2.3.2 The Development Plan for Water Resources Sectors in the Second Five-Year Plan

(1) The Ministry of Agriculture and Fisheries (MAF)

MAF is responsible for water resources development for agricultural use and overall management of available water resources. The Northern Region is under the Directorate General of Water Resources and Irrigation, and the Southern Region is under the Directorate General of Agriculture and Fisheries in Salalah. The current organization is shown in Fig. 2-2-1. During the Second Five-Year Plan, the priority of objectives are summarized as follows:

1. Providing sufficient water to maintain existing agriculture area.
   - Maintaining the falaj system
   - Ensuring that adequate groundwater exists to supply existing irrigation wells.
   - Developing alternative water supplies if the proceeding two options prove impossible.

2. Providing sufficient water to support government priorities
   - Water exploration, identification, and evaluation
   - Water development and transport (if necessary)
   - Water distribution (on farms) and management
   - Water enhancement for the future

3. Locating additional water for possible new agricultural lands
   - 200,000 additional hectares by the year 2000*.

4. Improving Water Management
   - Existing problem areas where management can solve or ease the problem
   - Propose projects where a planned management system will hopefully insure that water problems do not arise
   - Regional water catchment basins where planned management can prevent present problems.

Note: * "SECOND FIVE YEAR AGRICULTURAL DEVELOPMENT PLAN(1981-1985)"
Ministry of Agriculture and Fisheries, September 1980

5. Conducting research necessary to support the short-term (five-year) and long-term water objectives of the country

6. Water-related projects in:
   - The Batinah coast
   - The Southern Region
   - Remote areas
   - Villages of Jabal Akhdar

(2) The Ministry of Electricity and Water

1. The installation of an additional desalination unit in the Capital.
2. The construction of a number of water pump works for the Capital.
3. The construction of a large storage dam at Wadi Deika with water supply facilities to the Capital.
4. The extenstion of the water supply networks in the major towns.
5. Others

(3) The Ministry of State and Wali of Dhofar

1. The construction of two water projects
2. The extension of water distribution network in Salalah
3. The construction of water distribution networks in the major towns
4. The construction of three small recharge dams
5. Others

(4) The Musandam Development Committee

1. The construction of water projects in three towns
2. Exploration drilling
3. The construction of a small flood-control dam

(5) Public Authority for Water Resources

In order to complete a basin assessment of the resources and to determine how these may be exploited, the following four surveys shall be undertaken:

1. Data collection and analysis
2. Regional drilling surveys
3. Intensive exploration drilling
4. Surface water surveys

2.4 Surveys and Development of Water Resources

Basic Surveys for water resources development in Oman where undertaken both in the northern region and the southern region from 1973 to 1976 by the consultants listed below:

- Southern Region : Sir William Halcrow (England)

- Northern Region : ILACO (The Netherlands)
  Sir Alexandar Gibb and Partners (England)
  Renardet-Sauti ICE (Switzerland)

These surveys form the basis for the later surveys. In 1979, the United States Army Corps of Engineers initiated a two-phase study of the future development of water resources in Oman by the request of the Government of Oman, and set development priorities for Wadi Samail and others.

However, since accurate long-term hydrological data is lacking, there are problems in planning a large-scale water resources development project.

MAF is now undertaking the rehabilitation of falaj. systems and the construction of dams for recharging the wadi alluvium and aquifers of the Batinah Plain as pilot projects.

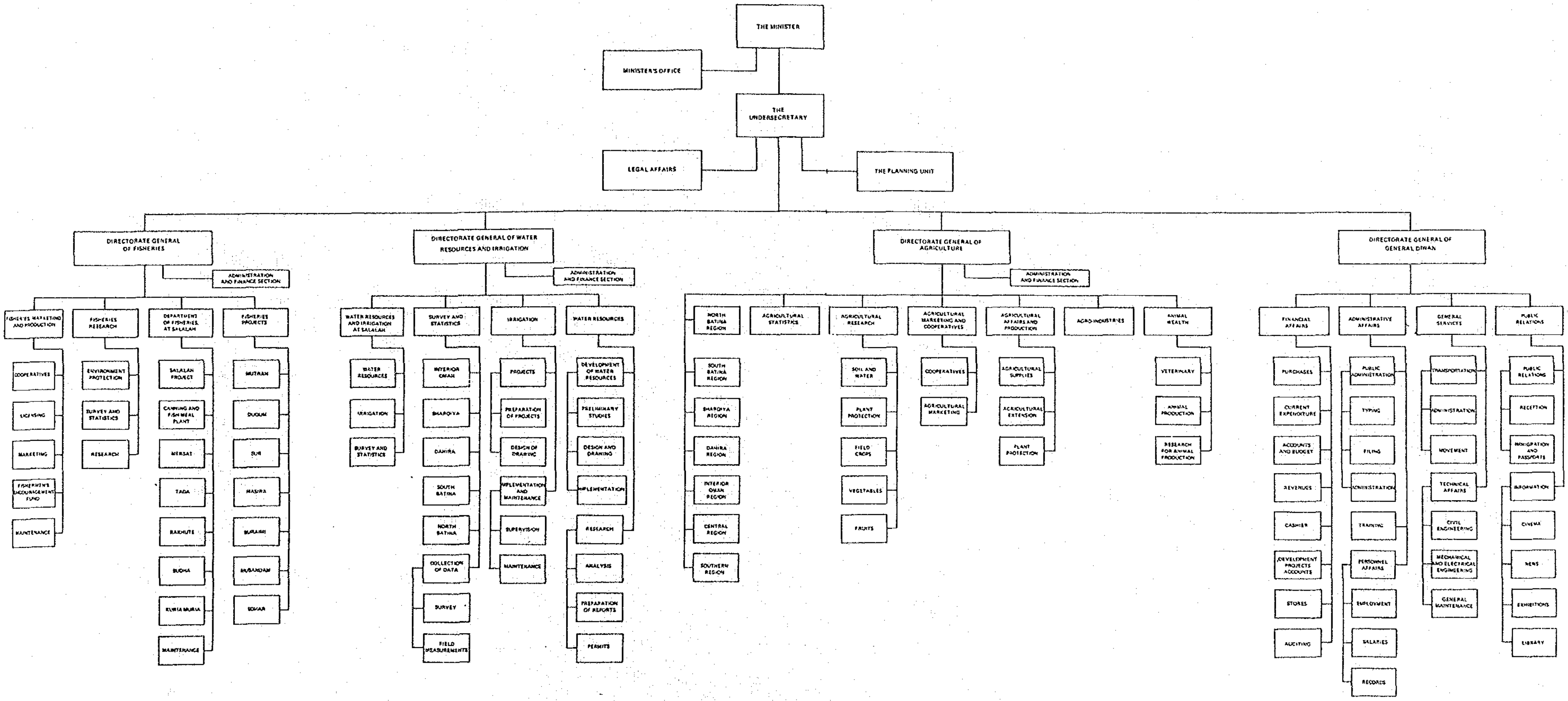
MAF has identified 7,000 falaj systems and 20,000 to 30,000 collection branches in Oman. The Ministry reports mapping or data are available on 4,000 systems.

The Ministry is now implementing the repairs and maintenance works of afalaj..

Regarding recharge dams, the Ministry has completed the construction of four (4) recharging Dams (Wadi Al Khaud, Khor Al Rusagh, Sohar Recharge Scheme, Wadi Quriyat) during the Second Five-Year Plan.

The Ministry has prepared the Draft of Master Plan based on the previous studies as "Catchment Water Conservation and Recharge Schemes for Irrigation" (Hydroconsult 1985).

Fig. 2-2-1 Current Organization: Ministry of Agriculture and Fisheries



CHAPTER 3. NEW OBSERVATION NETWORK IN THE BATINAH COAST

CHAPTER 3 NEW OBSERVATION NETWORK IN THE BATINAH COAST

3.1 Installation of New Observation Facilities

3.1.1 General

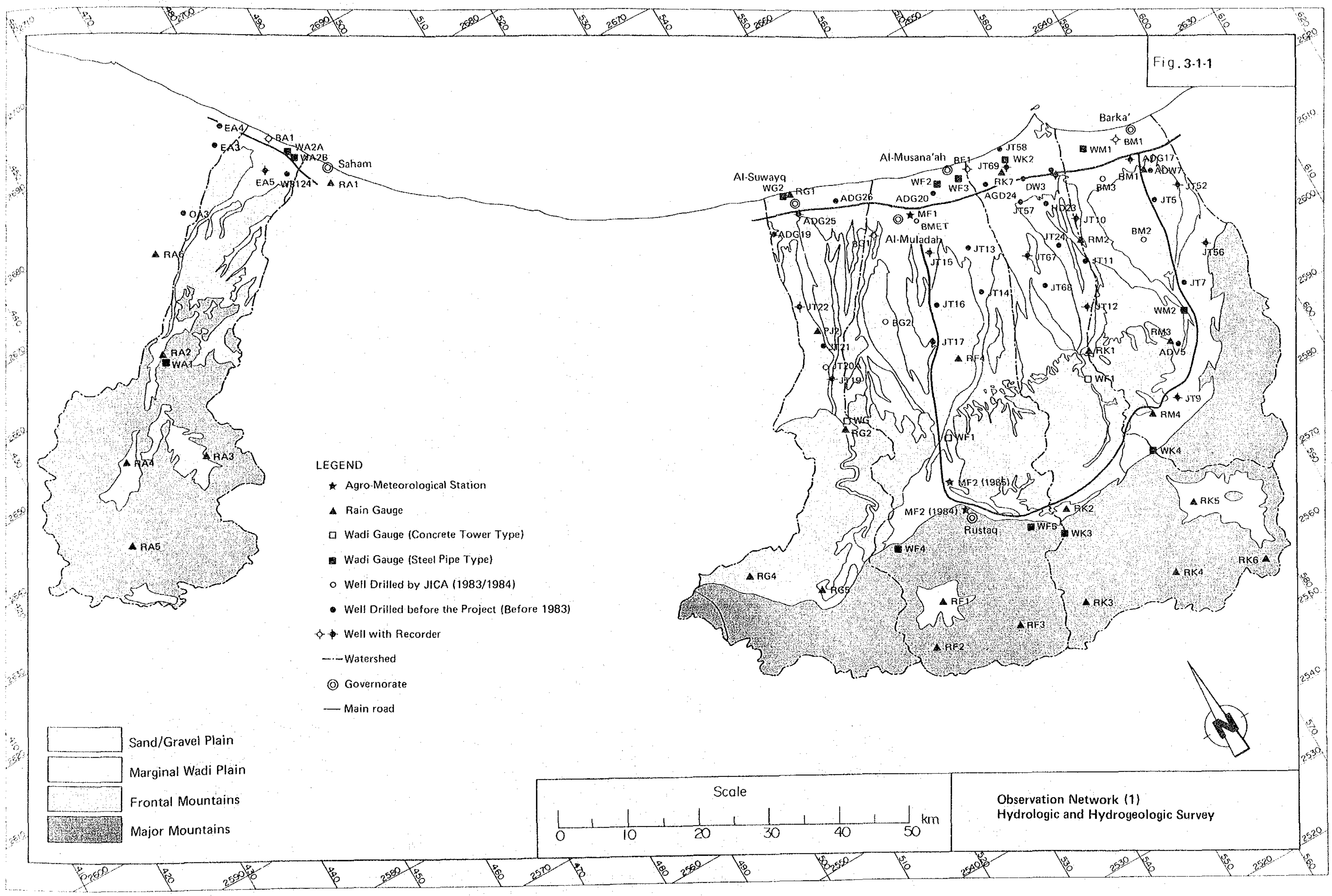
New hydrologic observation facilities were set up to promote integration of water resources development in the five wadi basins of the Batinah coast by the JICA survey team. They are listed in Table 3-1-1.
The location map of the observation network is shown in Figs. 3-1-1 and 3-1-2.

