THE GOVERNMENT OF SULTANATE OF OMAN

HYDROLOGIC OBSERVATION PROJECT IN THE BATINAH COAST OF SULTANATE OF OMAN

FINAL REPORT

VOLUME 2

SUPPORTING REPORT I

A. SURFACE GEOLOGY AND FLUVIAL MORPHOLOGY
B. METEOROLOGY AND SURFACE HYDROLOGY

MARCH 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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SURFACE GEOLOGY AND FLUVIAL MORPHOLOGY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 GEOMORPHOLOGY

Geomorphological surveys were carried out with the relief map (1:100,000), aerial photographs (1:30,000 approx.) and LANDSAT imageries. The survey region covers an area of about 6,000 km^2. The mountain region comprises ridges of Jabal Akhdar and Jabal Nakhal with peaks of over 2,000 meters above sea level and with deep and steel wadi valleys. Wadis dissect mountains and flow down to the gravel plains. Wadi channels cut through the mountain-foot terraces and fans and develop alluvial plains in the lower reach.

The study area is divided into four distinct geomorphologic areas, each of which is shown in Figure A-1-1.

1) Major Mountains
2) Frontal Mountains
3) Marginal Wadi Plain
4) Sand/Gravel Plain

1) Major Mountains

Major Mountains situate on the north slope of the Jabal Akhdar - Jabal Nakhal ridge at the eastern end of Hajor Al Gharbi. The general relief is pronounced with a peak, named Jabal Shams (3,000 m.a.s.l. approx.) and with deep wadi channels of flat bed and steep side slopes. The mountains comprise limestone, dolostone and marl of Permian to Upper Cretaceous age, totalling over 3,000 meters in thickness.

Major mountains show two distinct trend of ridges. Jabal Akhdar stretches east-west trend. While Jabal Nakhal, which frames the eastern limit of the study area, trends NW-SE direction. This arrangement is derived from the folding complex consisting of anticlines with many subordinate faults. Due to this structure, there are tectonic basins along the anticline axis. And erosion of these anticlines has resulted in monoclinal ridge topography, where scarp faces are formed at the hard limestone bands.

The drainage pattern in the monoclinal zone is rectangular. There are superpositions of valley as seen near Wadi Sahtan, Wadi Bani Awf and Wadi Sabt, where channels cut across vertical beds. A few secondary sediment is seen on the mountain flank and it may contain relic deposit inherited from previous erosion periods.

2) Frontal Mountains

Frontal Mountains area, which consists of ophiolites, is situated at the outskirt of Major Mountains.

The topography of Frontal Mountains consists of gentler slopes and fewer scarps than those of the Major Mountains. In spite of the various lithology the weathering proceeds homogeneously and develop many drainage channels.

The drainage pattern is dendritic, controlled by joints and faults, as seen in Wadi Bani Kharus. Elsewhere, it is superimposed and free from the joint, fault and lithological structure.

Four among the five major wadis flow down and dissect this mountain area and divide it into the distinct land mass. Wadi Al-Fara' and Wadi Al-Ma'awil have wider outlets than the others. This geomorphologic distinction suggests that the wadis have been developed under a different condition in the past.

In Pleistocene, valleys were filled by gravels and locally cemented to form conglomerate. Later on extensive deposition of alluvial gravels and silts followed. Sebsequent downcuttings by wadis produced several terraces. In places this erosion cut through the conglomerate and exposed the bedrock.

3) Marginal Wadi Plain

Marginal Wadi Plain consists of the composite fans, pediments and terraces. The surface of the plain is largely covered by lag gravels which range from boulder size at the foothills to fine pea pebble size on the lower reach. The gravels are of rocks from the mountains, which are transported by wadi run-off and are winnowed away of its silty fractions. They are found not only on the main gravel plain but also on the sand flats east of Jamma' and south of Billah.

The run-off from the mountain is disgorged from the mountain wadis on to the gravel plain. The deposits at the foot of the mountains gives rise to a coalescing series of gravel fans. The most distinctive one is found at the right bank of Wadi Al-Ma'awil. It spreads out over ten kilometers and is terminated by a semicircular bordering line. Similar fan systems develop at most of the outlets mountain channels to the Wadi Plain. These fans are overlapped by recent wadi beds at the terminus.

At least three terrace surfaces, including both the depositional and erosional surfaces, can be discriminated in the study area; Terrace I-III. Among these three, the lower terrace (Terrace I), which is marked by 7 to 30 meters height from wadi bed, is widely found near Hibra , Jamma' and Hazam. Decreasing its relative height, it extends downstream over several kilometers and it is finally overlapped by the recent fluvial deposits.

The lower terrace deposit is characterized by the un-consolidated facies consisting of the poorly sorted gravel and clay, intercalated by the consolidated layers.

Well-concreted terrace deposits are found along the mountain channels. These are correlated to the lowest member of wadi deposit since this layer directly lies on basement rocks and contain talus breccia at the lower horizon.

The higher terrace (Terrace III) is also found at the high mountain area. In the Sahtan Basin, it is possible to trace up to about 1,000 meters above sea level.

4) Sand/Gravel Plain

Gravel Plain forms a wide floodplain thickly filled with gravel. The lower part is marked by a gentle slope of 1/500 in average, whereas the slope of the upper wadi exceeds 1/200. The gentle slope is characteristic to a relief accompanied by active wadis and sand dunes. The plain can be divided into two geomorphologic units: Alluvial plain and coastal strip.

Alluvial plain is closely channeled and its interfluvial systems form broad braided pattern. The braided wadis rapidly diminish the width downstream and become a single channel at the coastal strip. Among the wadi courses, ancient ones are also found as depressions, down-cutting to the old cemented horizon. They are covered by a significant amount of gravels so that the erosional streaks are not sharp on the surface.

The coastal strip adjoining the flood plain is covered by the silt-dominant deposits. Although some wadis bring coarse fragments, the wider flats are of silty alluvium and extensively cultivated. The large sabkha occurs along the coast of Suwadi al Batha, and littoral sands extend to the sabkha fringe. They contain shell fragment referrable to the progradation in the past.

Fig. A-1-1

Geomorphological Classification of Project Area

CHAPTER 2 FLUVIAL MORPHOLOGY

The project area is made of five drainages. The average drainage area ranges from 900 to 1,500 square kilometers.

In order to clarify the fluvio-morphological characteristics of wadi drainage system, several analyses were applied and some factors were determined. These were a set of topographical analyses of cross-sectional drainage profile, hypsometric cross-section and stream order profile. Analysed fluvio-morphological factors were shape factor (F) (Table A-2-1), drainage density (Dd) (Table A-2-2), stream frequency (Fs) (Table A-2-2) and bifurcation ratio (Rb) (Table A-2-4). For the sake of these caliculation, moutain zones, which extend upstream from the wadi gauges at the mountain/plain boundary, were selectively used, for fluvial erosions proceed predominantly there.

The longitudinal cross-profiles of each basin are shown in Fig. A-2-2. The drainage slopes are pronounced to have a transitional zone at around 800 m.a.s.l. which divide the basin into gentle slope area and steep slope area.

The shape factors are summarized within a range of 0.1 to 0.2, approximately.

Hypsometric curves for drainages are shown in Fig. A-2-3. From the analysis of these curves, they can be classified into tree types: the first type (Wadi Ahin), the second (Wadi Bani Kharus and Wadi Bani Ghafir) and the third (Wadi Al-Ma'awil and Wadi Al-Fara'). Since the integral ratios of drainages are 0.37, 0.2 and 0.16, for respective type, Wadi Ahin is supposed to have the younger topography whereas Wadi Al-Fara's and Wadi Al;-Ma'awil are of the older topography.

Fig. A-2-4 shows semi-logarithmic diagrams of stream number against stream order. The relation between stream number and stream order is not generally linear but concave to the upper side. Especially at the high ordered stream of wadi plain, the bifurcation ratio is smaller (cf. Table A-2-3), the relation curve is also a gentle in comparison with low order stream of the mountain area.

The drainage density and drainage frequency, shown in Table A-2-2, take the highest values at Wadi Bani Ghafir, i.e. 1.92 and 1.72 respectively.

Table A-2-1 Shape Factor (F) of Wadi Basin : F = B/L

	Drainage Area (A)	Basin Length (L)	Mean Basin Width (B)	Shape Factor of Basin (F)
	km^2	km	km	
Wadi Ahin	1127.5	96	11.7	0.12
Wadi Bani Ghafir	951.9	104.3	9.1	0.09
Wadi Al-Fara'	1546.8	93.6	16.5	0.18
Wadi Bani Kharus	1292.3	113.4	11.4	0.10
Wadi Al-Ma'awil	1029.8	67.8	15.2	0.22

Table A-2-2 Drainage Dencity and Stream Frequency of Mountain Wadi Basin Area

Drainage Density(Dd) : Dd = L/A

	Drainage Area (A)	Total Length of Stream (L)	Drainage Density(Dd)
Wadi Ahin	768.3 km^2	1093.0 km	1.42
Wadi Bani Ghafir	591.1	1134.0	1.92
Wadi Al-Fara'	698.2	1233.8	1.77
Wadi Bani Kharus	750.6	1336.4	1.78
Wadi Al-Ma'awil	319.1	532.7	1.67

Stream Frequency(Fs) : Fs = N/A

	Drainage Area (A)	Number of Streams (N)	Stream Frequency(Fs)
Wadi Ahin	768.3	931	1.21
Wadi Bani Ghafir	591.1	1018	1.72
Wadi Al-Fara'	698.2	905	1.30
Wadi Bani Kharus	750.6	858	1.14
Wadi Al-Ma'awil	319.1	338	1.06

Table A-2-3 Number of Streams and Total Length of Each Stream Order in Mountain Wadi Basin Area

Stream Order, u	Wadi Ahin Nu	Wadi Ahin ΣLu (Km)	Wadi Bani Ghafir Nu	Wadi Bani Ghafir ΣLu (Km)	Wadi Al-Fara' Nu	Wadi Al-Fara' ΣLu (Km)	Wadi Bani Kharus Nu	Wadi Bani Kharus ΣLu (Km)	Wadi Al-Ma'awil Nu	Wadi Al-Ma'awil ΣLu (Km)
1	732	795.8	811	723.7	699	773.9	647	841.7	263	334.6
2	146	27.7	168	201.3	158	228.0	158	263.8	56	91.7
3	39	136.0	30	110.5	36	120.8	39	114.1	12	58.6
4	11	78.3	8	49.1	9	43.2	11	73.0	4	31.1
5	2	48.5	1	49.5	2	61.9	2	26.2	2	12.1
6	1	6.7			1	1.0	1	17.5	1	4.6
Total	931	1,093.0	1,018	1,134.1	905	1,233.8	858	1,336.3	338	532.7

Note
u : Stream Order
Nu : Number of streams of Stream Order u
ΣLu : Total Length of the Streams of the Stream Order u

Table A-2-4(1) Wadi Basin Characteristics, Wadi Ahin

Stream Order u	Number of Streams N_u	Bifurcation Ratio R_b *1	Mean Length of Streams (Km) $\bar{L}_u$ *2	Cumulative Mean Length, (Km) $\Sigma \bar{L}_u$	Length Ratio R_L *3
1	732		1.1	1.1	
		5.0			0.2
2	146		0.2	1.3	
		3.7			17.5
3	39		3.5	4.8	
		3.5			2.0
4	11		7.1	11.9	
		5.5			3.4
5	2		24.2	36.1	
		2.0			0.3
6	1		6.7	42.8	

