REPORT ON THE SURVEY

FOR

MINERAL RESOURCES DEVELOPEMENT

IN

THE SULTANATE OF OMAN

SEPTEMBER 1979

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Sultanate of Oman, the Government of Japan with the Japan International Cooperation Agency as the implementing arm has carried out the survey for mineral resources development for thirty four days from March 15 to April 17, 1979, mainly in the southern, northern and eastern districts of Oman. The development of mineral resources is a priority project of the Sultanate of Oman in promoting the local economic development.

The Japan International Cooperation Agency (JICA) formed a mineral resources survey team consisting of five experts with Dr. Shusaku Ikeda of Bishimetal Exploration Co., Ltd. as team leader.

The team, in close collaboration with the Government of the Sultanate of Oman and its various instrumentalities, was able to complete the survey works on schedule during the given period of stay.

The team reviewed, collected, and interpreted the observed data and collected samples. Presented herewith is the report of the team. I sincerely hope that the report will be of further help in the mineral resources development and will advance further the frontiers of science and friendship between our two countries.

In closing, I wish to express my heartfelt gratitude to the team members for their efforts, the officials of the Government of the Sultanate of Oman, the officials of the Japanese Embassy in Saudi Arabia for their kind cooperation, and the Ministries of Foreign Affairs and of International Trade and Industry for their unstinted supports in dispatching the survey team.

September 1979

Shinsaku Hogen
President
Japan International Cooperation Agency

Letter of Transmittal

Mr. Shinsaku Hogen
President
Japan International Cooperation Agency

Dear Sir,

Submitted herewith is a report on the Survey for the Mineral Resources Development in the Sultanate of Oman.

The survey was carried out by the Japan International Cooperation Agency as a part of the technical cooperation of the Government of Japan. The survey was conducted for 34 days from March 15 to April 17, 1979 with five experts dispatched from Metal Mining Agency of Japan, Bishimetal Exploration Co., Ltd., Sumiko Consultants Co., Ltd. and Nittetsu Mining Consultants Co., Ltd..

The target areas of the survey were selected in three districts, namely, southern, northern and eastern districts of Oman. Among three, the southern was the major target, and the field study was carried out mainly on the major one.

Under the close cooperative works of many organizations concerned in Oman, the team collated and collected abundant informations on the mineral resources and those in general as possible.

On the occasion of the completion of field survey, whole informations collected were involved in the interim report of the team and advanced to the Government of Oman forward.

The team, after returning to Japan, analyzed the samples, collected data, and through the discussions within the team members, drew up the exploration plans for the target areas. As the result of these studies, the final report, presented here, was prepared.

The Sultanate of Oman is, as a whole, rich in various mineral resources, however, almost all are undeveloped, and only a little is on the way to exploitation. I earnestly hope that the report will be of further help in the development of mineral resources of the country.

In closing, I wish to express my heartful gratitude to those who are concerned to the Ministry of Agriculture, Fisheries, Petroleum and Minerals of the Sultanate of Oman. Also, heartfelt appreciations are given to the Japanese Embassy of Saudi Arabia who takes charge of Oman, the Government of Japan and the Metal Mining Agency of Japan.

Sincerest best wishes and highest esteem.

Respectfully yours,

September 1979

S. Ikeda

Shusaku Ikeda, Leader
Japanese Survey Team
for
Mineral Resources Development
in the Sultanate of Oman

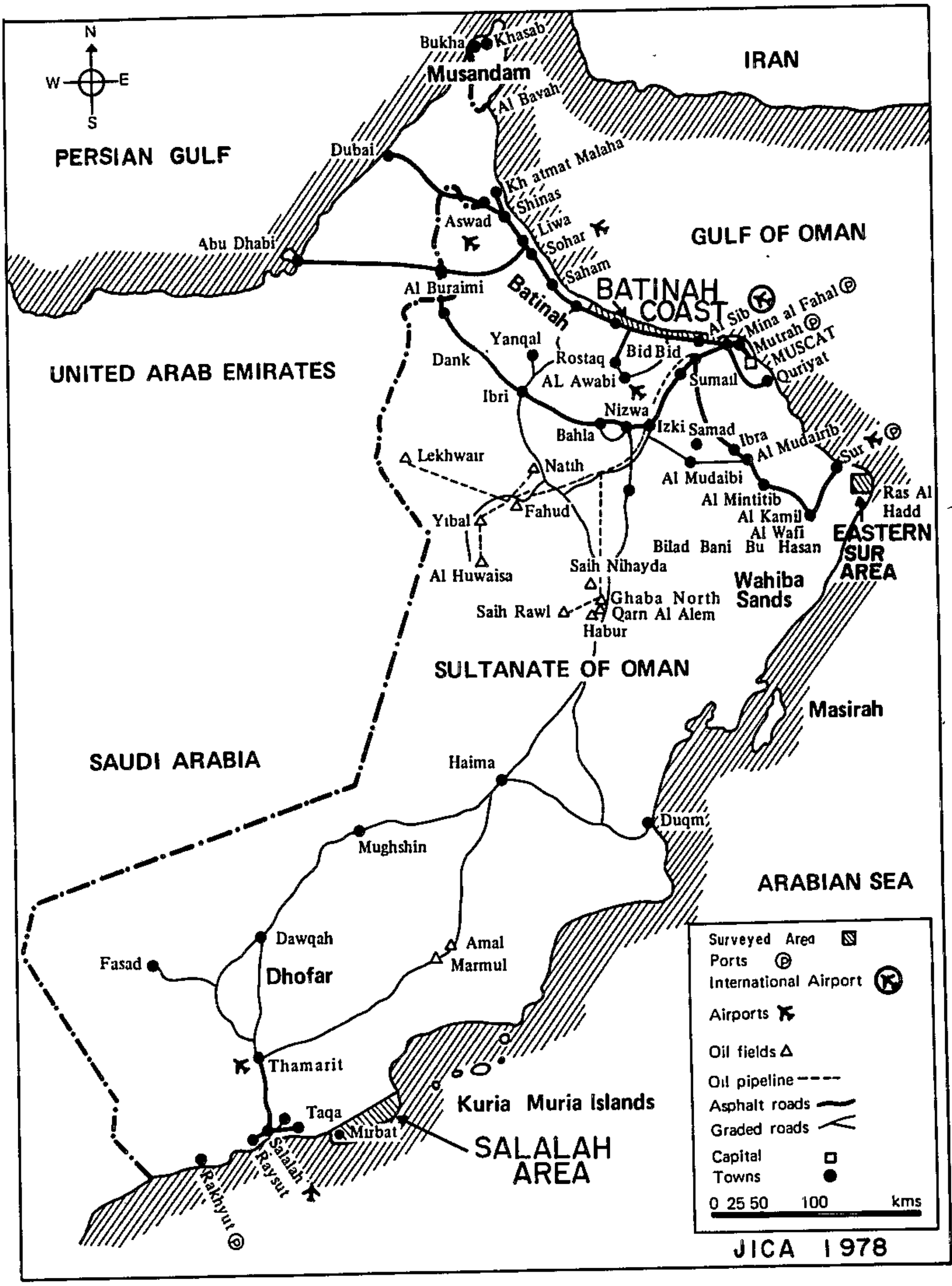

Fig. 1 Location map

Conclusions and Recommendation

Judging from the field survey and laboratory investigation of the three areas, it is recommended that the Salalah area and the Eastern Sur area should be surveyed in more detail.

1. SALALAH AREA

Mineral showings of copper, lead, etc. have been observed in pegmatite and acidic dykes intruded to the Precambrian gneiss. Radioactivity with two– to three–fold of background value and 0.004% U_3O_8, which is ten–fold of common siltstone, have been observed in the siltstone of the Ordovician Mirbat sandstone formation which overlies the Precambrian basement unconformably.

It is difficult to lead the conclusion related to the possibility of discovering economic mineral deposits in the area only by the present study, owing to the scantiness of available data up to the present. Therefore, a basic and systematic survey including the following items is recommendable:

1) Survey to investigate the distribution, sedimentary structure and radioactivity of the Mirbat sandstone formation.
2) Survey to confirm the mineralization around the acidic igneous rocks such as acidic dyke, stock and batholith.

In the survey, it is desirable to make the topographic map in scale of 1:50,000 and also to carry out photogeological interpretation followed by ground check.

2. EASTERN SUR AREA

The manganese dioxide deposit is distributed in the chert zone of the Halfa formation belonging to the Permian to Cretaceous Hawasina group and its outcrop continues intermittently nearly 6,000 m to the strike side.

Samples from some outcrops have been tested and confirmed to be available for ferro alloy and for buffer in dry battery. The Hawasina group is widely distributed to the south where manganese gossan is partly observed.

Therefore, it is recommendable to carry out detailed survey of the already known manganese outcrops as well as drilling for evaluation, and it is also recommendable to carry out the regional geological survey for the investigation on the possibility of occurrences of manganese deposits throughout the whole Hawasina group.

3. BATINAH COAST AREA

Possibility of sand chrome concentration is poor in the area and the grade of the primary chromite outcrop is insufficient and the ore is unavailable for ferro alloy.

Therefore, the Batinah Coast is not favorable for further survey.

Report on the Survey for Mineral Resources Development
in
the Sultanate of Oman

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PART I

Chapter 1 Introduction

1−1 Background and Objectives of the Survey

The Government of Japan in response to the request of the Government of the Sultanate of Oman dispatched the survey team of Prefeasibility Study for Industrial Development from February to March, 1978. Also, Japan International Cooperation Agency and Metal Mining Agency of Japan dispatched the survey team to find out projects on mineral resources in Oman in December, 1978, and at that time, the survey team made in−site inspection and exchange of opinions with the related Oman Government Organization.

As the result, the Government of the Sultanate of Oman requested the three concrete areas namely, Salalah area, Eastern area of Sur and Batina Coast area, for mineral resources survey to the Government of Japan. The Japan International Cooperation Agency in response to this request formed a mineral resources survey team consisting of four experts with Dr. SHUSAKU IKEDA of BISHIMETAL EXPLORATION CO., LTD. as team leader to select the most promising area and to make an optimum plan for the next phase of the survey and dispatched the survey team to Oman.

The Sultanate of Oman is an oil-producing country and daily production is about 350,000 barrels which corresponds to about 90% of the Government income, but, the Government puts a priority to the industries based on other natural resources under the apprehensions of future decrease of oil production. The Government considered that the potentiality of occurrences of mineral resources other than petroleum is promising owing to the topographical and geological conditions, and started to carry out mineral resources survey under the guidance of the Bureau of Minerals, Ministry of Agriculture, Fisheries, Petroleum and Minerals. But, reconnaissance of the natural resources throughout the whole Oman has not been sufficient up to the present owing to the insufficiency of topographic maps and Oman specialists.

Occurrences of copper, chrome, lead, zinc, iron, nickel, manganese, asbestos, limestone, marble, dolomite, silica stone, feldspar, talc, etc. have been confirmed, but only copper, limestone and marble are under operation or under preparation for development. The Oman Government considers that these mineral resources may be of large ore reserves and expects the reserves as hopeful resources to replace petroleum in the future and so has an ardent wish to carry out detailed survey for these mineral resources.
Especially, in spite of the importance of the Salalah area from the political, economical and social points of view in the country, the information on geology and mineral deposit is very poor. Because of the reason, the Government earnestly equests the urgent survey of the area.

The survey team, after returning to Japan, made comprehensive investigations on field survey and laboratory work of geology and mineral deposit in the three areas to select the most promising area and to make an optimum plan for the next phase of the survey.

1–2 Detail of the Survey

1) Priority of areas

The three requested areas are the Salalah area, Eastern area of Sur and Batina Coast area. Main object of mineral resource in each area is base-metals, uranium, etc. in the Salalah area, manganese in the Eastern area of Sur and chrome sand in the Batinah Coast area. Table 1 shows the brief information on these three areas up to the present. Especially the Salalah area was strongly requested area by the Government, because it is only one area composed of the Precambrian basement in Oman where high potentiality of mineral occurrences may be present.

2) Field survey

Field survey was carried out chiefly on the brief understandings of the geological succession and structure of the area and the environmental features of the mineralization. In addition to the fundamental survey above mentioned, analyses of the aerophotograph, geochemical exploration and radioactive prospecting were also carried out in the Salalah area.

3) Laboratory work

Following samples collected in the surveyed area were brought back to the laboratory in Japan and various analyses, measurements and observations were carried out.

thin section	44 samples
polished section	4 samples
X–ray powder diffraction	6 samples
fossil identification	3 samples
age determination	5 samples
chemical analysis (rock)	10 samples
ditto (ore)	25 samples
emission spectrochemical analysis	10 samples
atomic absorption analysis	100 samples
colorimetric analysis	7 samples

1–3 Members of the Survey Team

Team leader	Dr. Shusaku Ikeda Bishimetal Exploration Co., Ltd.	Geologist
Coordinator	Mr. Kazunori Kano Metal Mining Agency of Japan	Mining Engineer
Member	Dr. Tadao Hamachi Sumiko Consultants Co., Ltd.	Geologist
Member	Mr. Tadao Aoyama Nittetsu Mining Consultants Co., Ltd.	Geologist

Table 1. Brief information on the surveyed area

Name	Location	Geology	Mineral deposit	Works in the past
Salalah	15°55′ ~ 17°20 N 54°40′ ~ 55°15′ E 100 km east of Salalah City.	Gneiss, granodiorite, pegmatite, dykes of Precambian age. Sandstone of Ordovician. Cretaceous ~ Tertiary layers, chiefly limestone.	Veins of copper, lead and iron accompanied to pegmatite or dykes. Uranium deposit in the Mirbat sandstone (Ordovician period) grade : U_3O_8 = 0.004%	Geological mapping Geochemical prospecting (Cu, Pb, Zn) Radiometric survey.
Eastern Sur Area	22°20′ ~ 22°30′ N 59°45′ ~ 59°50′ E 25 km east of Sur	Hawasina group (sandstone, siltstone, limestone, shale, chert) of Permian to Cretaceous. Limestone of Late Cretaceous to Paleogene.	Sedimentary manganese deposits in alternations of siltstone and chert. Ore mineral is Pyrolusite, manganese dioxide. About 6 km in strike length. Grade : 86.93 ~ 42.24% in MnO_2. Thickness: 0.10 ~ 5.0 m.	Geological mapping in scale 1 : 60,000.
Batinah Coast	23°30′ ~ 23°50′N 57°30′ ~ 58°40′ E Coastal area between Muscat & Al Musanaa.	Hinterland : metamorphic rocks of Pre-Permian, Permian ~ Cretaceous layers (sandstone, shale, limestone, siltstone, chert), Ophiolite of Upper Cretaceous, limestone & dolomite of Paleogene. Coastal area : clastics of the rocks mentioned above.	Placer deposit of chromite derived from peridotite in ophiolite.	None

Member	Mr. Tsuyoshi Suzuki Bishimetal Exploration Co., Ltd.	Geologist

Counter part (Bureau of Minerals)

Dr. El Boushi	Geologist
Dr. Leif Carlson	Geologist
Mr. Cherian Zacharia	Geologist

1–4 Itinerary

No.	Date	Place of Stay	Place of visit, persons interviewed
1	Mar. 15 (Thu)		Lv. Tokyo (Ikeda and Kano)
2	Mar. 16 (Fri)	Jidda (Ikeda and Kano)	Ar. Jidda
3	Mar. 17 (Sat)		Embassy of Japan (Ohguchi Ambassador and Matsumoto First Secretary) Lv. Jidda (Ikeda and Kano) Lv. Tokyo (Hamachi, Aoyama and Suzuki)
4	Mar. 18 (Sun)	Muscat	Ar. Muscat
5	Mar. 19 (Mon)	Muscat	Ministry of Agriculture, Fisheries, Petroleum and Minerals Mr. M. H. Kassim (Director) Dr. Leif Carlson (Geologist) Mr. Omar Al Amin (Geologist) Mr. Fida Karim (General Affairs)
6	Mar. 20 (Tue)	Muscat	Ditto Dicussion and arrange for the survey Short field trip in Muscat area
7	Mar. 21 (Wed)	Salalah	Seeb Airport → Salalah Airport Branch of Bureau of Minerals Mr. Omer Abdul Aziz (Manager)
8	Mar. 22 (Thu)	Salalah	Field trip to eastern area of Salalah (Salalah area) by helicopter for observations of typical exposures of each type of rocks
9	Mar. 23 (Fri)	Salalah	Field trip to Kuria Muria Islands (four islands) by helicopter via Sadh Mr. Mohammed Said (Manager of Sadh)

No.	Date	Place of Stay	Place of visit, persons interviewed
10	Mar. 24 (Sat)	Salalah	Branch of Bureau of Minerals (Salalah) Discussion and arrange for the survey Mr. Omer Abdul Aziz and Dr. Leif Carlson
11	Mar. 25 (Sun)	Wadi Shaat	Salalah → Mirbat → Wadi Shaat Mr. Amer Ali (Manager of Mirbat) Field survey
12	Mar. 26 (Mon)	Wadi Shaat	Geochemical exploration
13	Mar. 27 (Tue)	Wadi Shaat	Camp → Juffa → Wadi Hadabin → Wadi Morir → Camp, Field Survey
14	Mar. 28 (Wed)	Wadi Marsham Salalah (Kano)	Camp → Juffa → Wadi Jish–Jesh → Sadh (Mr. Mohammed Said) → Wadi Kohrhant → Wadi Ayn → Ras Ayn → Mirbat → Wadi Marsham, Field Survey Camp → Salalah (Kano)
15	Mar. 29 (Thu)	Wadi Marsham Muscat (Kano)	Field survey for the lower member of Mirbat sandstone formation. Salalah → Muscat (Kano)
16	Mar. 30 (Fri)	Wadi Marsham	Field survey for the Middle and Upper members of Mirbat sandstone formation Lv. Muscat (Kano)
17	Mar. 31 (Sat)	Salalah	Wadi Marsham → Salalah Visit to Raysut Ar. Tokyo (Kano)
18	April 1 (Sun)	Salalah	Branch of Bureau of Minerals (Salalah) Mr. Omer Abdul Aziz and Dr. Leif Carlson
19	April 2 (Mon)	Muscat	Salalah Airport → Seeb Airport
20	April 3 (Tue)	Muscat	M. A. F. P. M. Director of Technical Cooperation Mr. Itusaa Alimussah (Temporary Resident Ambassador to Japan) Dr. El Boushi (Chief Geologist) Dr. Leif Carlson Discussion and arrange for the survey
21	April 4 (Wed)	Muscat	M. A. F. P. M. Mr. M. H. Kassim Dr. El Boushi Oral report on the result of the Salalah area.