Table 3-1-1 List of Observation Facilities

Observation Facility	Nos. of Sites			Nos installed by JICA			Remarks
	Total	MAF	JICA	1982/83	1983/84	1984/85	
· Agro-meteorological Station, Al-Muladdah	1	-	1	1	-	-	Observation house (96m^2) Automatic meteorological observation system
· Meteorological Station, Al-Rustaq	1	-	1	1	-	-	Reinforcement of instrumentation
· Rain-gauge	28*	(12)**	28	25	-	3	Automatic rain gauge
· Wadi Gauge	16	-	16	2	14	-	Concrete tower type: 3 sites Steel pipe type : 13 sites *Radio flow-meter: 3 sites*
· Observation Well - Well for water level gauging - Well for salinization monitoring	 46 3	 41 -	 5 3	 - -	 4 3	 1 -	- Drilled well: 12 wells - Cleaned well: 12 wells - Water level recorder: 14 wells
· Water use - Cumulative flow meter for pumping Staff-gauge for falaj discharge - Falaj observation sites by staff-gauge	 20 6	 - -	 20 6	 20 6	 - -	 - -	 Coastal area Mountain area

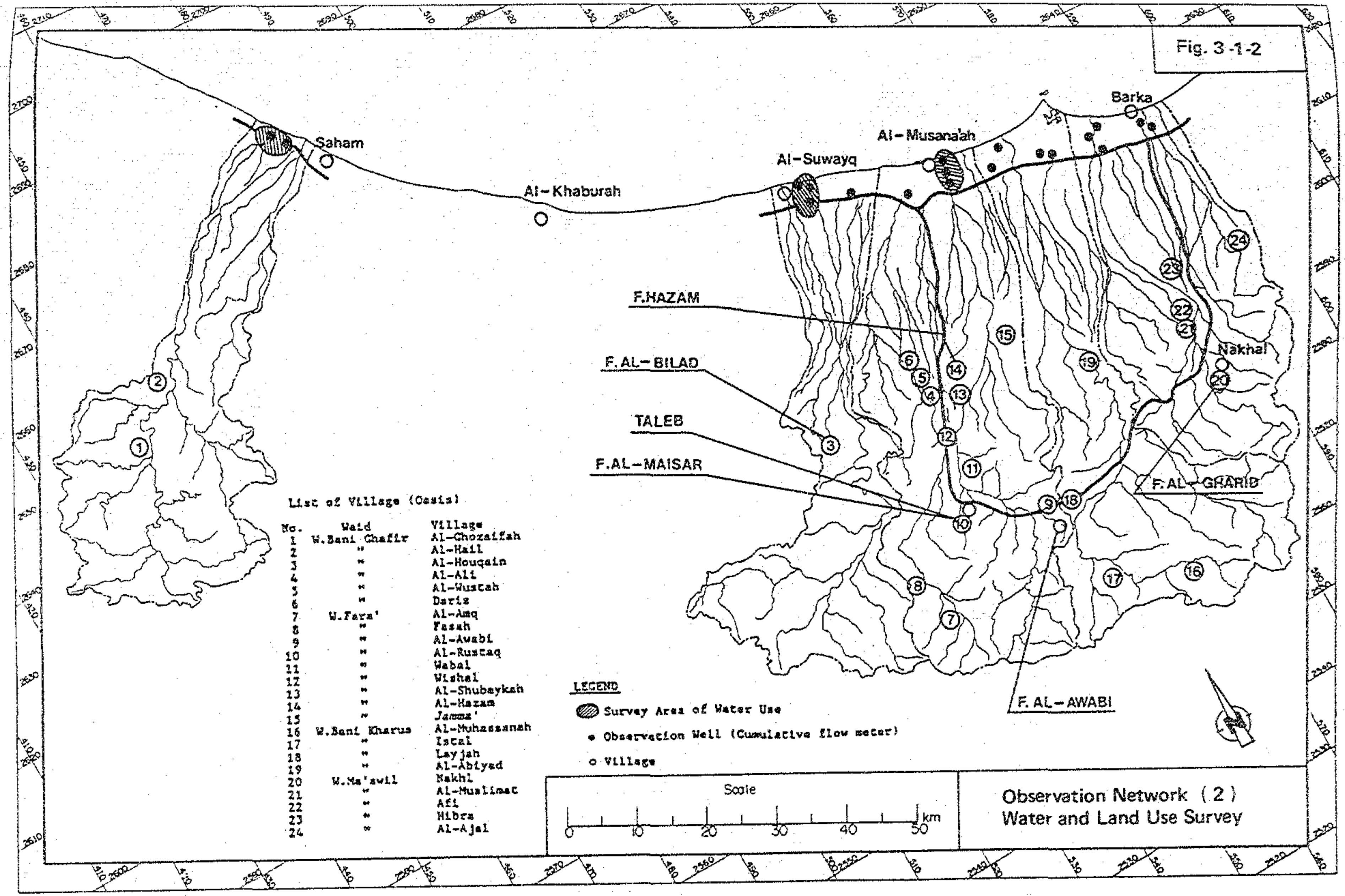
Note: * included in Al-Muladdah Agro-meteorological Station

** not included in the observation network of the Project.



Observation Network (1)
Hydrologic and Hydrogeologic Survey

Fig. 3-1-2



List of Village (Oasis)

No.	Waid	Village
1	W.Bani Ghafir	Al-Ghozaifah
2	"	Al-Hail
3	"	Al-Houqain
4	"	Al-Ali
5	"	Al-Wustah
6	"	Daris
7	W.Fara'	Al-Amq
8	"	Fasah
9	"	Al-Awabi
10	"	Al-Rustaq
11	"	Wabal
12	"	Wishal
13	"	Al-Shubaykah
14	"	Al-Hazam
15	"	Jammz'
16	W.Bani Kharus	Al-Muhaszanah
17	"	Istal
18	"	Layjah
19	"	Al-Abiyad
20	W.Ma'awil	Nakhl
21	"	Al-Muslimat
22	"	Afi
23	"	Hibra
24	"	Al-Ajal

LEGEND

- Survey Area of Water Use
- ● Observation Well (Cumulative flow meter)
- ○ Village

Scale: 0 10 20 30 40 50 km

Observation Network (2)
Water and Land Use Survey

3.1.2 Agro-meteorological Station

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 are insufficient due to improper maintenance of the observation equipment and unsuitability of sites.

An Agro-meteorological station has been newly established at Al-Muladdah and necessary additional instruments have been installed at the meteorological Station at Al-Rustaq, in order to obtain general meteorological data and the necessary items for estimating the amount of annual evaporation, which are wind speed, net radiation, soil heat flux, air temperatures and humidities of two layers (50 and 270 cm in height).

3.1.3 Rain Gauge

There were twelve rain gauges in the study area before the Project. Those rain gauges are shown in Fig. 3-1-3. Daily rainfall was observed at nine sites but the distribution of sites was not uniform in the area.

Twenty-eight rain gauges were installed in the study area (Fig. 3-1-1) to observe more widely and densely. The density of rain gauges is approx. 1/200 km^2. Their distribution was planned more densely in the mountain area than in the coastal plain based on the annual rainfall frequency which is greater in the mountains than in gravel plains.

Since surface run-off of arid zones depends heavily on the rainfall intensity, rain gauges are planned to record the amount of rainfall once in every 15 minutes.

3.1.4 Wadi Gauge

Nine wadi gauges were installed in the study area in 1973 and 1974 by ILACO and Gibb during their survey. Their locations are shown in Fig. 3-1-3. They were handed over with other gauges to MAF in 1975. However, all the wadi gauges in the study area stopped functioning before 1981. Most of them were damaged or washed away by flash floods .

In order to study the surface water hydrology, wadi gauges were installed in accordance with the three distinct geographical areas;

- At the outlet valley zone of Major Mountains in the upper reach of wadi (4 sites)
- Between Frontal Mountains and Marginal wadi Plain (5 sites)
- At the coastal strip zone (7 sites)

These wadi gauge sites were selected for the purpose of estimating the hydrologic systems and evaluating the groundwater recharge system in the Batinah coast.

The sixteen(16) wadi gauges of which five sites were selected near the former gauges, were installed and are shown in Fig. 3-1-1. The structure of wadi gauges was designed to withstand the flood. Three wadi gauges were made of concrete and the other gauges were of steel pipes.

A float type water-level recorder was installed at each gauge. The water-level recorder is the same type as the former gauge used by DGWRI. A radio flow meter with an automatic switch was installed for measuring the surface-velocity of floods at each gauge of the three concrete tower-type wadi gauges. The drawings of those wadi gauges are attached in the Supporting Report B.

3.1.5 Observation Well

The major aquifer of the Batinah is located in the coastal plain.

In order to observe the aquifer behavior, a groundwater observation network was built to cover the area of 2700 km^2. When this project started, many observation wells had been drilled by the preceding projects: ILACO (1975) and Gibb (1976). However, many of these wells were already so deteriorated that they could not perform scientific observation. The deterioration was caused by objects dumped inside the wells. Such deterioration was caused due to the lack of fencing or well-top capping. Villagers could have easy access to the wells and dumped objects into them.

Prior to network designing, the condition of all wells was checked and 41 wells were selected as the network elements. Twelve from these 41 underwent rehabilitation work.

In addition to the old wells, twelve new wells were drilled by the Project. Their drilled depth totalled 803 meters. The new network consisted of 49 observation wells including newly drilled wells. Newly drilled wells command 350 km^2. The average command area of observation well was 44 km^2, which was determined by the Thiessen method. The distance between the grid of the observation well network is still large.

The project installed fourteen water level recorders which can record without mannual attention for one month. Water level recorders totaled twenty, including six previously installed ones. These recorders were aligned along the presumed groundwater flow lines for the purpose of correlation analysis for the neighbouring hydrographs. However, the network grid distance is still not small enough, so more recorders are needed to be installed in order to realize the original intention.

Manual water level measurements have been carried out for all the observation wells once a month.

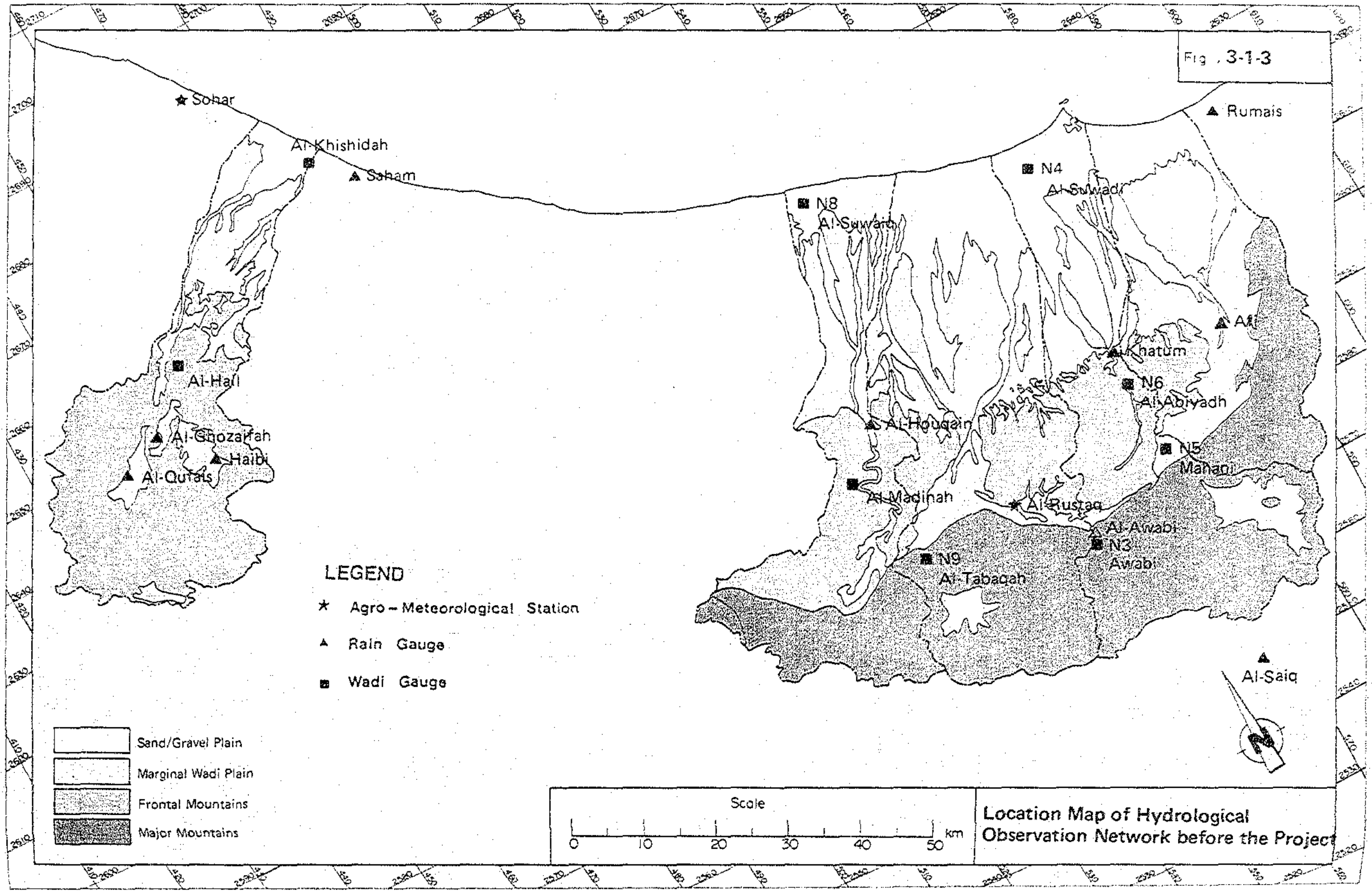
Three new wells of 100 m depth each, drilled near the coast, are the salinity monitoring wells. Screens were set for the total well depth. Electric conductivity (EC) and temperature loggings of these wells have been made once a month regularly. Water level recorders were installed for these wells to adjust for tidal influence. Fig. 3-1-1 shows the positions of the observation wells with identification of new and old wells, and identification of the installation of water level recorders. This network map depicts the present situation where observation station density is biased in favour of the coast side.

The new wells were all lined by PVC casing except for the steel cased BM2 which was dry at the 90 m bottom. PVC casing does not cause any corrosion problems which shorten the well life and prevents accurate chemical analysis of well water. Previously established wells were all lined by steel casing, thus the new wells show a considerable improvement. New wells were furnished with well-top caps. Some had a locking bar in case no recorder was present on the top. Recently MAF undertook fencing works around all the existing observation wells, so the present situation of the facilities can be regarded as quite satisfactory.

At present there are sixty-six wells in MAF's possession in the project area. But nineteen of them are in extremely bad condition or at unfavorable sites. In addition, most of the old wells have lost their original depth. These deteriorated conditions should be rectified at some suitable occasion in the future.

Besides the well-observation, spring and falaj discharge observation has been carried out, originally for the water use survey of this project. This observation is very meaningful for the mountain aquifer study. The observation should not be discontinued after the end of this project.