Table A-2-4(2) Wadi Basin Characteristics, Wadi Bani Ghafir

Stream Order u	Number of Streams N_u	Bifurcation Ratio R_b *1	Mean Length of Streams (Km) $\bar{L}_u$ *2	Cumulative Mean Length, (Km) $\Sigma \bar{L}_u$	Length Ratio R_L *3
1	811		0.9	0.9	
		4.8			1.3
2	168		1.2	2.1	
		5.6			3.1
3	30		3.7	5.8	
		3.8			1.6
4	8		6.1	11.9	
		8.0			8.1
5	1		49.5	61.4	
6					

Table A-2-4(3) Wadi Basin Characteristics, Wadi Al-Fara

Stream Order u	Number of Streams N_u	Bifurcation Ratio R_b *1	Mean Length of Streams (Km) $\bar{L}_u$ *2	Cumulative Mean Length, (Km) $\Sigma \bar{L}_u$	Length Ratio R_L *3
1	699		1.1	1.1	
		4.4			1.3
2	158		1.4	2.5	
		4.4			2.4
3	36		3.4	5.9	
		4.0			1.4
4	9		4.8	10.7	
		4.5			6.5
5	2		31.0	41.7	
		2.0			0
6	1		1.0	42.1	

Table A-2-4(4) Wadi Basin Characteristics, Wadi Bani Kharus

Stream Order u	Number of Streams N_u	Bifurcation Ratio R_b *1	Mean Length of Streams (Km) $\bar{L}_u$ *2	Cumulative Mean Length, (Km) $\Sigma \bar{L}_u$	Length Ratio R_L *3
1	647		1.3	1.3	
		4.1			2.3
2	158		1.7	3.0	
		4.1			2.0
3	39		2.9	5.9	
		3.5			2.1
4	11		6.6	12.5	
		5.5			2.0
5	2		13.1	25.6	
		2			1.7
6	1		17.5	43.1	

Table A-2-4(5) Wadi Basin Characteristics, Wadi Al-Ma'awil

Stream Order	Number of Streams	Bifurcation Ratio	Mean Length of Streams (Km)	Cumulative Mean Length, (Km)	Length Ratio
u	N_u	R_b *1	$\bar{L}_u$ *2	$\Sigma\bar{L}_u$	R_L *3
1	263		1.3	1.3	
		4.7			2.2
2	56		1.6	2.9	
		4.7			2.7
3	12		4.9	7.8	
		3.0			2.0
4	4		7.8	15.6	
		2.0			1.4
5	2		6.1	21.7	
		2.0			1.2
6	1		4.6	26.3	

Note *1 : $Rb = \frac{Nu}{N_u + 1}$ *2 : $Lu = \frac{\Sigma Lu}{Nu}$ *3 : $RL = \frac{Lu}{Lu-1}$

Stream order, u, was measured after Horton's method.

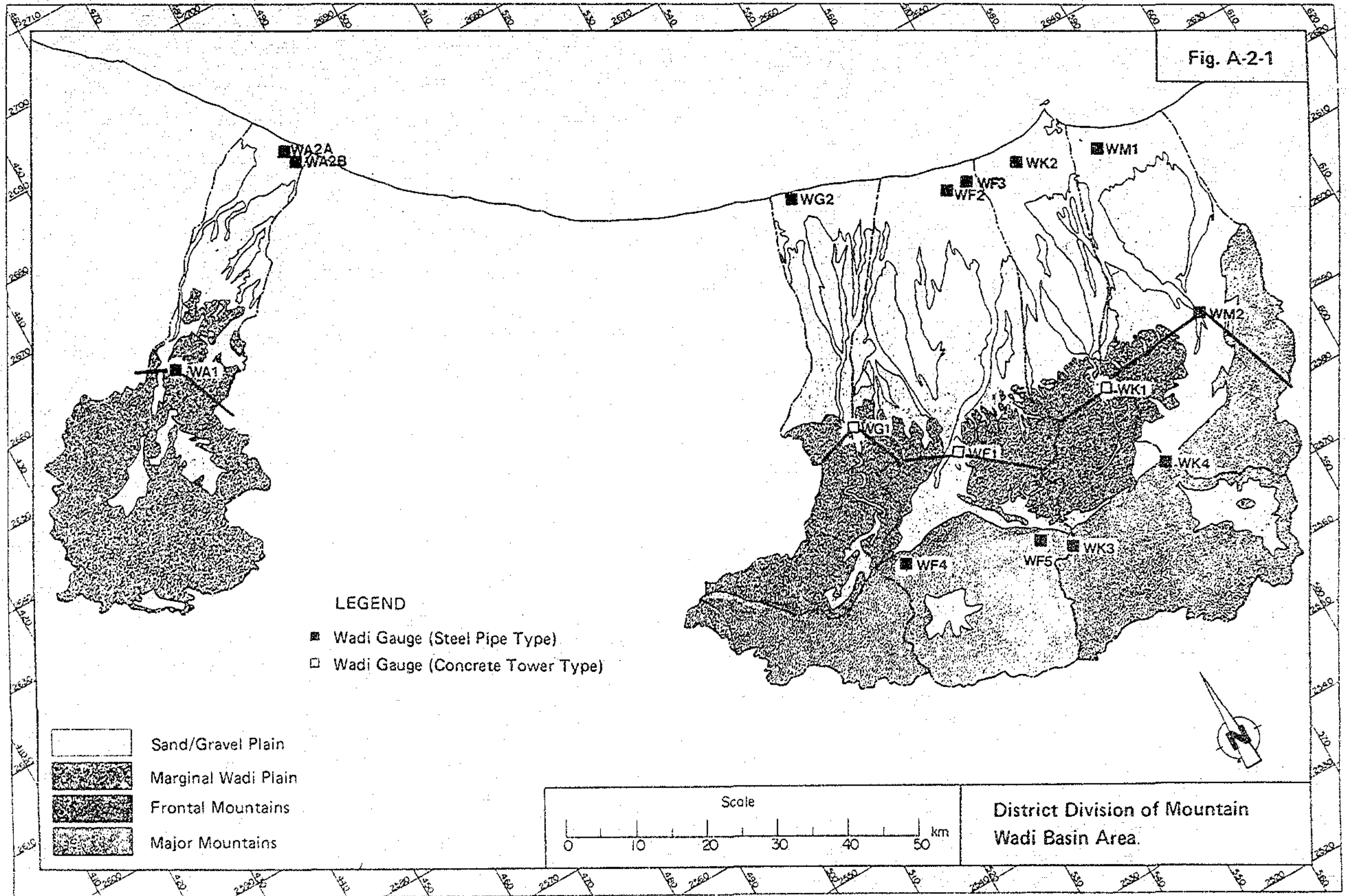
Table A-2-5 Drainage Area by Elevation

Elevation (m;a.s.ℓ)	Wadi Ahin		Wadi Bani Ghafir		Wadi Al-Fara'		Wadi Bani Kharus		Wadi Al-Ma'awil	
	Whole Wadi Basin Area (Km^2)	Mountain Wadi Basin Area (Km^2)	Whole Wadi Basin Area (Km^2)	Mountain Wadi Basin Area (Km^2)	Whole Wadi Basin Area (Km^2)	Mountain Wadi Basin Area (Km^2)	Whole Wadi Basin Area (Km^2)	Mountain Wadi Basin Area (Km^2)	Whole Wadi Basin Area (Km^2)	Mountain Wadi Basin Area (Km^2)
0- 200	234.243	0.000	287.039	0.000	586.957	0.000	406.315	0.000	515.602	0.000
200- 400	136.522	39.615	99.926	32.381	284.934	81.842	134.855	45.192	242.354	130.572
400- 600	135.039	114.673	126.525	120.310	189.397	145.515	161.113	126.856	64.519	41.478
600- 800	150.943	144.265	139.913	139.913	133.945	121.877	132.697	121.653	45.527	27.463
800-1000	295.653	294.647	61.412	61.412	115.511	112.911	114.887	114.466	44.226	29.450
1000-1200	140.553	140.553	47.466	47.466	83.388	83.388	80.936	80.936	40.036	28.903
1200-1400	34.292	34.292	41.760	41.760	61.929	61.929	63.572	63.572	39.616	32.529
1400-1600	.255	.255	35.946	35.946	45.434	45.434	56.715	56.715	14.346	8.373
1600-1800	0.000	0.000	31.742	31.742	19.061	19.061	41.086	41.086	13.676	11.393
1800-2000	0.000	0.000	25.810	25.810	11.680	11.680	39.661	39.661	7.226	6.267
2000-2200	0.000	0.000	22.972	22.972	7.807	7.807	29.474	29.474	2.046	2.046
2200-2400	0.000	0.000	22.736	22.736	2.001	2.001	29.932	29.932	.626	.626
2400-2600	0.000	0.000	5.804	5.804	1.714	1.714	1.057	1.057	0.000	0.000
2600-2800	0.000	0.000	2.308	2.308	2.011	2.011	0.000	0.000	0.000	0.000
2800-3000	0.000	0.000	.540	.540	1.030	1.030	0.000	0.000	0.000	0.000
Total	1127.500	768.300	951.900	591.100	1546.800	698.200	1292.300	750.600	1029.800	319.100

Table A-2-6 Percentage Drainage Area by Elevation

Elevation (m;a.s.ℓ)	Wadi Ahin		Wadi Bani Ghafir		Wadi Al-Fara'		Wadi Bani Kharus		Wadi Al-Ma'awil	
	Whole Wadi Basin Area (%)	Mountain Wadi Basin Area (%)	Whole Wadi Basin Area (%)	Mountain Wadi Basin Area (%)	Whole Wadi Basin Area (%)	Mountain Wadi Basin Area (%)	Whole Wadi Basin Area (%)	Mountain Wadi Basin Area (%)	Whole Wadi Basin Area (%)	Mountain Wadi Basin Area (%)
0- 200	21.396	0.000	30.159	0.000	39.759	0.000	27.584	0.000	51.350	0.000
200- 400	12.316	3.464	10.498	3.401	18.741	4.984	9.894	3.807	23.089	11.957
400- 600	11.889	10.029	13.291	12.638	11.834	8.861	13.011	10.685	6.093	3.798
600- 800	13.226	12.616	14.697	14.697	8.239	7.422	10.997	10.247	4.314	2.515
800-1000	25.860	25.768	6.451	6.451	7.052	6.876	9.670	9.642	4.168	2.697
1000-1200	12.292	12.292	4.986	4.986	5.078	5.078	6.817	6.817	3.755	2.647
1200-1400	2.999	2.999	4.387	4.387	3.771	3.771	5.355	5.355	3.684	2.979
1400-1600	.022	.022	3.776	3.776	2.767	2.767	4.777	4.777	1.362	.767
1600-1800	0.000	0.000	3.334	3.334	1.161	1.161	3.461	3.461	1.271	1.043
1800-2000	0.000	0.000	2.711	2.711	.711	.711	3.341	3.341	.669	.574
2000-2200	0.000	0.000	2.413	2.413	.475	.475	2.483	2.483	.187	.187
2200-2400	0,000	0.000	2.388	2.388	.122	.122	2.521	2.521	.057	.057
2400-2600	0.000	0.000	.610	.610	.104	.104	.089	.089	0.000	0.000
2600-2800	0.000	0.000	.242	.242	.122	.122	0.000	0.000	0.000	0.000
2800-3000	0.000	0.000	.057	.057	.063	.063	0.000	0.000	0.000	0.000
Total	100.000	67.191	100.000	62.092	100.000	42.518	100.000	63.225	100.000	29.220

Fig. A-2-1



District Division of Mountain Wadi Basin Area.