No.	Date	Place of Stay	Place of visit, persons interviewed
22	April 5 (Thu)	Muscat	M. A. F. P. M. Mr. M. H. Kassim Mr. Cherian Zacharia (Geologist) Muscat → Wadi Jahfan → Muscat Survey of chromite outcrop
23	April 6 (Fri)	Muscat	Muscat → Batinah Coast → Muscat Survey of chrome sand
24	April 7 (Sat)	Khawr Al Jaramah	Muscat → Khawr Al Jaramah (Eastern area of Sur), Dr. El Boushi
25	April 8 (Sun)	Khawr Al Jaramah	Survey of manganese deposits
26	April 9 (Mon)	Muscat	Khawr Al Jaramah → Ibra → Bidbid → Muscat Short visit to exposures of layered type gabbro and pillow lava
27	April 10 (Tue)	Muscat	Interim report making
28	April 11 (Wed)	Muscat	M. A. F. P. M. Mr. M. H. Kassim Dr. El Boushi Explanation and discussion on Interim report Packing and sending samples and instruments
29	April 12 (Thu)	Muscat (Ikeda) Singapore (the others)	M. A. F. P. M. Mr. M. H. Kassim Lv. Seeb Airport Ar. Singapore (Hamachi, Aoyama and Suzuki)
30	April 13 (Fri)	Jidda (Ikeda)	Lv. Muscat Ar. Jidda (Ikeda) Lv. Singapore Ar. Tokyo (Hamachi, Aoyama and Suzuki)
31	April 14 (Sat)	Jidda	Embassy of Japan (Ikeda)
32	April 15 (Sun)		Lv. Jidda (Ikeda)
33	April 16 (Mon)	Hongkong	Ar. Hongkong (Ikeda)
34	April 17 (Tue)		Lv. Hongkong Ar. Tokyo (Ikeda)

PART II

Chapter 1 General Features of the Geology and Mineralization in Oman

1–1 Regional Geology

Published papers on the Oman geology are quite scanty except on the Oman Mountains area in the north. Fig. 2 illustrates the general geological features of the Oman, and Fig. 3 shows schematized correlation of stratigraphic units in Saudi Arabia and Oman (Dhofar, Oman Desert, Oman Mountains). Data concerning on the Oman Mountains were taken from Gealey (1977) with some simplification, and on the other areas Beydoun's data (1966) were used with supplemental addition of the Precambrian data.

In Saudi Arabia, Precambrian rocks (data so far show the age younger than 1,200 million years) widely compose the shield in the west, and the Phanerozoics accumulate by turns to the east without showing any remarkable tectonic movements. In Oman, on the contrary, Precambrian rocks are limitedly distributed in the east of Salalah, Dhofar and in the Kuria Muria Islands.

Paleozoics, chiefly composed of conglomerate, chert, sandstone, mudstone, limestone, etc., are distributed in the Sayh Hatat, Akhdes, Haushi mountains in the north, and Huqf area surrounding Masira bay at the central Oman, and also at the northeast of Mirbat, west of Salalah in the southern part of Oman.

Mesozoics including Triassics, Jurassics and Cretaceous rocks are widely seen in the almost whole area of the Oman Mountains, on the Masira Island and Huqf and in the southwest of Dhofar. They are composed of limestone, dolomite, shale, sandstone, chert, conglomerate, metamorphic rocks and so-called ophiolite.

Tertiary rocks are distributed on the eastern coast of Sur-Qurayat, hills of Ibre-Buraimi, Huqf and Watif-Salalah-Abarut in the south.
Their main members are limestone, dolomite, etc..

These sedimentary rocks constitute Oman's main petroleum bearing members at present and the pure limestones are able to utilize for the cement industry.

In Dhofar, almost whole layers belong to post Aptian-Barremian in age, and the remainders are the Paleozoic and Mesozoic (Jurassic) layers scatteringly left on the Precambrian basement.

In the Oman desert, no exposures of the Precambrian basement can be observable, and almost whole rocks are the same to Dhofar, except some outcrops of Paleozoics around Huqf-Houshi.

The Oman Mountains extended 650 km from the south of the Strait of Holms at the Persian Gulf to the south of Sur, having maximum width of several tens of km. The highest peak of the Mountains is 3,018 m in altitude.

Geological features of the Oman Mountains are rather different from the other areas in their tectonics. Tectonically, in the Early Cretaceous, the Arabian Plate was underthrust to the Iranian Plate. Nearly at the end of Cretaceous (Early Maestrichtian), oceanic basements of the Iranian Plate were thrust up on the Arabian Plate (obduction process) by the north-northeastern collision force. At this occasion, some sediments composing the upper part of the Arabian Plate seem to have been brought up together will the oceanic basements of the Iranian Plate. Present day features of the area have been generated by those complicated tectonic movements and the sedimentation of the younger (post Maestrichtian) strata.
In the column of the Oman Mountains in Fig. 3, the allochthon and the autochthon are shown in the parts of right and left respectively. In this opinion the Hawasina group and the Semail ophiolite are thought to be involved in the allochthon.

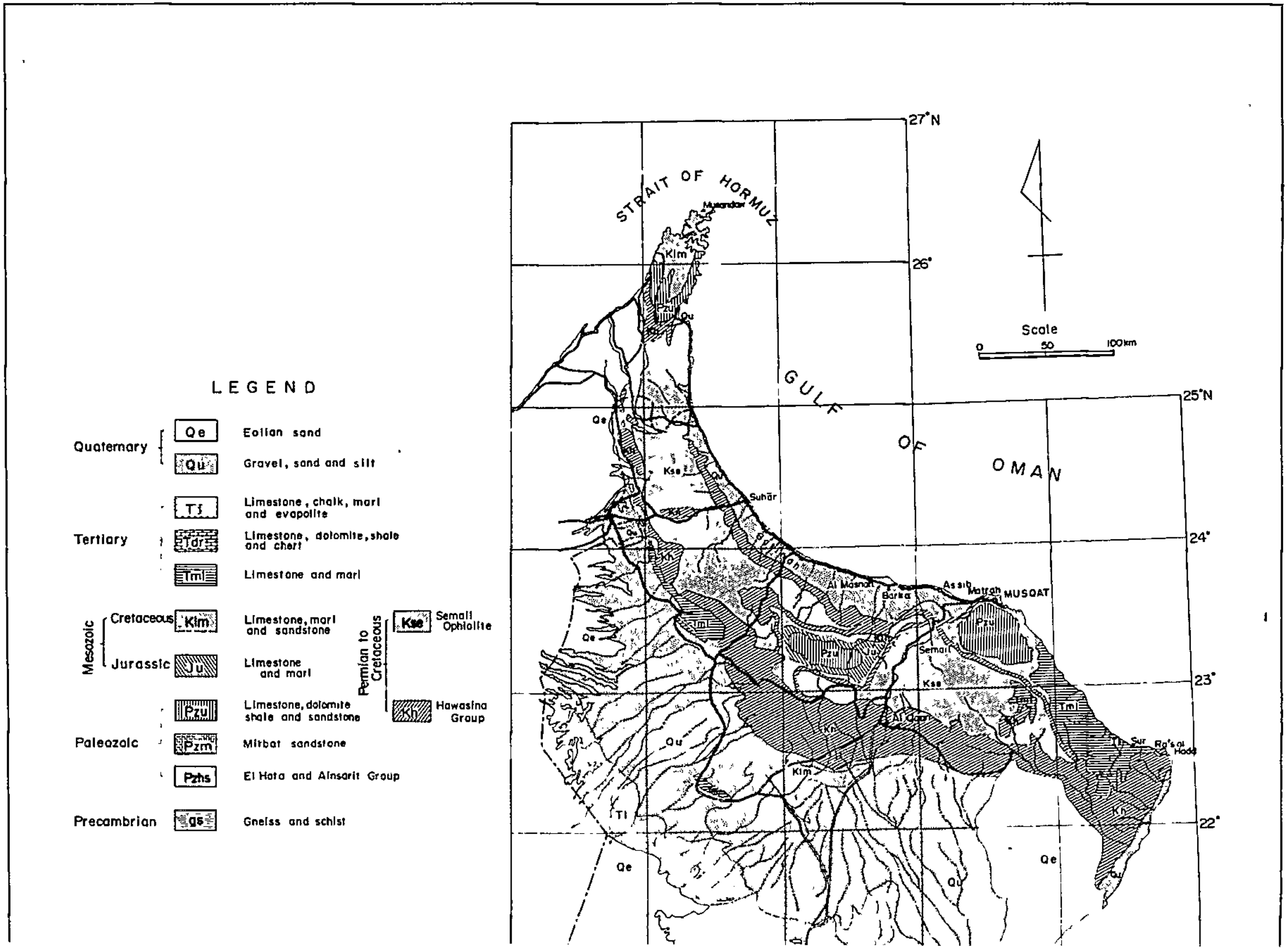
1–1–1 Dhofar area

Precambrian and Paleozoic rocks in Dhofar area are limitedly distributed. Gneiss and igneous rocks in the east of Mirbat and in the Kuria Muria Islands have been correlated with the rocks in the Island of Socotra, Somalia and Yemen. From these correlations, it has been concluded that the age of those rocks might be Precambrian, although the data were quite scanty because little study was carried out on geology of these areas.
Present study confirmed the age of these rocks as Precambrian, 550~750 million years.

Varicolored greywacke sandstone, chert and shale are narrowly distributed in El Hota and Ain Sarit near the border line between South Yemen at the west of Salalah, and are covered with the sedimentary rocks of Cretaceous age. The rocks are intensely folded, more than 3,000 m (?) in apparent thickness, and are penetrated by quartz veins. The area occupied by these rocks shows hilly landscape or peneplain. Beydoun (1966) described the age of these rocks as Cambrian, owing to the resembrance of rock facies to the upper part of the Ghabar group in South Yemen. Also, he noticed that the materials of these rocks could have been derived from metamorphosed basement distributed in the Mirbat area.

The Mirbat sandstone formation is distributed quite narrowly in the Mirbat area, unconformably covering the Precambrian rocks. Thickness is about 1,300 m. The formation is covered with the Cretaceous strata in an unconformity. The age of the Mirbat sandstone formation is unclear, because no fossils were found in the strata. Beydoun (1966) decided temporalily the age of the formation as Ordovician, owing to the assumption that the stratigraphic position of the formation is later than the folded strata observed in the areas of El Hota and Ain Sarit mentioned above. Also, he noticed that the appearance of the formation is similar to the unfolded lower Ordovician rocks in the Oman desert.

The strata, which are chiefly composed of limestone, constitute the main part of Dhofar area and are later than Middle Cretaceous in age. The strata are distributed on the mountainous area higher than several hundred meters in altitude at Jabal Samhan covering


LEGEND
Quaternary
Qe Eolian sand
Qu Gravel, sand and silt
Tertiary
Ti Limestone, chalk, marl and evapolite
Tdr Limestone, dolomite, shale and chert
Tml Limestone and marl
Mesozoic
Cretaceous Kim Limestone, marl and sandstone
Jurassic Ju Limestone and marl
Permian to Cretaceous
Kse Semail Ophiolite
Kh Hawasina Group
Paleozoic
Pzu Limestone, dolomite shale and sandstone
Pzm Mirbat sandstone
Pzhs El Hata and Ainsarit Group
Precambrian
gs Gneiss and schist
STRAIT OF HORMUZ
GULF OF OMAN
Scale
0 50 100km
27°N
26°
25°N
24°
23°
22°
Musandam
Suhār
Al Masnah
Barka
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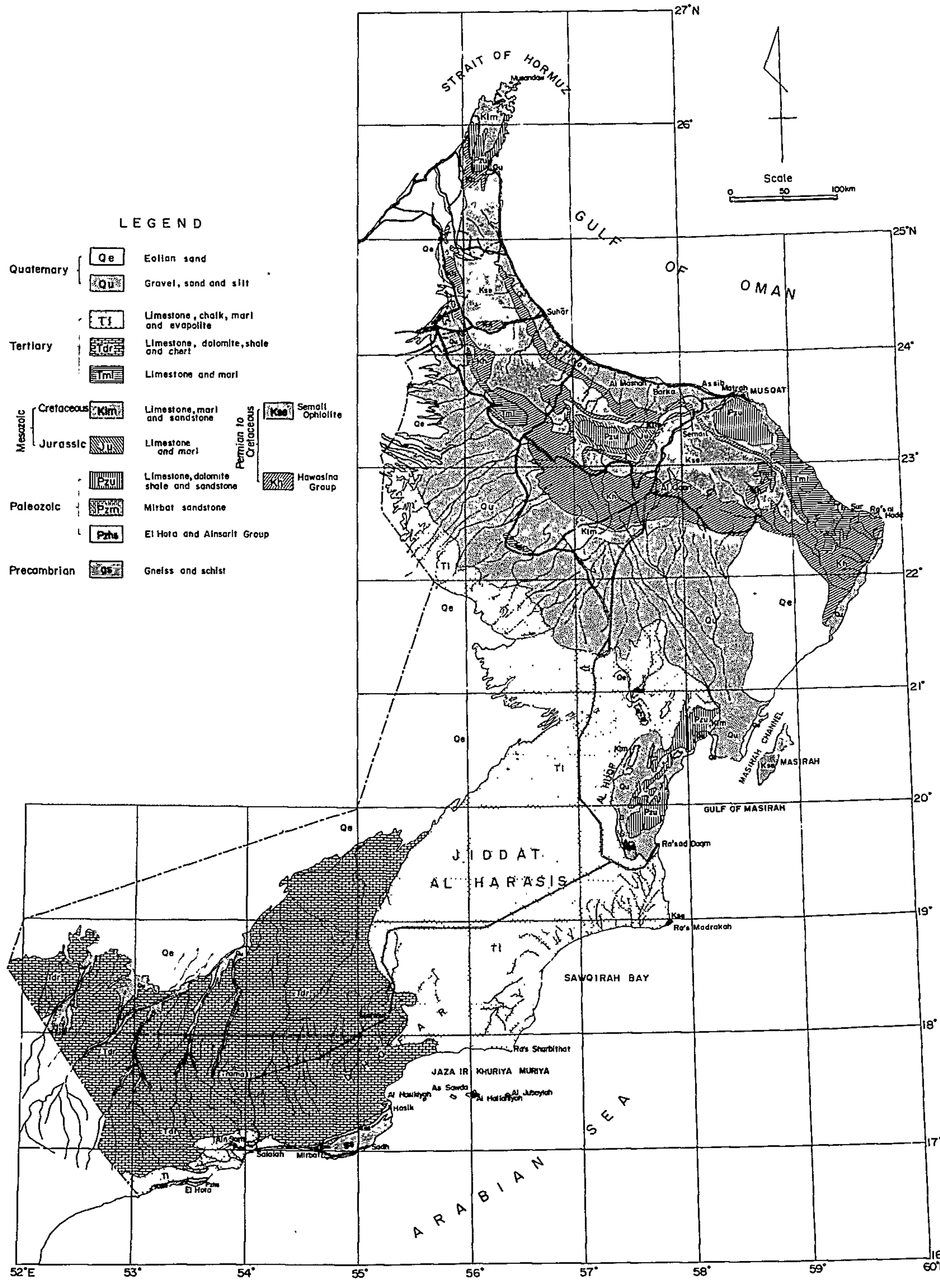


Fig. 2 Geologic Map of the Sultanate of Oman

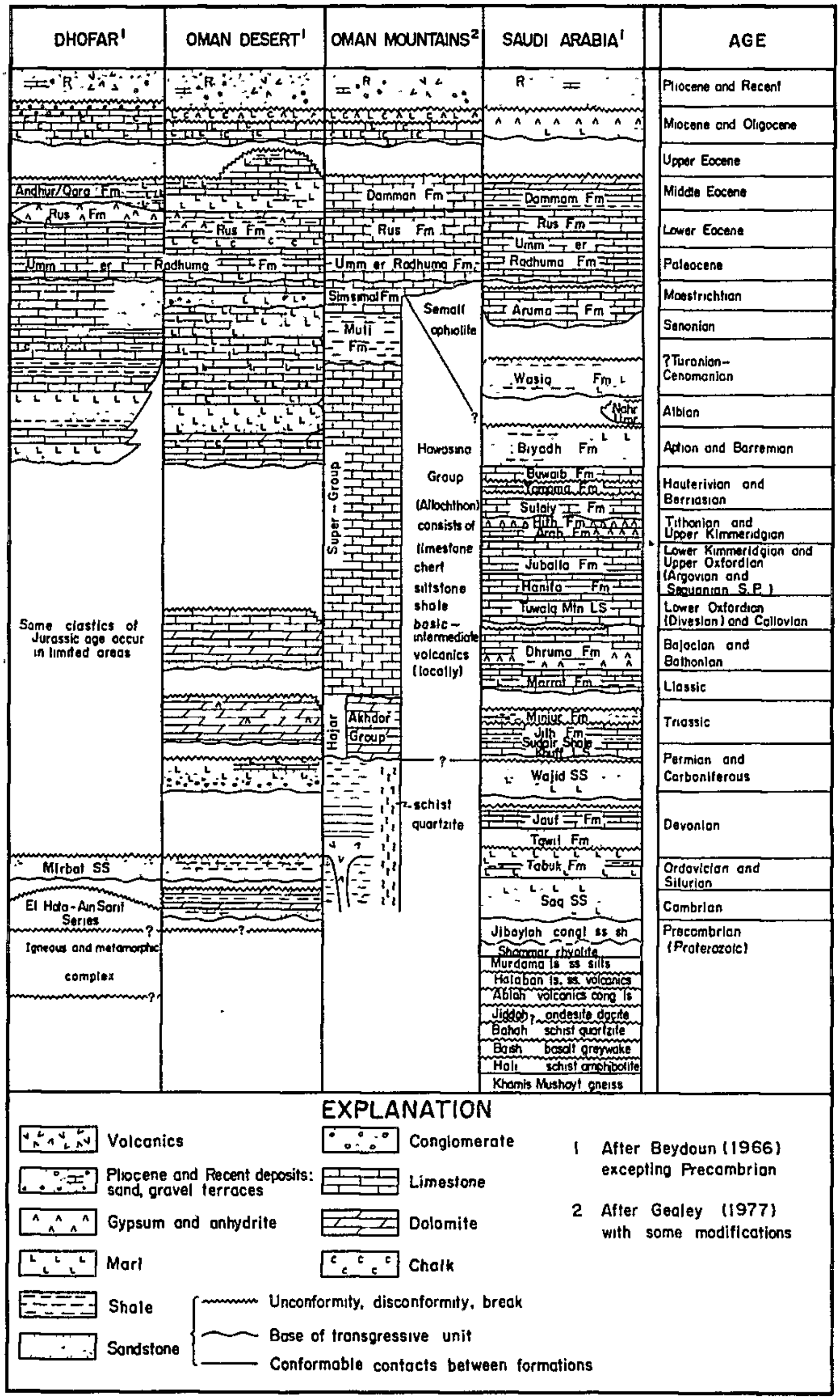


Fig. 3 Schematized correlation of stratigraphic units in Oman and Saudi Arabia

the old layers. Also, the strata are accumulated from the foot of the mountainous area where no old layers can be found. In the area of Qarn Skaiba, a large scale anticlinal axis extends in the direction to Jabal Qara.