Fig. 3-1-3



Location Map of Hydrological Observation Network before the Project

3.2 Reinforcement of Staff for Hydrological and Hydrogeological Observation

3.2.1 Present Status in MAF

At present, the hydrologic observation works belong to MAF. Department of Water Resources, Directorate General of Water Resources and Irrigation (DWR, DGWRI) which has the responsibility for observation works in the northern region. The Directorate General of Agriculture and Fisheries in Salalah has the responsibility in the southern region. In the future, the observation facilities which were installed by the JICA survey team and the monitoring wells for four recharge structures recently constructed, will be added to the existing observation network of DGWRI.

The DWR's observation works are operated by ten staff (including four expatriate experts) in the research section, three staff in the Sohar office and one staff in the Sharqiyha office. These staff are participating in hydrologic observation field work and office works in the Batinah coast, the Sharqiyah and the Interior area. The observation works for agro-meteorological stations and rain gauges are carried out by local people under contract. Six junior counterparts who have been trained by the JICA survey team will be transfered to the research section of DWR at the end of the survey period.

The current organization of DGWRI, MAF is shown in Table 3-2-1.

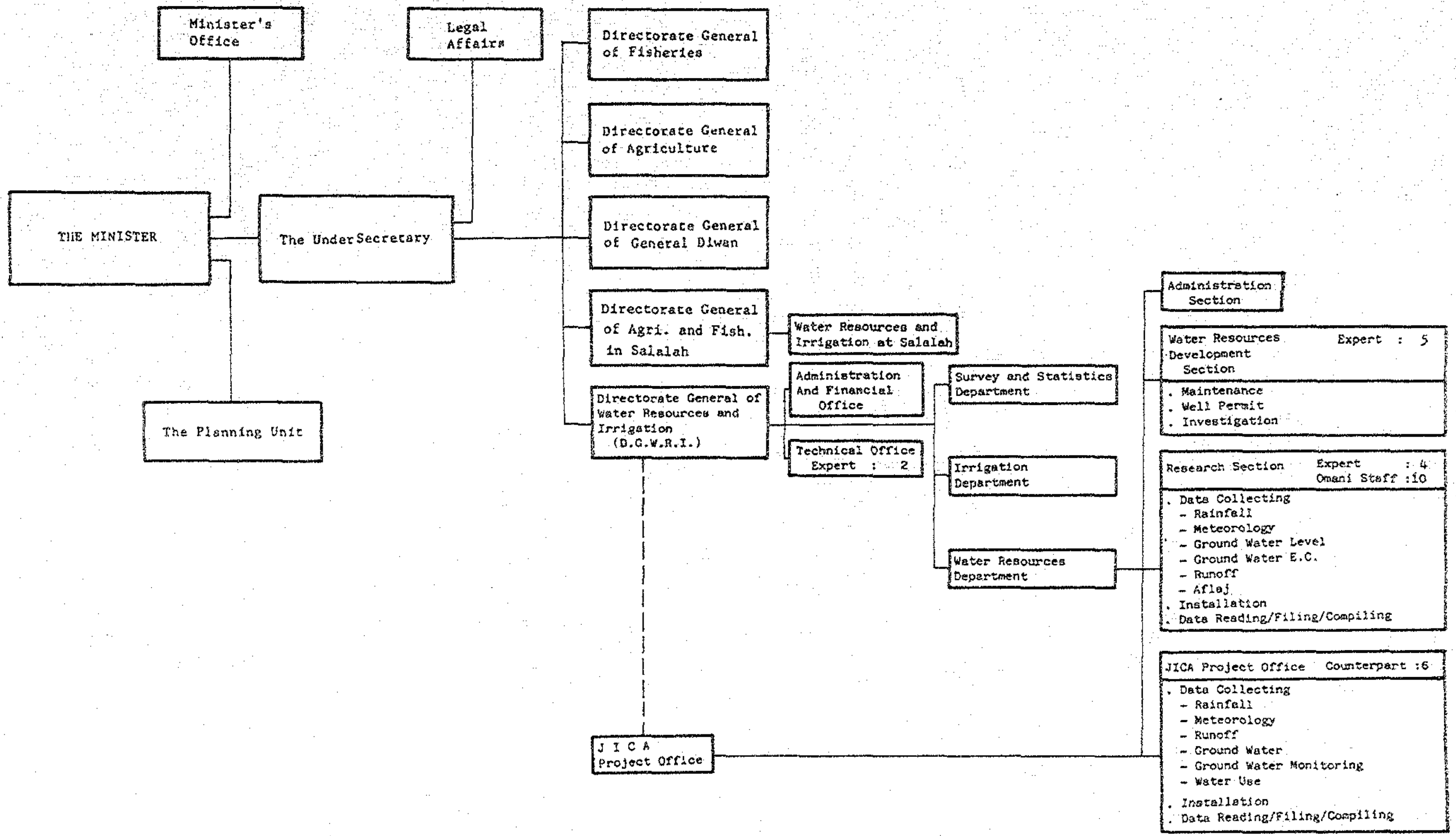
At present, the observation facilities in DGWRI consist of 5 agro-meteorological stations, 64 rain gauges and 399 observation wells (185 boreholes and 214 handdug). Most of the facilities were installed in 1973-1974 by ILACO, Gibb and Renardet Sauti ICE during their water resources survey and were handed over to MAF after their survey.

All the original data and records which collected by DWR staff have been filed and stored in the cabinets of the DWR office. The rainfall data were tabulated on a monthly basis. However the well level data are raw data. Reading and ploting hydrographs of the well data have been carried out by the JICA survey team and compiled in the hydro-meterological year book of 1984.

According to the actual situation of DWR for water resources development, only a few of the operations required have been carried out satisfactorily from a technical viewpoint due to understaffing. There is a big gap between the manpower in the current organization and the manpower required.

DWR technical staffing should be increased both for field operations and for office operations. Most of the staff are now employed in field operations and are unlikely to participate in the office operations. Although the level of office operations is still quite low, professional staff and qualified staff in techincal fields are indispensable for performing accurate hydrological observation. DWR should do move towards an organization with staff who focus on developing a national water development plan.

Table 3-2-1 Organization of Directorate General of Water Resources and Irrigation



3.2.2 Observation and Technology Transfer

(1) Observation

Observations which have been carried out during the survey period are summarized as follows:

1) Meteorological Station

Meteorological observation started on July 26, 1983 at the two agro-meteorological stations of Al-Muladdah and Al-Rustaq after installation and reinforcement of all the instruments.

At Al-Muladdah agro-meteorological station, all the data except rainfall and evaporation are recorded by strip charts and cassettes.

Routine observation and maintenance works at the two stations are carried out twice a month. The tabulation and processing of data are made by a personal computer in the office.

2) Rain Gauge

The observation of rainfall started in June, 1983 at 28 rain gauge sites after the installation of the recorders.

The rain gauge is the tipping-bucket type with a three-month recorder. The rainfall data are read hourly and are recorded on a monthly data sheet by using a personal computer.

Routine observation and maintenance of gauges are carried out every three months and take 7 days.

3) Wadi Gauge

The observation started in Sept. 1983 at 16 wadi gauges after the installation of the recorders.

The water level recorder is the self-recording type with a float for 50 days recording period.

Water level is recorded on the data chart.

The routine observation and maintenance of gauges are carried out every 50 days and take 4 days.

4) Observation Wells

There are two routine observations of the groundwater level: manual measurement and automatic recording.

Manual measurement had been maintained since 1976 in the project area by DGWRI. Our project staff took over the duty in March, 1984.

Automatic recording started in January, 1984, at 14 wells by A. OTT R-16 type recorders, the recording period of which was set for one month. There are six more recorders already installed by the previous project in the project area. So altogether twenty recorders have been in action. Monthly manual measurements take three or four days to complete, and the chart-change of the recorders also takes three or four days.

5) Water Use Survey

At six aflaj systems in the mountain area and twenty private wells in the coastal area, observation of water supply and water quality for the irrigation are carried out twice a month.

The routine observation items for falaj flow survey are reading the water depth of falaj by staff gauges, measuring the velocity of falaj stream by current meter, water temperature and electric conductivity.

The routine observation items for pumping stations are reading cummulative flow meter, water temperature and measuring electric conductivity.

(2) Technology transfer

Technology transfer to the Omani counterparts was carried out for upgrading the level of their hydrologic observation abilities through on-the-job training in the course of the survey. Periodic observation activities were managed and carried out to a certain extent by the counter-parts under the supervision of the JICA team. The training period of Omani counterparts is presented in Table 3-2-2.

Senior counterparts are incharge of the Project officers.
They have been employed by MAF after graduation of industrial high school, and performed data collection and its filing prior to the commencement of the JICA study. The counterparts selected for the survey are newly employed by the Ministry after they finish junior high school or vocational training center.

For the development of the Sultanate of Oman, the nation has been promoting the establishment of educational institutions. However, it is pointed out that the fundamental knowledge and training in the hydrologic and scientific field have not been improved sufficiently. In these areas, there are few Omani counterparts who can be engaged in the captioned project, who have the required standard level of knowledge of technology. On-the-Job training carried out during the ordinary investigation and observation works has not fully upgraded their basic knowledge of science technology. Department of water resources of the Ministry of Agriculture and Fisheries of Oman has been conducting the routine works in compliance with advice given by the technical experts during these ten years, however, few staff could understand the technical concept of what they are doing.

In consideration of above situation encountered, technology transfer through the Project has been carried out with the aim of the accurate continuity of the observation works by the Oman people for the observation network system which will be transferred to the Ministry.

The following points were considered important for the technology transfer during the project period:

1 To instruct counterparts in observation and maintenance of the observation network

2 To instruct counterparts in filing and compilation of observation data

3 To expand the general knowledge of counterparts in hydrologic observation and water resources development.

For effective technology transfer, basic study programmes and materials were prepared during the survey period.

The technical transfer materials are summarized as follows:

1 Observation and maintenance manual of hydrologic observation networks

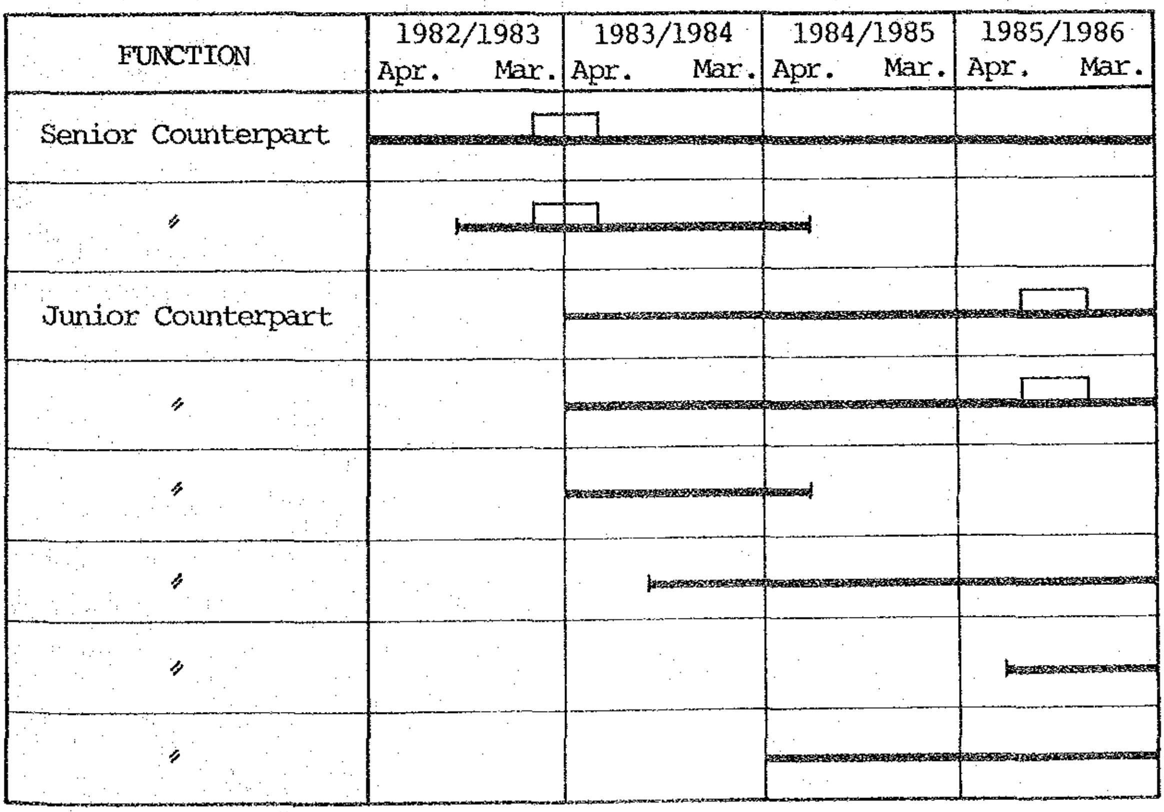
2 Facility inventory of the hydrologic observation project

3 Yearbooks (1984) of meteorological, hydrological, hydrogeological and water use data

4 Textbooks on basic knowledge of hydrology

In total, seven Omani people including project counterparts and technical staff of MAF were invited to Japan to participate in a short JICA training programme on four occasions in the course of technology transfer.