Fig. A-2-2 Longitudinal Cross-profile of Wadi Basin

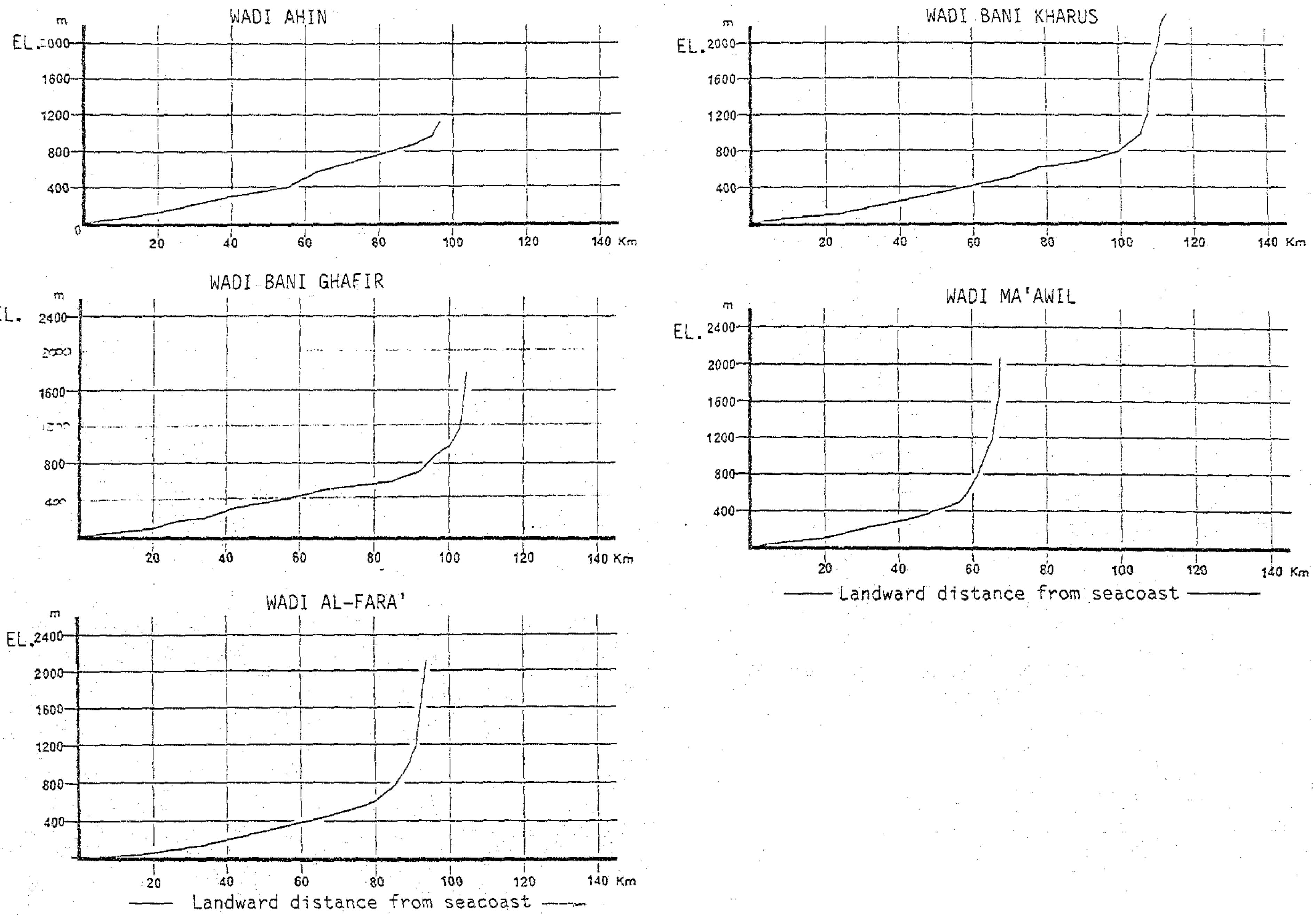
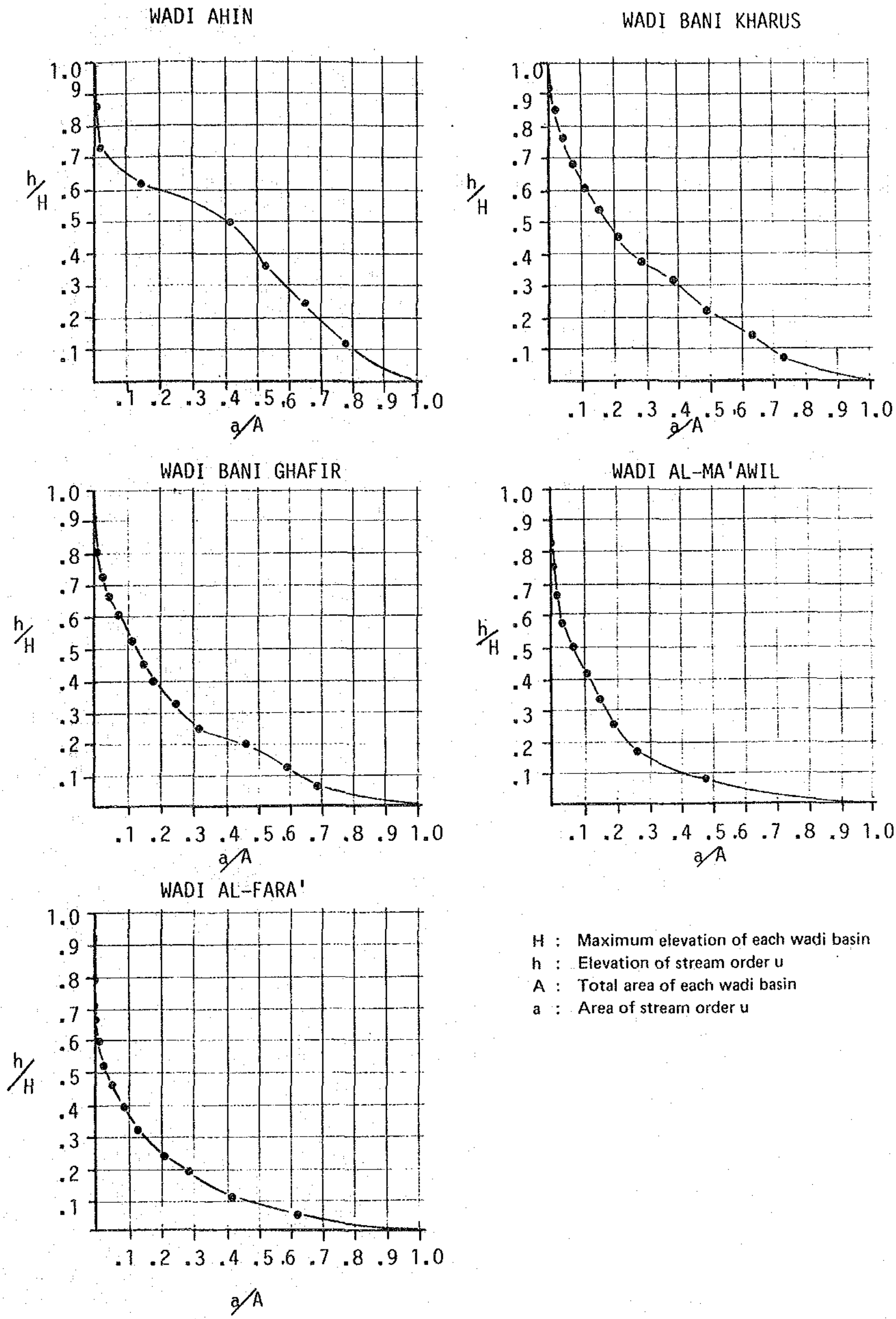
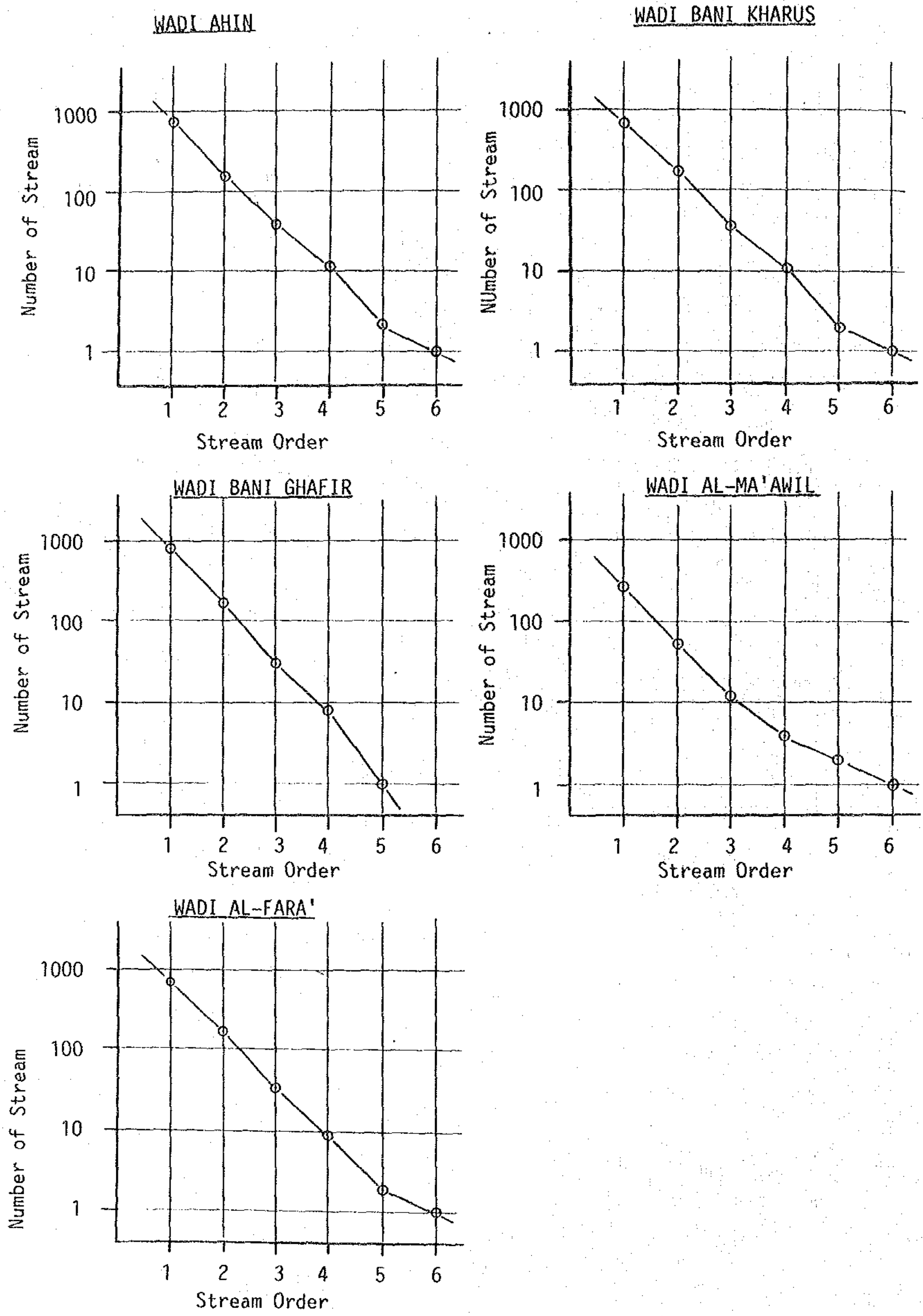


Fig. A-2-3 Hypsometric Curve of Wadi Basin



H : Maximum elevation of each wadi basin
h : Elevation of stream order u
A : Total area of each wadi basin
a : Area of stream order u

Fig. A-2-4 Stream Numbers against Stream Order



CHAPTER 3 SURFACE GEOLOGY OF EACH WADI BASIN

Surface Geology of the Projcet area was explored by three methods; (1) Field exploration, (2) Aerial photograph analyses and (3) Satellite imagery analyses.

