60    -0.24    I******************************************************+
   248   27.13    -0.22    I**************************************************************
   246   29.64    -0.20    I*************************************************************+
   281   32.51    -0.18    I**********************************************************************+
   280   35.36    -0.16    I**********************************************************************
   289   38.31    -0.14    I************************************************************************+
   341   41.79    -0.12    I*************************************************************************************+
   296   44.81    -0.10    I**************************************************************************
   333   48.21    -0.08    I***********************************************************************************+
   342   51.70    -0.06    I*************************************************************************************+
   326   55.02    -0.04    I*********************************************************************************+
   363   58.73    -0.02    I******************************************************************************************+
   317   61.96     0.00    I*******************************************************************************+
   291   64.93     0.02    I************************************************************************+
   250   67.48     0.04    I**************************************************************+
   213   69.66     0.06    I*****************************************************+
   202   71.72     0.08    I**************************************************+
   210   73.86     0.10    I****************************************************+
   181   75.71     0.12    I*********************************************+
   177   77.51     0.14    I********************************************+
   155   79.09     0.16    I**************************************+
   121   80.33     0.18    I******************************+
   153   81.89     0.20    I**************************************+
   115   83.06     0.22    I****************************+
   108   84.16     0.24    I***************************
   131   85.50     0.26    I********************************+
   116   86.69     0.28    I*****************************
   114   87.85     0.30    I****************************+
    96   88.83     0.32    I************************
    95   89.80     0.34    I***********************+
    91   90.73     0.36    I**********************+
    84   91.58     0.38    I*********************
    77   92.37     0.40    I*******************+
    71   93.09     0.42    I*****************+
    72   93.83     0.44    I******************
    56   94.40     0.46    I**************
    55   94.96     0.48    I*************+
    58   95.55     0.50    I**************+
    58   96.14     0.52    I**************+
    50   96.65     0.54    I************+
    46   97.12     0.56    I***********+
    42   97.55     0.58    I**********+
    43   97.99     0.60    I**********+
    33   98.33     0.62    I********+
    48   98.82     0.64    I************
    29   99.11     0.66    I*******+
    16   99.28     0.68    I****
    22   99.50     0.70    I*****+
    22   99.72     0.72    I*****+
     8   99.81     0.74    I**
     7   99.88     0.76    I*+
     6   99.94     0.78    I*+
     3   99.97     0.80    I+
     1   99.98     0.82    I+
     2  100.00     0.84    I+
     0  100.00     0.86    I
     0  100.00     0.88    I
     0  100.00     0.90    I
     0  100.00     0.92    I
     0  100.00     0.94    I
     0  100.00     0.96    I
     0  100.00     0.98    I
     0  100.00     1.00    I

PLOTTED VALUES  9801
```

Fig. 5.9

```
VALUES BETWEEN
  -1.00   -0.32   -0.16    0.0    0.16    0.32
   : : :   +++     000     θθθ     ⊗⊗⊗     ███
   : : :   +++     000     θθθ     ⊗⊗⊗     ███
   : : :   +++     000     θθθ     ⊗⊗⊗     ███

ALARTA 100m MATRIX
PROFILE CONVEXITY WITH ARCTAN TRANSFORMATION
```



5.4.5 Plan convexity

The map of plan convexity shows the ridges (black) and valleys (dotted) very clearly (Fig.5.10). The histogram of plan convexity has a classic symmetrical distribution (Fig.5.11) with a sharp peak at 0.00 and the tails are also equal. After the arctangent transformation, plan convexity has a maximum of +0.96 and minimum -0.96, with a mean of +0.01, which is as close to zero as may be expected. The skewness is only -0.05 and standard deviation +0.34. Without transformation the standard deviation is 127°/100m, the mean 1.05°/100m and skewness is 0.38. Table 5.2 shows there are 3844 convexities compared with 3441 concavities in the range 0.01 to 0.41, while in the range 0.51 to 0.81 there are 645 concavities compared with 587 convexities. Thus in plan, convexity is rather more common than concavity, but the imbalance is not great. Ridges are slightly broader (more rounded) than valleys. The strongest correlation is +0.24 between profile convexity and plan convexity (Table 5.2).