1–1–2 Oman Mountains

The oldest rocks distributed in the Oman Mountains are the metamorphic rocks found at the anticlinal cores in the areas of Sayh Hatat and Akhdar mountains, which are composed of phyllite, schist, chert, acidic volcanics, etc.. Covering these rocks, there is a thick unit of sedimentary layers containing limestone, conglomerate, sandstone, shale, etc.. These rocks and layers are considered to be the autochthonous ones, originally generated in their present position. The Hawasina group, Permian to Cretaceous in age, are widely distributed in the whole area of the Oman Mountains, namely, on the southern and northern slopes and at the eastern area of the Mountains. The thickness of the group is estimated at several thousand meters. The group are considered to be the allochthonous part by the collision force. The group is composed mainly of chert, sandstone, siltstone, shale, and is partly accompanied with dolerite. The Semail ophiolite is distributed widely at the Oman Mountains or Masira Island and is also considered to be the allochthonous part extending more than 500 km in length. Stratigraphical succession of the ophiolite is as follows in ascending order, peridotite, gabbro, diabase, and basalt with pillow structure.

The ophiolite has an intimate relation to the genesis of metallic ores in the northern areas, and because of this relation, the ophiolite is considered to be quite important for the investigation of mineral resources. Absolute age of the ophiolite determined by K–Ar method (using muscovite and biotite) showed 85±5 million years (Early to Middle Cretaceous), but there is another opinion saying Senonian.

The strata belonging to upper Cretaceous~Paleogene are composed chiefly of siltstone, shale, cherty limestone, etc. and seem to be shallow sea sediments. Their thicknesses are about 2,500 m in the east and about 2,000 m in the west Oman Mountains.

Generally, the direction of the Oman Mountains varies to the north at the western part, northwest at the center and east-west to southeast at the eastern part. Probably these changes might have been caused by close relations to the geological structure of each part (Fig. 4, Fig. 5, Glennie et al.). Faults extending in the directions of NW–SE and NE–SW dominate in the area. Folded features are quite common in the whole Mountains, and sometimes passed to the complicated overthrusts. Directions of the folding axis are N–S in the west and NW–SE in the east.

1–2 Mineral Deposits

1–2–1 General Features of Mineral Deposits

Many kinds of mineral deposits are known so far in Oman, such as, petroleum,

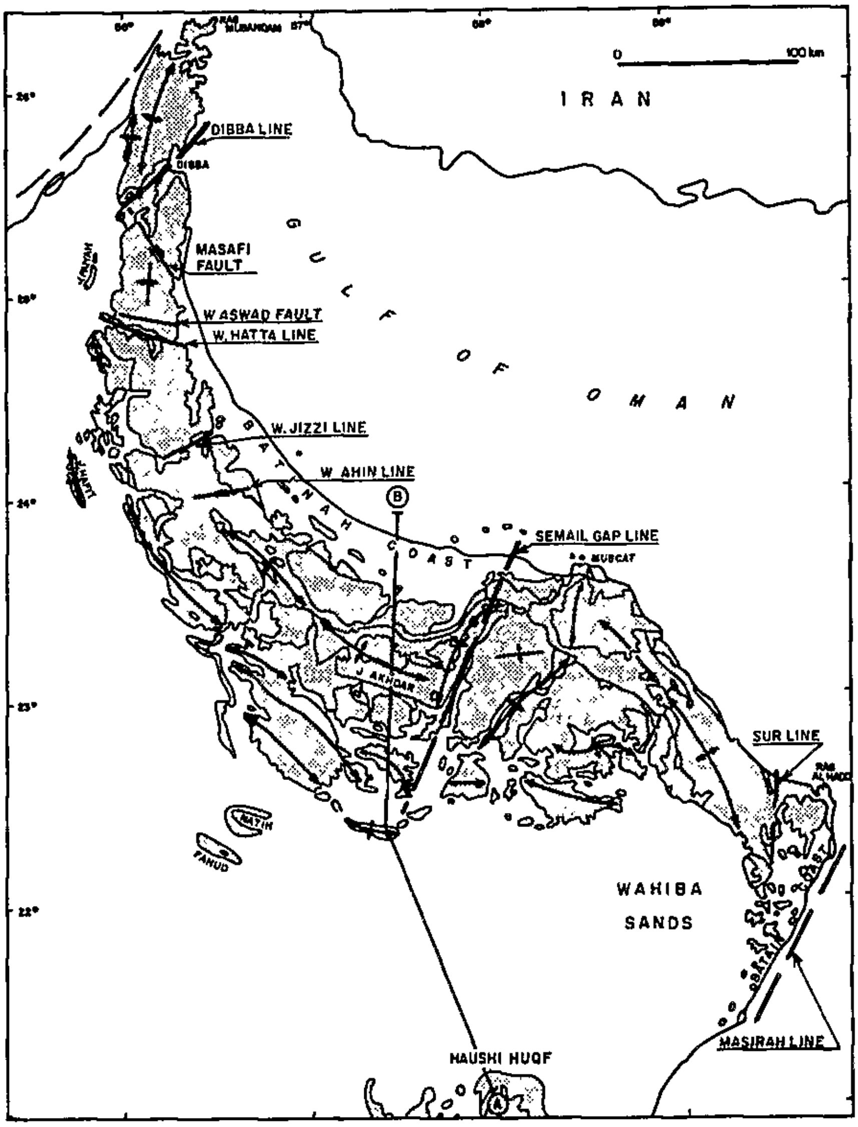


Fig.4 LINES OF TECTONIC DISLOCATION IN THE OMAN MOUNTAINS

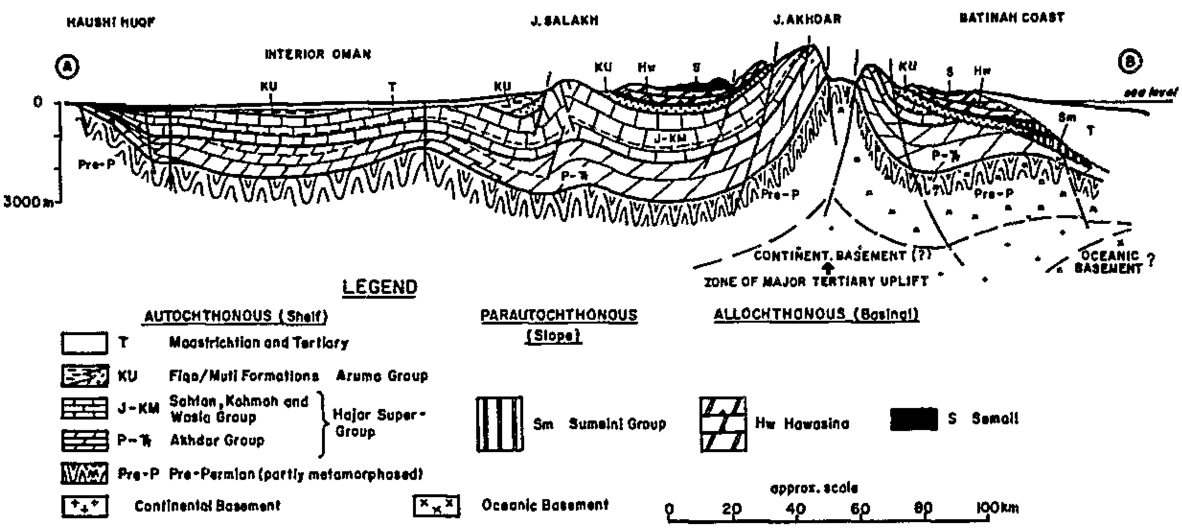


Fig.5 STRUCTURAL FRAMEWORK OF THE OMAN MOUNTAINS

(BY K. W. GLENNIE, ET., 1974)

natural gas, copper, chrome, manganese, lead, zinc, limestone, marble, etc.. Among them, petroleum, natural gas, limestone and marble are under working at present, and copper is now under development.

Fig. 6 shows the occurrences of those mineral resources around the Oman Mountains. Concerning the genesis of these metallic minerals, intimate relation between the ophiolite and these minerals has been noticed.
Especially, ores of copper, iron, lead and zinc are thought to have been formed in relation to the eruption of the pillow lava.

Occurrences of the mineral resources in Oman are shown in Table 2.

1–2–2 Copper Ore

History of the workings of copper ore in Oman goes back to B. C. 2,500.
Several ancient copper mines in Islamic era are supposed to have been worked chiefly on brochantite ore, because of the easiness of its smelting comparing with that of sulphide copper ore. The most hopeful copper deposit —— that means the most hopeful metallic deposit —— is located at Bowling Alley about 30 km west of Sohar. Nine ore bodies occur in the area of 40 km longitudinal extension as shown in Fig. 7. The footwall of all orebodies is composed of gabbro or diabase, and the hanging wall is pillow lava.
Sedimentary rocks distributed in the Hawasina group have their strike in the direction of N $30^{o} \sim 40^{o}$ W, and their dip in $60^{o} \sim 70^{o}$ E. Strike and dip of the orebody are N–S~N 10^{o} W and $30^{o} \sim 70^{o}$ E respectively. Echèlon arrangement of the orebodies is more clear in the northern part of the area. Orebodies are generally massive or networked, partly breccia–like, and the ore minerals are mainly chalcopyrite, pyrite (sometimes marcasite), partly bornite, magnetite, tennantite and sphalerite. These all are fine in grain size.
Near the ground surface, marcasite, hematite and limonite become abandunt.
Fault systems in the area are obserbable in two directions, namely, NW–SE and NE–SW, and the latter is younger in age. Generally speaking, the area around the ore bodies is complicated in its geologic structure having many faults, and is strongly suffered silicification and pyritization. These facts might be used as a clue to exploration for copper ore bodies.

1–2–3 Chrome Ore

Surrounding area of the chrome ore deposit is tectonically complicated by the existence of many faults and brecciated zones. In addition to these tectonic features, the fact that ore body varies horizontally in scale and grade seems to make it difficult to find out a large scale chrome deposit in Oman. However, distributed area of peridotite (host rock of chrome) is quite large enough to find high grade ore in future.

1–2–4 Manganese Ore

Several manganese deposits have been found in the red chert of the Hawasina group, and it is hopeful to find large scale deposits by the detailed investigation in future.

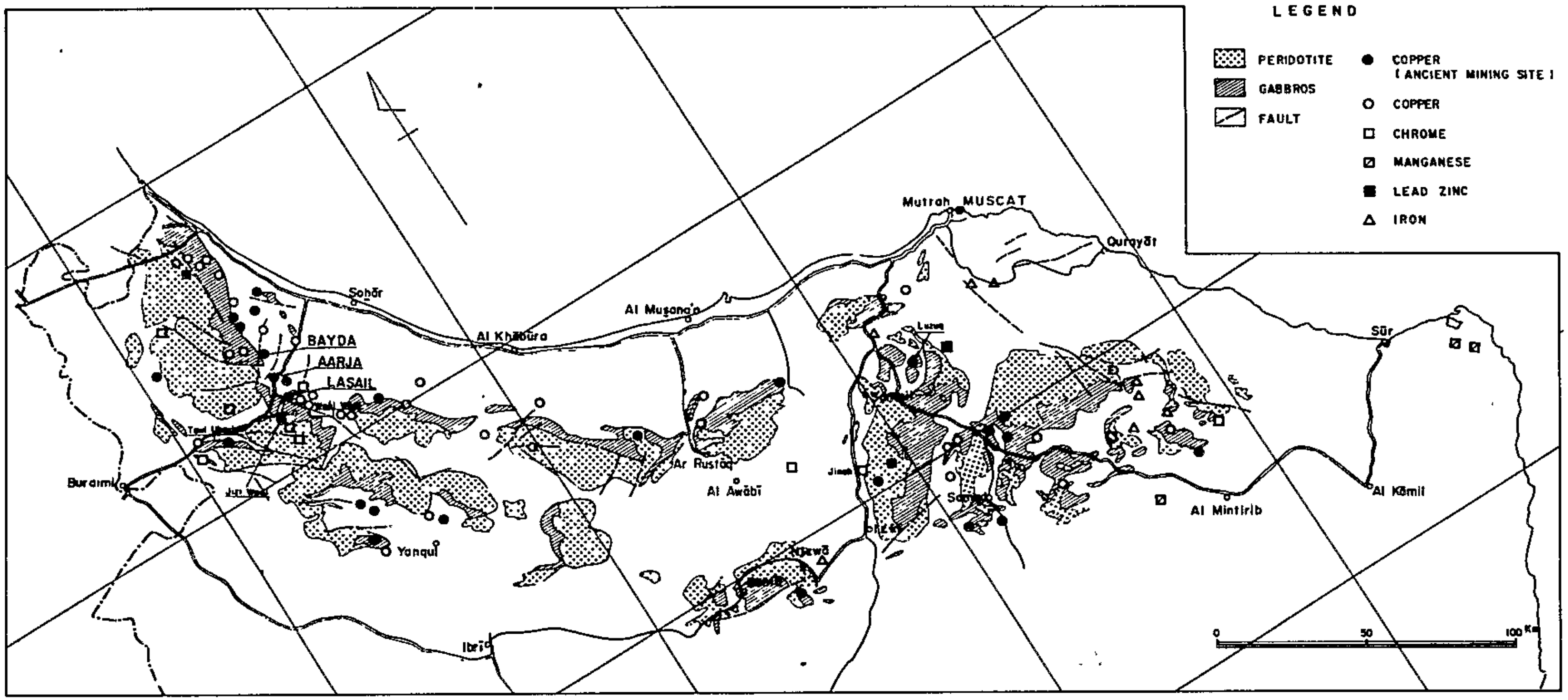


Fig. 6 Location map of mineral occurrences in the Oman Mountains (by J I C A 1978)

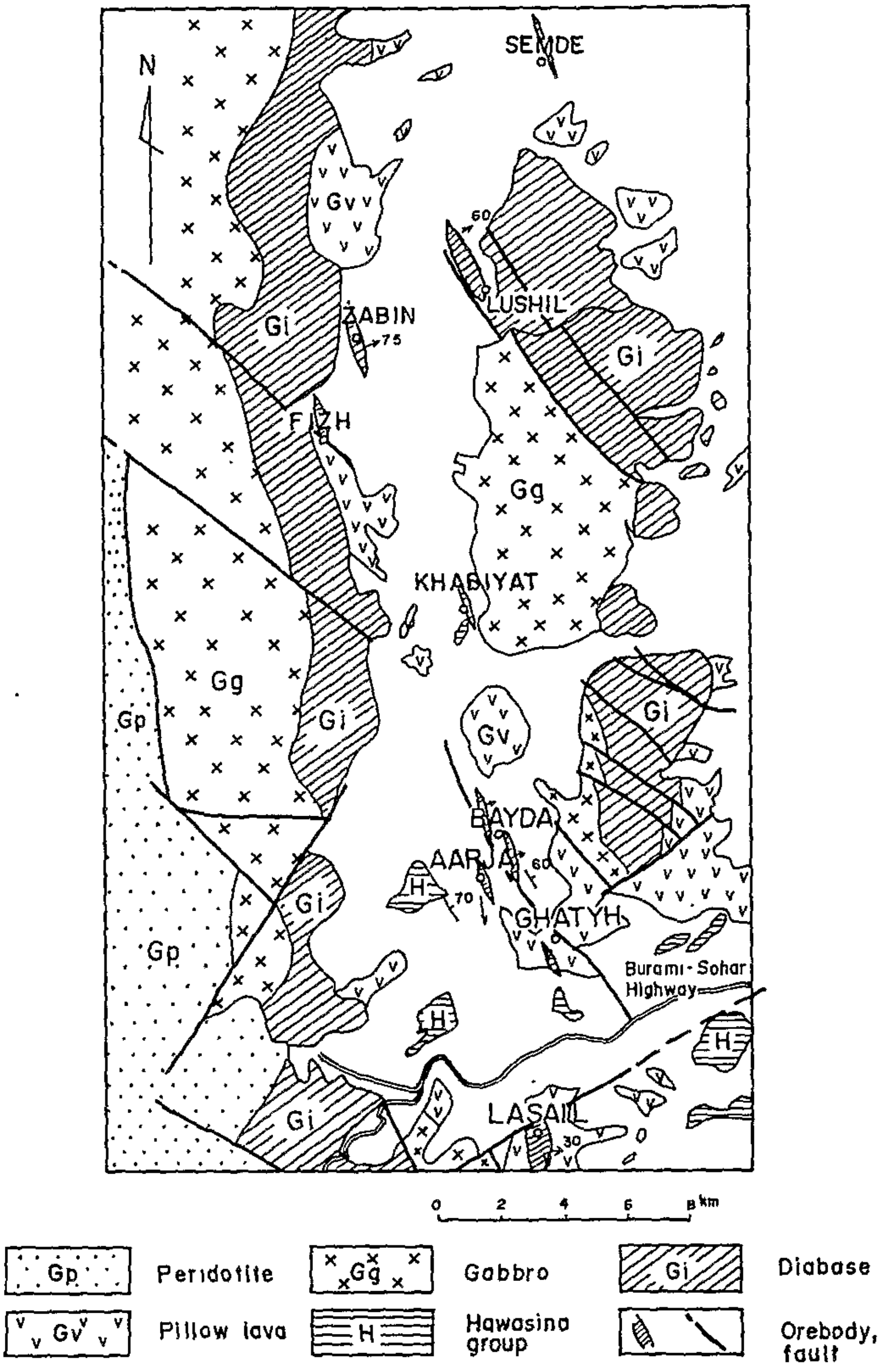


Fig. 7 Geological map of the "Bowling Alley" area
(Compiled from U.S.G.S. and others)