Table 3-2-2 Training Period of Counterparts



Note: ▭ JICA Training in Japan
├─┤ Training Period

3.2.3 Recommendation for Follow Up of Observation Network

(1) Staffing and Training

DGWRI is seriously understaffed for participating in long-range water resources development activities. In order to plan water resources development work, it is indispensable to solve the staffing situation or few results can be expected from water resources development activities of the department.

Increase in both field operation and office operation manpower based on the recruitment schedule in the DGWRI is believed to be indispensable for future water resources development in the country. It takes a long time to reach the required level of manpower and training of the staff, so DGWRI will require the assistance from outside groups in order to implement the programme effectively throughout the next five-year period.

However, DGWRI should take some action immediately, such as employing university graduates as staff.

In order to upgrade the technical level of Omani staff, it is advisable to make effective use of the technical and managerial abilities of experts, and to implement a programme for technical transfer through on-the-job training by such experts.

(2) Data Collection and Observation

In order to succeed in routine data collection and observation in the observation network, it is desirable to establish an observation schedule and guidelines to control the work based on the operation manual made by the survey team for planning of observation and maintenance. For this purpose, specific recommendations are summarized below.

1) During the survey period, two observation schedules were prepared monthly and weekly. The monthly observation schedule was determined considering the required work volume and available resources. At each end of a week, the weekly schedule for the next week confirmed the staff participants and date to carry out the works.

For preparing the monthly schedule, manpower analysis of observation works was made by the volume of required man-days for quantitative evaluation.

The same method will be applied for the balance of the operation of the work with limited resources.

2) Facility inventory of the observation network was prepared for understanding and confirming the details of the facilities including specification of equipment, location and necessary remarks. The inventory must be maintained in good working condition to obtain accurate data from the observation network.

3) During observation, the work has to be made according to the observation network operation manual made by the survey team for effective observation and maintenance. It is also strongly recommended to make use of the checklist which was made also by the survey team for the purpose of accurate data collection. The checklists have to be always be filled in to record the conditions of each observation.

In addition a systematic data record will be required to record the data itself and working record of equipment at each station. These records will be utilized for determination of observation and maintenance schedules of the networks.

Finally all recorded data should be distributed and filed in order in the cabinet according to the operation mannual.

(3) Supply and Storage of Equipment Spare Parts

Recording charts, spare parts, etc. have to be stored and supplied in order. At present, recording charts and spare parts of equipment for one year will be handed over to MAF.

A complete list of equipment and spare parts was prepared by the survey team. This list has to accurately reflect the latest situation of the storage. For this purpose, a supply and storage system has to be established and controlled by the staff in charge.

Required spare part items and consumables for all facilities for each year in detail are also attached to the spare parts list. This attachment will be referred to for estimation of operation and maintenance cost for budgeting.

(4) Filing of Data and Publication of Yearbook

In order to utilize the data collected for various kinds of projects, it is strongly recommended to publish a yearbook in addition to data collection and filing. For this purpose, data filing, processing and publication system has to be established and controlled by the staff in charge.

The hydro-meteorological yearbook of 1984 was compiled by the survey team as one of outputs of this project. The data refers specifically to hydrological and agricultural needs as should the continuous publication of the yearbook.

Finally it is strongly recommended to store this valuable raw data and recorded charts at DGWRI.

CHAPTER 4. SURVEY RESULTS

CHAPTER 4 SURVEY RESULTS

4.1 Geomorphology and Geology

4.1.1 General Features

The most prominent geomorphological feature in Northern Oman is the Oman Mountains, which run from the Musandam Peninsula in the north-west to Sharqyah region in the south-east. The mountain axis is laid along a curve which is concave to the north-east. Geomorphological units develop in areas which parallel the mountain range. The Oman Mountains consist of the Western and Eastern Hajar Mountains. The Western Hajar Mountains are also called Al Akhdar Mountains. The crest of the Akhdar Mountains is about 3000 meters above sea level. They also form the watershed which divides surface drainage systems into the coastal system and the inland system.

The Akhdar Mountains are a folded mountain mass along anticlinal axes.

In the project area four geomorphological zones develop from the mountain to the coast: (1) Major Mountains, (2) Frontal Mountains, (3) Marginal Wadi Plain and (4) Sand/Gravel Plain.

In the Major Mountains area, several inland basins are formed along geologically weak parts on the anticlinal axes. Wide valley plains cut through the Frontal Mountains and run between Major Mountains and Frontal Mountains.

Major Mountains are mainly composed of limestone and dolostone except for the outcrops of old metamorphic rocks in the inland basin. The limestone and the dolostone are monoclinally laid and overlie the old metamorphic rocks. These rocks are resistive against weathering and erosion, so the valleys and ridges are walled by steep rock faces.

Frontal Mountains area is mostly made of ophiolite nappes which are marine volcanic rocks in origin. The mountain elevation is one step lower than Major Mountains and reaches the altitude of only about 1,000 m. Due to the significant weathering of ophiolite, Frontal Mountains have relatively gentle terrain. Marginal Wadi Plains spread out from the foot of

Frontal Mountains. Old pediments and old alluvial fans are the major geomorphological elements there. Outward from Marginal Wadi Plain to the coast, stretches Sand/Gravel Plain. Alluvium deposits and sand/gravel deposits of present fluvial activities are dominant in this area.

4.1.2 Characteristics of Geomorphology and Geology

Geomorphology and Geology of the project area are summarized in Fig. 4-1-1 - 5 and Table 4-1-1. An explanation of these Figures and Table is presented below.

To begin with, Major Mountains have high altitudes of 3,000 m, represented by Jabal Shams. They work as watershed boundaries in the eastern and the southern fringes. At the coast side, due to the prevailing monoclinal beddings, monoclinal ridges and cuestas are remarkably developed. Along the mountain axis inland basins are eroded in a chain-like alignment. The trend of ridges takes northwest-southeast direction in the southern edge, but northeast-southwest direction in the eastern boundary.

Frontal Mountains are located at the front of Major Mountains. The altitudes of their crests reach approximately 1,000 m.

At the outskirts of Frontal Mountains or Major Mountains, Marginal Wadi Plain stretches coastward, consisting of terraces and eroded alluvial fans. Its slope often exceeds 1/200, but the gradient gradually decreses and transforms into Sand/Gravel Plain at 1/500 on average.

Sand/Gravel Plain is formed of modern alluvial fans, wadi beds and flood plains. In the upper reach this geomorphological unit can only occupy the narrow space between terraces and eroded fans. It becomes dominant as it spreads to lower reach. At the extreme coast side coastal dunes and silt plain are the major land forms.

The oldest formation, which crops out in the project area, is the slightly metamorphosed Pre-Permian rocks which prevail in the inland basins of Major Mountains.

In the bare rock zone of Major and Frontal Mountains, rocks of Permian to Cretaceons are predominant. The rocks of Major Mountains are autochthonous sedimentary rocks, but ophiolites of Frontal Mountains are allochthonous marine volcanics.

The tectonic of Major Mountains is determined by the Akhdar anticline in the south division and by the Nakhal anticline in the east division.

There are nappe structures trending from north to south in Frontal Mountains.

Marginal Wadi Plain and Sand/Gravel Plain develops on the Tertiary and Quaternary gravely deposits which overlie the lower Tertiary (Palaeogene) mudstones and limestones as the basement (Fig. 4-1-5). These lower Tertiary sedimentary rocks abut the Frontal Mountains formation. These gravely deposit do not have extensive lithofacies, but they can be divided into three divisions from the bottom: concreted (cemented) gravels, muddy gravels and modern sand/gravels. Among these three, concreted gravels and muddy gravels contained layered sand and limy mud, and maintain different features against the overlying modern sand/gravel deposits. At the outer fringe of Sand/Gravel Plain, where some wadi beds terminate, there remain trace of Pleistocene and Holocene transgression.

The discussion above is summarized in Table 4-1-1.

Table 4-1-1 Geomorphological Divisions and Their Geologic Formations

Geomorphological Division	Geologic Formation
Major Mountains	Pre-Permian Basement Rocks, Hajar Super Group, Hawasinah Complex
Frontal Mountains	Semail Ophiolite
Marginal Wadi Plain	Tertiary Limestone and Clastics
Sand/Gravel Plain	Pleistocene/Holocene Clastics

(1) Geomorphological and Geological Divisions

The project area is divided into four divisions, characterized by the geomorphic/geologic features discussed above. A typical geological cross-section of the project area is schematically drawn in Fig. 4-1-5 where the geomorphic/geologic divisions are also indicated.

In the following sections, each division are to be explained focusing on its characteristics in accordance with the notation of Fig. 4-1-5.

1) Major Mountains

The rock facies of Major Mountains are composed of Mesozoic/Permian dolomite, limestone, chert, conglomerate and metamorphic rock. Among these rocks, the oldest ones are the Pre-Permian basement formation formed by metamorphics. They show the wide distribution at the center of the mountain area where the Sahtan basin and the Ghubrah bowl are located. These basins are marked as an anticlinal valley, and therefore the oldest Pre-Permian member outcrops at the center of these basins. The upper horizon, made of the Hajar Super Group, is traceable to the north and south side of the Pre-Permian outcrops. In the south of the anticline axis, the ridges form the Akhdar Mountains including the highest peak of Jabal Shams. North of anticline, similar ridges are formed upon the surrounding wadis.

Although both dolomitic Akhadar formation and the limestone of the Upper Hajar Group are hard rocks, it also contains fissures and solution holes. Especially in the outcrop of dolomite, the crack dominant zone, including bedded planes, many solution holes are observed.

2) Frontal Mountains

Frontal Mountains are of Semail Ophiolite facies, consisting of peridotite, gabbro, dyke rock and minor metamorphics. In general, durability of the rock is not much, therefore the erosion of the mountain proceeds so intensively to make gentle slope in comparison with the steep slope of the Major Mountains. However, V-shaped valley or gorge are also found at some locations where dyke rocks are exposed: at Al-Hail of Wadi Ahin and Al-Houqain of Wadi Bani Ghafir. From the viewpoint of rock composition, the mountains extending from Wadi Al-Ma'awil to Wadi Bani Ghafir are marked by a dominant peridotite and gabbro, while mountain of Wadi Ahin is marked by some metamorphics.

3) Marginal Wadi Plain

As for the surface geology the coastal plain is extensively covered by the terrace gravel, and some Tertiary limestone crops out at the border area between Frontal Mountains and Marginal Wadi Plain. Marlstone or mudstone is recognized in borehole logs as the sub-surface facies. The classification of these facies found in the project area is shown in Table 4-1-2.

Table 4-1-2 Geologic Formation and Stratigraphy of Marginal Wadi Plain

Geologic Period			Lithofacies	Correlative Geomorphology
Cenozoic	Quaternary	Holocene	Recent Wadi Gravel, Recent Fan Gravel	Recent Wadi Bed, Recent Fan
		Pleistocene	Sand and Gravel	Old Fan, Sand and Gravel Plain
			Clayey Gravel	Lower Terrace
			Concrete/Consolidated Gravel	—
	Tertiary	Neogene	Mudstone, Gravely Mudstone (Marine Deposit)	Middle Terrace
			Marlstone, Gravely Marlstone (Marine Deposit)	Higher Terrace
			Marlstone (Marine Deposit)	—
		Palaeogene	Limestone, Marlstone (Marine Deposit)	—
Mesozoic to Palaeozoic			Semail Ophiolite, Mesozoic to Palaeozoic Erathem	—

As shown in Table 4-1-2 the lower horizon is characterized by dominant sandy and clayey sediments and the upper horizon is composed mainly of gravely facies.

The top facies in the project area are the Holocene gravel facies which are unsorted and clean recent wadi gravel and fan gravel. Its distribution in the upper reach is restricted to narrow zones such as present wadi courses and fans.

The terrace gravel of the Pleistocene series distributes most widely in this sub-area and shows many geomorphological forms such as old fan, sand and gravel plain, and terrace.

The Tertiary formation, which consists of marlstone, mudstone and limestone with marine fossil, underlies the terrace gravel. Among these Tertiary deposits, sand/gravel dominant horizon is observed in the upper marlstone and mustone facies.

The terrace surfaces in this sub-area can be divided into three: lower, middle and upper surfaces according to their relative height and sedimentary structure. The lower terrace is traceable from the lowest reach and is marked by several to ten-odd meters of relative height from the middle terrace surface. The facies components are mainly unconsolidated gravel with much amount of clayey and sandy materials and is pronounced to distribute widely in Wadi Al-Fara' and Wadi Bani Kharus. The middle terrace shows the widest distribution among three which is traceable from midstream to the mountainous area such as Sahtan basin and Ghubrah bowl. However, the relative height from wadi bed is several meters at downstream, and it rises abruptly toward upstream and reaches several tens of meters at the mountain-foot. The facies often contain unconsolidated layer and the general facies are characterized by the carbonate materials, and can be correlated with the concreted gravel in the aforesaid stratigraphy. The terrace surface is an erosional plane at the upper stream and forms an eroded surface over the ophiolite and Palaeogene limestone mountains. The higher terrace has eroded terrace surface which distributes from the north of Major Mountains to inland basins like the Sahtan basin, reaching 1,000 meters above sea level.

4) Sand and Gravel Plain and Coastal Strip

The area is made of the recent wadi gravel, marine silt layer and beach sand. The recent wadi gravel is composed of poorly sorted and unconsolidated deposits, which are coarser at the upstream and finer at the downstream, changing to sand-dominant facies near the sea coast. The distribution is restricted to narrow zones at the upper stream area, but at the lower reach a wider distribution is attained. At the boundary area between coastal strip and gravel plain, the wadi deposit contracts its distribution and many wadi courses thin out within the coastal strip.