Table 5.2 : Summarised frequency distributions of convexity for Wadi Umm Alarta. Numbers of convexities (+) and concavities (-) are juxtaposed, for each magnitude range

Range	Profile convexity		Plan convexity	
	+	-	+	-
0.91 to 1.00	0	0	17	10
0.81 to 0.91	3	0	64	60
0.71 to 0.81	35	10	118	131
0.61 to 0.71	144	66	198	238
0.51 to 0.61	227	251	273	276
0.41 to 0.51	301	449	415	375
0.31 to 0.41	445	758	589	575
0.21 to 0.31	582	1051	830	737
0.11 to 0.21	798	1452	1063	945
0.01 to 0.11	1192	1715	1365	1184
	3727	5752	4932	4531
+0.01 to -0.01	322		338	
Overall total	9801		9801	

Fig. 5·10

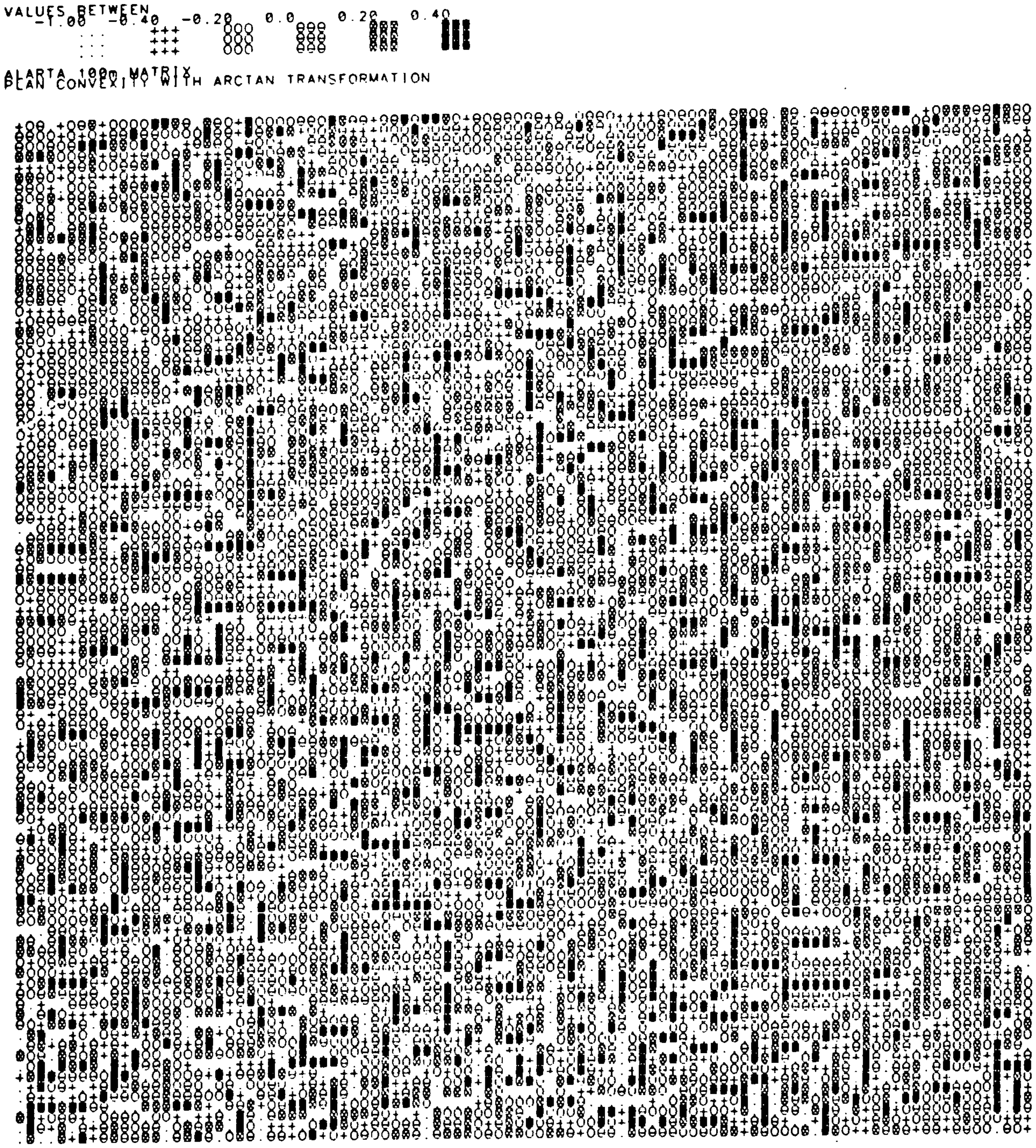

VALUES BETWEEN
-1.00
-0.40
-0.20
0.0
0.20
0.40
ALARTA 100m MATRIX
PLAN CONVEXITY WITH ARCTAN TRANSFORMATION

Fig. 5.11

```
ALARTA 100m MATRIX

  HISTOGRAM OF PLANC    ARCTAN TRANSFORM PLANC            CLASS WIDTH =    0.02
   EACH • IS  4 POINTS  + IS 1 TO  3 POINTS

  COUNT   TOTAL%  MIDPOINT
      0    0 0     -1.00    I
      0    0.0     -0.98    I
      1    0.01    -0.96    I+
      4    0.05    -0.94    I•
      5    0.10    -0 92    I•+
      9    0.19    -0.90    I••+
      8    0.28    -0.88    I••
     10    0 38    -0.86    I••+
     14    0.52    -0.84    I•••+
     19    0.71    -0.82    I••••+
     27    0.99    -0.80    I••••••+
     27    1.27    -0.78    I••••••+
     25    1.52    -0.76    I••••••+
     25    1.78    -0.74    I••••••+
     25    2.03    -0.72    I••••••+
     42    2.46    -0.70    I••••••••••+
     46    2.93    -0.68    I•••••••••••+
     54    3.48    -0.66    I•••••••••••••+
     50    3.99    -0.64    I••••••••••••+
     45    4.45    -0.62    I•••••••••••+
     55    5.01    -0.60    I•••••••••••••+
     46    5.48    -0.58    I•••••••••••+
     56    6.05    -0.56    I••••••••••••••
     59    6.65    -0.54    I••••••••••••••+
     59    7.25    -0.52    I••••••••••••••+
     65    7.92    -0.50    I••••••••••••••••+
     73    8.66    -0.48    I••••••••••••••••••+
     72    9.40    -0.46    I••••••••••••••••••
     73   10.14    -0 44    I••••••••••••••••••+
     88   11.04    -0.42    I••••••••••••••••••••••
    101   12.07    -0.40    I•••••••••••••••••••••••••+
    118   13.27    -0.38    I•••••••••••••••••••••••••••••+
    107   14.37    -0.36    I••••••••••••••••••••••••••+
    131   15.70    -0.34    I••••••••••••••••••••••••••••••••+
    125   16.98    -0.32    I•••••••••••••••••••••••••••••••+
    128   18.28    -0.30    I••••••••••••••••••••••••••••••••
    142   19.73    -0.28    I•••••••••••••••••••••••••••••••••••+
    151   21.27    -0.26    I•••••••••••••••••••••••••••••••••••••+
    153   22.83    -0.24    I••••••••••••••••••••••••••••••••••••••+
    162   24.49    -0.22    I••••••••••••••••••••••••••••••••••••••••+
    159   26.11    -0.20    I•••••••••••••••••••••••••••••••••••••••+
    177   27.92    -0.18    I••••••••••••••••••••••••••••••••••••••••••••+
    195   29.91    -0.16    I••••••••••••••••••••••••••••••••••••••••••••••••+
    201   31.96    -0.14    I••••••••••••••••••••••••••••••••••••••••••••••••••+
    215   34.15    -0.12    I•••••••••••••••••••••••••••••••••••••••••••••••••••••+
    209   36.28    -0.10    I••••••••••••••••••••••••••••••••••••••••••••••••••••+
    223   38.56    -0.08    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    228   40.88    -0.06    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    255   43.49    -0.04    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    269   46.23    -0.02    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    338   49.68     0.00    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    298   52.72     0.02    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    297   55.75     0.04    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    256   58.36     0.06    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    244   60.85     0.08    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    273   63.64     0.10    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    264   66.33     0.12    I••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    237   68.75     0.14    I•••••••••••••••••••••••••••••••••••••••••••••••••••••••••••+
    216   70.95     0.16    I••••••••••••••••••••••••••••••••••••••••••••••••••••••
    183   72.82     0.18    I•••••••••••••••••••••••••••••••••••••••••••••+
    169   74.54     0.20    I••••••••••••••••••••••••••••••••••••••••••+
    191   76.49     0.22    I•••••••••••••••••••••••••••••••••••••••••••••••+
    163   78.16     0.24    I••••••••••••••••••••••••••••••••••••••••+
    160   79.79     0.26    I••••••••••••••••••••••••••••••••••••••••