Table 2. Mineral Resources in Oman

Ores		Location & Name of Deposit	Geology	Type of Ores	Ore Reserves and Grade of Ore	Production	Remarks
Hydrocarbon	Petroleum	Fahud { Lekhwair, Naith, Yibal, Al Huwaisah	Middle-Lower Cretaceous & Upper Middle Permian	bedded	} 5,900 x 10^4 barrels (Fahud & Ghaba)	} 350 x 10^3 b/d (Fahud & Ghaba)	now under prospecting at the offshore of Musandam Isl. the offshore of Masirah Isl the NW of Central Oman
		Ghaba { Ghaba North, Quam Alam, Nihaydah, Saih Rawl	ditto	ditto			
		Dhofar { Amo, Marmul	ditto	ditto	heavy & light	under construction	production in 1980, 30 x 10^3 b/d
	Gas	Fahud Yibal	ditto	ditto	140 million ft^3/day x 80 years		oil gas and natural gasoline are partly obtained
Metals	Copper	Sohar { Bayda, Aarja, Lasail	ophiolite	massive or vein	12 x 10^4 tons Cu = 2 10%	under construction	20,000 t/y Cu
		Rakah		massive	4 14 x 10^4 tons Cu = 1.36%, Zn = 0 19%		
		Wadi Waal	ditto	vein			average width of vein: 2m length 200m
		Wadi Jizzi	ditto	massive	250 x 10^3 tons		networks of thin veins (1 cm ±)
		Nizwa	ditto	vein			average width of vein 1.5m lower part might be hopeful.
		Masira Island	ditto	ditto			average width of vein 0 3m length 200m
	Chrome	Farfar	in peridotite at contact with gabbro	massive	160,000 tons, Cr_2O_3 = 39%		thickness 10 ~ 15m, length 150m
		Jinah	ditto	ditto	Cr_2O_3 = 37%		maximum thickness 10m, length 50m
		Al Awabi	ditto	ditto	Cr_2O_3 = 42%, Al_2O_3 = 24.5%		ditto 10m, length 35m
		Masakirah	ditto	ditto	Cr_2O_3 = 36%, Al_2O_3 = 21 4%		
	Iron	Ghazayu	ophiolite	ditto			
		Sayh Hatat Mayh	contact between metamorphite & limestone	ditto	150 x 10^3 tons		thickness 3m, length 100m width 100m, abandoned adit.
	Lead & Zinc	Hadadibah Nujum	ophiolite	vein	chipped sample from a vein 1 35m wide Cu = 3.0%, Pb = 15%, Zn = 7%		
		Dhofar, East of Mubat	Precambrain dyke	ditto	chipped sample Pb = 48 6%, Ag = 4 6 g/t		grade is the result of chemical analyses at this time
	Nickel		ophiolite	vein			in veins of pyrrhotite & quartz
	Manganese	Sur Jaramah	alternation of siltstone & chert,	bedded			in the area of present survey, hopeful. Mn nodule type
		Ibra Hamoah	Trias to Gretaceous	ditto			
		Sohar Mulayginah	ditto	ditto			ditto
Nonmetals	Limestone	Muscat Rusayl	limestone of Trias to Cretaceous	ditto	several hundred million tons		for mostly aggregate, partly slaked lime
		Oman Mountains			CaO = 55 2%		Construction of a cement-plant of a *million tons a year is under discussion.*
	Marble	Ghubrah	ditto	ditto	partly best quality	under production	thickness 10m, palegrey or reddish grey
		Bidbid	ditto	ditto	ditto		thickness 20m, width 120m, length 200m, milky white.
	Dolomite	Muscat Sayh Hatat	Trias to Paleogene	ditto	MgO = 20 7%		*So far unutilized*
		Dhofar	ditto	ditto	$MgCO_3$ = 45 14%		
	Coal	Sur	ditto	ditto	10 x 10^3 tons anthracite		details unknown
	Asbestos		ophiolite	vein	unknown	2,500 t/month	details unknown used to make asbestos cement pipe

(Compiled from Greenwood J.E.G M. and others)

1–2–5 Dhofar Area

There is little information concerning ore deposits in the Dhofar area. Also, metallic minerals have not been reported from the basemental rocks of South Yeman, west neighbouring area. Probably, it might be due to the fact that detailed, systematic investigations have not been carried out in the Dhofar area or South Yemen so far. However, the only one instance of mining in past is guano mining, that is, at the end of 19th century, Dutch people worked guano in a large scale as materials of phosphatic fertilizer in Al Qibliyah Island and Al Haskikiyah Island, Kuria Muria Islands.

It is reported that light petroleum has been recently found in the area around Marmul, eastern Dhofar. New prospecting is said to be planned in western Dhofar to examine the results of the former prospects.

Chapter 2 Salalah Area

The Salalah area is the largest and most strongestly requested area among the three requested areas to carry out a preliminary geological and mineralogical survey by the Government of Oman from a political and economical background. Therefore, the survey team spent the longest term in this area.

The geology of the area has been reported to be composed of Precambrian basement complex, Paleozoic and Cretaceous to Tertiary sedimentary rocks though published papers are quite scanty. Beydoun (1966) studied geology of the eastern Aden and Dhofar areas and he concluded that the Mirbat sandstone formation is Ordovician in age on the assumption that it is later than the folded El Hota and Ain Sarit formations in the west to Salalah and its rock facies is similar to that of the Lower Ordovician in the Oman Desert. He also describes the Cretaceous and Tertiary strata, but, does not explain the Precambrian basement rocks in detail.

Three field surveys have been carried out recently, that is, geological reconnaissance by Mackay & Schnellmann Ltd. (England) including radiometric recinnaissance, phosphate prospecting by Federal Institute for Geoscience and Natural Resources (West Germany) and photogeological and geochemical reconnaissance by Taylor Woodrow-Towell Co. (Muscat-Wales), but, these results have not yet been published.

Though the geological reconnaisance by Mackay & Schnellmann Was carried out for the purpose of iron ore, a preliminary survey for other metallic minerals and uranium was also carried out. As to uranium, a radiometric survey with a portable surveymeter was carried out along two lines on the ground surface as well as along four flight lines by aircraft. As the result, four-fold radioactive anomalies of background were detected on the plateaus at Juffa and Williams Ville, but, any radioactive anomaly was unable to be detected in the same site of Juffa at this time.

The phosphate prospecting by Federal Institute for Geoscience and Natural Resources was carried out mainly for the Umm er Radhuma and gypsum bearing Rus formations, and the Precambrian complex was not of main purpose.

The geological and geochemical reconnaissance by Taylor Woodrow-Towell Co. gives the most useful informations on geology and geochemical exploration in the Salalah area. The photogeological interpretation gives a brief but general idea of the distribution, succession and structure of the Precambrian basement complex. The geochemcial exploration was carried out on the wadi sediments under 80 mesh at the rate of about one sample per one square kilometer, and they also reported that sampling under 80 mesh was very difficult because the grain size of wade sediments was very coarse. The same condition was confirmed at this time.

Base metal anomalies by the geochemical exploration were scarecely recognized and it is doubtful that geochemical exploration on coarse-grained wadi sediments in the arid zone like this area is effective.

As mentioned above, the published and unpublished reports on geology and mineral deposit in this area are very few and not detailed. Therefore, at this time, the survey team tried to collect many field informations and samples necessary to carrying out a fundamental and systematic mineral survey in the near-future. Chemical analysis, microscopic observation, age-determination, etc. of the collected samples were executed in Japan to establish a more exact geological succession and to estimate mineral showings exactly. An outline of the geological succession and lithology in the whole area was understood most efficiently by two-day's helicopter survey prior to the ground survey which was carried out through the two field camps

2–1 Location

The surveyed area is located in the Dhofar district of the Southern Oman, and Mirbat village on western corner of the area is located at about 73 kilometers eastward from Salalah, the second largest city next to Muscat. The area covers about 30 km x 70 km, about 2,000 km^2, in the east-northeast from Mirbat (Fig. 8). It is also located from 15°55' to 17°50' in north latitude and from 54°40' to 55°15' in east longitude. And Kuria Muria Islands are located on eastward of Hasik.

2–2 Transportation

The west part of the road from Salalah to Mirbat is paved to Taqa but the east part from Taqa is unpaved.

In the surveyed area, a two-laned, hard surface road is under construction from Mirbat to Juffa and will be completed in the near future. But, the other roads from Juffa to Hadabin, from Jaffa and from Sadh to the above-mentioned two-lane road are narrow, rough and partly one-laned. The main wadis in the area are passable for four-wheel drive vehicles. The route of helicopter and surface survey is schematically shown in Fig. 8.

2–3 Topography

The topography in the area is classified into two types (Fig. 9).

The main part of the area from the ajacent area of Mirbat to the northern Hadabin, forms almost a flat peneplain. On the other hand, there develops a tableland accompanied with an escarpment with 1,000 to 1,500 meters elevation difference (called Jabal Samhan) on the north side of the peneplain.

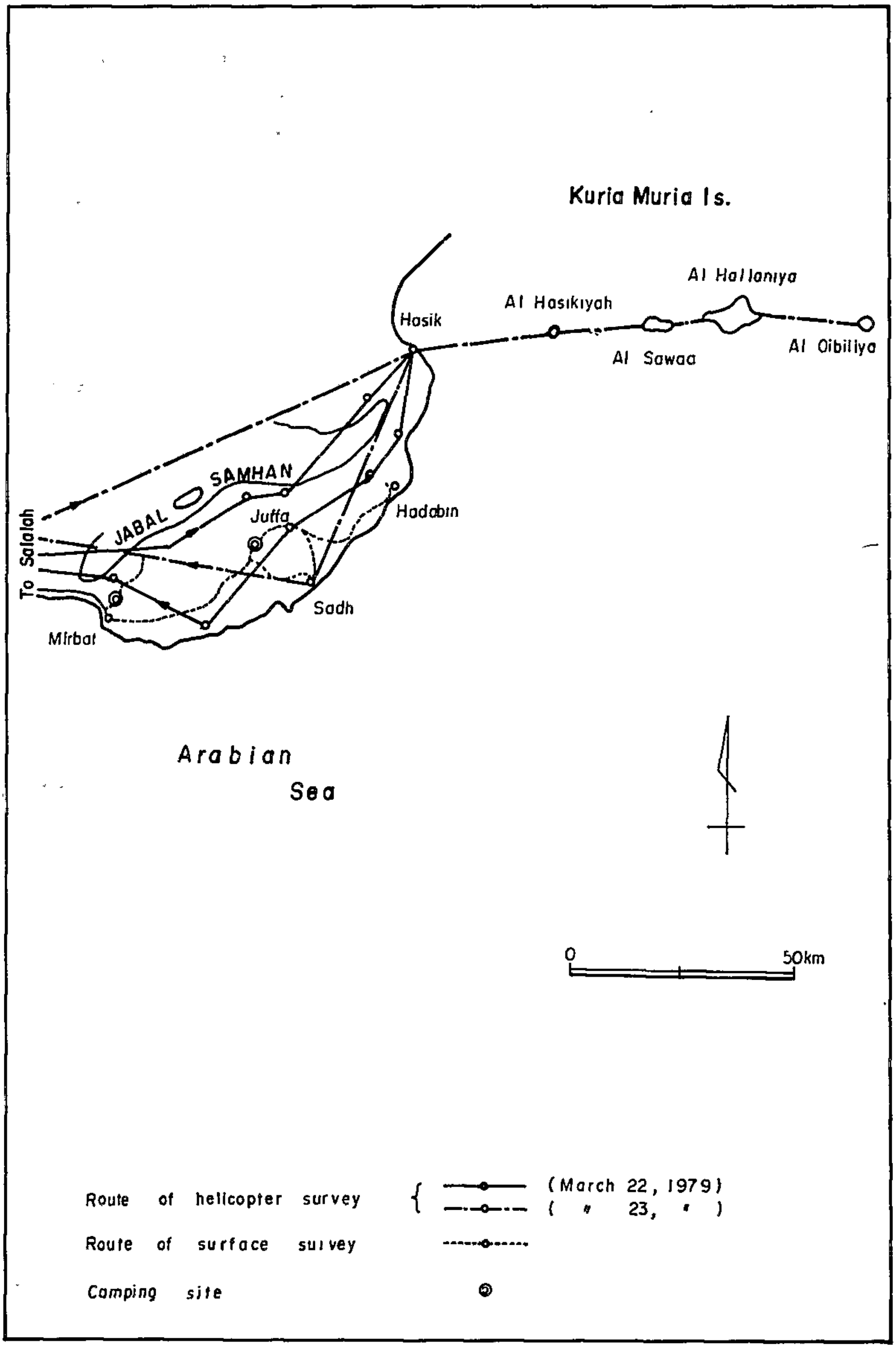


Fig. 8 Schematic route of helicopter and surface survey

The major part of peneplain is thought to belong to a part of the Arabian Shield and is composed of Precambrian gneisses and intrusive igneous rocks. Gently rolling hills are formed by the influence of numerous intruding dyke swarms in NW–SE direction.

The tableland at the Jabal Samhan is almost flat and composed of gently inclined Cretaceous to Tertiary sedimentary rocks, Umm er Radhuma formation. Though the name of this formation is originally given to the layers comprising the Paleocene to Lower Eocene sedimentary rocks, the name is used to represent the Cretaceous to Tertiary sedimentary rocks in this report for convenience. Surrounding area shows an inmature topography accompanied with deep valleys due to erosion of main wadis.

Talus sediments develop at the lower most of the escarpment of 300 to 600 meters in altitude and form a rather steep slope.

In the inner part of the Precambrian peneplain, same as on the Jabal Samhan, the Umm er Radhuma formation is distributed on the tops of Jabal Qinquri, Jabal Musayrah, Jabal Nuss, etc. making mesa.

2–4 Drainage System

The drainage system in the area is composed of wadis with stream only in the monsoon season.

The main direction of drainage system in the peneplain area is NW–SE, and the direction in N–S or NNE is predominant near Mirbat in the western area. All these wadis flow down to the sea and the pattern of drainage system is dendritic, parallel, rectangular, etc.. The parallel pattern is fundamental because of the effect of distribution of dyke swarms and is emphasized where the effect of dyke swarms is large.

The drainage system on the tableland of Jabal Samhan shows E–W, NW–SE and NE–SW directions and flows into the inland. The main wadi is eroded deeply accompanied with escarpments on the both sides. The tributary shows a short grid pattern together with dendritic pattern.

2–5 Aerophotogeological Interpretation

The surveyed area belongs to an arid zone and is suitable for photogeological interpretation owing to sparse vegitation and continuous exposure. Many informations obtained by the photogeological interpretation are very useful for the ground geological survey as a supplementary aid during such a short term stay as this time.

The aerophotograph of this area is provided for military use and is monochromatic in a scale of 1:60,000. The aerophotograph covers the whole surveyed area of about 2,000 km^2 and shows a distinct image which is sufficient enough for geological interpretation. The report of the Taylor Woodrow – Towell Co., mentioned already, was very useful for the geological