In addition, available references were widely considered to draw up the maps and construct the concept.

In the followings characteristics of each wadi basins are explained, based on the Fig. A-3-1～5.

1) Wadi Ahin

The mountain and the hilly terraces develop widely. The hilly terrace stretches to the sea coast. For these geomorphological features, the wadi channel is clearly traceable down to the Coastal Strip and the slope of wadi bed is steeper than other drainages.

The mountains are formed of Semail Ophiolite which presents the different geological component from other drainages. And the drainage texture shows a uniform river density and stream frequency over all mountainous area; therefore, the drainage pattern typical dentritic pattern.

The cross-sectional profile of the valley is similar to that Wadi Bani Ghafir which shows the V-shape at the high ordered stream with the exception at the upstream of Al-Hail and around Haibi and Al-Qufais where the valley has a wide wadi bed to make the synclinal valley. The valley running down the hilly terrace, make clear contrast to the surrounding terrace surface by over 10 meters relative height at the upper stream. The material of wadi bed is characterized by the dominant coarser deposits than other drainages, because the facies contain boulder sized gravel even in the lower reach of the wadi. However, it reduces the width and splits into branches, and the main stream course can be recognized at the coast by the well-defined channel which deepens the beach sand and silt flat.

2) Wadi Bani Ghafir

The geomorphological feature of Wadi Bani Ghafir is similar to that of Wadi Bani Kharus, which is marked by the larger coverage of mountainous area than the gravel plain area. The wadi plain is occupied mostly by hilly terraces, therefore the channel networks do not develop widely at the lower reach in the same way as Wadi Al-Ma'awil and Wadi Al-Fara'. The total drainage area covers 952 km^2 which consist of 617 km^2 of the mountain and 227 km^2 of the terrace and old fan area.

The mountain drainage is characterized by the dentritic pattern; however, when examined into detail, geomorphology along wadi course shows some difference betweem Major Mountains and Frontal Mountains, the drainage density and frequency are higher in Frontal Mountains than in Major Mountains. The mountain wadi channel generally presents a flat-floored valley except for the synclinal valley observed near Difa's. As described above, the wadi plain is marked by the widely developed hilly terraces at the upstream and midstream, where the wadi channels are not scattered and run down on the hilly terrace.

Sand and Gravel Plain is observed at the midstream and downstream of the drainage. On Sand and Gravel Plain, the channel is divided into three kinds. The widest stream among three flows at the west side of the drainage area. This main channel develops the broadest reticulated stream pattern and finally reaches the sea.

3) Wadi Al-Fara'

Wadi Al-Fara' occupies the widest drainage area among the five wadis. The total drainage area is 1,547 km^2, including 653 km^2 of the mountainous drainage and 894 km^2 of wadi plain. The mountain area occupies about 40% of the whole area, and the drainage pattern and cross-sectional profile of valley similar to those of other wadis. In general, the drainage shows a structural valley in Major Mountains, while in the dentritic valley in Frontal mountains. The valley in these mountains is commonly marked by V-shaped valley or Kerbtal valley with the exception of a synclinal valley in the Sahtan basin: a flat-floored valley of Pre-Permian area. The wadi courses in the mountain area take two specific courses, one of which runs from the eastern mountains and the other from the western mountains. Wide wadi beds between the Major Mountains and the Frontal Mountains and both are confluent at the upstream of the wadi plain. At the junction of the two, there is a flat-floored wadi valley with the broad terraces like in the Wadi Al-Ma'awil area.

An old alluvial fan stretches, from the mountain-foot to the coastal strip in the wadi plain, and the main wadi bed runs along the both side of the fan. The wadi along the eastern side continues from the aforesaid mountainous tributaries and shows the wider and more distinct wadi bed than the one along the western side. The western wadi is characterized by its tributary which is located within Frontal Mountains and the upstream of the wadi plain. The wadi also shows the wide reticulated flow pattern composed of many small channels.

Several depressions on the old fan are supposed to be old channels, for the recent channels are not traceable around them. The old fan is formed of sand and gravel. There are many thinning-out smalll channels at the border area between the Coastal Strip and the Sand and Gravel Plain, only the widest channel runs along the east-side of the old fan down to the seam.

4) Wadi Bani Kharus

Wadi Bani Kharus is marked by larger mountainous area than the other wadi drainages. The total drainage area is 1,292 km^2, consisting of 777 km^2 of the mountainous area and 517 km^2 of the wadi plain area. The surface water, collected on ridge of the Major Mountains at over 2,000 meters level, runs through both the Ghubrah bowl and the mountain channel at Al-Awabi, and finally flows into broad valley plain located between Frontal Mountains and Major Mountains. Later on, both tributaries join together in Frontal Mountains, forming typical V-shaped valley, and flow into the boundary area between Marginal Wadi Plain and Frontal Mountains.

The drainage pattern is generally dependent on geological structure, therefore the direction of channels varies by facies. The valleys in the Hajar Super Group at the limb of Akhdar anticline shows south to north trend, and in the Pre-Permian area surrounded by the Hajar Super Group northwest to southeast one. In the Semail Ophiolite area dentritic pattern is observed commonly.

The cross-sectional profile of the valley also varies by geologic units. The Hajar Super Group is composed of hard limestone and dolomite and shows the V-shaped valley and saw-cut valley, while the strongly disturbed Pre-Permian area is characterized by flat-floored valley. Frontal Mountains generally present the V-shaped valley. The broad old fan is not recognized in this wadi plain, and is marked by the Sand and Gravel Plain at the western part of this drainage. The old wadi courses are also observed on the eastern plain. Both the old and recent wadi show the reticulated stream courses and widely distribute at the middle stream of wadi plain. These old channels are marked by slightly higher elevation than that of recent wadi bed. At the coastal strip many wadi channels thin out abruptly, and only a single channel is traceable from the upstream to the sea.

5) Wadi Al-Ma'awil

Wadi Al-Ma'awil occupies an area of 1,030Km^2 which consist of 409 km^2 of mountainous area and 621 km^2 of wadi plain. As shown in Fig. 4-3-5, the eastern mountains are of Major Mountains and the western mountains are of Frontal Mountains.

In the mountainous area, the marginal area of anticlinal basins, which is made of Hajar Super Group, is characterized by dominant linear valleys, especially at the northern mountain area adjacent to Nakhal. Transverse valley crossing Major Mountains are also observed. Frontal Mountains of ophiolite and the upper stream area of Pre-Permian formation are dissected into the dentritic drainage pattern.

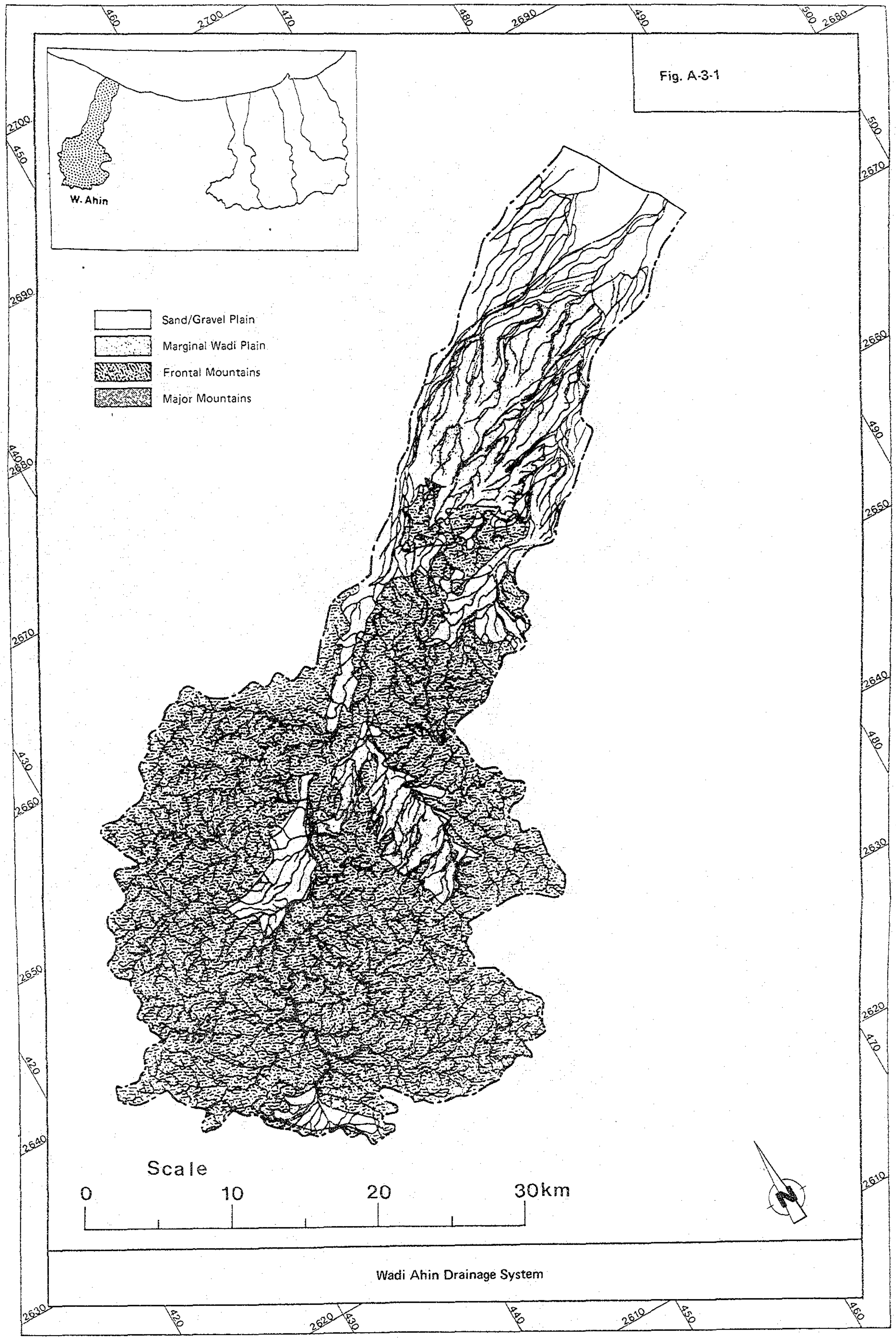
Surface water, collected on these mountains, flows into the valley plain which is located between the Major Mountains and Frontal Mountains. These channels cut down the terrace deposits, making the precipice of 10 m relative height at the upper stream. The distinctive channels fan out abruptly at the upstream of wadi plain and splits into many small channels. At the midstream of the wadi plain, the channels widely form reticulated pattern in which the small streams repeat joining and splitting.