    169   81.51     0.28    I••••••••••••••••••••••••••••••••••••••••••+
    142   82.96     0.30    I•••••••••••••••••••••••••••••••••••+
    146   84.45     0.32    I••••••••••••••••••••••••••••••••••••+
    131   85.79     0.34    I••••••••••••••••••••••••••••••••+
    107   86.88     0.36    I••••••••••••••••••••••••••+
    105   87.95     0.38    I••••••••••••••••••••••••••+
     97   88.94     0.40    I••••••••••••••••••••••••+
    101   89 97     0.42    I•••••••••••••••••••••••••+
     78   90.77     0.44    I•••••••••••••••••••+
     77   91.55     0.46    I•••••••••••••••••••+
     85   92.42     0.48    I•••••••••••••••••••••+
     76   93.19     0.50    I•••••••••••••••••••
     69   93.90     0.52    I•••••••••••••••••+
     44   94.35     0.54    I•••••••••••
     52   94.88     0.56    I•••••••••••••
     59   95.48     0.58    I••••••••••••••+
     50   95.99     0.60    I••••••••••••+
     41   96.41     0.62    I••••••••••+
     43   96.85     0.64    I••••••••••+
     31   97.16     0.66    I•••••••+
     41   97.58     0.68    I••••••••••+
     38   97.97     0.70    I•••••••••+
     29   98.27     0.72    I•••••••+
     24   98.51     0.74    I••••••
     23   98.75     0.76    I•••••+
     22   98.97     0.78    I•••••+
     21   99.18     0.80    I•••••+
     16   99.35     0.82    I••••
     20   99.55     0.84    I•••••
     13   99.68     0.86    I•••+
      8   99.77     0.88    I••
      7   99.84     0.90    I•+
      9   99.93     0.92    I••+
      5   99.98     0.94    I•+
      2  100.00     0.96    I+
      0  100.00     0.98    I
      0  100.00     1.00    I

PLOTTED VALUES  9801
```

Comparisons may be made with two areas studied by Evans by the same method as Wadi Umm Alarta in two different areas and topography. Keary is 5 x 5 km in the Bendor Range in British Columbia. A 100 m grid mesh was used to collect the altitude values, as for Wadi Umm Alarta. Its area is smaller than Wadi Umm Alarta but it has a maximum altitude of 2597 m, which is higher than Umm Alarta. Statistics for 2304 altitude points in Keary show the mean of altitude is 1648 m and the minimum 592 m. Standard deviation is 429 m, compared with only 39 m in Umm Alarta. Kurtosis and skewness are both negative, -0.40 and -0.38 respectively : the distribution is skewed further (-1.00; kurtosis +0.68) by square root of sine transformation. The gradient mean is +0.71 on the square root of sine scale and standard deviation is +0.134.

Its altitude map shows the high land is in the south west and slope to northeast, like Wadi Umm Alarta. The untransformed profile convexity for Wadi Umm Alarta is skewed but the Keary histogram is not.

Ferro is a fluvially very dissected basin in north Calabria, Italy around 16°22'E and 39°59'N. Its dimensions are 12.8 x 22.2 km. This region has no summit plateaux, but it has a broad range of altitude between a maximum of 1147 m and minimum of 7.78 m, with a mean of 445m, and median of 431 m. It has a relatively low standard deviation, 211.5 m. Frequency distributions of altitude and gradient are almost unskewed. This area has moderate and steep slopes, with variation in gradient between a maximum of 0.76 and a minimum of 0.13 (or 0.0 on parts of the flood plain) both facing north, with a mean of 0.46.

The correlation between altitude and gradient is strong at +0.45. The aspect map shows clearly the ridges and valleys, when the upper part of the valleys face the northeast and the lower part are facing southeast. The highest part of the basin has east and north facing slopes.

Profile convexity has a symmetrical frequency distribution with maximum +0.80, minimum -0.77 and mean -0.03. The plan convexity histogram has sharp peaks and long balanced tails, with mean, mode and median of Zero. The correlation between profile and plan convexity is weak at +0.28, but this is strong relative to that in most other areas. This area is similar to Wadi Umm Alarta in that both are fluvially dissected, but Ferro has greater relief than Wadi Umm Alarta (high maximum and very low minimum). Both areas have relatively strong correlations between altitude and gradient, and between profile convexity and plan convexity.

CHAPTER 6

CONCLUSION

CHAPTER 6

Conclusion

6.1 General Remarks

As pointed out in Chapter 1, the primary objective of this study was to use computer-based techniques for the terrain analysis of an area representative of the arid terrain in Saudi Arabia. Although the Thaniyat Turayf study area was chosen mainly due to the availability of topographic maps of the area, it turned out to be an appropriate choice as it offers a variety of landforms.