The boundary area is located at about several to some ten kilometers from the sea coast at 20 to 30 meters above sea level, and the seaside area of this boundary is covered by the marine deposits. These deposits are of beach sand dune and saline silt, forming sabkha, sandysilt flat and old beach sand dune. The data of bore holes show the marly layer as subsurface member which is interbeded to the shallower horizon especially between Wadi Al-Ma'awil and Wadi Bani Kharus.

(2) Geomorphological and Geological Feature of Each Drainage

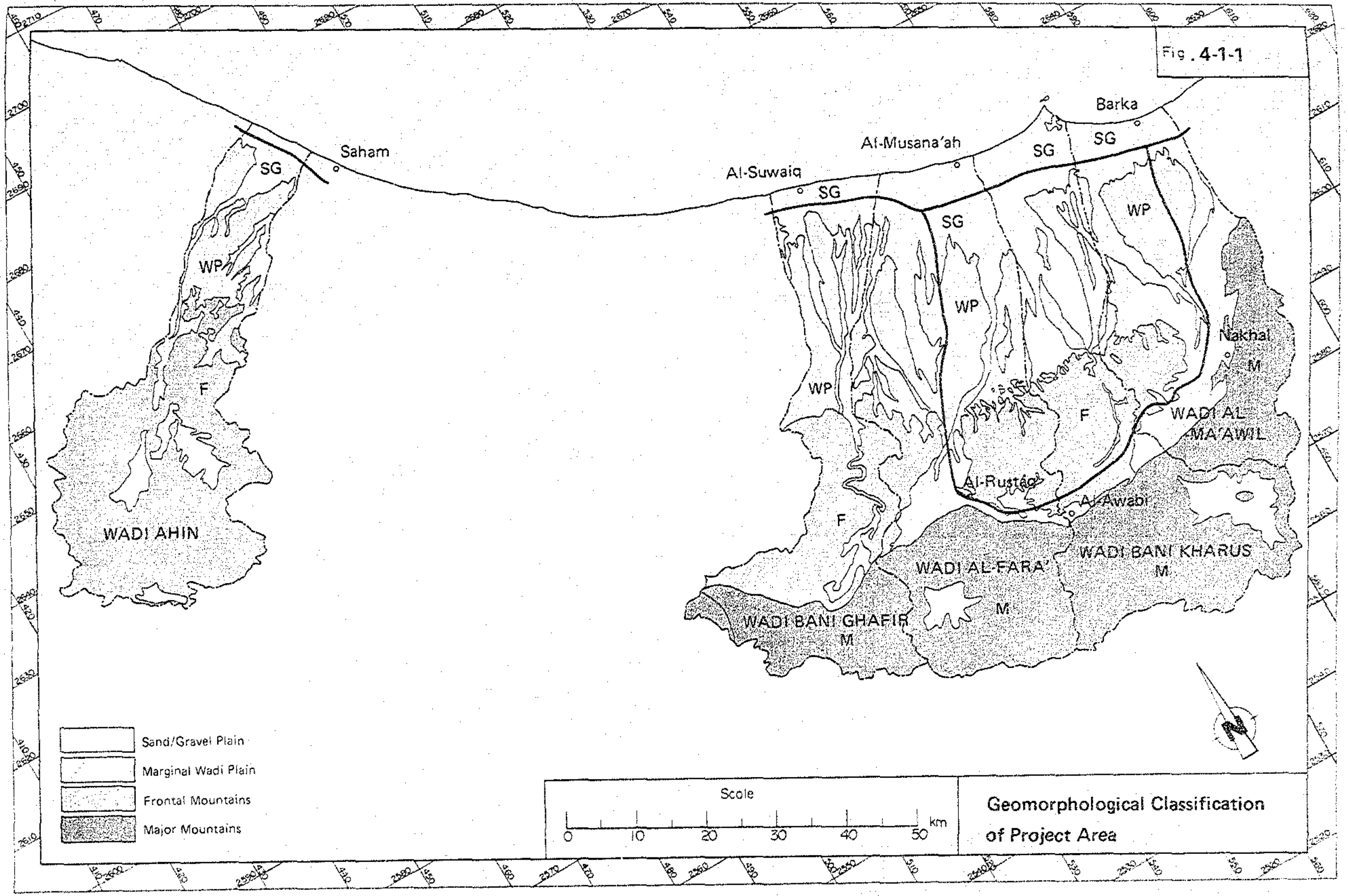
The geomorphological and geological classifications and charactristics of project Area are described in the section above. The classified sub-areas develop almost throughout the project area. Wadi courses run through these sub-areas and reach the coastal strip. There are some differences in the development of each classified sub-area between wadi basins. Wadi Ahin area has no Major Mountains rock facies and Wadi Al-Ma'awil and Wadi Al-Fara' have widely developed wadi plain even near the mountain-foot of Major Mountains. The details of the drainage area are shown in the following Table 4-1-3.

Among five drainages, Wadi Al-Fara' occupies the largest total drainage area of 1,546.8 km^2. The mountainous area of Wadi Bani Kharus occupies an area of 540.1 km^2 which is the largest among those of five wadis. Details of geomorphology and geology of each wadi basin are presented in Supporting Report A.

Table 4-1-3 Geomorphological Divisions in Each Wadi Basin

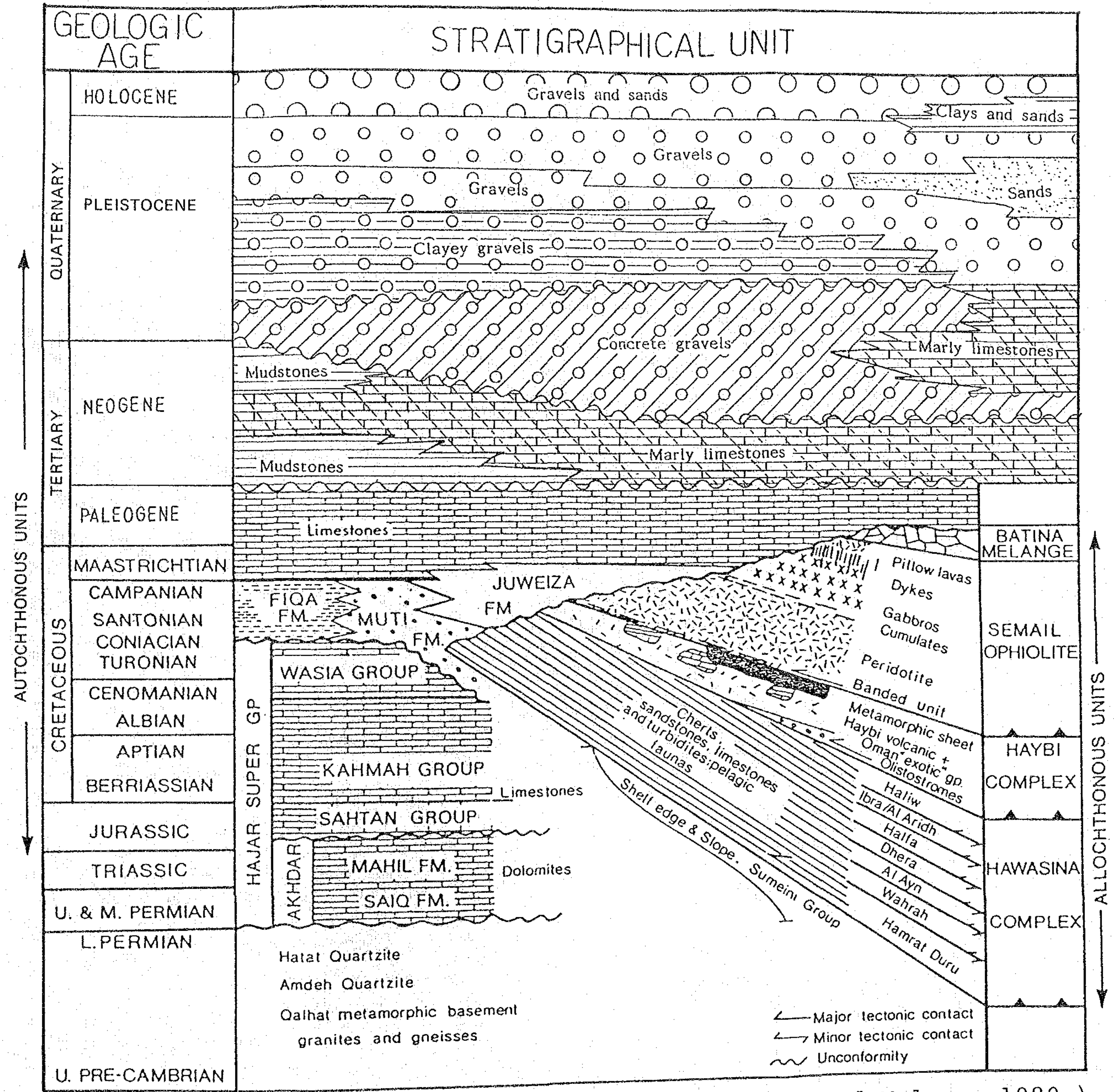
Wadi Basin	Geomorphological Division (km^2)				
	Major Mountains	Frontal Mountains	Marginal Wadi Plain	Sand and Gravel Plain	Total
Wadi Ahin	0.0	738.9	282.2	106.4	1,127.5
Wadi Bani Ghafir	271.7	345.4	227.1	107.7	951.9
Wadi Al-Fara'	390.6	262.4	550.6	343.2	1,546.8
Wadi Bani Kharus	540.1	235.0	216.1	300.8	1,292.3
Wadi Al-Ma'awil	307.1	101.9	422.1	198.7	1,029.8
Total	1,509.5	1,683.6	1,698.1	1,056.8	5,948.3

Fig. 4-1-1



Geomorphological Classification of Project Area

Fig. 4-1-2 General Geologic Scheme and Stratigraphy of Project Area



(after Searle and Malpas, 1980)

Fig. 4-1-3 (1) Geologic Map A: Wadi Ahin

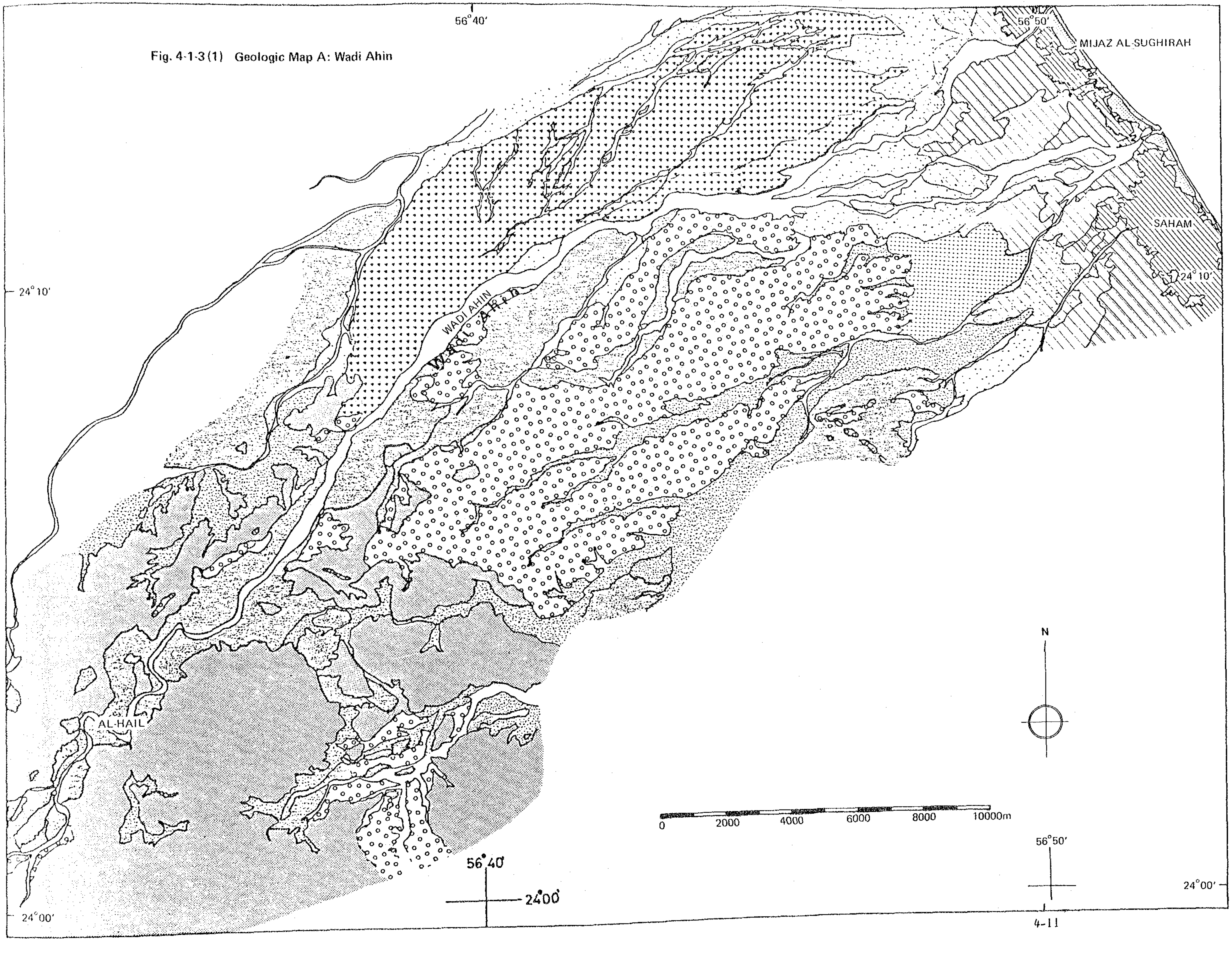


Fig. 4-1-3 (2) Legend of Geologic Map A

HOLOCENE WADI DEPOSITS

MODERN WADI BED — Active wadi channels across interfluvial plains. Facies are made of poorly sorted gravel and sand with a few clay component.