There are two densely reticulated zones of channels in the eastern and western sides of the wadi plain. Although these zones can be recognized from surrounding fluvial plain by one meter relative height high above the wadi bed, the main channel cannot be determined since most of the channels are too small and connected each other.

The area surrounded by these zones and the fluvial plain is supposed to be an old fan which is convex and slightly higher than the adjacent area. Geomorphologically, the recent wadi courses run through the depressions of this old fan. However, the channels are scarce and, the channels in this old fan are initiated most within itself.

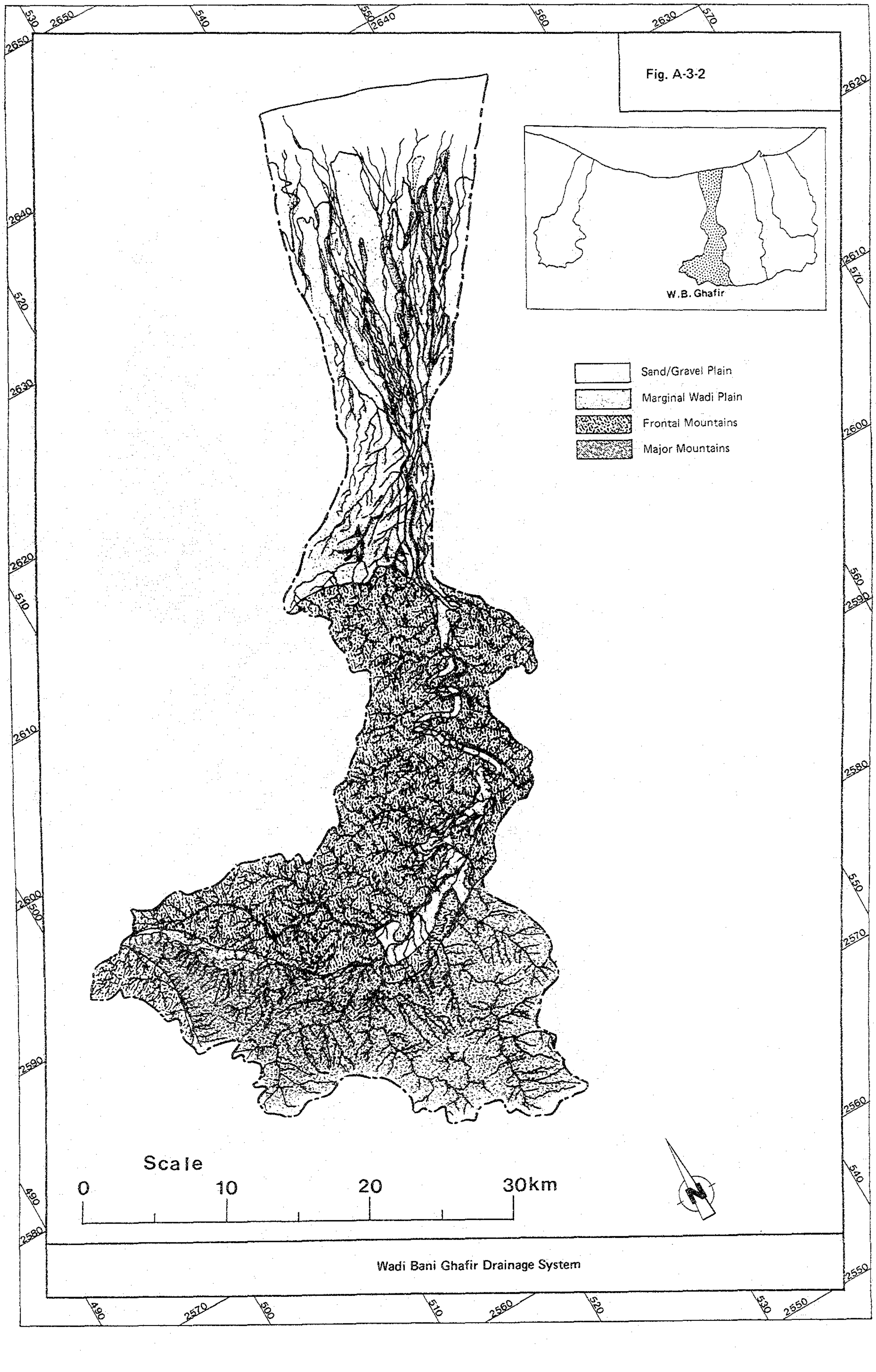
At the downstream of the drainage, the widely reticulated channels gradually thin out and only two channels, the aforesaid eastern and western channels, survive from the upper reach.