The geomorphological analysis of the study area was carried out by a manual method of summit analysis presented in Chapter 3, as well as by using a partly computer-based approach of relief analysis which is outlined in Chapter 4. The discussion of the results will focus on a comparison of the two techniques, to assess how successfully the various quantitative terrain parameters evaluated capture the terrain characteristics. In addition, it should be of interest to determine the correlation, if any, which may be apparent between the results obtained for the same area by using different techniques.

The results presented in Chapter 5 are based on a computer analysis of Al-Arta valley area which is a 10 x 10 km subset of the total Thaniyat Turayf area. This analysis, however, was carried out by collecting elevation data at 100 m grid interval which is 1/10th of the 1 km interval used for the relief analysis of Thaniyat Turayf area. The discussion, in comparing these two sets of results, will focus on the effect of varying grid interval and on the correlation, if any, that may be apparent between the results obtained for part of the area, with those resulting from analysis of the total area.

Such comparative evaluation of the different analytical approaches should provide useful guidelines for the practical application of different techniques used for geomorphometric terrain analysis.

6.2 Comparison of Summit Analysis with Relief Analysis

The techniques used for the summit analysis and the relief analysis are somewhat similar because both do not depend on the measurement of absolute altitude above sea level, but instead, are based on height defined in relation to the adjacent land surface. But the similarity ends here and even the definition of relative height varies in the two methods.

Summit mapping requires very tedious delineation of the ridge lines and location of the summits. For this study summits were defined to be points with at least two closed contours. For the 10 m contour interval of the maps used, this represented an average relative height of 20 metres. Consequently, the number of summits included is directly dependent on the number of closed contours defining the summit and the contour interval. Obviously, with a 5 m contour interval, summits would have been more numerous.

The number of summits and the ridge length will also increase with the areal extent of a mountain block. 867 km of ridge length is measured for Al-Howsa block against the total of 1348 km for the total area (Table 3.1). Of the total 912 summits in the Thaniyat Turayf area, 579 fall in Al Howsa block. The summit density expressed as the number of summits per square km may be used for comparing different areas, as done by Evans (1972b), but instead the statistic for summit density used in this study is the number of summits per km of ridge length. Although the summit density varies between 0.38 (Block B) and 0.93 (Block D) of Al-Howsa mountain block, the average for the entire mountain block is 0.67 which is the same as for the total Thaniyat Turayf study area.

The closure intensity in m/km, which is derived by dividing the total summit height in metres (number of contour closures multiplied by the contour interval) by the ridge length in km, is a measure of gradient along ridges, except that summits below the (20 m) threshold are excluded. For the Al-Howsa mountain block it ranges in value from a minimum of 8.52 m/km (Block B) to a maximum of 24.28 m/km (Block D). The average for the Al-Howsa mountain block is 16.32 m/km which is almost the same as 16.80 m/km for the entire Thaniyat Turayf study area. There is a strong correlation between the summit density and the closure intensity for the entire area. This is because the average summit height varies only slightly from the lowest, 22.34 m for Jabal Jualah, to the highest, 26.95 m for Jabal Wailah, with an average of 24.85 m for the entire study area. This is to be expected since 658 summits out of a total of 912 have just two closed contours (Table 3.2). Thus the average summit height does not correctly convey the variability in the landform of the study area. It is easy to see that any change in the definition of summit or contour interval will not cause a large change in the closure intensity, which is, therefore, not only the most stable parameter resulting from summit analysis, but also the most meaningful for comparing different areas.

Relief, as defined in this study, is the difference in height between the highest and the lowest altitude points within a 1 x 1 km grid spacing. Although the highest and the lowest points were interpolated manually from the 1:25,000 scale topographic maps of the study area, such relief data could be extracted through automated processing of a digital elevation model of the area. The distribution of relief as shown in Figure 4.3 provides a more easily interpretable view of the terrain than can be obtained from the ridges and summits map of Figure 3.1 or the ridge order map of Figure 3.9. It shows that the higher relief occurs primarily in the Jabal Wailah block and block D of Al-Howsa mountain block where the closure intensity was also the highest while the lowest relief mostly falls in the Jabal Jualah block and in block B of Al-Howsa mountain block, which has the lowest closure intensity.

As stated earlier, the closure intensity is the only stable and meaningful statistic obtained from the summit analysis. A comparison with the relief analysis confirms that both these parameters represent quite similar characteristics of the land form. The average closure intensity of 16.8 m/km for Thaniyat Turayf area (Table 3.1) represents an average ridge slope of 0.96°. A mean relief value of 38.7 m for a 1 x 1 km grid for the same area (Table 4.4) on the other hand would translate into a surface slope of 2.2°. But it should be kept in mind that while 0.96° is the slope along the ridge line, the slope of 2.2° derived from the relief can occur in any direction, and perhaps is more likely to be in a direction across the ridgeline. The relief analysis based on 2 x 2 km grid results in an average surface slope of 1.7° (59.5 m in 2 km).

Just like average summit height, the average relief itself is not a very useful statistic because the values may change with the grid spacing. As shown in Table 4.6, the relief gradient i.e. the rate of change in relief is not dependent on the grid spacing over which relief is measured.

Heavy dissection of the terrain would mean an increase in the number of summits in an area, which should also result in a higher value for the relief gradient. This is supported by the data in Table 3.1 where the largest number of summits occurs in the Jabal Wailah block and in Al-Howsa Block C. The relief gradient map of Figure 4.4 also shows the highest values to be concentrated in these mountain blocks.