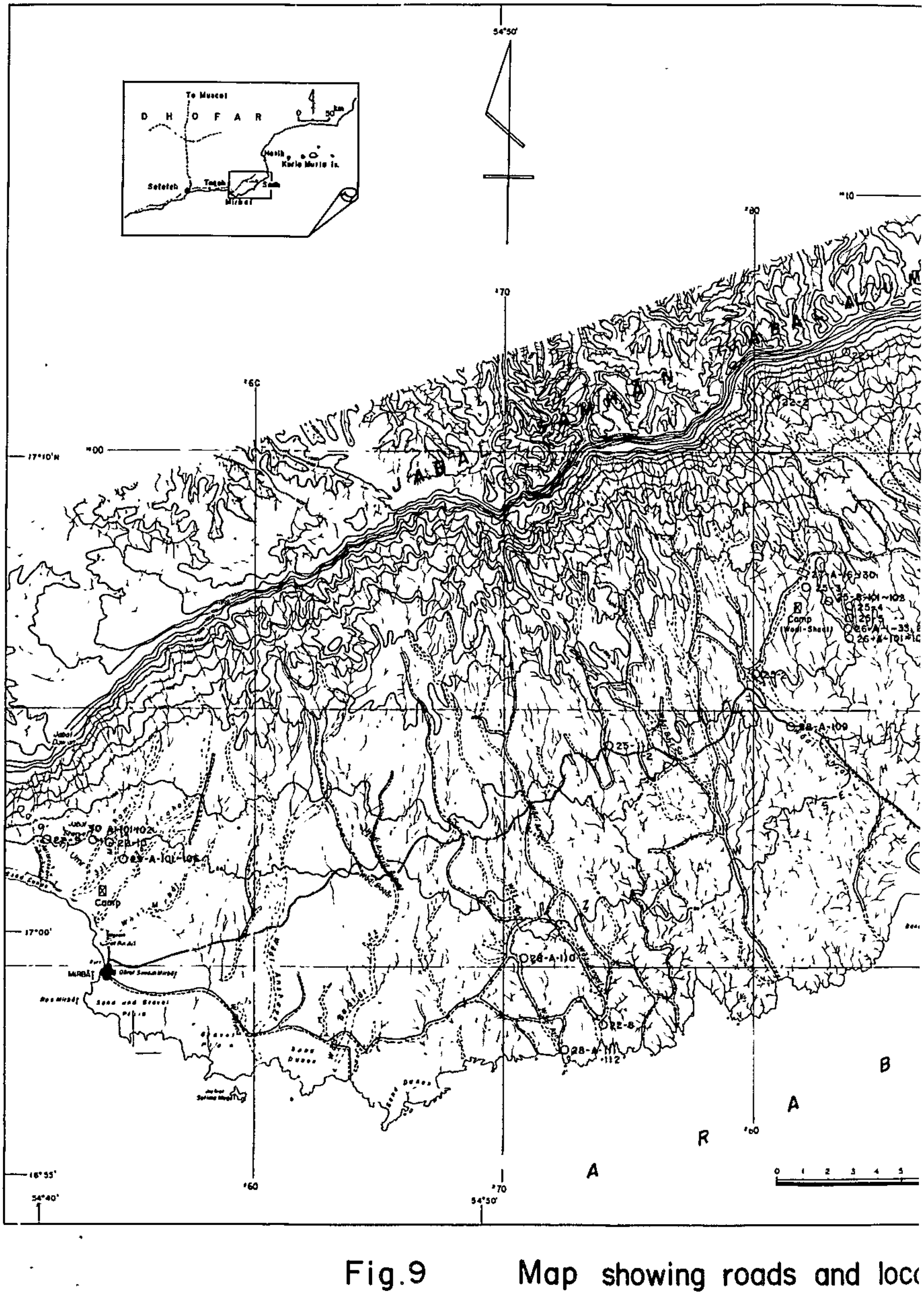


Fig.9 Map showing roads and loc

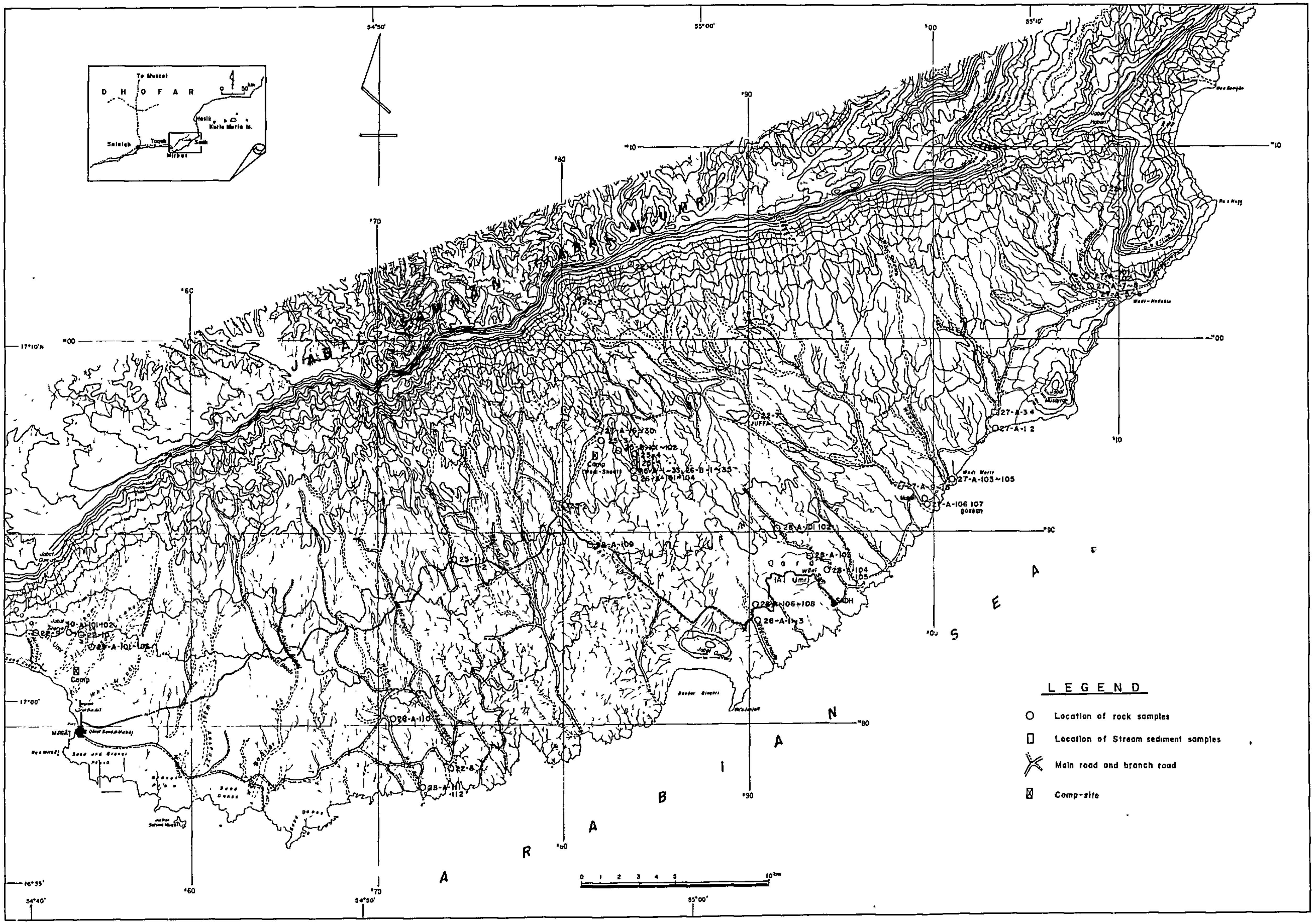


Fig.9 Map showing roads and locations of samples

interpretation at this time.

Photogeologically, mica gneiss showing dense liniar pattern and hornblende gneiss showing complex banding pattern are roughly distinguishable in the Precambrian gneiss area, though the boundary between the both is not clear.

The igneous rocks are distrubuted as batholith, stock and dyke intruding the gneisses. The light toned part corresponding to a batholith in the northeastern part of the surveyed area is widely distributed, and in that part, lithological change was supposed to exist from the change of tone and it became distinct as the result of field survey that some are quartz dioritic and others are granodioritic.

A stock-like intrusive body is discriminated by lighter tone from the surrounding gneiss in the northwest to Juffa, and a part of dyke swarms extends continuously to this stock. Numerous dyke swarms develop in NW–SE, N–S, etc. directions, but it is impossible to discriminate the rock types only by a monochromatic airphotograph, though quartz porphyry and dolerite are easily discriminated by ground survey. But, it may be possible if color aerophotographs are taken.

Alternations of well-bedded, gentle-dipping sandstone and shale, Mirbat sandstone formation, cover the Precambrian rocks near Mirbat. The strata wedge out eastward between the Precambrian complex and the overlying Umm er Radhuma formation.

A large escarpment observed like a fault-line scarp develops in the northern part of the area.

In the upper part of the escarpment, a well-bedded, gentle-dipping formation composed mainly of limestone, Umm er Radhuma formation, is widely distributed, and the same formation overlies the top of mountains forming mesa near the coast.

In the Precambrian area, the geological lineament in NE–SW discriminated by aerophotograph shows a direction of gneissose structure, and a NE–SW anticlinal structure is also recognized from Wadi Ahmilt to near Wadi Bayt Said.

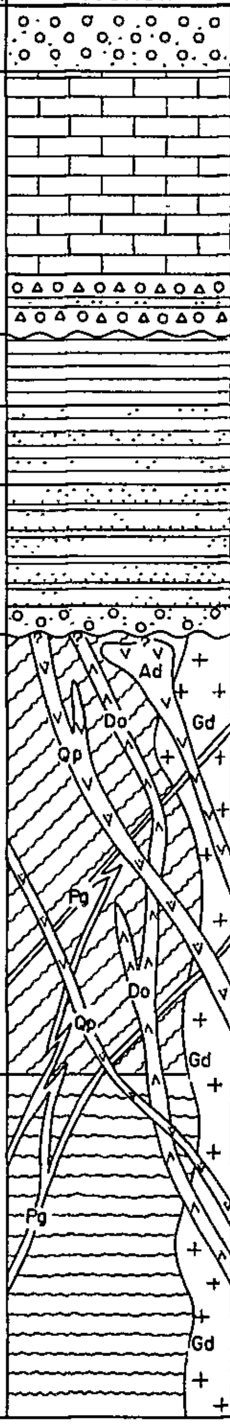
The Mirbat sandstone formation generally shows NE–SW strike and gentle NW dip.

The Umm er Radhuma formation shows almost flat distribution, and faintly dips to N in general but dips to E in the eastern area.

The main faults, combined with main NW–SE and subordinate NE–SW directions, develop in the area from Bandar Qinqari to the middle stream of Wadi Aingalf and also the faults in E–W and NEE–SWW directions develop cutting the Umm er Radhuma formation near Jabal Nuss.

2–6 Geology

The geological sucession of the surveyed area is as follows in ascending order (Figs. 10 ~ 13).



Geologic Age	Formation & Member		Thick-ness (m)		Columnar section	Rock Facies
Quaternary			5 ~ 30			raised beach materials, dune and wadi sand, gravels
Cretaceous to Tertiary	Umm er Radhuma Fm.		1,200 +			bedded and massive limestone with dolomite limestone conglomerate with fine grained sandstone
Ordovician	Mirbat Sandstone F.	Upper M.	1,300 +	315 +		well bedded silty shale, shaly siltstone
		Middle M.		310 ±		alternation of siltstone and sandstone
		Lower M.		690 +		medium to coarse grained arkose sandstone intercalating siltstone thin beds. basal conglomerate
Precambrian	Sadh Gneiss		2,000 +			hornblende gneiss ~ quartz diorite gneiss, intruded by granodiorite, pegmatite – quartz vein, dolerite, adamellite and quartz porphyry
	Juffa Gneiss		1,500 +			biotite gneiss intruded by grano-diorite, pegmatite – quartz, dolerite, adamellite and quartz porphyry

INTRUSIVES
Qp : Quartz porphyry
Ad : Adamellite
Do : Dolerite
Pg : Pegmatite – quartz vein
Gd : Granodiorite ~ quartz diorite

Fig. 10 Geological columnar section of Salalah area (Mirbat – Sadh)

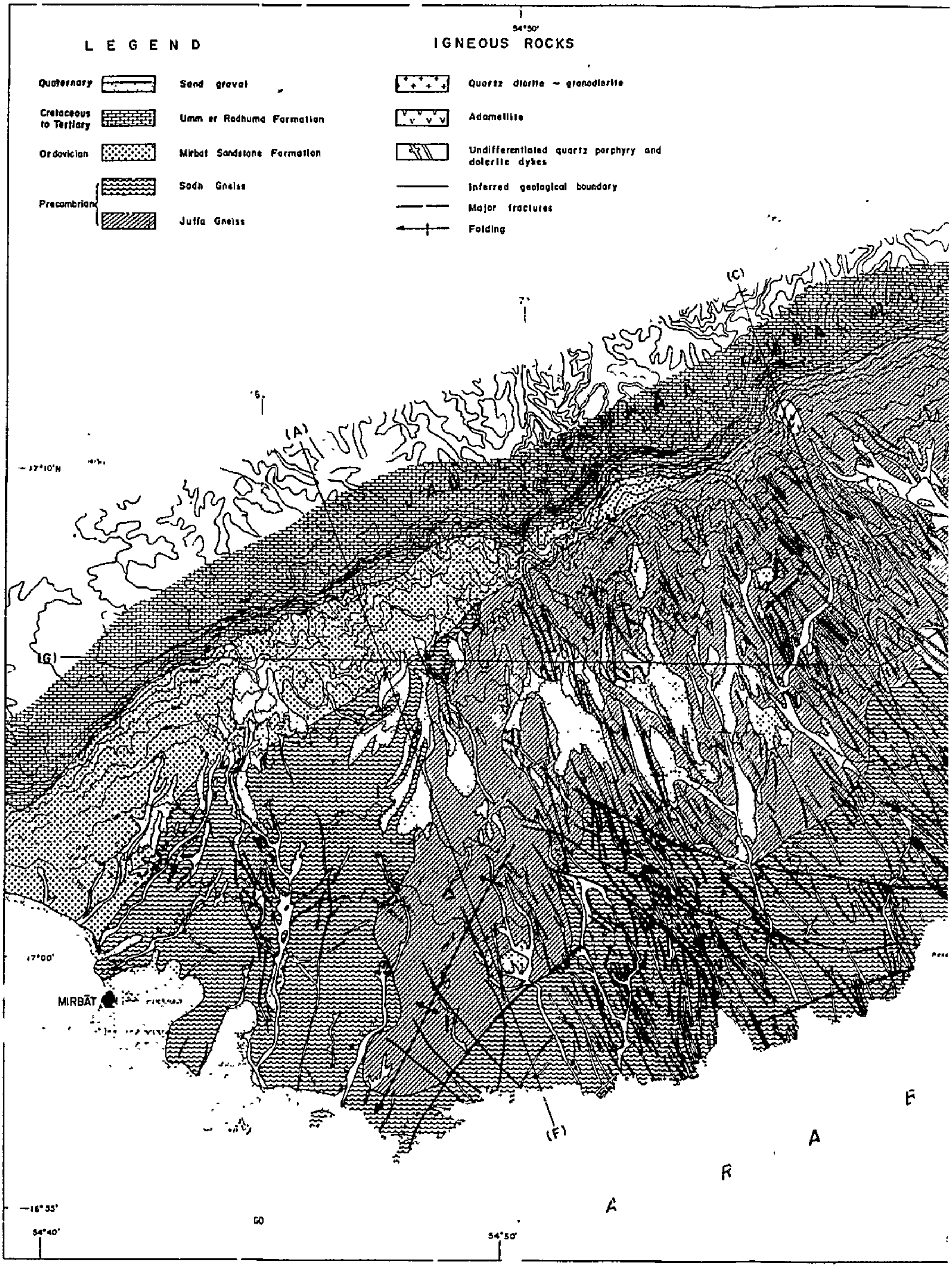


Fig.11 Geologic map of Salalah c

(by Taylor Woodrow – To

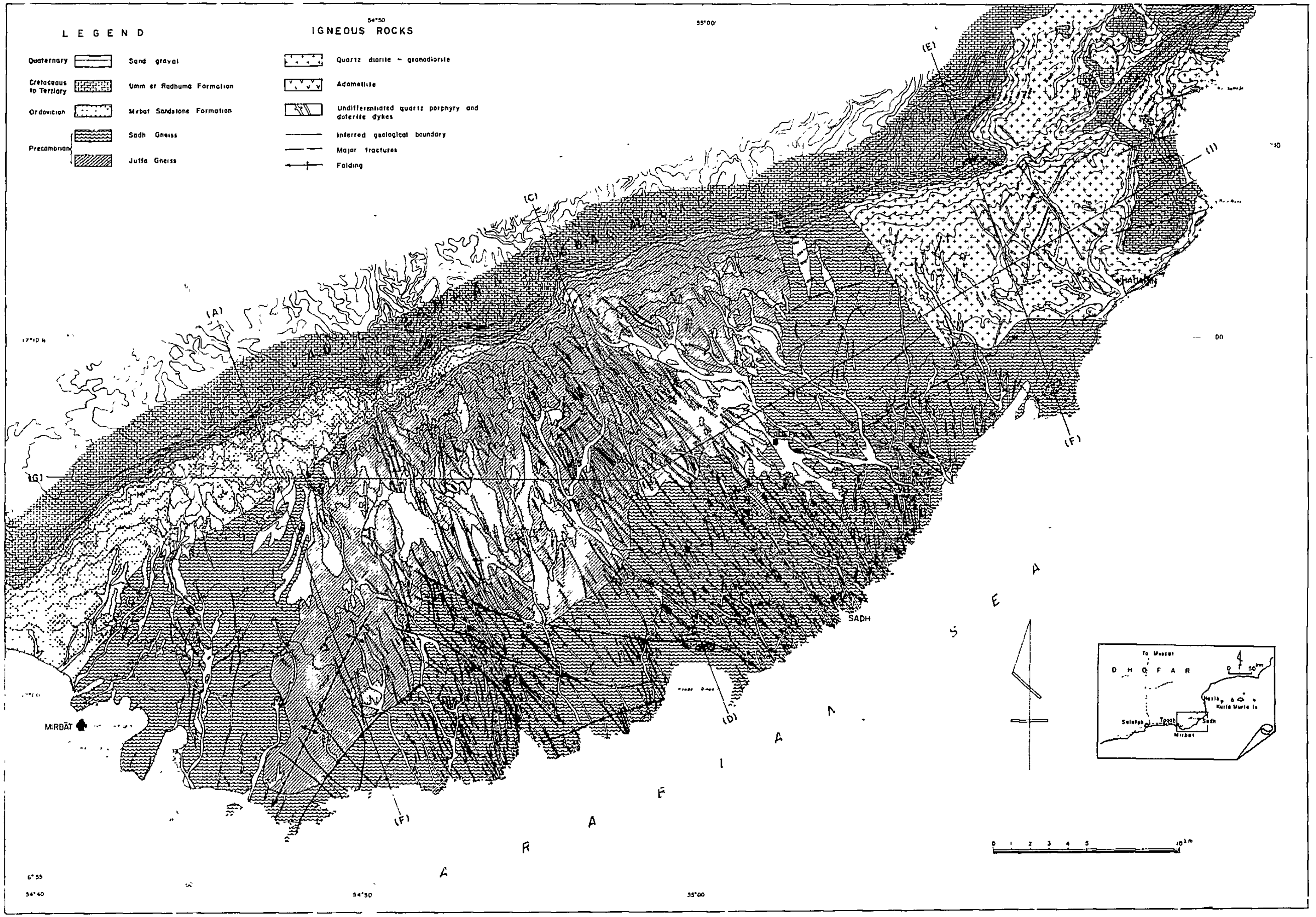


Fig.11 Geologic map of Salalah area (Mirbat − Sadh)
(by Taylor Woodrow − Towell Co. 1978 and others)

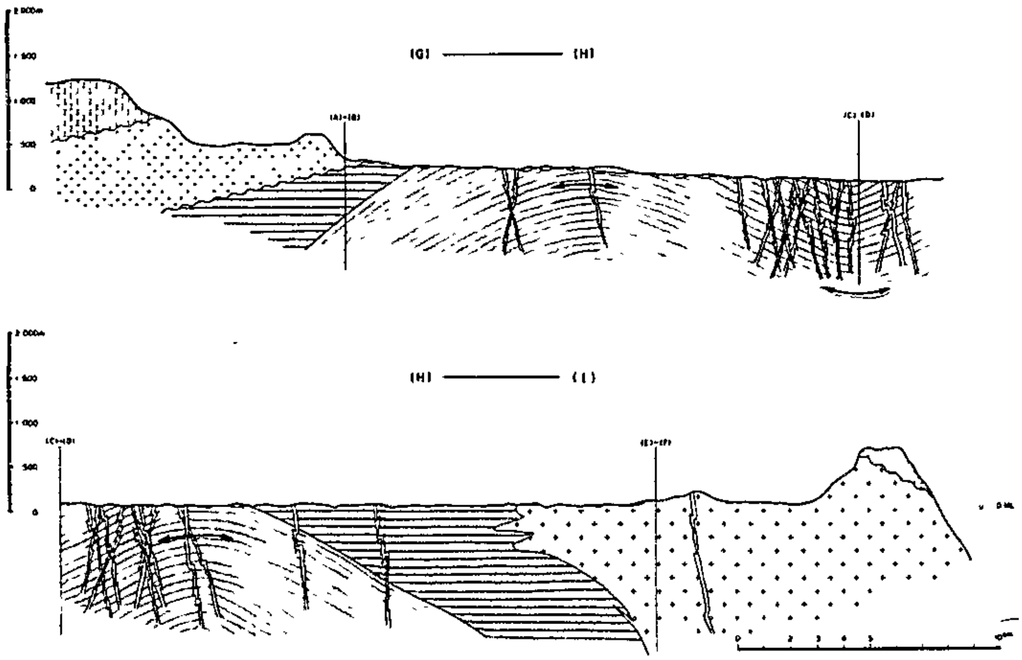


Fig. 13 Geological cross sections of Sololoh area (2)