FAN I — Recent fans washed out from mountain channels. Facies are of very poorly sorted gravel up to boulder size.

WIND BLOWN SAND — Medium sand to silty-sand flats overlie silt layers at the downsteam of wadi plains. The thickness of sand layer varies in localities.

FLUVIAL PLAIN — Interfluvial area of modern wadi. Extensive distribution along each wadi. Many of interfluvail plains are probably the relics of the ANCIANT CHANNEL. Facies are of the finer clastics than those of the surrounding MODERN WADI BED.

PEDIPLAIN — Widely extending rock-cuts and eroded surfaces formed by the coalescence of a number of pediments. Typical development occurs between mountain front and wadi plain.

HOLOCENE COASTAL DEPOSITS

COASTAL DUNE — Coastal sands with seif dunes or barchans.

SILT II — Silt dominant area with outlier mounds. Facies are marked by the intercalations of sand and granule.

SILT III — Silt flats composed of laminated layers of silt, clay and granule. Occasionally marine origins are included.

PLEISTOCENE-TERTIARY FORMATIONS

FAN II — Old composit fans with outwash deposits from mountain channels. The largest one is seen along Wadi Ma'awil Facies are composed of green schist, quartzite, breccia, mountain limestone gravel and clay rich matrix.

TERRACE I — Lower terrace remaining around Al Hibra, Sih Jamma and Howqain. The terrace surface slope of 1/500 is traceable up to 15 kilometers from mountain-foot to the downsteam. Facies is of the unconsolidated gravel with some intercalations of sand and gravel.

TERRACE II — Middle terrace having 20 to 30 meters relative height Extensive distribution is seen on the midstream area which is traceable over 10 kilometers downsteam from mountain channel. The steeper slope of 1/ 300 than TERRACE I or MODERN WADI BED is recorded. Facies are marked by the consolidated layers consisting of limestone, serpentinite and peridotite gravel. Surface gravel is well varnished and wind etched.

MIDDLE-LATE CRETACEOUS FORMATIONS

SEMAIL OPHIOLITE NAPPE — Ophiolite assemblage which consists of following rock facies.

1) Volcanic, extrusive rock
2) Subvolcanic feeder dike
3) Hypabyssal-gabbroid rock
4) Gabbro
4) Transional rock between gabbro and peridotite
6) Ultramafic rock

Ophiolite assemblage called SEMAIL OPHIOLITE NAPPE forms Frontal Mountains which stand up to the 1000 meters height above sea level.

CULTIVATION — Main cultivated area.

— MAIN MORTORABLE ROAD

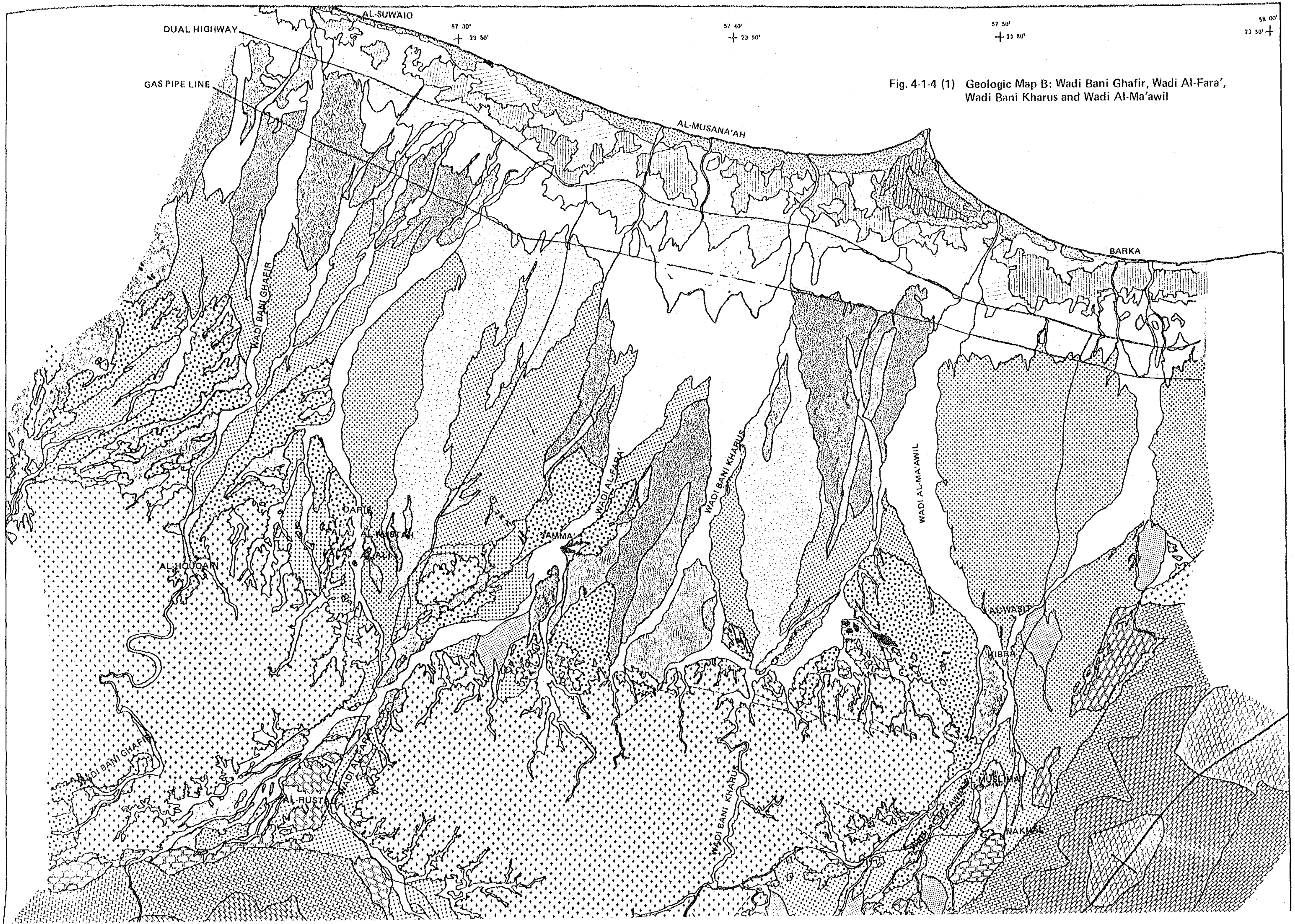


Fig. 4-1-4 (1) Geologic Map B: Wadi Bani Ghafir, Wadi Al-Fara', Wadi Bani Kharus and Wadi Al-Ma'awil


DARIS
AL-HOUQAIN
JAMMA'
WADI AL-FARA'
WADI BANI KHARUS
WADI AL-MA'AWIL
AL-WASIT
HIBRA
WADI BANI GHAFIR
AL-RUSTAQ
WADI BANI KHARUS
AL-MUSLIMAT
NAKHAL
AL-AWABI
N
57 20'
23 10'
57 50'
23 10'
23 10'
0 2000 4000 6000 8000 10000 15000m

Fig. 4-1-4 (2) Legend of Geologic Map B

Topographycal lineament

Dip of strata

Axis of foulding

Main cultivated area

Main mortorble route

WATER-BEARING PROPERTY FOR AQUIFER

LITHOLOGY

HOLOCENE DEPOSITS

ZONE I Mainly made of un-cemented sand and gravel layers. The zone is very close to the wadi bed and is excellent in re-permeability. The zone is, therefor deemed to be main zone of recharge for the productive aquifers in the lower reach. The productivity is poorer in the place of thin thickness. so lage in thickness.

- MODERN WADI BED
- FLUVIAL PLAIN

Active wadi channels and interfluvial deposits compose MODERN WADI BED. Active wadi channels across interfluvial plains. Facies are made of poorly sorted gravel and sand with a few clay component. Interfluvial area extends along each wadi. Many of interfluvial plains are probably the relics of the ANCIANT CHANNEL. Facies are of the finer clastics than those of MODERN WADI BED.

ZONE I' Consisting of sand and silt layers. The layers inter-finger with ZONE I and form the actual productive aquifers

- WIND BLOWN SAND — Medium sand to silty-sand flats overlie silt layers at the downsteam of wadi plains. The thickness of sand layer varies in localities.
- SILT FLAT — Silt flat consisting of laminated layers of silt, clay and granule. Occasinally, marine origin and saline facies are included.

ZONE I'' Mainly consisting of coastal deposits and intruded by salt-water wedge.

- COASTAL DUNE — Coastal sands with self dunes or barchans.
- SABKHA — Shallow sand flats overlying extensive SABKHA deposits.
- SAND FLAT — Shallow sand flats with shell debris and silt layers.

HOLOCENE-PLEISTOCENE DEPOSITS

ZONE II The facies are of the main gravel layers. Since the zone situates high and far from the active wadi channels, the groundwater productivity is to be low.

- FAN — Recent fans; wash-out from mountain channels. Facies are of very poorly sorted gravel up to boulder size.
- ANCIENT CHANNEL — Ancient wadi courses remain as topographical depressions on the older fans and terrace plains. Typical developments are seen around the midstream of Wadi Bani Kharus and Wadi Al-Fara.

WATER-BEARING PROPERTY FOR AOUIFER

LITHOLOGY

PLEISTOCENE-TERTIARY FORMATION

ZONE III Mainly made of cemented thick clayey layers. The groundwater is, if any, deemed to be independent from the hydrogic cycle and poorly in storage.

- SAND AND GRAVEL FLAT — Sandy flat plains remain between modern wadi channels. Facies are marked by much amount of sand. Surface condition is slightly weathered and varnished. Occasionally self dunes are developped.
- ERODED FAN — Old composit fans with eroded plain. the largest one is seen along Wadi Al-Ma'awill. Facies are composed of green schist, quartzite, breccia, mountain limestone gravel and clay rich matrix.
- ERODED TERRACE — Remained terrace. Most of terrace surfaces are eroded in the later geological events. Facies are similar to other terrace deposits which is pronounced by well cemented layers.
- TERRACE I — Lower terrace remaining around Al Ilibra, Slh Jamman and Howqain. The terrace surface slope of 1/200 is traceable up to 10 kilometers from mountain-foot to the downstream. Facies are of the unconsolidated
- TERRACE II — Middle terrace having 20 to 30 meters relative height. Extensive distribution is seen on the midstream area which is traceable over 10 kilometers downstream from mountain channel. The steeper slope of 1/20 than Facies are marked by the consolidated layers consisting of limestone, serpentinite and peridotite gravel. Surface gravel is well varnished and wind etched.
- TERRACE III — Erosional high terrace occasionally covered by well cemented layers. In the mountain area, terrace surface is over 50 meters high from modern wadi channel. Typical developments are seen near Nakhal and in the Sahtan basin. Highest surface is over 1000 meters above sea level.
- SEIF DUNE — Seif dunes develop between Wadi Bani Kharus and Wadi Al-Fara. Many of dunes align N-S to NNE-SSW direction having over 20 meters high above MODERN WADI BED.

WATER-BEARING FOR AQUIFER

ONE IV Mainly Inperm facies. water and o and Jo

WATER-BEARING PROPERTY FOR AQUIFER

LITHOLOGY

PLEISTOCENE-TERTIARY FORMATION

ZONE III Mainly made of cemented thick clayey layers. The groundwater is, if any, deemed to be independent from the hydrogic cycle and poorly in storage.

SAND AND GRAVEL FLAT — Sandy flat plains remain between modern wadi channels. Facies are marked by much amount of sand. Surface condition is slightly weathered and varnished. Occasionally self dunes are developped.

ERODED FAN — Old composit fans with croded plain. the largest one is seen along Wadi Al-Ma'awill. Facies are composed of green schist, quartzite, breccia, mountain limestone gravel and clay rich matrix.

ERODED TERRACE — Remained terrace. Most of terrace surfaces are eroded in the later geological events. Facies are similar to other terrace deposits which is pronounced by well cemented layers.

TERRACE I — Lower terrace remaining around Al Hibra, Sih Jamman and Howqain. The terrace surface slope of 1/200 is traceable up to 10 kilometers from mountain-foot to the downstream. Facies are of the unconsolidated

TERRACE II — Middle terrace having 20 to 30 meters relative height. Extensive distribution is seen on the midstream area which is traceable over 10 kilometers downstream from mountain channel. The steeper slope of 1/20 than Facies are marked by the consolidated layers consisting of limestone, serpentinite and peridotite gravel. Surface gravel is well varnished and wind etched.

TERRACE III — Erosional high terrace occasionally covered by well cemented layers. In the mountain area, terrace surface is over 50 meters high from modern wadi channel. Typical developments are seen near Nakhal and in the Sahtan basin. Highest surface is over 1000 meters above sea level.