6.3 Analysis of Wadi Umm Al Arta

Wadi Umm Al Arta area is 10 x 10 km and constitutes a small portion of the central Thaniyat Turayf area (see Figure 5.1). Detailed morphometric analysis of the area was carried out based on altitude data extracted at a uniform grid interval of 100 metres, using computer programs developed at the University of Durham. The results of this analysis which are presented in Chapter 5 cannot be compared directly with those obtained from the relief analysis of the entire Thaniyat Turayf area (Chapter 4). However, the processing approach used for the analysis of the altitude data of Umm Al Arta was also used for the lowest point data, and separately for the highest point data of Thaniyat Turayf. Such a comparison between the results of Umm Al Arta with the lowest point analysis results of Thaniyat Turayf may be valid, as long as it is kept in mind that Wadi Umm Al Arta area cannnot be regarded as a true geomorphologic representative of the entire Thaniyat Turayf area.

The altitude varies from 756 m to 959 m over Umm Al Arta area with a mean altitude of 855 m. Compared with this the variation in altitude over the entire Thaniyat Turayf area is from 631 m to 999 m with a mean value of 751 m for the lowest points; and from 639 m to 1039 m with a mean value of 790 m for the highest points. The standard deviation in altitude of 39.5 m for Umm Al Arta is far smaller than the standard deviation of 77.0 m for the lowest points or 91.2 m for the highest points. This is obviously due to a much larger range in the altitude data covering Thaniyat Turayf area.

The gradient for Al Arta varies from a minimum of 0.1° to a maximum of 12.9° with a mean value of 2.7° and standard deviation 1.6°. Corresponding gradient values for the lowest point Thaniyat Turayf data range from 0.02° to 4.8° with a mean of 0.6° and standard deviation 0.44°. This considerable decrease in the maximum and mean gradient values for Thaniyat Turayf is to be expected because not only are flatter areas included for Thaniyat Turayf, but also the gradient is based on the lowest altitude values within successive grid squares 1 km across. Both the type of the altitude data and the large spacing of 1 km assumed for successive data points have a considerable smoothing effect on the calculated gradient.

A smoothing effect is equally noticeable in the profile curvature data. For Umm Al Arta, profile convexity varies from -14.8° to +20.9° per 100 m with a mean of -0.3° and standard deviation of 2.99°. Corresponding values for lowest point Thaniyat Turayf data are only -0.53° to +0.58°, 0° and 0.06° per 100 m respectively. The plan curvature values range from -1924° to +1918° per 100 m with a mean of 1.0° and standard deviation of 127° for Umm Alarta, and -168° to +148° with a mean of 0.3° and much lower standard deviation of 7.8° for the lowest point Thaniyat Turayf data. Again, the large standard deviation of 127.0° is indicative of the fact that the shorter grid interval of 100 metres used for Umm Al-Arta analysis has captured much more detail in the contours. Although these comparisons are not entirely appropriate, they do illustrate the great importance of scale (grid mesh) in this type of geomorphometric analysis.

6.4 Concluding Remarks

Three different methods have been successfully demonstrated in this study of the geomorphology of arid desert terrain in north western Saudi Arabia. Each of these methods is based on the collection of data pertaining to some landform characteristic and then transformed into more meaningful terrain characteristics to provide quantitative representation of the geomorphologic character of the area.

The summit mapping approach, described in Chapter 3, is considered the least satisfactory approach for analyzing the geomorphology. It is essentially a manual data collection procedure and extremely tedious. This method is suitable only for the analysis of an area covering an entire mountain block, the limits of which cannot always be defined using any standard criterion. As pointed out earlier, the only stable and meaningful landform parameter resulting from this analysis is the closure intensity, which represents the average ridge line gradient and may be used to compare the geomorphology of two mountain blocks.

The approaches used for the altitude analysis of Wadi Umm Al Arta in Chapter 5 and for relief analysis of Thaniyat Turayf area presented in Chapter 4 are both dependent on altitude data interpolated from a topographic map at some regular grid interval. Although a manual procedure was used to extract the altitude data in this study, techniques are now well-developed to generate digital elevation models of any terrain surface of interest photogrammetrically through aerial photography. Thus the entire process of altitude data collection as well as processing can easily be automated.

Altitude above sea level, by itself, does not provide full information about the landform as Evans (1972b) has so convincingly pointed out; its derivatives such as gradient, aspect, profile convexity and plan convexity together provide a complete and meaningful quantitative portrayal of the local land form. However, the spacing at which the altitude data is captured should be dictated by the topography. It should rarely be necessary to use grid spacing smaller than 100 metres. In fact the digital photogrammetric technology available today can provide very dense terrain elevation data. Once captured, the data can be processed using any grid spacing commensurate with the topography of the terrain.

There is no doubt that the relief is a far more informative statistic than the altitude above the sea level. But the magnitude of relief is dependent on the horizontal interval over which relief is measured. For the same Thaniyat Turayf study area, the average relief is 38.7 m for 1 x 1 km spacing and changes to 59.5 m when the grid spacing is enlarged to 2 x 2 km (Table 4.6). So if two areas are to be compared, then relief must be measured at the same grid spacing. The derivatives of relief such as relief gradient and relief profile convexity are relatively independent of the grid spacing used and are more stable terrain parameters for comparison. The physical significance of the plan convexity for relief is not very clear.

In conclusion, it may be stated that although each of the methods demonstrated in this study can be used for the morphometric analysis of landform, the measurement of evenly spaced altitude data and the computation of altitude derivatives - gradient, aspect, profile convexity and plan convexity - provide the most complete and meaningful information about the landform. The fact that this approach can easily be adapted to the use of digital computers for data capture, data analysis as well as for graphical display of the computed results should add further impetus to wider application of this approach.