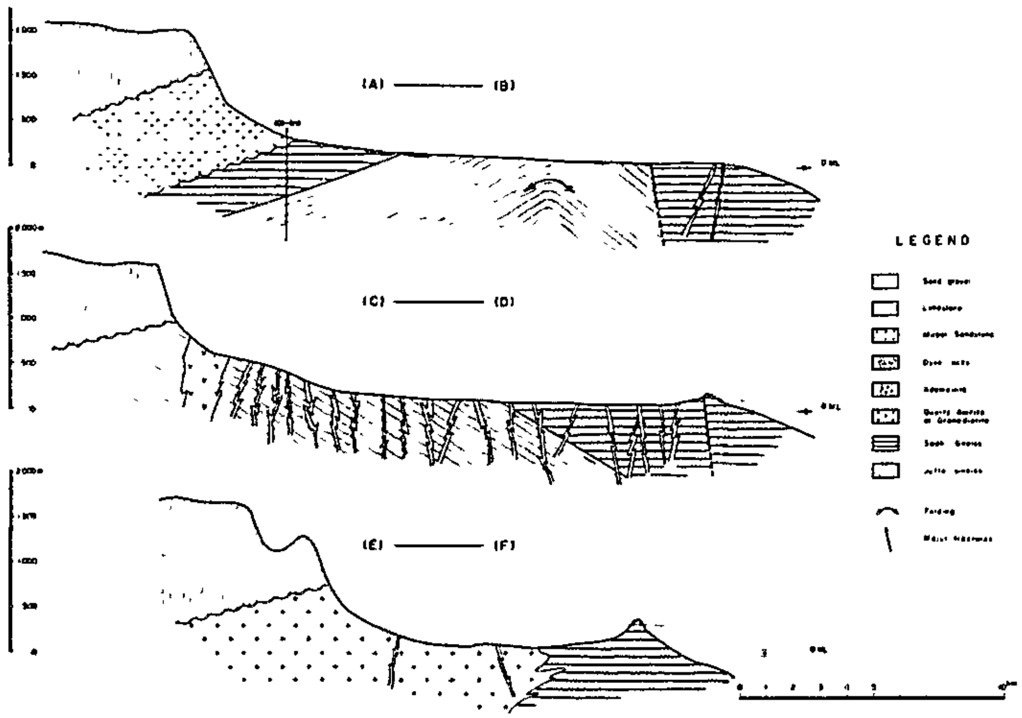


Fig 12 Geological cross sections of Sololoh area (1)

1) Precambrian system
2) Ordovician system
3) Cretaceous to Tertiary system
4) Quaternary system

2–6–1 Precambrian system

The Precambrian system is correlated with that of South Yemen and Somalia by Beydoun (1970).

The Precambrian metamorphic rock is classified into the lower micaceous chloritic schist and the upper series of granitic gneiss and amphibolitic gneiss accompanied with amphibolite by the Taylor and Woodrow-Towell Co..

As the result of this time survey, the Precambrian system is classified as follows:

1) Juffa gneiss — composed mainly of garnet bearing muscovite-biotite gneiss partly with intercalations of hornblende gneiss and quartz diorite gneiss.
2) Sadh gneiss — composed mainly of hornblend gneiss and quartz diorite gneiss accompanying gneissose hornblendite and gabbro in some places.
3) Quartz diorite ~ granodiorite —— batholith form intrusion.
4) Pegmatite and quartz vein — vein like, network, lenticular and irregular in the above-mentioned rocks.
5) Stock and dyke — hornblende adamellite stock, dolerite dyke and quartz porphyry dyke.

The Juffa gneiss corresponds to the micaceous chloritic schist of T. W. T and the Sadh gneiss corresponds to the granitic gneiss and amphibolitic gneiss of T. W. T..

1) Juffa gneiss

Because a military camp called Juffa is the only one place having name in the gneiss area of this type, so the name "Juffa gneiss" is tentatively given to the gneiss of this type.

<u>Distribution</u>

The Juffa gneiss occurs in the nearly central part of the surveyed area, northeastward from near Wadi Ahamilt about 10 km east from Mirbat, to the north of Juffa through Wadi Bayt Said and Wadi Shaat with an area of about 35 km in length and 10 to 15 km in width.

<u>Lithology</u>

The Juffa gneiss is mainly composed of garnet bearing muscovite-biotite gneiss (Photo. 1. 2) and partly intercalated by hornblende gneiss (Photo. 2) and quartz diorite gneiss (Photo. 3. 4).

The garnet bearing muscovite-biotite gneiss is gray and shows thinbanded gneissose structure, but it is called micaceous chloritic schist by T.W.T. owing to its schistosity.

In this report, it is called gneiss because the grain size is rather coarse (Photomicrographs 1 ~ 4), and the quantity of involved plagioclase exceeds 20%. Remarkable development of the gneissose, injected quartz dioritic part is also observed along gneissosity (Photo. 3).

Under the microscope, it is composed of plagioclase, biotite, muscovite and garnet as main constituent minerals, and magnetite and apatite as accessory minerals. Holocrystalline, gneissose structure composed of felsic minerals (quartz and plagioclase) and mafic minerals (biotite, muscovite, etc.) is clearly observed.

Quartz: Anhedral grains of 1.5~3.0 mm are distributed in the interstices of plagioclase.

Plagioclase: Anhedral ~ subhedral crystals of 1.5 ~ 3.0 mm are distributed in the interstices of mica and quartz. Some are partly altered to sericite.

Biotite: Flakes smaller than 1 mm are arranged parallel to one direction showing gneissose structure. Biotite is pleochroic ranging reddish brown to light brown.
Some are partly altered to chlorite.

Muscovite: Colorless flakes of 1.0 ~ 1.5 mm with high birefringence arrange in parallel or somewhat oblique to gneissosity.

Garnet: Euhedral isotropic grains smaller than 0.5 mm are sparsely scattered.

Magnetite: Associating with mica, a small amount of opaque magnetite is present.

Apatite: A small amount of small colorless apatite is also present as accessories.

Generally it is slightly altered and a volume ratio of each constituent mineral is estimated as follows:

Plagioclase ≥ Quartz ≥ Biotite > Muscovite >> Garnet > Magnetite · Apatite

The chemical composition and C.I.P.W. Norm of Nos. 25–1–1 and 25–2 are shown in Table 4. These chemical compositions are somewhat similar to those of phyllite, unmetamorphosed sandstone and biotite gneiss of the Ryoke metamorphic belt in Japan as shown in Table 5, but, the SiO_2 content shows remarkable difference between Juffa and Rhyoke biotite gneisses and the chemical composition of the Juffa gneiss is rather similar to sandstone and phyllite except Na_2O and K_2O. The Juffa gneiss seems to be originated from a mixture of psamitic and pelitic sediments.

On the Q–Pl–Kf diagram plotted by C.I.P.W. Norm as shown in Fig. 14–A, which is used for classification of felsic plutonic rocks, two samples of the Juffa gneiss are plotted in a granodiorite region though potash feldspar is absent under the microscope. But, because of the scantiness of CaO and K_2O in the chemical component of two samples, it seems to be difficilt to consider that the Juffa gneiss is originated from granodiorite or other felsic plutonic rocks. On the other hand, on the ($FeO + Fe_2O_3$) — ($Na_2O + K_2O$) – MgO diagram as shown in Fig. 14–B, which shows a nature of volcanic rocks, the Juffa gneiss is clearly discriminated from the felsic igneous rocks in the surveyed area.

Also, on the ACF diagram plotted by molecular ratio as shown in Fig. 14–C, which is originally made by P. E. Eskola (1939) for the interpretation of the relation in metamorphic grade, mineral component and chemical composition of metamorphic rocks, two samples of the Juffa gneiss are plotted in a greywacke – argillaceous rock region.

The garnet bearing muscovite – biotite gneiss is thought to be probably originated from a series of alternation of sandstone and mudstone.

Hornblende gneiss is dark gray to dark greenish gray and several meters thick and occurs concordantly in the above-mentioned garnet bearing muscovite-biotite gneiss (Photo. 5. 6). Lithology is quite same as that of the hornblende gneiss of the Sadh gneiss. This gneiss occurs especially in the uppermost horizon of the Juffa gneiss near the boundary between the Juffa and Sadh gneisses, and an alternation zone of two types of gneiss is observed on the Wadi Ayn (Photo. 6).

The quartz diorite gneiss occurs concordantly or slightly in oblique to gneissosity in the garnet bearing muscovite-biotite gneiss as already mentioned (Photo. 3). The lithology of this gneiss is quite similar to that of quartz diorite ~ granodiorite gneiss. But, occurrence of the rock is confirmed only in the small wadi in the east to Wadi Shaat and continuity and stratigraphic horizon of the rock still unknown.

Geological Structure

The Juffa gneiss shows general gneissosity of NE–SW strike and gentle dip (Photo. 3. 5).

An anticlinal structure develops in a NE–SW direction from Wadi Ahamilt to the upstream of Wadi Bayt Said and the Juffa gneiss forms a core of the anticlinal structure. In the southeastern wing of the anticline, the gneissosity shows a gentle undulation in the area near Juffa and is disturbed by faults near Wadi Ainfalf and Wadi Ayn.

Stratigraphic Relationship

The Juffa gneiss occurs in the lowest part of the geological succession of the Salalah area and grades up into the overlying Sadh hornblende gneiss with intervening of hornblende gneiss its uppermost part and it is thought that there is no stratigraphical grap between the both gneisses. The uppermost limit of the Juffa gneiss is an uppermost surface of the garnet bearing muscovite-biotite gneiss in this report.

The Juffa gneiss is penetrated by pegmatite, quartz vein, stock and dyke, and is covered unconformably with the overlying Mirbat sandstone formation in the middle western part of the area and with the overlying Umm er Radhuma formation in the central northern part.

2) Sadh gneiss

Because the Sadh village, situated approximately in the central part of the coast in the surveyed area, is the largest village. The name of Sadh gneiss is tentatively given to the gneiss of this type.

Distribution

The Sadh gneiss is extensively distributed on the eastern, southern and western sides of the Juffa gneiss just like surrounding it.

Near Mirbat, the Sadh gneiss overlies the Juffa gneiss at the western wing of the already mentioned anticline and unconformably underlies the Mirbat sandstone, forming a triangular shape. At the eastern wing, the former also overlies the latter and occurs extensively in an area comprising Wadi Ayn, Wadi Khorhant, Sadh village, upstream of Wadi Shiliyarn and Jabal Musayrah. The distribution is intermitted near Hadabin by a batholith of quartz diorite ~ granodiorite but the gneiss occurs again in the northeasternmost end of the area.

Lithology

The Sadh gneiss megascopically shows various lithological changes and it is roughly classified into hornblende gneiss and quartz diorite gneiss though there exist gneissose hornblendite and gabbroic types.

Complicated, megascopic appearance is due to the variations of volume ratio of felsic minerals (quartz and plagioclase) and mafic minerals (mainly hornblende), and of grade of assimilation, but generally it shows banded structure due to alternations of felsic and mafic bands (Photos. 7 ~ 10). Hornblendite which occurs as xenoligh as sample 27–A–101 in the quartz diorite-granodiorite batholith, probably belongs to the Sadh gneiss (27–A–101).

Therefore, the part megascopically composed of abundant hornblende with or without assimilation and blackish-gray to dark grayish-green in color is called hornblende gneiss under the microscope, and the white to light greenish part megascopically composed of abundant felsic minerals is called quartz diorite gneiss ~ gneissose quartz diorite under the microscope. A rock name, hornblende gneiss ~ amphibolite, could be adopted to represent the whole rock type of the Sadh gneiss.

Under the microscope, the hornblende gneiss is coarse-grained, holocrystalline and is composed of hornblende, plagioclase, quartz, as main constituent minerals and magnetite and sphene as accessory minerals. Holocrystalline gneissose structure composed mainly of hornblende and plagioclase is clearly observed (Photomicrographs 11 ~ 14).

Hornblende: Subhedral crystals of 3.0 ~ 3.5 mm are arranged parallel to one direction showing gneissose structure. Pleochroism is green to light green.

Plagioclase: Anhedral ~ subhedral crystals of 1.0 ~ 2.0 mm are arranged parallel to gneissosity between hornblende crystals. Most crystals are strongly altered to sericite and epidote.

Quartz: Anhedral grains of 1.0 ~ 3.0 mm are present among plagioclase and hornblende.

Magnetite: A small amount of opaque magnetite of 0.2 ~ 0.5 mm is sometimes scattered in hornblende and includes sometimes sphene.

Sphene · Apatite: A small amount of sphene and apatite is generally associated with hornblende.

The constituent minerals are altered commonly to sericite and mostly to chlorite, epidote and zoicite, and rarely to serpentine. Volume ratio of each constituent mineral is estimated as follows:

Hornblende >> Plagioclase > Quartz > Magnetite > Sphene · Apatite

The chemical composition and C.I.P.W. Norm of Nos. 28–A–109 and 28–A–110 are shown in Table 4. No. 28–A–110 decreases its SiO_2 content owing to strong sericitization and it is unadequate to compare its chemical composition with the other chemical composition known already.

The chemical composition of No. 28–A–109 is quite similar to that of basalt and diabase after R.A. Daily (1933) and it is also similar to that of actinolite-epidote schist after H. Shibata (1968) originated from submarine basaltic rock in the Sambagawa metamorphic belt in Japan.

On the ACF diagram plotted by molecular ratio as shown in Fig. 14–C, No. 28–A–109 is plotted in a basic igneous rock region.

The hornblende gneiss is thought to be probably originated from the basic lava ~ basic pyroclastic rock rather than from the basic plutonic rock such as hornblendite, owing to its transitional contact to the garnet bearing muscovite-biotite gneiss.

The quartz diorite gneiss ~ gneissose quartz diorite is white to greenish gray, massive and gneissose (Photos. 7. 9).

Under the microscope, it is coarse grained, equigranular and holocrystalline. It is composed of plagioclase, quartz mostly hornblende and/or biotite, a small amount of sphene, magnetite and/or apatite rarely associated with a small amount of potash feldspar showing indistinctive gneissose structure (Micropho to graphs 7 – 10).

Plagioclase: Subhedral crystals smaller than 5.0 mm showing distinctive albite twin are altered mostly or partly to sericite.

Hornblende: Subhedral crystals of 2.0 ~ 5.0 mm showing yellowish green to green pleochroism are altered partly or mostly to epidote, zoicite and chlorite.

Quartz: Anhedral grains of 2.0 ~ 5.0 mm are interstitially scattered.

Biotite: Flakes smaller than 1.0 mm showing brown to dark brown pleochroism are associated with hornblende. Some parts are altered to chlorite and epidote.

Sometimes it is strongly ~ moderately altered to sericite, chlorite, epidote and zoicite and volume ratio of each constituent mineral is estimated as follows:

Plagioclase >> (hornblende) > Quartz > (Biotite) > Magnetite · Sphene (Apatite)

Most of the Sadh gneiss is thought to have been probably formed by metamorphism from basic volcanic material associated with quartz dioritic injection.

Geological Structure

The gneissosity of the Sadh gneiss is generally concordant with that of the Juffa gneiss, but, is complicated and steep near Wadi Aingalf and Wadi Shiliyarn owing to the effect of faults.

Stratigraphic Relationship

As mentioned already, the relation to the underlying Sadh gneiss is concordant and intergradational. Also, the Sadh gneiss is penetrated by pegmatite, quartz vein, stock and dyke, and is covered unconformably with the overlying Mirbat sandstone formation in the northwestern part to Mirbat and with the Umm er Radhuma formation in the northern part to Juffa and near the coast.

3) Quartz diorite – granodiorite

Distribution

Quartz diorite ~ granodiorite is extensively distributed as a batholith of about 20 km in diameter in the northeastern part of the area. Also, a small body occurs about 3 km northward from Mirbat underlying the Mirbat sandstone formation unconformably.

Lithology

Megascopically it is light gray to gray, coarse-grained and holocrystalline.

Under the microscope, it is equigranular, holocrystalline and is composed of quartz, plagioclase, sometimes potash feldspar, mostly biotite and/or muscovite, and sometimes hornblede as main constituent minerals and magnetite, sphene and apatite as accessory minerals.

Quartz: Anhedral grains of 5.0 ~ 8.0 mm is distributed in the interstices of feldspar. Very small liquid ~ gas inclusion occurs generally in quartz, and rarely biotite is included.

Plagioclase: Subhedral ~ euhedral crystals of 2.0 ~ 5.0 mm show Albite and Carlsbad twins in unaltered crystals. Most of crystals are altered to feather-like sericite.

K-feldspar: Anhedral, subhedral or euhedral crystals smaller than 5.0 mm show perthite and micrographic textures.

Biotite: Subhedral ~ euhedral flakes of 1.0 ~ 3.0 mm show light brown to brown pleochroism and some parts are altered to chlorite and epidote. Apatite and magnetite are sometimes included in biotite.

Muscovite: A small amount of tiny flakes is scattered.

Hornblende: Subhedral crystals smaller than 4.0 mm including magnetite, apatite and sphene show yellowish green to green pleochroism.

Some parts are altered to zoicite.

Magnetite: A small amount of opaque magnetite smaller than 0.5 mm is distributed associated with biotite and hornblende.
Some include apatite.

Sphene: A small amount of subhedral~euhedral sphene smaller than 2.0 mm shows brown color and high index, generally associated with biotite or hornblende.

Apatite: Small crystals of colorless and low birefringence apatite are included in mafic minerals.

Most of these felsic plutonic rocks are weakly altered to sericite, chlorite, epidote and zoicite in general. Quartz diorite includes little or no potash feldspar, and on the other hand, granodiorite includes a fair amount of potash feldspar. These rocks are characterized by a large amount of plagioclase and quartz. Trondjemite (22–5–1) occurs as a dyke in quartz diorite at the outside of the geologic map shown in Fig. 11.

On the Q–Kf–Pl diagram shown in Fig. 14–A, Nos. 22–5–1 and 22–6 are plotted in quartz diorite and granodiorite regions respectively.

Geological Structure

The structural influence of the intrusion of batholith to the Sadh gneiss is still dissolved at this time. Also, an anticlinal appearance of gentle-dipping joints observed in the north to Hadabin may be due to cooling of the batholith. These problems will be solved by a further field survey.