SEIF DUNE — Seif dunes develop between Wadi Bani Kharus and Wadi Al-Fara. Many of dunes align N-S to NNE-SSW direction having over 20 meters high above MODERN WADI BED.

WATER-BEARING PROPERTY FOR AQUIFER

LITHOLOGY

EARY TERTIARY-MAASTRICHTIAN FORMATIONS

ONE IV Mainly formed of inpermeable rock facies. High groundwater flow are rare and only in faulted and jointed area.

MEASTR. TO TERTIARY — Late Createceous to Eary Tertiary limestones which are stuated on SEMAIL OPHIOLITE NAPPE with uncomformity. Facies is composed of chert conglomerate, chalk,chalky marl with some reworked pebble and rubby weathered foraminiferal limestone. The bed dips 10° to 20° to north-east.

MIDDLE CRETACEOUS FORMATIONS

SEMAIL OPHIOLITE NAPPE — Ophiolite assemblage which consists of following rock facies.

1) Volcanic, extrusive rock
2) Subvolcanic feeder dike
3) Hypabyssal-gabbroid rock
4) Gabbro
4) Transional rock between gabbro and peridotite
6) Ultramafic rock

Ophiolite assemblage called as SEMAIL OPHIOLITE NAPPE forms frontal mountains where stand up to 1000 meters high above sea level.

MIDDLE CRETACEOUS-PERMIAN FORMATIONS

HAWASINA ALLOCHTHONOUS UNIT — Mainly pelagic sediments which are composed of 12 tectonical subunits including Hamrat Duru Group and other six formations. Facies consists of grainstone, limestone turbidite, Radiolarian chert and some volcanic in general. This formation is possible to recognize a consistent tectonic order within the pile of the HAWASINA UNIT. However, some of the lower unit may be missing locally, so that a formation otherwise found in a relative high tectonic position may directly over lie the lower units.

MIDDLE CRETACEOUS-JURASSIC FORMATIONS

MUSANDAM LIMESTONE — Massive shelf limestones consisting of foraminiferal wackestone and packstone with subordinate skeletal grainstone. Facies includes the shallow marine origin.

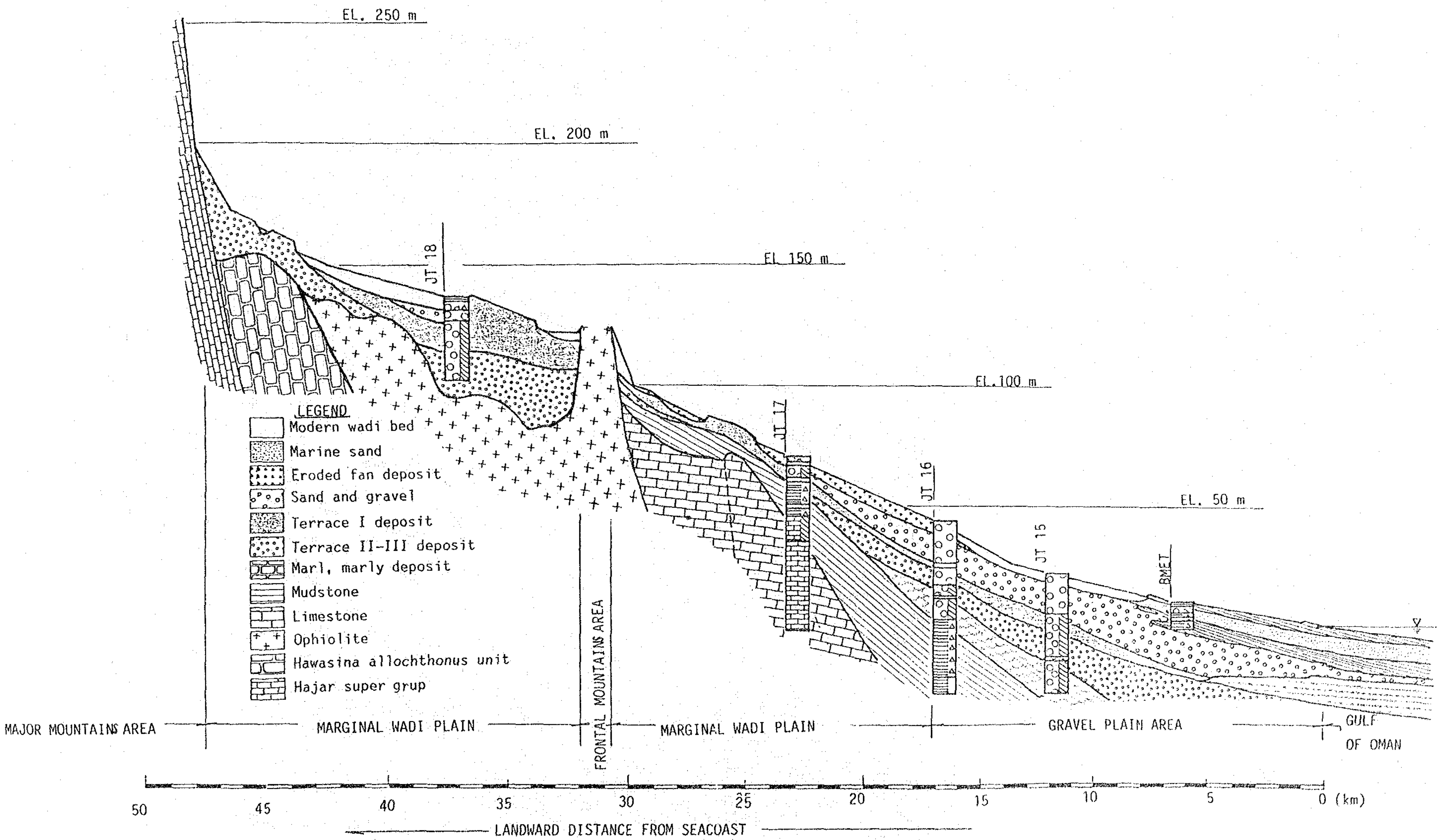
TRIASSIC-PERMIAN FORMATIONS

AKHDAR DOLOMITE — Dolomite and dolomitic limestones indicate the age ranging from Permian to Triassic and are made up of Mahil Formation and Saiq Formation. Saiq Formation is the basal unit of carbonite-shelf sequence consists of up to 700 meters thick of the Middle to Upper Permian. The facies is composed of coral bearing limestone and overlying dolomitic limestone. Mahil Formation, the Triassic facies, consists of several hundred meters of monotonous, commonly saccharoidal dolomite in which poorly developped stromatolitic beddings are common.

PRE-PERMIAN FORMATIONS

PRE-PERMIAN BASEMENT — The static basements are made up of dolomite, limestone, quartzite, graywacke and conglomerate.

Fig. 4-1-5 Geological Cross-section along Wadi Al-Fara'



4.2 Meteorology and Surface Hydrology

4.2.1 Characteristic Features of Meteorology

The climate of the Project area is characterized by two seasons -- summer and winter. In the Project area the wet season continues 6 months from approx. November to April, but this varies yearly.

In the summer season, seasonal winds are south-westerlies affected by the location of low pressure over North-West India and the Arabian Gulf and the location of high pressure over the South Indian Ocean. The inter-tropical convergence zone (ITCZ) formed over the Arabian Penisula, is not active.

In the winter the high pressure over continent of Asia stretches to the Arabian Peninsula and the low pressure over the Indian Ocean forms ITCZ. Synoptic disturbances (cyclones and fronts) moving from west, bring wide-spread rainfall in the Batinah Coast.

The tropical cyclones born in the Indian Ocean or in the Arabian Sea, sometimes move towards the Arabian Peninsula, but it is very rare for them to affect the Batinah Coast.

Since an agro-meteorololgical station (MF1) has been newly established at Al-Muladdah, 7 km inland from the coast, and some instruments have been reinforced at another station (MF2), and twenty-eight rain gauges have been installed by the Project (Fig.4-2-1), local meteorological characteristics are discernible through the observed data.

Meteorological time series data which were observed for two years (from August 1983 to August 1985) are shown in Table 4-2-1 and Fig. 4-2-2, 4-2-3 at Al-Muladdah Agro-meteorological Station. The values which are shown in the table and figure are monthly mean values. The following are the summaries of characteristics of each observation item.

(1) Solar radiation

Annual mean solar radiation was 490 $cal{\cdot}cm^{-2}{\cdot}day^{-1}$; the maximum value was 610 $cal{\cdot}cm^{-2}{\cdot}day^{-1}$ and the minimum value was about 330 $cal{\cdot}cm^{-2}{\cdot}day^{-1}$.

The maximum value was recorded before the summer solstice. It is supposed that the solar radiation which increases with altitude is attenuated by water vapour pressure which has been increases steadily from February to August.

(2) Air temperature

Annual mean air temperature was 27.6°C. In June monthly mean daily maximum temperature exceeds 40°C, monthly mean temperature 34°C, and monthly mean daily minimum temperature 29°C. Monthly mean temperature was more than 20°C almost all the year round, and moreover it was over 30°C during six months from April to September. Monthly mean daily maximum temperature was more than 30°C during nine months from March to November and more than 40°C in May and June. The absolute maximum air temperature during the period from August 1983 to August 1985 was 48.3°C on August 3, 1985.

Air temperature varies with a little phase lag after solar radiation. The order of the time lag tends to increase in the order of daily maximum, mean and minimum.

(3) Relative humidity

Annual mean relative humidity was 64%. The maximum monthly mean relative humidity exceeds 70% in summer (August) and in winter (November to January). The minimum was less than 50% from April to June and 70% in September and/or October. Relative humidity changes with two cycles in a year.

(4) Water vapour Pressure

Annual mean vapour pressure was 23.7 mb. The maximum monthly mean vapour pressure was about 36 mb in July or in August and the minimum was about 16 mb in February. Vapour pressure changes with a little phase lag after air temperature.

(5) Soil Temperature

The annual mean soil temperature at 5 cm in depth was 32.8°C. The maximum monthly mean soil temperature exceeds 41°C in June or July and the minimum was less than 24°C in January. At lower depths, the annual change of soil temperature becomes smaller.

(6) Wind

Annual mean wind speed was 2.2 $m \cdot s^{-1}$. The maximum monthly mean wind speed was 2.6 $m \cdot s^{-1}$ during from April to August and the minimum was less than 2.0 $m \cdot s^{-1}$ from November to January. The maximum monthly mean daily maximum wind speed exceeds 6.6 $m \cdot s^{-1}$ from April to June and the minimum was less than 5.5 $m \cdot s^{-1}$ during December and January. Although the variation of wind speed was small, wind speed was strong in summer and weak in winter.

Diurnal variations of winds in summer (June 1984) and winter (December 1983) are shown in Fig. 4-2-3. North or north-northeast wind was 4 to 6 $m \cdot s^{-1}$ in the afternoon both summer and winter. The wind during daytime in summer was stronger than in winter. South or southwest wind blows during night and early morning, but it is not so clear as the northerly wind in the afternoon. These winds are sea breeze during daytime and land breeze during night.

Thermal differences between land and sea surfaces cause the sea and land breezes. The sea breeze is stronger than the land breeze and can generally reach inland as far as 50 km in tropical climates.

(7) Evaporation

Pan evaporation observed at Al-Muladdah Agro-meteorological Station is shown in Table 4-2-1. The potential evaporation estimated from observed meteorological values with Penman's Equation is shown in Table 4-2-2 and in Fig. 4-2-2. Calculated pan coefficient (the ratio of potential evaporation to pan evaporation) is about 0.64. It is near the value of 0.70 which is generally adopted. The potential evaporation estimated from Penman's Equation can be considered as the potential evaporation. The annual potential evaporation estimated by Penman's Equation is 2218 mm.

As for evapotranspiration, reference crop evapotranspiration (FAO Irrigation and Drainage Paper 24-1977) estimated from pan evaporation are shown in Table 4-2-2. The estimated annual evapotranspiration is 2052 mm. The details of the method to estimate potential evapotranspiration is explained in Supporting Report B.