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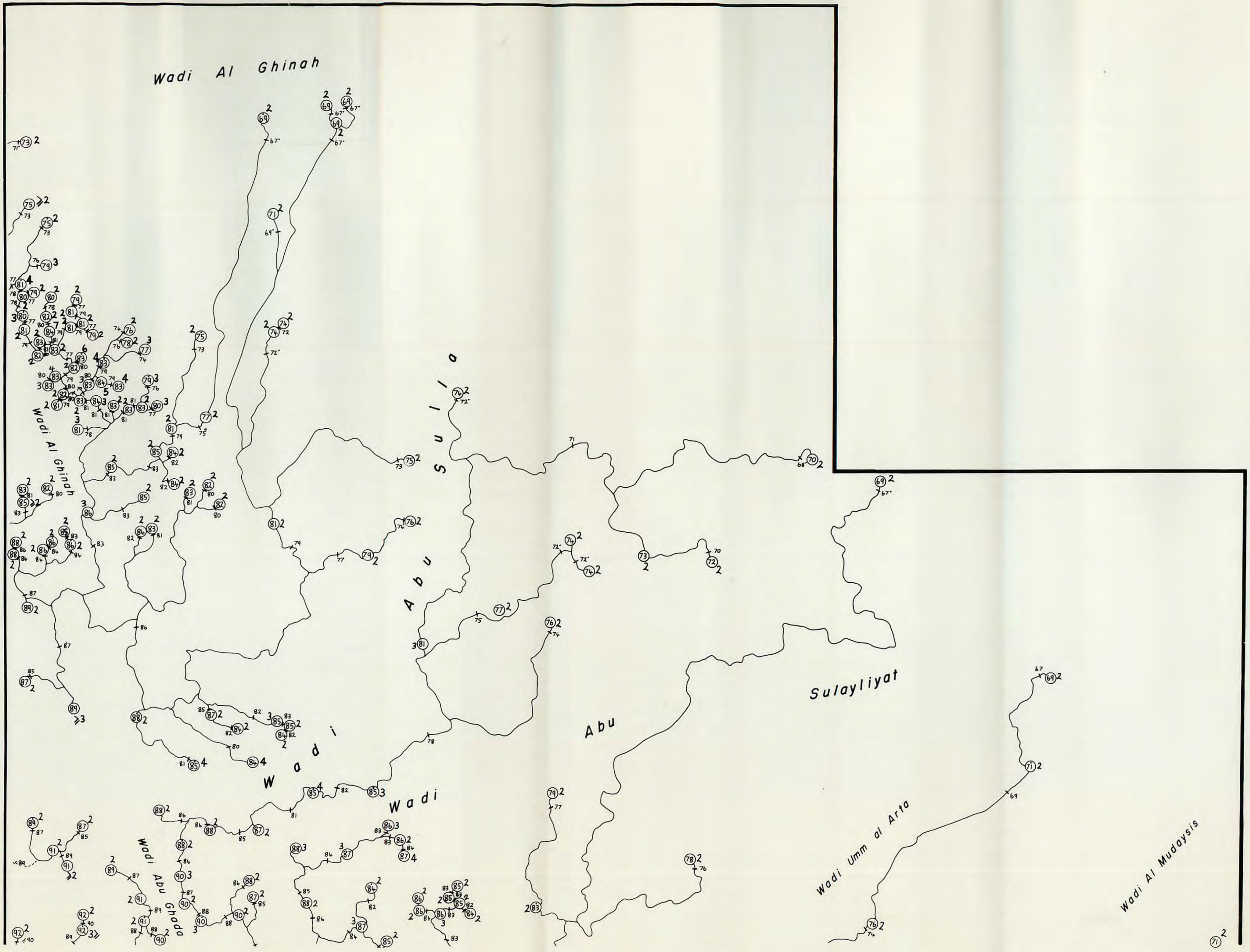
THE THANIYAT TURAYF AREA — N.W. SAUDI ARABIA



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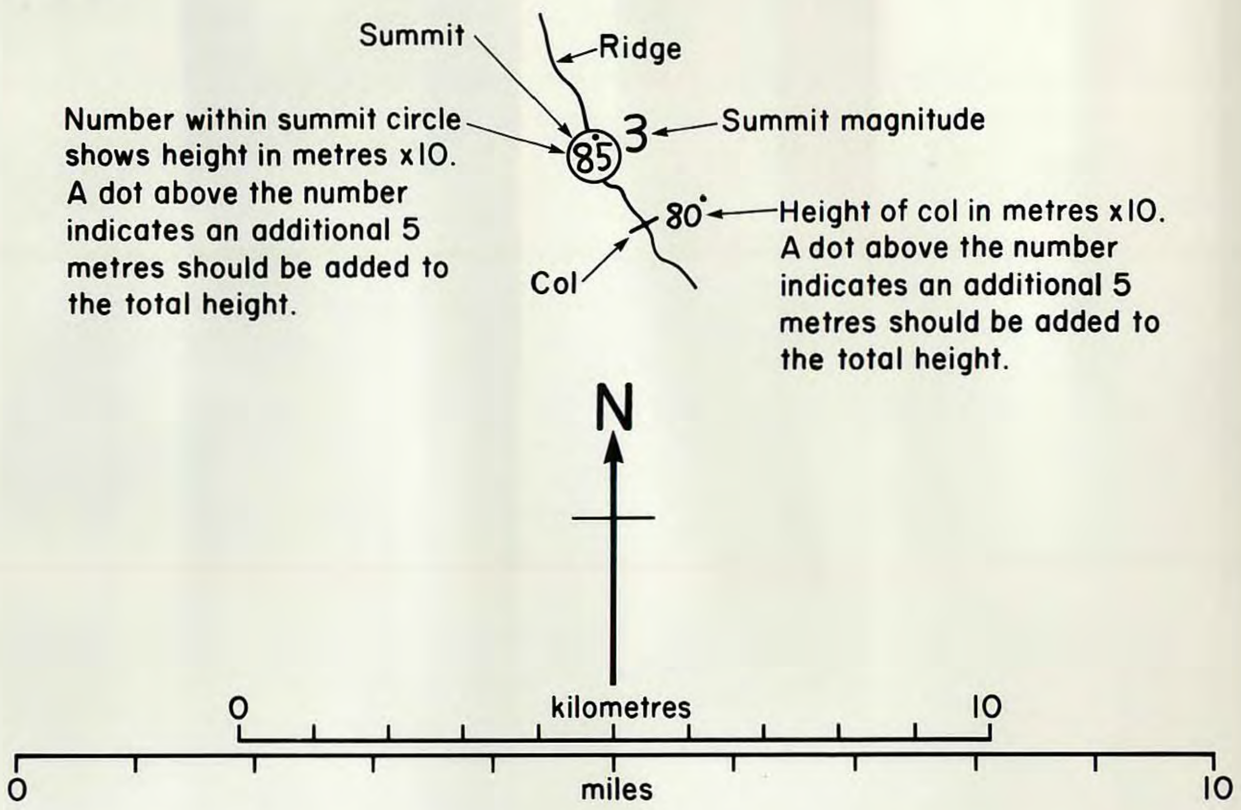
Summit
Ridge
Number within summit circle shows height in metres x10. A dot above the number indicates an additional 5 metres should be added to the total height.