Stratigraphic Relationship

The quartz diorite~granodiorite intrudes the Sadh gneiss and is penetrated by pegmatite, quartz vein, stock and dyke. Also, it is unconformably covered with the Mirbat sandstone formation in the north to Mirbat and with Umm er Radhuma formation in the north and partly in the east of the intrusive body.

4) Pegmatite and quartz vein

Distribution

Pegmatite and quartz vein are commonly distributed throughout the entire Precambrian area, showing vein-like, lenticular and network shapes.
These show about 1 m wide in average though some range up to several meters.

Lithology

Concerning quartz vein, it is almost composed of quartz and it is generally difficult to find out megascopically any other minerals.

Pegmatite is composed of large crystals of potash feldspar, mica and quartz and it is characterized by pink-coloured perthite.

Under the microscope, a part of pegmatite is described as follows (Photomicrograps 21, 22):

Quartz: Anhedral grains smaller than 5.0 mm constitute the most part of pegmatite and show mosaic structure.

Perthite: Huge crystals of perthitic structure are developed in quartz and plagioclase.

Plagioclase: Subhedral crystals smaller than 6.0 mm are present between perthite and quartz, showing well developed Albite twinning. Many crystals of muscovite~sericite are enclosed in the plagioclase crystals. Maximum size of muscovite crystals ranges up to 0.3 mm.

Stratigraphic Relationship

The age of intrusion of pegmatite is clearly later than the already mentioned Juffa gneiss, Sadh gneiss and quartz porphyry~granodiorite, and the pegmatite is clearly cut by the stock and dyke as described below.

5) Stock and dyke

Distribution

a) Stock

A hornblende adamellite stock in the Sadh gneiss with about 100 m diameter located about 13 km northwestward from the Juffa Camp is the largest one in the area. The others are distributed in the quartz diorite-granodiorite batholith in a smaller scale.

b) Dyke

Dyke is dominant in NW–SE strike and in the central area. It is also distributed near Mirbat in the western area and near Hadabin in the eastern area running in N–S. Furthermore, some dykes of NE–SW strike run obliquely to the above-mentioned directions. It is generally 10 to 30 m in width but continues up to several kilometers in strike length making ridges of undulating hills owing to their high registance for weathering and erosion.

Lithology

a) Stock

The adamellite stock is reddish gray to reddish brown and holocrystalline.

Under the microscope, it is holocrystalline, equigranular and composed of quartz, potash feldspar, plagioclase, hornblende, magnetite, sphene and apatite (Photomicrographs 27,28).

Quartz: Anhedral grains up to 2.0 mm ocuppy the interstices of feldspar.

K–feldspar: Anhedral-subhedral crystals smaller than 2.5 mm are abundantly present. Carlsbad twin and perthite structure are well developed.

Plagioclase: Subhedral crystals smaller than 2.5 mm are distributed showing Albite twin. Some parts of crystals are altered to sericite.

Hornblende: Small amount of hornblende smaller than 0.8 mm is sporadically scattered. Some parts are altered to chlorite.

Magnetite: Associating with hornblende, small crystals are present including frequently tiny crystals of apatite.

Sphene: Sphene with high birefringence, exsolution product of titaniferous magnetite, occurs in magnetite.

This hornblende adamellite (quartz monzonite) slightly suffers chloritization and sericitization. Volume ratio of each constituent mineral is estimated as follows:
K–feldspar > Quartz > Plagioclase >> hornblende > Magnetite, Sphene or Apatite.

The chemical composition and C.I.P.W. Norm of No. 22–2 are shown in Table 4. The chemical composition is quite similar to that of the alkali granite after Daly (1933).

On the Q–Pl–Kf diagram as shown in Fig. 13, No. 22–2 is plotted in an adamellite (quartz monzonite) region.

A name of hornblende adamellite is tentatively given to the stock though the data on research are very few.

b) Dyke

Basic facies (dolerite) and acidic facies (quartz porphyry-rhyolitic dacite) are megascopically discriminated. Under the microscope, the dyke is classified to dolerite and quartz porphyry.

<u>Dolerite (Photomicrographs 23 ~ 26)</u>

It is remarkably holocrystalline, showing porphyritic texture and intersertal structure.

Phenocryst is composed commonly of phagioclase, sometimes of pyroxene, and quartz. Subhedral phagioclase crystals of 2.0 ~ 4.0 mm showing Carlsbad and Albite twins are mostly or partly altered to sericite, muscovite and chlorite. Anhedral~subhedral quartz smaller than 2.0 mm is scattered. Small amount of subhedral~euhedral augite of 1.0 ~ 2.0 mm is distributed but it is mostly altered to chlorite and carbonate and partly to montmorillonite.

Groundmass is composed of plagioclase lath smaller than 1 mm showing Carlsbad twin, and montmorillonized and chloritized pyroxene, biotite flake and intersertally distrubuted tiny quartz, magnetite, etc..

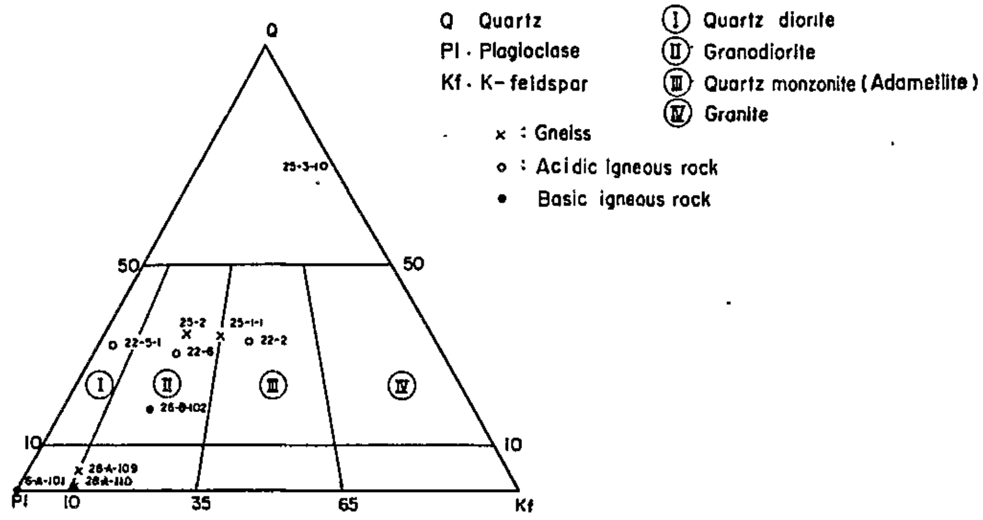
Generally speaking, alteration is modetate and volume ratio is estimated as follows:
Plagioclase >> Pyroxene > Quartz ≥ Biotite > Magnetite

A name "dolerite" is tentatively given to the basic dyke from the result of microscopic observation and chemical analysis.

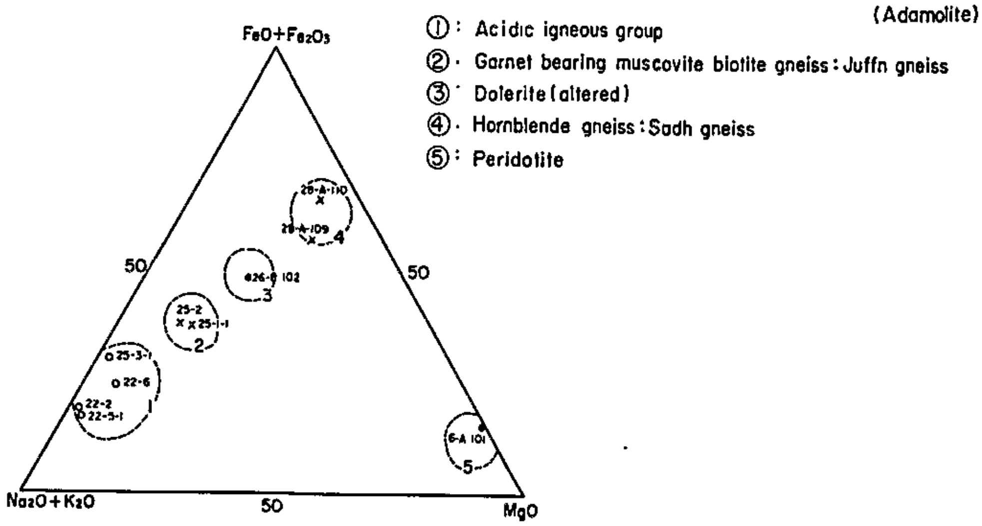
<u>Quartz Porphyry (Photomicrographs 29, 30)</u>

It shows remarkable holocrystalline, porphyritic texture.

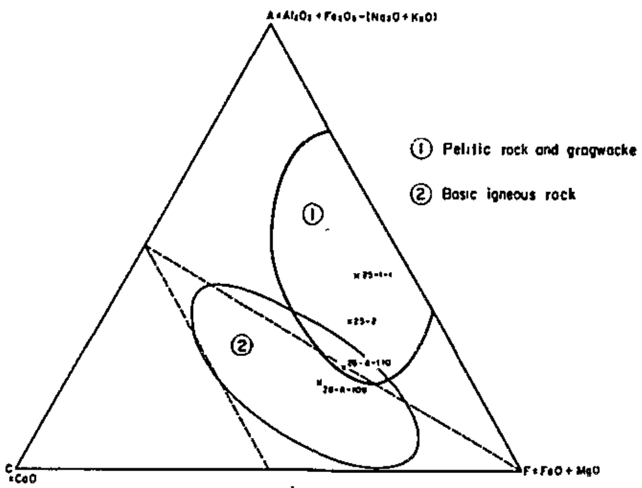
Phenocryst is composed of euhedral quartz of 2.0 ~ 3.0 mm and subhedral~euhedral plagioclase smaller than 2.0 mm. Plagioclase is often altered to sericite, carbonate, epidote, quartz, etc..



(A) Q-Pl-Kf diagram (Norm)



(B) (FeO+Fe2O3)-(Na2O+K2O)-MgO diagram



(C) A C F diagram

Fig. 14 Diagrams of Q-Pl-Kf, (Feo+Fe2O2)-(Na2O+K2O)-MgO, and A C F

Table 4 Chemical composition and C.I.P.W norm.

Area	Salalah area									Batinah Coast
Sample No.	25-1-1	25-2	28-A-109	28-A-110	22-6	22-5-1	26-B-102	25-3-1	22-2	6A-101
Rock name	Biotite gneiss	Biotite gneiss	Hornblende gneiss	Hornblende gneiss	Grano-diorite	Trondh-jemite	Dolerite	Quartz porphyry	Adamellite	Peridotite
SiO_2 %	65.26	68.86	49.80	37.16	70.39	72.82	54.62	78.99	74.29	42.39
TiO_2	0.61	0.60	1.35	3.21	0.21	0.07	0.95	0.06	0.14	0.10
Al_2O_3	17.54	14.70	14.08	12.63	15.55	16.03	16.44	12.93	13.27	2.21
Fe_2O_3	1.40	0.96	3.54	10.88	0.76	0.12	3.23	0.52	1.03	3.95
Feo	3.70	3.92	9.56	11.68	1.85	1.26	4.92	1 26	1.11	3.52
MnO	0.11	0.14	0.22	0.55	0.06	0.01	0.11	0.01	0.02	0.11
MgO	1.98	1.56	6.99	8.76	0 65	0.30	3.41	0.12	0.34	37.08
CaO	1.33	1.85	10.19	9.36	2.10	2.69	6.82	0.20	0.48	1.50
Na_2O	3.25	3.76	2.03	1.32	4.67	5.68	2.99	0.13	3.81	0.03
K_2O	2.97	2.35	0.86	0.77	2.41	0.45	2.10	3.80	4.85	0.03
P_2O_5	0.15	0.18	0.15	0.51	0.11	0.04	0.19	0.06	0.06	0.02
CO_2	–	–	–	–	–	–	1.94	–	–	0.44
$H_2O^{(+)}$	1.07	0.83	0.38	2.48	0.14	0.15	1.82	1.21	0.09	8.00
$H_2O^{(-)}$	0.22	0.12	0.18	0.08	0.23	0.08	0.18	0.52	0.24	0.42
Total	99.59	99.83	99.33	99.39	99.13	99.70	99.72	99.81	99.73	99.80

Q	27.3	29.4	1.9		27.8	30.7	13.0	62.3	32.0	
C	6.8	2.9			1.8	1.2	1.6	8.3	0.9	0.5
Or	17.8	13.9	5.0	4.5	14.5	2.8	12.2	22.3	28.4	
ab	27.3	32.0	17.3	11.0	39.3	48.2	25.2	1.0	32.0	
an	5.8	8.3	26 7	26.4	9.5	13.4	20.9	1.1	2.5	4.7
di wo			9.6	7.0						
di en			5 3	4.7						
di fs	4.9	3.9	3.9	1.8						
hy en	4.9	5.7	12.0	3.9	1.6	0.7	8.5	0.3	0.8	39.0
hy fs			8.9	1.5	2.5	2.1	5.0	1.8	0.9	1.4
Ol fo				9.3						37 4
Ol fa				3.9						1.5
mt	2.1	1.4	5.1	15.7	1.2	0.2	4.6	0.7	1.4	5.8
il	1.2	1.2	2.6	6.1	0.5	0.2	1.8	0.2	0.3	0.2
ap	0.3	0.3	0.3	1.3	0.3		0.3			
cc							4.4			
Total	98.4	99.0	98.6	97.1	99.0	99.5	97.5	98.0	99.2	91.5
Q+Or+ab	72.4	75.3	24.2	15.5	81.6	81.7	50.4	85.6	92.4	0
D I	73.6	76.1	24.5	16.0	82.4	82.1	51.7	87.3	93.1	0

Table 5 Chemical composition of various rocks

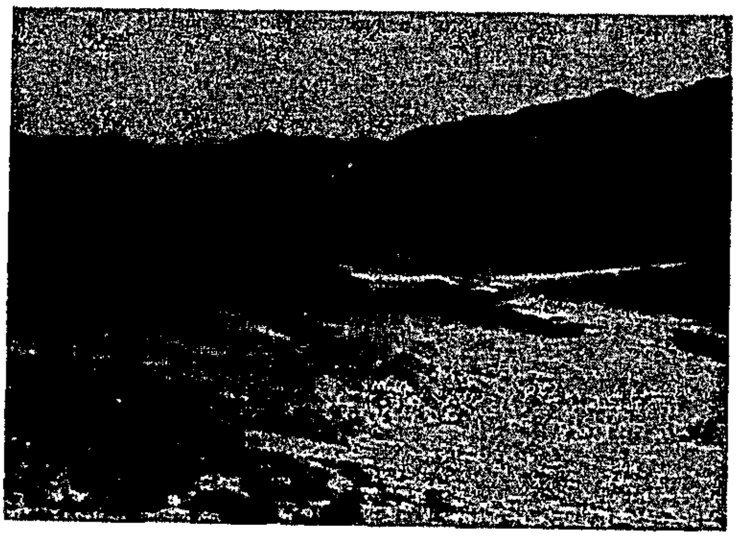
Composition \ Sample No.	1	2	3	4	5	6	7	8	9
SiO_2	63.50	69.60 ~ 77.74	79.03	49.06	50.48	45.31 ~ 47.63	66.34 ~ 74.12	70.18	73.30
TiO_2	0.71	0.18 ~ 0.50	0.40	1.36	1.45	1.51 ~ 3.37	0.15 ~ 0.39	0.39	0.11
Al_2O_3	16.88	7.29 ~ 11.32	10.81	15.70	15.34	13.33 ~ 16.94	13.18 ~ 16.92	14.47	12.33
Fe_2O_3	2.18	0.73 ~ 1.05	0.55	5.38	3.84	3.98 ~ 6.67	0.62 ~ 2.14	1.57	2.58
FeO	3.25	0.66 ~ 2.62	1.63	6.37	7.78	4.69 ~ 7.97	0.70 ~ 2.81	1.78	1.28
MnO	0.05	0.01 ~ 0.07	0.04	0.31	0.20	0.16 ~ 0.21	0.01 ~ 0.02	0.12	0.02
MgO	2.23	0.72 ~ 1.94	0.94	6.17	5.79	5.34 ~ 7.67	0.51 ~ 2.33	0.88	0.26
CaO	0.64	1.57 ~ 4.23	1.68	8.95	8.94	7.09 ~ 11.59	2.08 ~ 5.85	1.99	0.46
Na_2O	1.97	1.56 ~ 2.96	3.08	3.11	3.07	2.33 ~ 3.38	3.09 ~ 5.10	3.48	4.55
K_2O	4.00	2.14 ~ 3.16	1.43	1.52	0.97	0.52 ~ 0.67	0.24 ~ 2.45	4.11	4.20
P_2O_5	0.18	0.07 ~ 0.18	0.08	0.45	0.25	0.04 ~ 0.27	0.02 ~ 0.06	0.19	0.05
H_2O+	2.70	0.73 ~ 2.00	0.39	1.62 (H₂O+ and H₂O−)	1.89 (H₂O+ and H₂O−)	3.03 ~ 4.15 (H₂O+ and H₂O−)	0.58 ~ 1.62	0.84 (H₂O+ and H₂O−)	0.86 (H₂O+ and H₂O−)
H_2O-	0.53	0.01 ~ 0.40	0.01				0.11 ~ 0.66		
Total	98.82		100.10						

1. Average of 17 slates and their metamorphosed equivalents in the northern Kiso district in Japan [Katada M. (1967)]
2. Range in Compositions of 7 non-metamorphosed sandstone [ditto]
3. Biotite-gneiss [ditto]
4. All basalt (198 samples) [Daly, R.A. (1933)]
5. All diabase (90 samples) [ditto]
6. Actinolite epidote schist (4 samples)[Shibata H. (1968)]
7. Trondjemite (9 samples) [ditto]
8. All granite (546 samples) (Daly)
9. Alkaline granite (12 samples) (Daly)

Photo. 1 Juffa gneiss (25–1)

The Juffa gneiss showing a typical appearance of thin-banded structure composed of dark (biotite, muscovite) and light (quartz and plagioclase) parts.

Photo. 2 Juffa gneiss (25–1)



The hornblende gneiss, a few-meter-thick, black part distributing approximately horizontally in the middle of photograph, exists as an intercalation of granet bearing muscovite-biotite gneiss.