Table 4-2-1 Monthly Data of Al Muladdah Agro-Meteorological Station

Year		1983					1984												1985								Annual
Month		Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	mean
Solar Radiation ($cal.cm^{-2}.day^{-1}$)		512.2	516.3	491.4	411.3	354.5	369.7	447.8	503.9	593.6	610.7	599.8	543.5	518.1	498.7	469.1	404.6	325.9	343.5	462.0	493.4	572.9	580.1	600.0	492.6	535.1	488.7
Air Temperature (°C)	Daily Mean	32.3	32.0	28.5	23.3	20.9	19.9	19.7	26.2	31.0	32.1	33.7	34.6	33.7	31.9	26.3	22.9	20.9	20.5	19.7	24.0	28.8	32.3	34.1	33.5	31.8	27.6
	Daily Max.	36.4	36.3	35.5	29.9	26.5	25.6	26.0	33.6	38.2	39.7	40.6	39.7	38.2	38.1	33.8	30.5	27.0	25.9	26.8	30.9	35.3	40.0	41.7	38.4	38.2	34.0
	Daily Min	28.6	27.9	22.1	16.5	15.4	14.1	13.3	19.1	23.2	23.7	26.6	29.9	29.6	26.1	18.8	15.6	15.2	15.4	12.5	16.9	21.4	24.5	26.6	29.1	26.3	21.3
Relative Humidity (%)		72	71	59	70	72	70	66	63	53	53	59	68	71	59	59	66	75	82	70	63	56	42	55	69	67	64
Vapour Pressure (mb)		34.7	33.5	22.5	19.9	18.1	16.6	15.3	21.2	23.6	24.8	30.7	36.8	39.3	26.8	20.0	18.1	18.4	19.0	16.3	18.2	20.7	18.8	25.6	33.7	30.7	23.7
Wind Speed ($m.sec^{-1}$)	Daily Mean	2.7	2.2	2.2	1.9	1.9	2.0	2.1	2.1	2.4	2.5	2.4	2.5	2.3	2.3	2.0	1.9	1.8	1.7	2.1	2.1	2.7	2.4	2.5	2.4	2.3	2.2
	Daily Max.	6.4	6.0	6.3	5.6	5.4	5.8	6.0	6.4	6.7	6.7	6.4	6.3	6.2	6.5	6.0	5.6	5.2	5.2	6.1	5.9	6.8	6.3	6.8	6.1	6.0	6.1
Soil Temperature (°C)	5 cm Deep	38.7	38.3	33.1	27.6	23.8	22.7	23.9	30.3	35.2	38.0	40.0	40.9	39.7	38.0	31.8	27.5	24.8	23.8	24.7	29.3	34.4	38.3	40.8	40.6	39.4	32.8
	120 cm Deep	34.2	34.5	33.8	32.3	30.8	29.2	28.5	28.8	30.2	31.5	32.7	33.8	34.3	34.5	33.8	32.3	31.0	29.7	29.2	29.2	30.2	31.3	33.1	34.2	34.6	31.8
Pan Evaporation ($mm. month^{-1}$)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	207	133	126	202	247	364	424	x	x	326	-

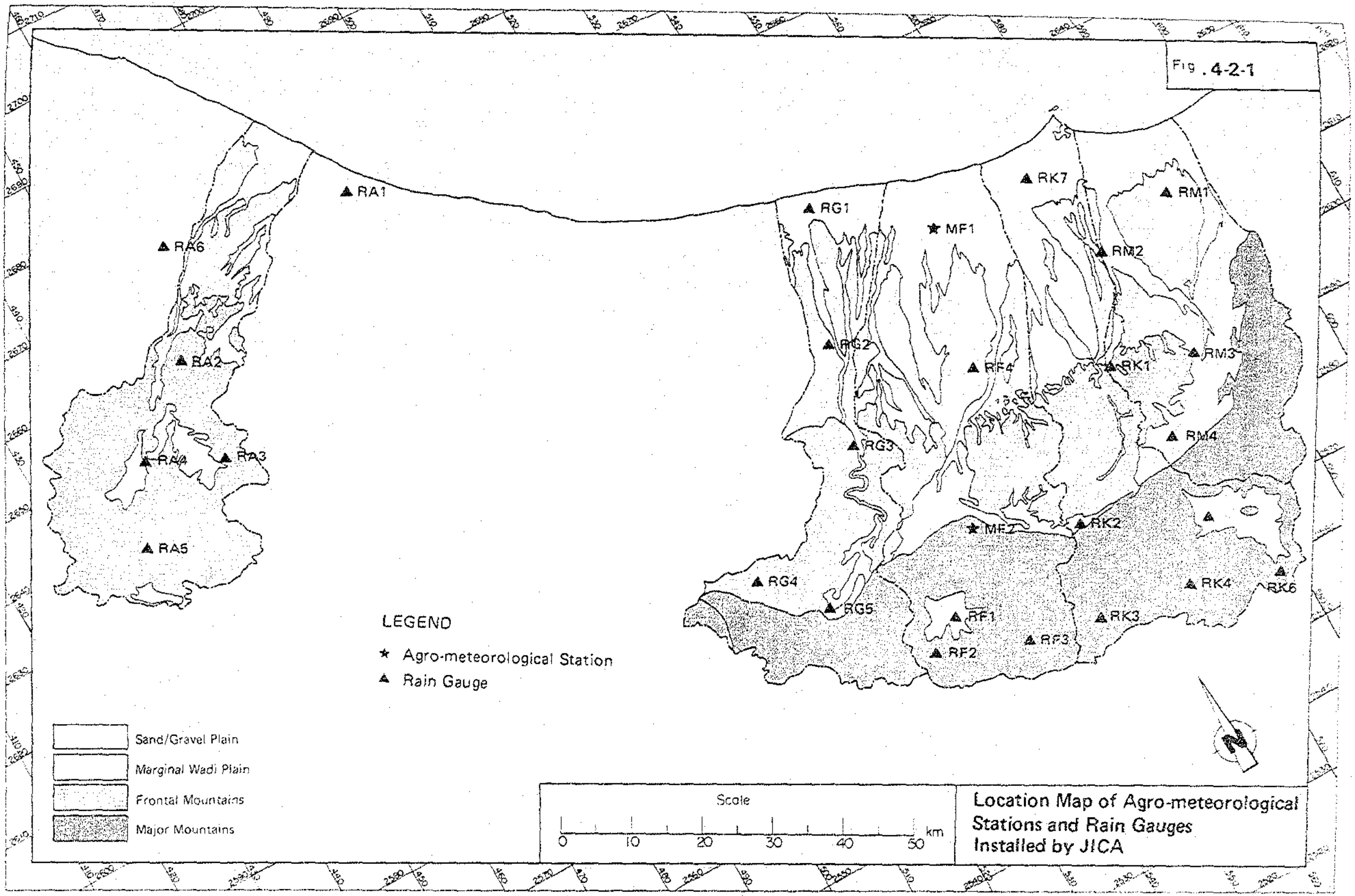
Note x: unreliable data

Table 4-2-2 Potential Evaporationand Reference Crop Evapotraspiration

(unit: mm)

month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nove.	Dec.	annual
potential evaporation	94	124	177	238	263	264	222	223	207	186	127	93	2218
reference crop evapotranspiration	79	127	148	211	246	231	242	200	192	162	130	84	2052

Fig. 4-2-1



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

Fig. 4-2-2 Weather Conditions at Al-Muladdah Agro-meteorological Station

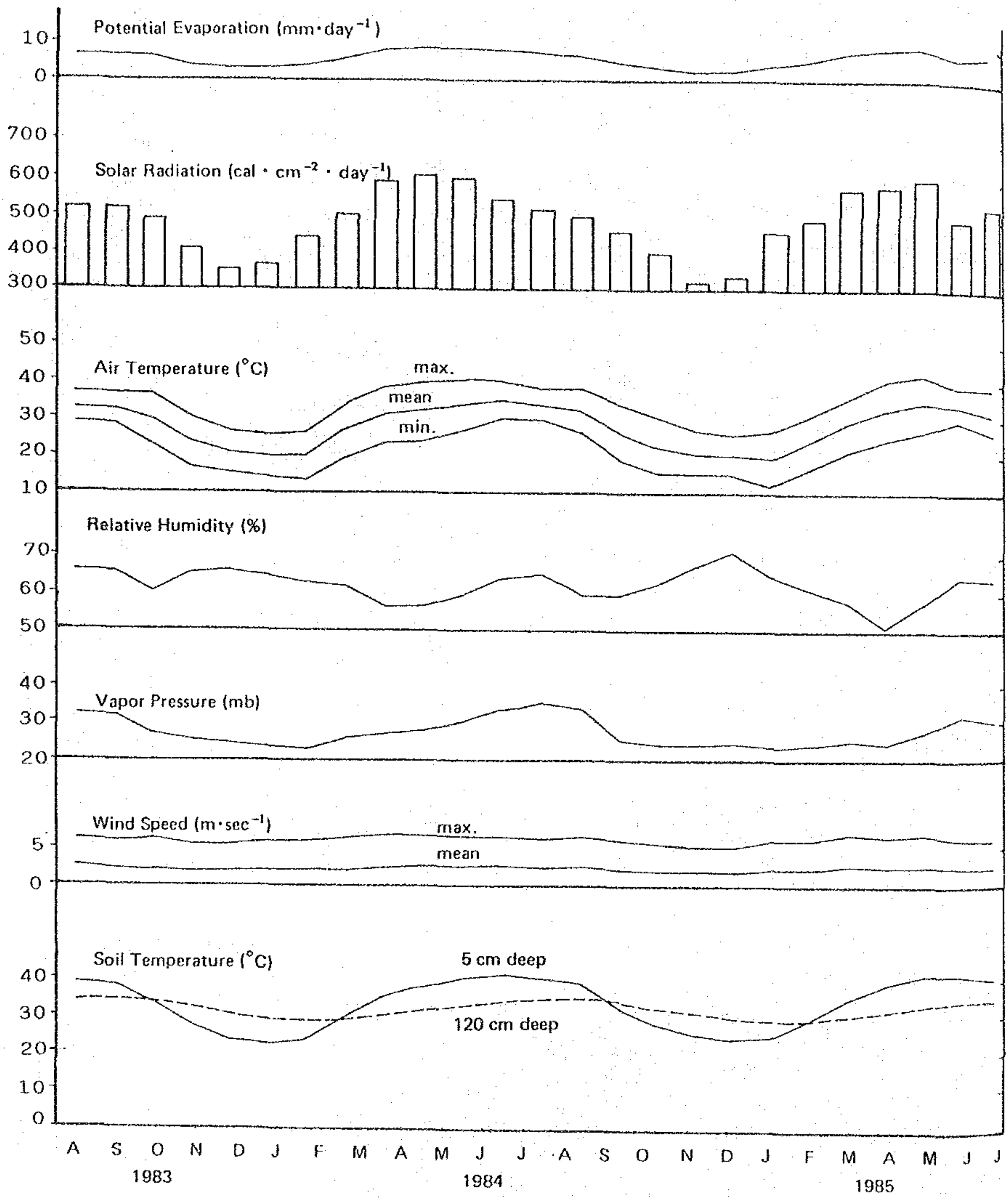
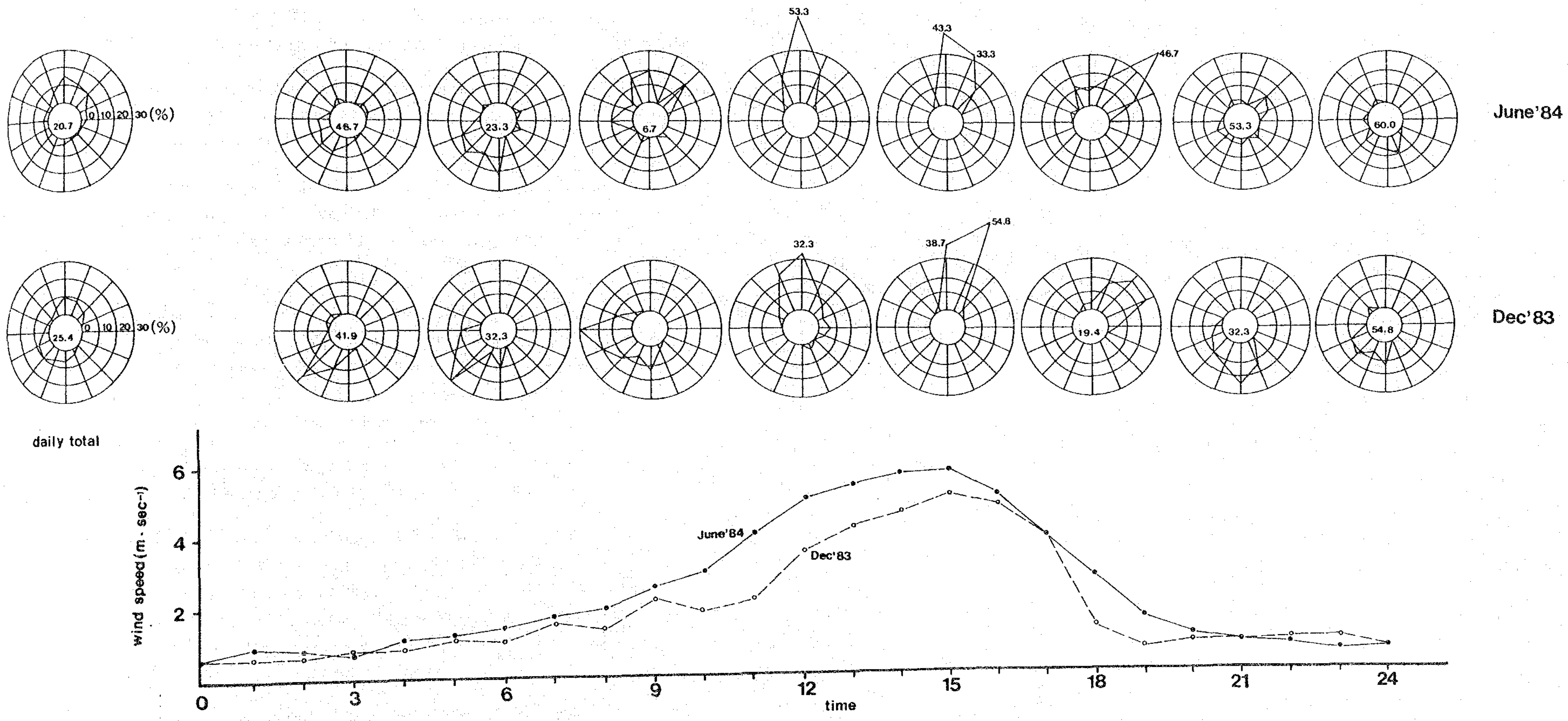


Fig. 4-2-3 Diurnal Wind Variation (Al-Muladdah)



note: number in the circle of windrose is the percentage of calm sequence