85
3
Summit magnitude
80
Height of col in metres x10. A dot above the number indicates an additional 5 metres should be added to the total height.
Col
N
0
kilometres
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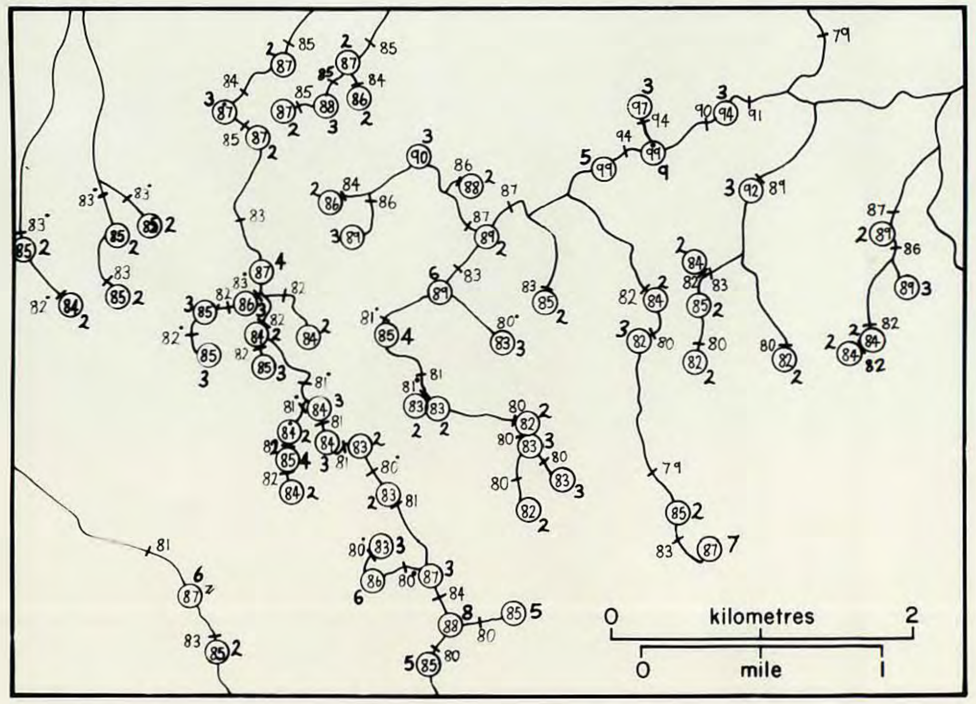
Inset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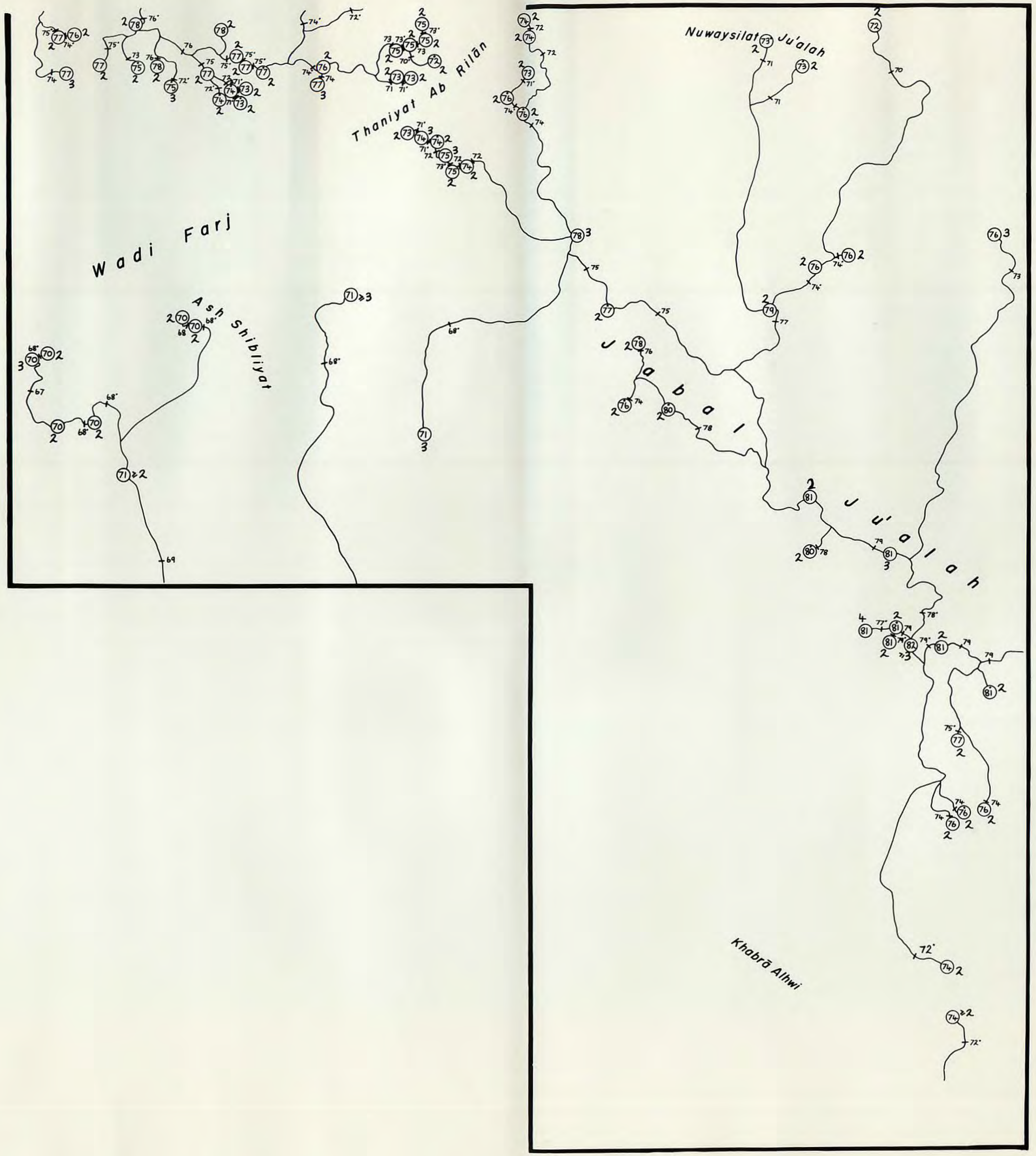
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Thaniyat Ab Rilān