Fig. A-3-1



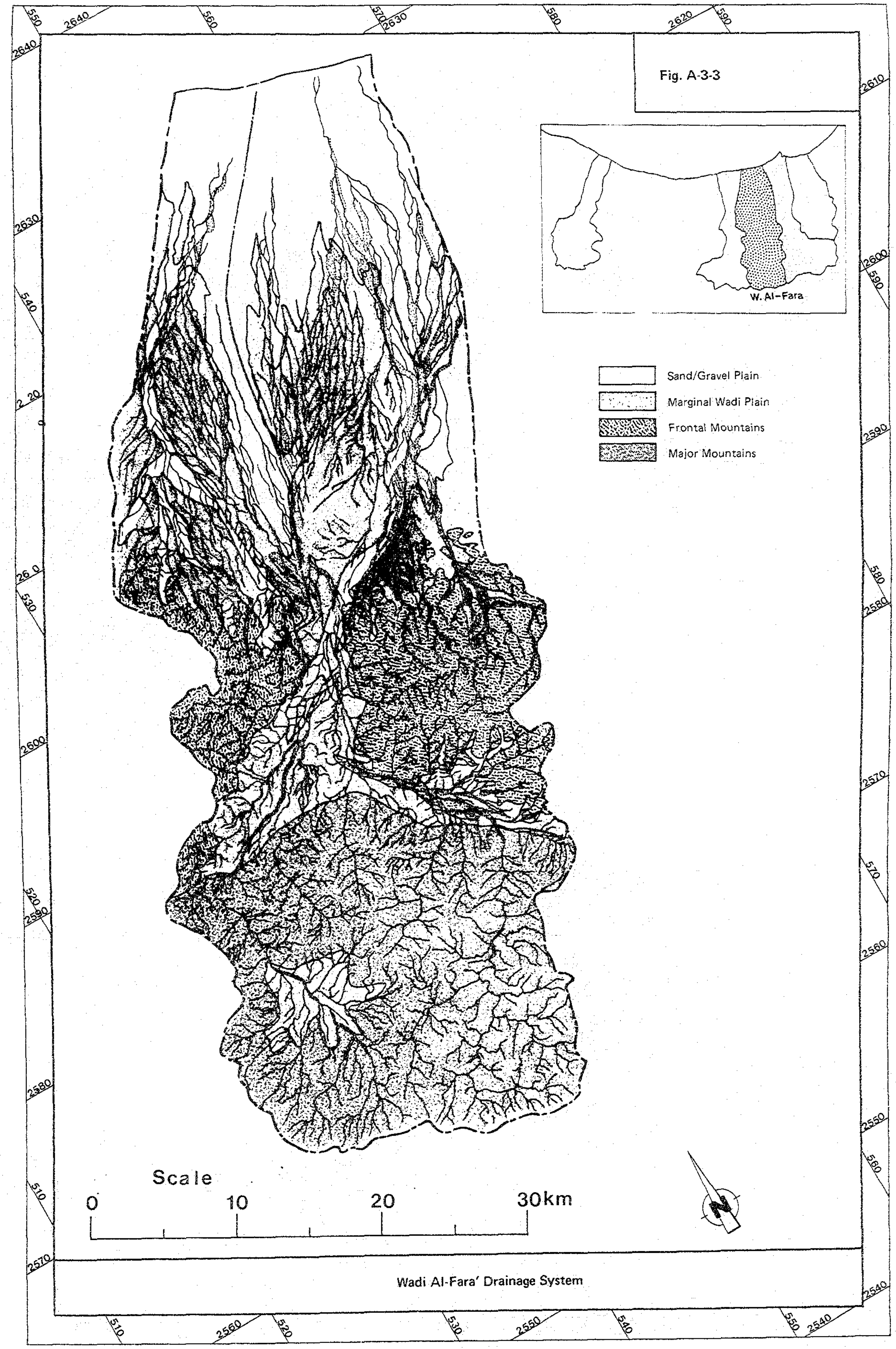
Wadi Ahin Drainage System

Fig. A-3-2



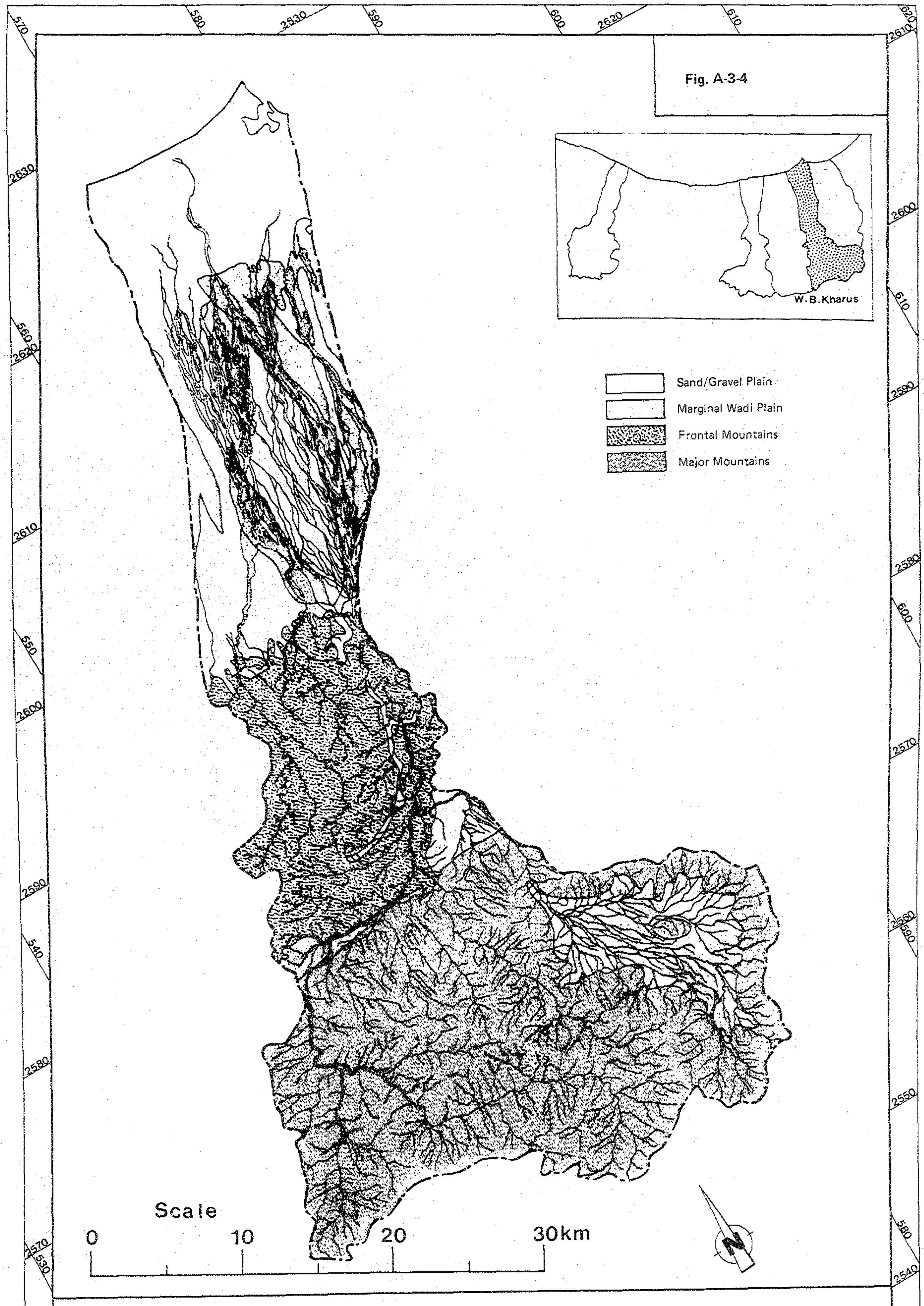
Wadi Bani Ghafir Drainage System

Fig. A-3-3



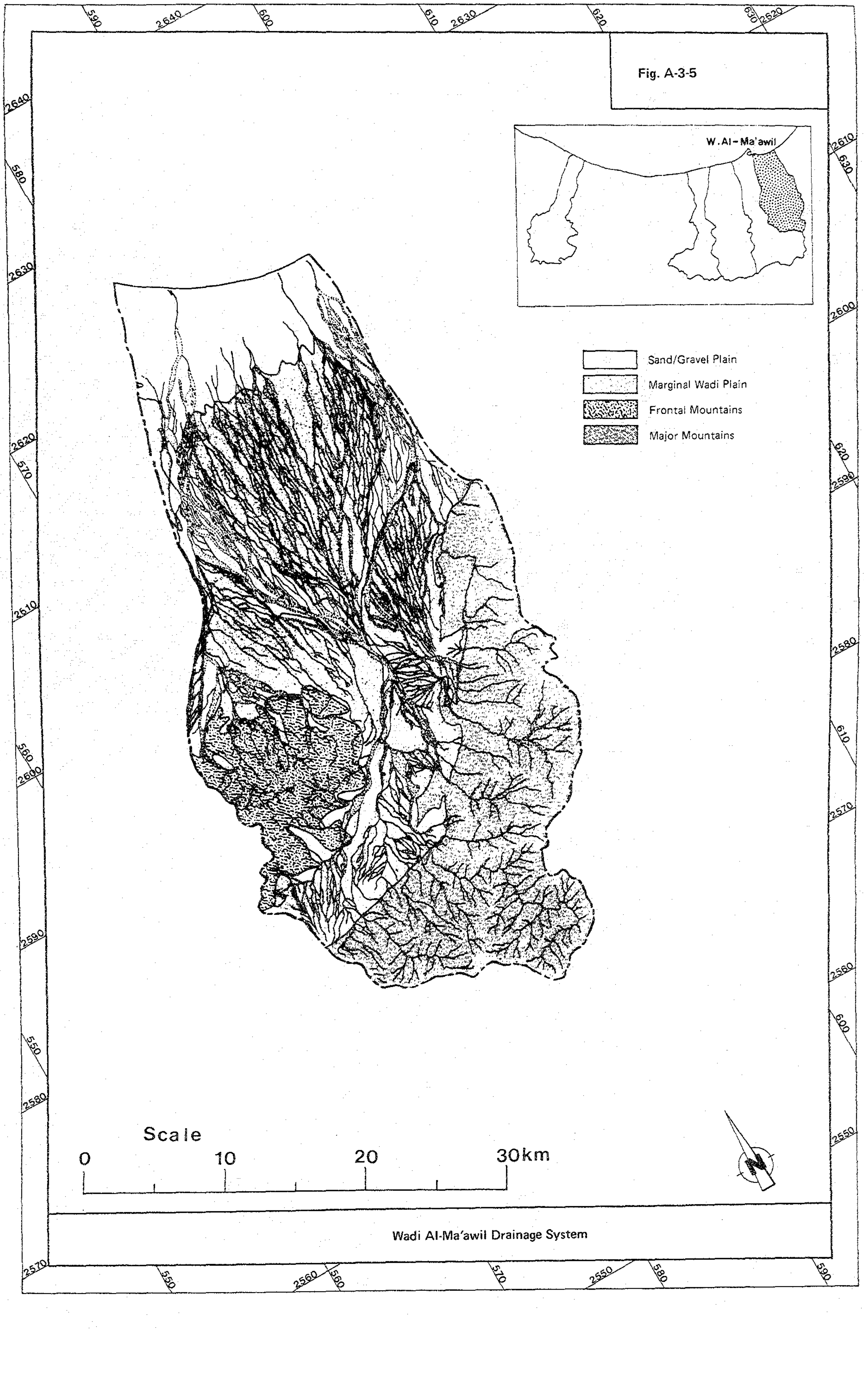
Wadi Al-Fara' Drainage System

Fig. A-3-4



Wadi Bani Kharus Drainage System

Fig. A-3-5



Wadi Al-Ma'awil Drainage System

SUPPORTING REPORT B

METEOROLOGY AND SURFACE HYDROLOGY

TABLE OF CONTENTS

Page

CHAPTER 4 ANALYSIS OF RAINFALL

CHAPTER 5 ANALYSIS OF INFILTRATION CAPACITY AND EVAPOTRANSPIRATION

CHAPTER 6 STUDY OF SURFACE RUNOFF

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1 OBSERVATION NETWORKS

1.1 Agro-Meteorological Stations

Prior to the Project, there were only two meteorological stations in and near the study area which are located at Al-Rustaq and Sohar. The observation items and accuracy were insufficient due to improper maintenance of the observation equipment and unsuitability of sites.

This Project established Al-Muladdah Agro-meteorological Station and reinforced some instruments at Al-Rustaq Agro-meteorological Station in order to observe general meteorological conditions and data necessary for estimation of accurate evaporation. The location of these stations is shown in Table B-1-1 and Fig. B-1-1. The observation items and instruments are shown in Table B-1-2. The arrangement of Al-Muladdah Agro-meteorological Station is shown in Fig. B-1-2.

All of the observation data except pan evaporation are recorded on continuous strip charts and on casette tapes every thirty minutes. The recorded data is processed by personal computer, daily and monthly meteorological reports are compiled.

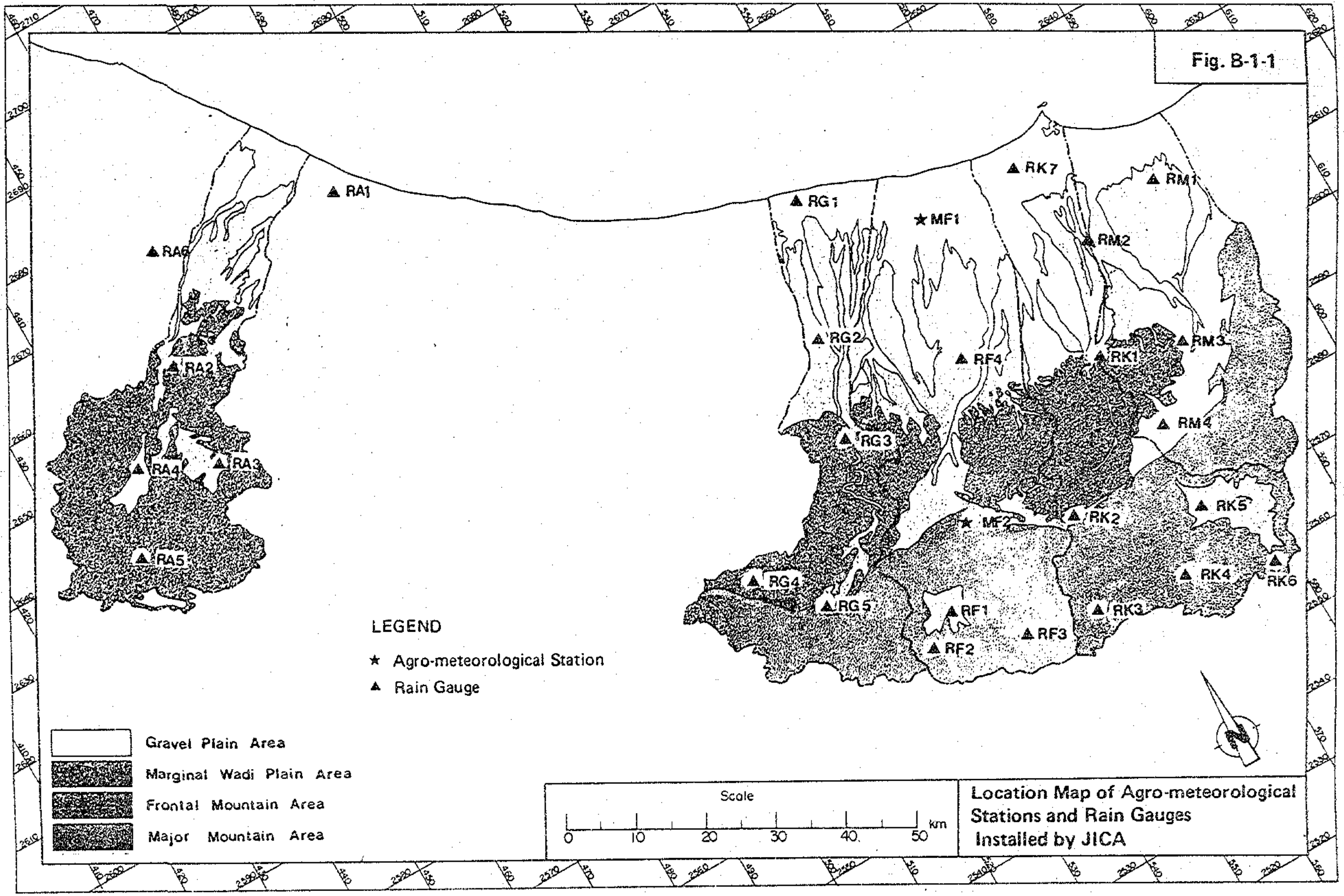
Table B-1-1 Agro-meteorological Station Sites

Location	Symbol	Altitude (m; a.s.l)	UTM-Grid	Data Commissioned
Al-Muladdah	MF1	18	40QEB248577	July 30, 1983
Al-Rustaq	MF2	340	40QEA430905	July 25, 1983