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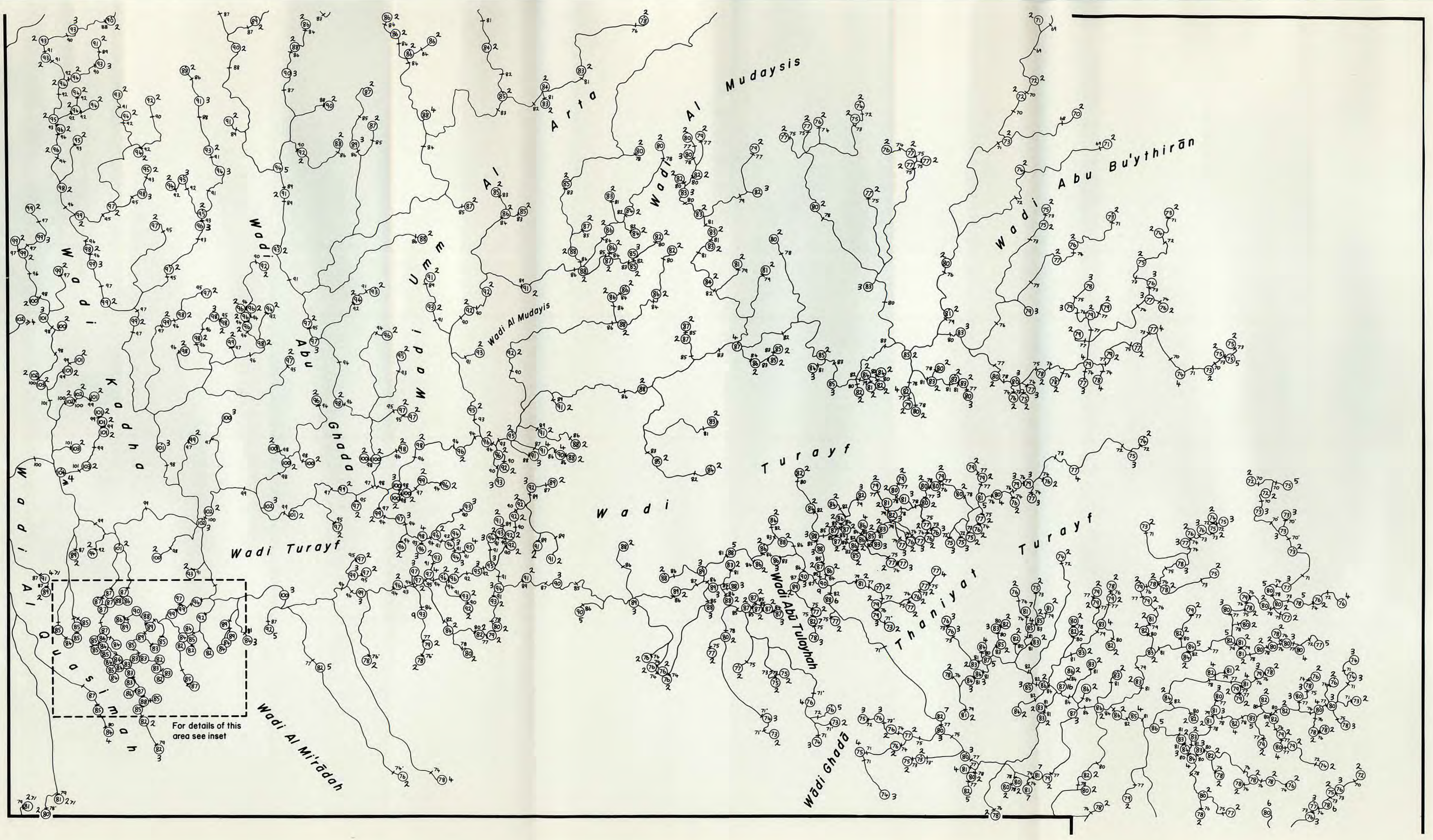
Ash Shibliyat
Jabal Ju'alah
Khabrā Alhwi


Wadi Kadhdha
Wadi Abu Ghada
Wadi Umm Al Arta
Wadi Al Mudaysis
Wadi Al Mudaysis
Wadi Abu Bu'ythirān
Wadi Turayf
Wadi Turayf
Wadi Abū Tulayhah
Thaniyat Turayf
Wādi Ghadā
Wadi Al Mi'ādah
Wadi Al Quasimah
For details of this area see inset