Table B-1-2 Observation Items of Agro-meteorological Stations

Station	Observation Items	Instruments
Al-Muladdah	Wind Speed	Propeller Type Wind Transmitter
	Wind Direction	- Do -
	Solar Radiation	Pyranometer
	Net Radiation	Net Radiometer
	Soil Heat Flux (5, 15, 45, 90 cm Deep)	Heat Flowmeter
	Soil Temperature (5, 15, 30, 60, 120 cm Deep)	Platinum Resistance Thermometer
	Dry and Wet Bulb Temperature (50, 270 cm High)	- Do -
	Rainfall	Tipping Bucket Type Transmitter Standard Rain Gauge
	Evaporation	Type-A Pan
Al-Rustaq	Wind Speed	Anemometer (2, 10 m high)
	Air Temperature	Thermohygrograph, Thermometer
	Relative Humidity	- Do -
	Rainfall	Raingauge
	Solar Radiation	Pyranometer
	Soil Heat Flux	Heat Flowmeter
	Soil Temperature	Soil Thermograph
	Evaporation	Evaporation Pan
Sohar	Wind Speed	Anemometer (2, 10 m High)
	Air Temperature	Thermohygrograph
	Relative Humidity	- Do -
	Sunshine Hour	Sunshine Recorder
	Rainfall	Raingauge
	Soil Temperature	Soil Thermometer
	Evaporation	Evaporation Pan

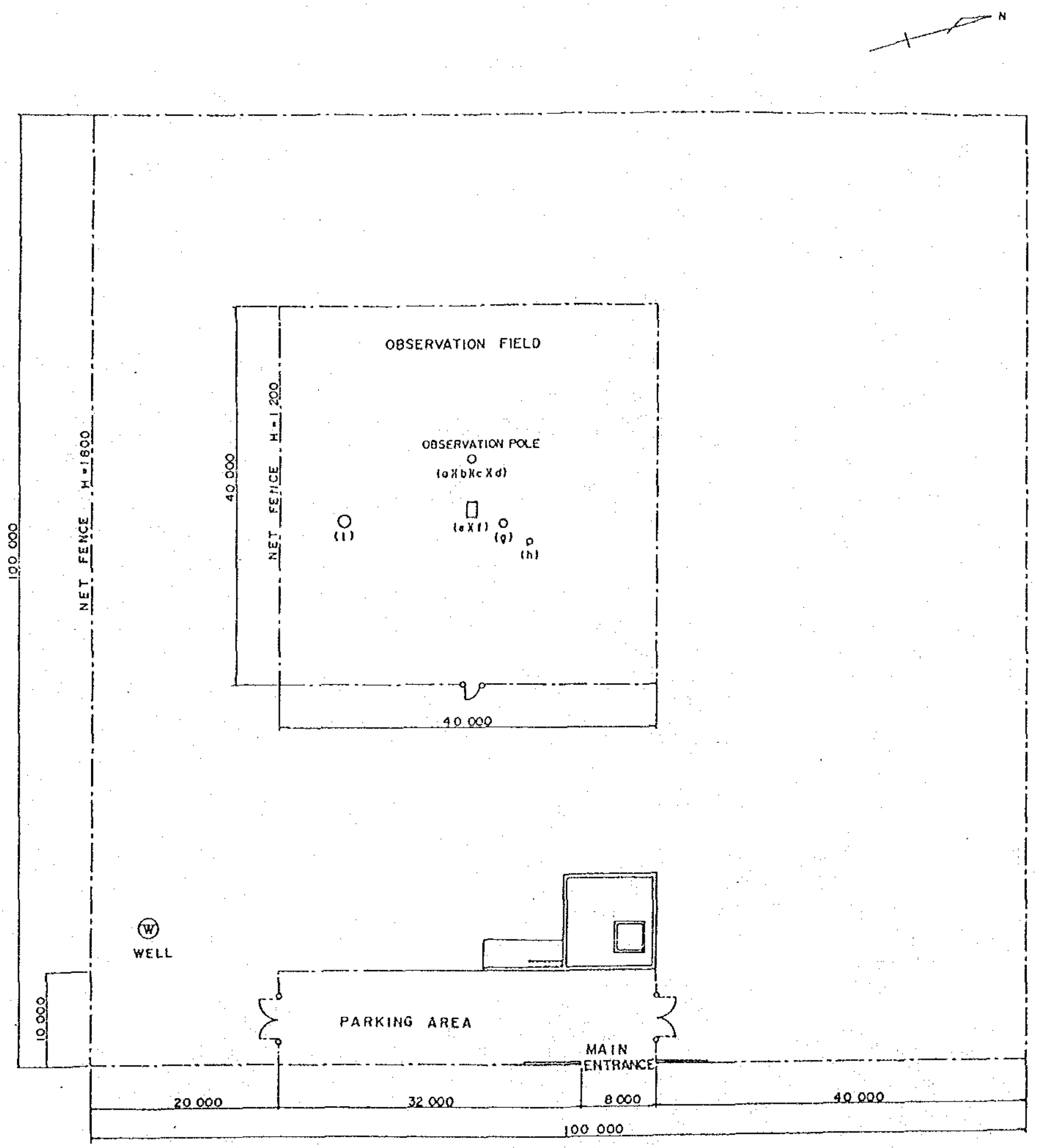
Fig. B-1-1



Location Map of Agro-meteorological Stations and Rain Gauges Installed by JICA

Fig. B-1-2 Arrangement Plan of Al-Muladdah Agro-meteorological Station

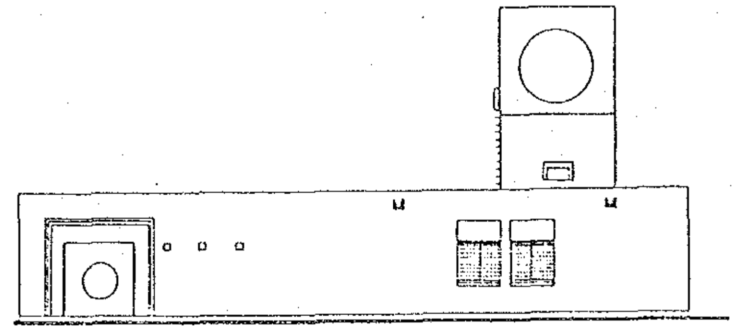
SITE PLAN Unit; mm



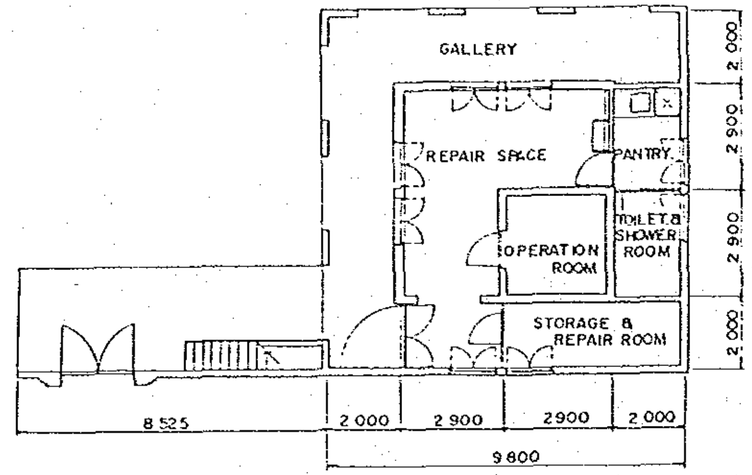
NOTE: Meteorological Instruments in Observation Field

(a) Wind speed and direction transmitter
(b) Pyranometer (Solar radiometer)
(c) Net radiometer
(d) Dry and wet bulb thermometer
(e) Heat flow meter
(f) Soil thermometer
(g) Rainfall transmitter
(h) Standard raingauge
(i) A-pan (Evaporimeter)

ELEVATION Unit; mm



GROUND FLOOR PLAN Unit; mm



SITE AREA		100.0 x 100.0		10 000.0 m²
INTERIOR	REPAIR SPACE	2.9 x 7.8 + 2.9 x 2.9	31.03	60.84 m²
	STORAGE & REPAIR ROOM	4.9 x 2.0	9.8	
	PANTRY	2.9 x 2.0	5.8	
	OPERATION ROOM	2.9 x 2.9	8.41	
	TOILET & SHOWER ROOM	2.9 x 2.0	5.8	
EXTERIOR	GALLERY	2.0 x 9.8 + 2.0 x 7.8	35.2	35.20 m²
			TOTAL	96.04 m²

1.2 Rain Gauges

There were twelve rain gauges including two agro-meteorological stations in and around the project area before the project started: five in Wadi Ahin and seven in the four-wadi basin. Those rain gauges are shown in Table B-1-3 and Fig. B-1-3. Daily rainfall was observed at only ten of them. As shown in Fig. B-1-3 they were not installed uniformly over the area.

This project installed twenty-seven rain gauges to observe rainfall widely and densely. The rain gauges were installed more densely in the mountains where rain comes more frequently than in the gravel plains. The locations are shown in Table B-1-4 and Fig. B-1-1.

The Thiessen polygons of the rain gauges are shown in Fig. B-1-4, and the areas of polygons are shown in Table B-1-5. It is provided that the lowest boundary of the polygons is the coastal highway. Average rainfall over each wadi basin was calculated by the use of the polygons.

As surface runoff depends mostly on rainfall intensity in arid zones, rain gauges recording rainfall over short durations -- fifteen minutes -- were installed.

The type of rain gauge is the tipping-bucket type and the minimum measuring unit is 0.5 mm. Routine maintenance was carried out every three months.

The rainfall amounts were read every hour generally and every fifteen minutes during floods. Monthly rainfall reports were compiled by processing with a personal computer.

Table B-1-3 Rain Gauge Sites of MAF

Name of Gauge Site	Location					Installation		Equipment
	Lat.	Long	UTM	Grid	Elevation (m a.s.l.)	Date	By	
Sohar	24°21'	56°43'	40R DB	715 928	20	1973		Standard BMO 5-inch Gauge
Saham	24°10'	56°53'	40R DB	888 732	5			- Do -
Al-Ghozaifah	23°59'	59°29'	40Q DB	480 524	480	24/12/73	ILACO	Thies, 200-sq.cm aparture Gauge
Haibi	23°55'	56°33'	40Q DB	540 450	(570)	5/ 3/74	ILACO	- Do -
Al-Qutais	23°57'	56°26'	40Q DB	422 493	(600)	14/ 1/76	WRD	Standard BMO 5-inch Gauge
Al-Hougain	23°33'	57°20'	40Q EB	342 039	225	27/ 1/74	Gibb	- Do -
Al-Rustaq	23°23'	57°21'	40Q EA	452 855	(350)	12/ 3/74	Gibb	- Do -
Al-Awabi	23°18'	57°32'	40Q EA	541 765	(500)	27/ 1/74	Gibb	Standard 5-inch Totalizer
Khatum	23°29'	57°41'	40Q EA	700 970	171	28/ 1/74	Gibb	- Do -
Afi	23°26'	57°49'	40Q EA	584 592	(300)	4/10/76	WRD	Standard BMO 5-inch Gauge
Al-Rumais	23°41'	58°00	40Q EA	026 195	15	1973		- Do -
Al Saiq	23°04'	57°39'	40Q EA	834 848	2000	1973		- Do -

Table B-1-4 Rain Gauge Sites of JICA

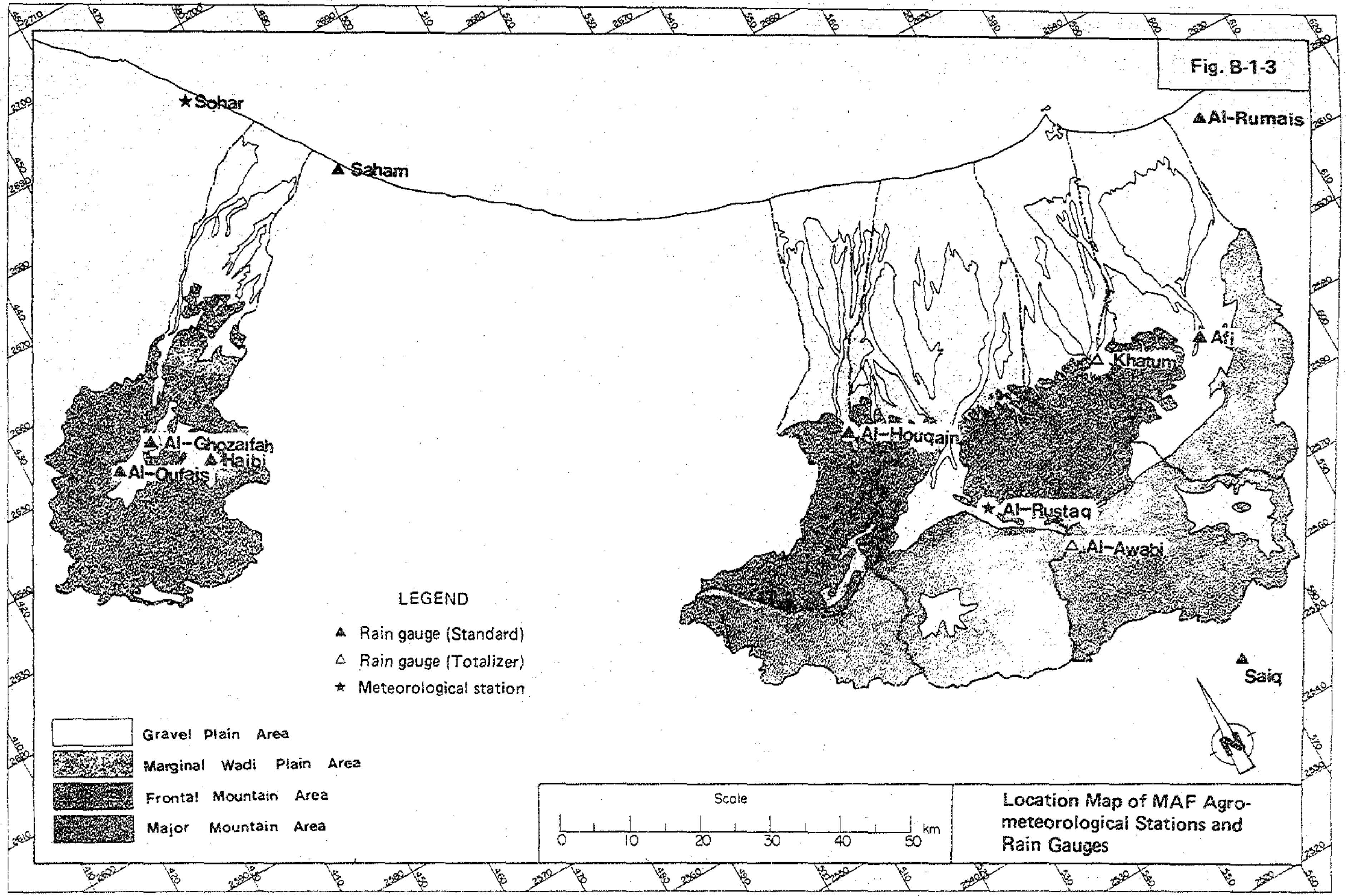
Wadi Basin	Code Number	Location	Altitude (m.a.s.l.)	UTM Gird	Starting Date of Observation	Remarks
W. Ahin	RA1	Saham	10	40R DB 880 697	Jun. 7, 1983	Automatic Recorder
	RA2	Al-Hail	300	40R DB 558 598	Jul. 3, 1983	"
	RA3	Haibi	500	40Q DB 543 449	Jul. 3, 1983	"
	RA4	Al-Qufais	570	40Q DB 441 493	Jul. 3, 1983	"
	RA5	Al-Wuqbah	750	40Q DB 391 390	Aug. 10, 1983	"
	RA6	Dhoharat	160	40R DB 620 730	Dec. 13, 1984	"
W. Bani Ghafir	RG1	Al-Suwaiq	10	40Q EB 440 367	Jul. 7, 1983	"
	RG2	Al-'Araq	120	40Q EB 374 180	May 31, 1983	"
	RG3	Al-Houqain	220	40Q EB 346 043	May 31, 1983	"
	RG4	Daba'	660	40Q EA 117 927	May 31, 1983	"
	RG5	Yiqa'	590	40Q EA 195 860	May 31, 1983	"
W. Al-Fara'	RF1	Al-Amq	700	40Q EA 336 759	May 26, 1983	"
	RF2	Madruj	1,000	40Q EA 298 710	May 26, 1983	"
	RF3	Al-Zammah	670	40Q EA 423 679	Jun. 8, 1983	"
	RF4	Sih Jamma	140	40Q EB 530 050	Jun. 7, 1983	"
	RF5	Al-Rustaq	340	40Q EA 432 858	Dec. 13, 1984	"
W. Bani Kharus	RK1	Khatum	180	40Q EA 698 970	Jun. 5, 1983	"
	RK2	Al-Awabi	480	40Q EA 562 788	Jun. 2, 1983	"
	RK3	Al-Hijir	710	40Q EA 516 659	May 30, 1983	"
	RK4	Al-Muhassanah	870	40Q EA 652 637	May 30, 1983	"
	RK5	Al-Ghubrah	610	40Q EA 720 710	Jun. 5, 1983	"
	RK6	Al-Khadrah	1,090	40Q EA 773 590	Jun. 5, 1983	"
	RK7	Abu-Abali	25	40Q EB 719 252	May 31, 1985	"
W. Al-Ma'awil	RM1	Barka'	30	40Q EB 897 156	May 16, 1983	"
	RM2	Sih Khatum	70	40Q EB 769 112	Jun. 8, 1983	"
	RM3	Afi	170	40Q EA 823 925	Jun. 5, 1983	"
	RM4	Ard Al-Mahbil	370	40Q EA 784 848	May 15, 1983	"

Table B-1-5 Areas of Thiessen Polygons

Wadi	Rain gauge	Area (km^2)
Wadi 'Ahin	RA1	98.3
	RA2	183.1
	RA3	152.0
	RA4	235.7
	RA5	296.8
	RA6	152.8
Wadi Bani Ghafir	RG1	104.3
	RG2	146.7
	RG3	156.8
	RG4	156.2
	RG5	274.8
	RF1	14.7
	RF2	45.9
	MF1	23.9
	MF2	8.1
Wadi Al-Fara'	RG2	74.8
	RG3	106.4
	RG5	15.4
	RF1	140.6
	RF2	75.9
	RF3	146.2
	RF4	353.4
	MF1	235.0
	MF2	212.7
	RK1	8.1
	RK2	99.2
	RK3	18.7
	RK7	25.2
	RM2	7.8

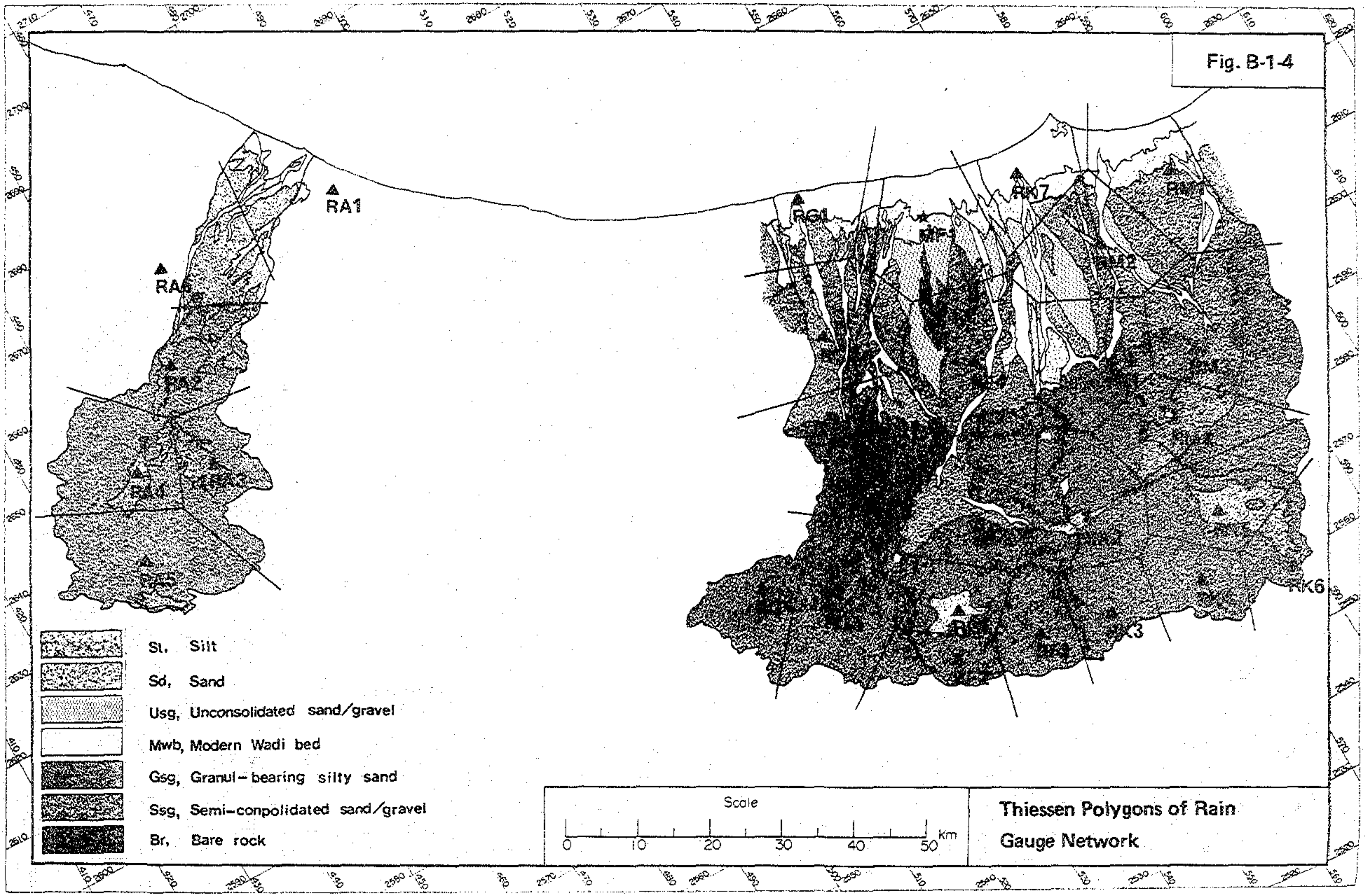
Wadi	Rain gauge	Area (km^2)
Wadi Bani Kharus	RF4	21.7
	RK1	186.9
	RK2	172.2
	RK3	120.8
	RK4	146.8
	RK5	176.7
	RK6	102.3
	RK7	106.6
	RM2	138.3
	RM4	73.7
Wadi Al-Ma'awil	RK1	62.0
	RK5	73.3
	RK7	3.1
	RM1	224.7
	RM2	116.7
	RM3	361.5
	RM4	158.4

Fig. B-1-3



Location Map of MAF Agro-meteorological Stations and Rain Gauges

Fig. B-1-4



Thiessen Polygons of Rain Gauge Network