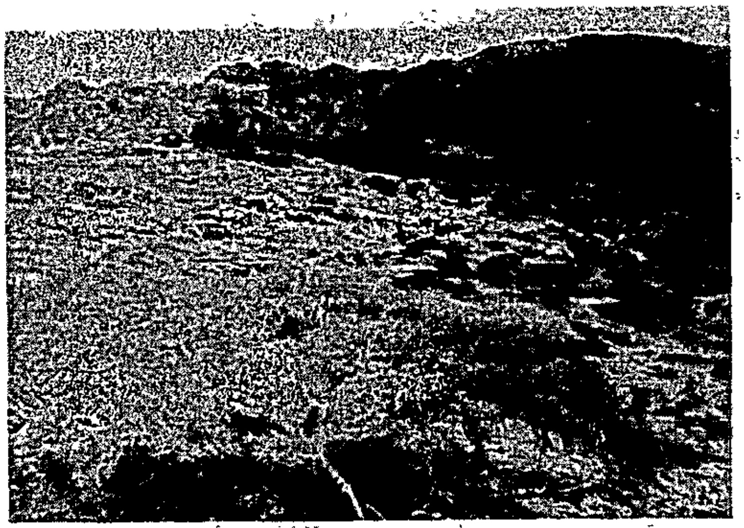
Photo. 3 Juffa gneiss (26–B–101～103)

The Juffa gneiss showing a typical gneissose structure. A dolerite dyke, the upper part, cuts clearly the gneissosity.

Photo. 4 Juffa gneiss (22–3–2)

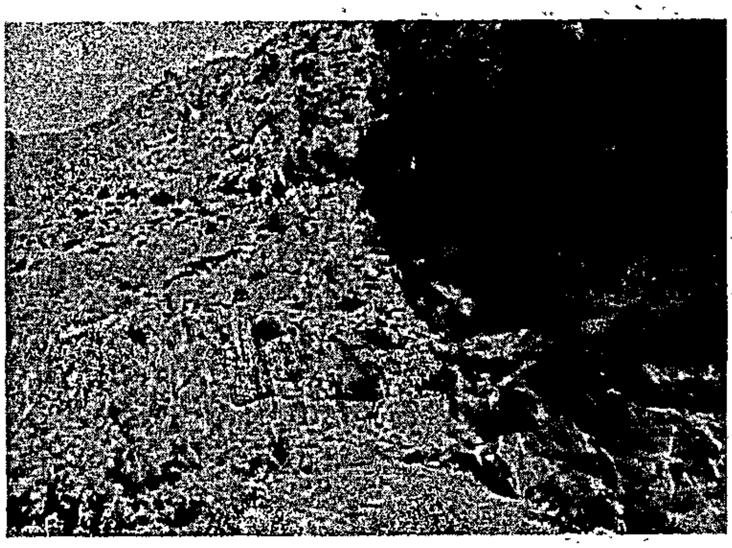
Biotite gneiss (black part along the hammer) in muscovite-biotite-quartz diorite (white part)

Photo. 5 The boundary between Juffa gneiss and Sadh gneiss (28–A–109)



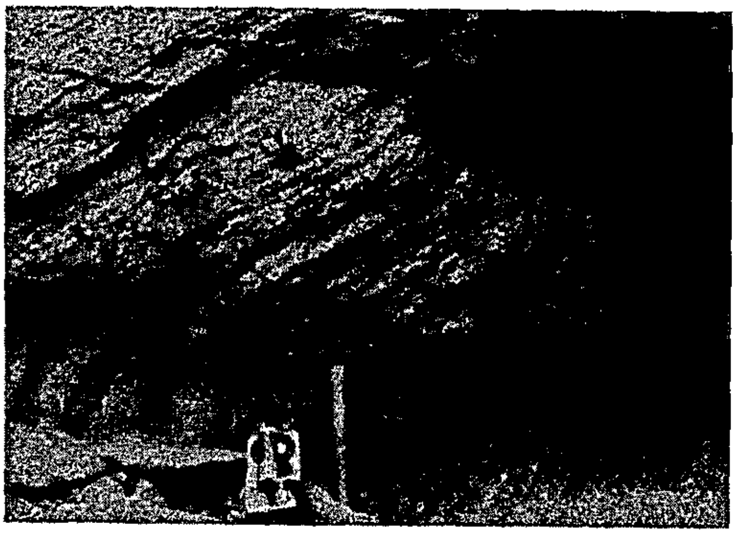
The Sadh gneiss overlies Juffa gneiss at Wadi Shaat.
The Sadh gneiss (black, upper part) forming a steep slope and the Juffa gneiss (gray, lower part) forming a gentle slope show a common gneissosity.

Photo. 6 Ditto (28–A–110)



The Sadh gneiss (black, right part) occupies apparently an upper position to the Juffa gneiss (gray, left part) at Wadi Ain. The Juffa gneiss has intercalations of hornblend gneiss (black part) and the both gneisses seem to have a gradual transition.

Photo. 7 . Sadh gneiss (28–A–104)

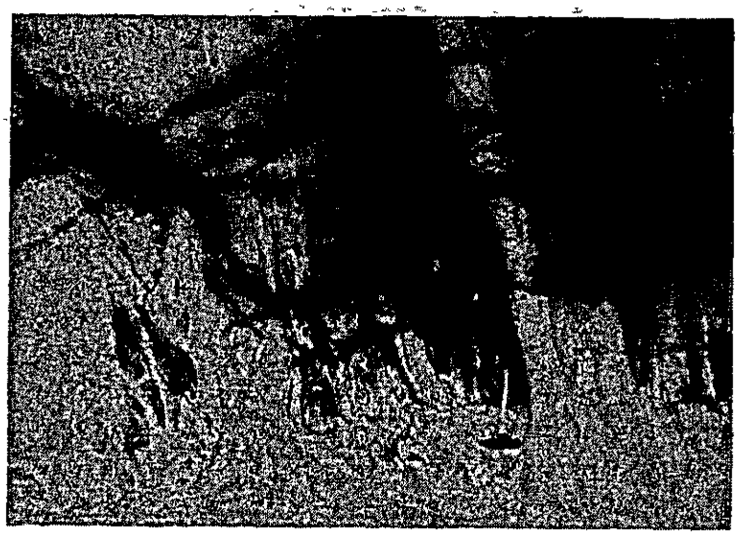


The Sadh gneiss showing a typical gneissose structure composed of banded dark hornblende gneissose part and light quartz dioritic part at Wadi Jish Jesh.

Photo. 8 Sadh gneiss and Juffa gneiss (28–A–110)

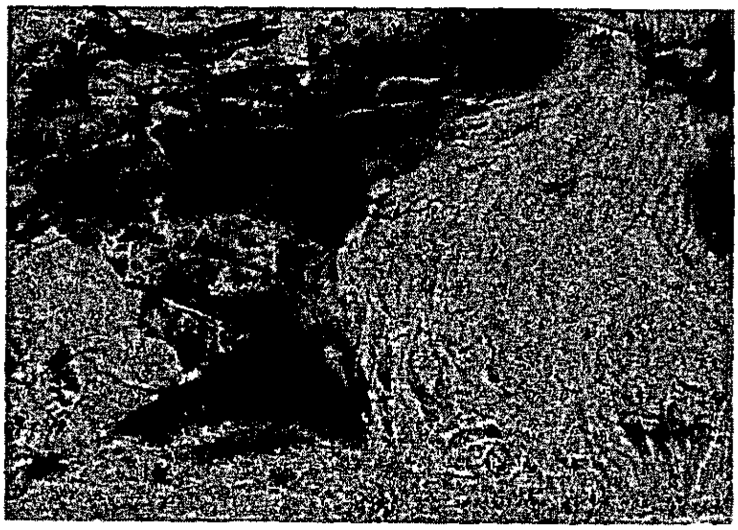
The Sadh gneiss showing various appearances on one outcrop at Wadi Ain. This part is very close to the boundary between Juffa gneiss and Sadh gneiss.

Photo. 9 Sadh gneiss (28–A–101 ~ 102)



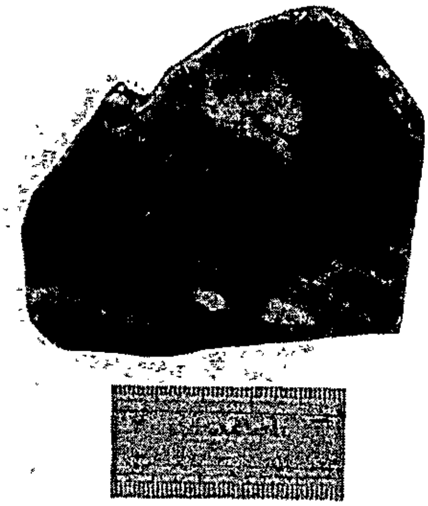
The Sadh gneiss showing a typical mode of occurrences on the bank of Wadi Jish Jesh. Black part is hornblendite or hornblende gneiss, gray part is gneissose hornblende rich quartz diorite, and white part is hornblende poor quartz diorite. The white part cutting the gneissosity is pegmatite.

Photo. 10 Sadh gneiss (28–A–101 ~ 102)



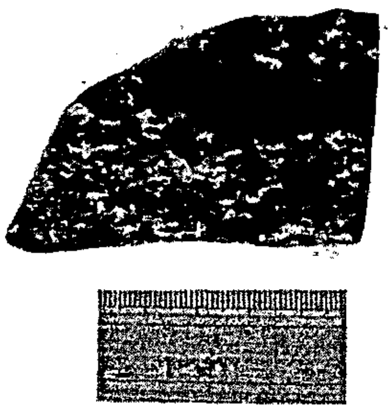
ditto
Veins (narrow white part in the gray, left middle part) and a pool (white, left, irregular part) in the Sadh gneiss.

Photo. 11 Sadh gneiss (22–8)



The polished surface of the Sadh gneiss near the mouth of Wadi Aingalf showing a typical banded structure. This rock shows the highest radioactivity in the surveyed area.

Photo. 12 Sadh gneiss (28–A–102)



The polished surface of the Sadh gneiss at Wadi Jish Jesh showing a parallel arrangement of hornblende crystal (black part).

Photo. 13 Granophyre dyke cutting quartz-vein (25–3–2)

The near-vertical granophyre dyke about 30 meters in width, which makes a ridge cuts the quartz vein which is white and runs apparently horizontally.

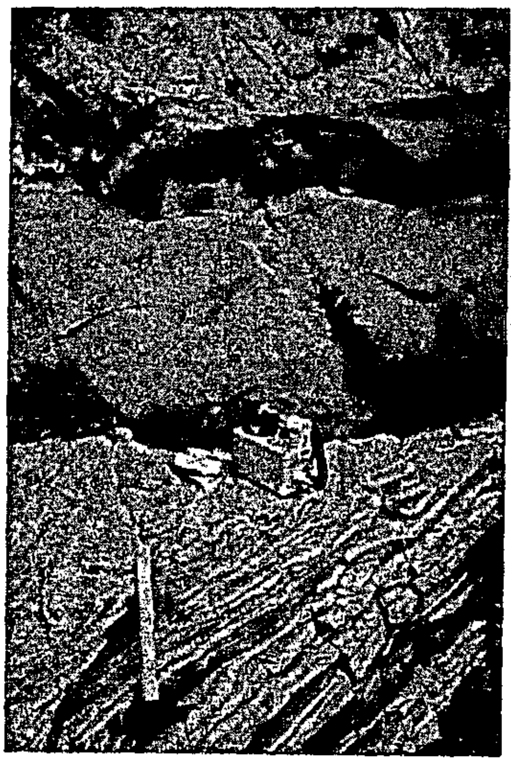
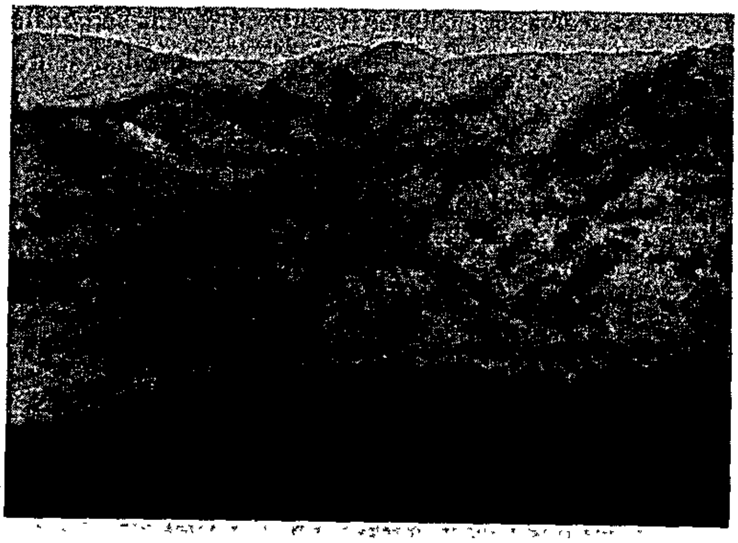


Photo. 14 Quartz parphyry and dolerite dykes (26–B–101 ~ 103)

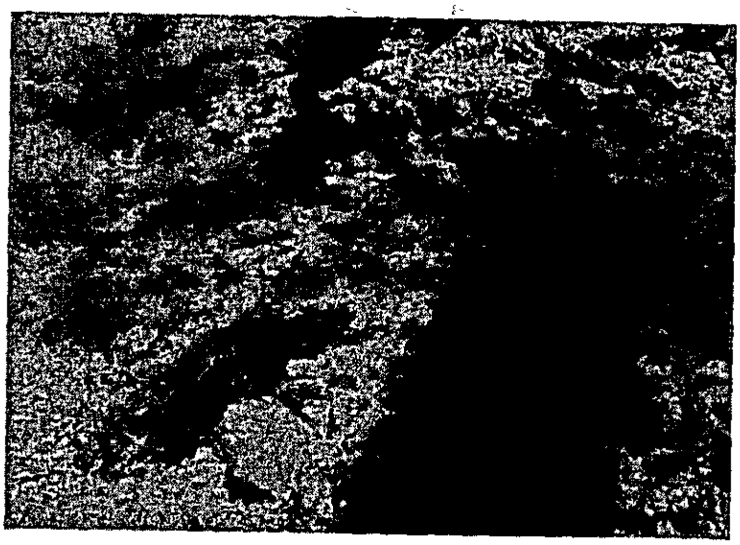
A dolerite dye, middle black part, cuts the Juffa gneiss, lower banded part, and a quartz porphyry dyke, upper white ~ gray part, cuts the dolerite dyke in which quartz porphyritic veinlets develop.

Photo. 15 Dykes in Juffa gneiss



Dykes (darker elongating part) develop and some form continuous ridges because of their higher resistance for weathering (from the vicinity of old lead pit).

Photo. 16 Dolerite dyke cutting pegmatite (26–A–101 ~ 104)



A dolerite dyke (black part) cuts a pegmatite dyke (white part) along strike side and both dykes are shifted about 3 meters to the left side by a fault.

Groundmass is composed of tiny quartz grain, plagioclase lath of 0.5 mm, muscovite up to 1.0 mm etc., showing mosaic structure, and one sample shows myrmekitic or granophyric structure. Plagioclase of groundmass is mostly altered to sericite and carbonate develops in druses.

The chemical composition of No. 25–3–1 shown in Table 4 is very peculiar in point of abundance of SiO_2 and scantiness of the composition other than Al_2O_3 and K_2O. The reason is due to strong silicification and moderate sericitization.

A name of quartz porphyry is collectively given to the acidic dyke.

Geological Structure

The dyke swarms develop abundantly on the Precambrian peneplain, mostly showing paralell arrangement in NW–SE making ridges of undulating hills, and the drainage system also develops paralell to the dyke swarms. This direction seems to correspond to the direction of maximum stress to the already mentioned anticline in the gneiss and the dyke swarms are thought to intrude into tension cracks formed in paralell to the maximum stress direction.

Stratigraphic Relationship

The dyke and stock are observable to penetrate gneiss and quartz diorite~granodiorite as well as pegmatite and quartz vein in many locations and dolerite is clearly penetrated by quartz porphyry in 25–4 and 26–A–101 points (Photos. 15. 16). The adamellite stock is contemporaneous with the quartz porphyry dyke because the latter develops radially from the former in the northwest to the Juffa Camp.

The relation to the overlying Mirbat sandstone formation could not be actually observed, it is obviously deduced that the stock and dyke are unconformably covered with the Mirbat sandstone formation because the result of age determination on the above-mentioned adamellite stock shows about 540 million years.

2–6–2 Ordovician System (Mirbat sandstone formation)

Distributution

The Mirbat sandstone formation unconformably overlying the Precambrian basement is distributed in the western area extending to NNE~NE from the coast about 2 km north-northwest of Mirbat to the point about 3.5 km west-southwest of the adamellite stock 900 m in altitude. The formation is unconformably covered with the Cretaceous to Tertiary Umm er Radhuma formation which is distributed in the area approximately over 1,000 m in altitude in the upper part of escarpement. The foramtion is thicker in the western part and wedges out eastward between the Precambrian basement and the Umm er Radhuma formation.

Lithology

The formation is divided into the Lower member mainly composed of arkose sandstone about 690 m thick, the Middle member mainly composed of sandstone and siltstone about

325 m thick and the Upper member mainly composed of shale, siltstone and sandstone about 315 m thick (Taylor Woodrow – Towell Co., 1977).

The Lower member consists of basal conglomerate and granule bearing fine-grained arkose sandstone intercalating thin beds of siltstone.

The Middle member consists mainly of alternations of fine to medium-grained sandstone and siltstone. The Upper member consists mainly of shaly silt-stone and silty shale though some sandstone intercalations in the upper part and 2 ~ 8 m thick massive sandstone with irregular base in the lowermost.

In this survey, two geologic columnar sections, showing geological sucession of a part of the Lower member from the base at the left bank of Wadi Marsham, and of a part of the Middle and Upper members at Jabal Shereef, are respectively made as shown in Figs. 15 and 16.

Geological succession on Wadi Marsham is as follows:

The basal conglomerate 1 ~ 3–m–thick develops on the sericitized Precambrian quartz diorite. Gravels of the basal conglomerate are composed of subangular cobble boulder of quartz diorite. The unconformity plane shows N 15° E strike, 20° NW dip in some parts and N 50° E strike, 10° NW dip other parts. Irregular, red jasper veins develop in some parts of the basement and basal conglomerate.

10 ~ 22m: coarse-grained sandstone and conglometate partly with siltstone intercalations.

22 ~ 35.5m: mainly medium-grained sandstone and an alternation of medium- and fine-grained sandstones 4–m–thick in the uppermost.

35.5 ~42.5m: alternations of mudstone and fine-grained sandstone.

42.5 ~ 50m: medium~coarse sandstone including some round granitic bouiders rarely up to 1 m in diameter.

50 ~ 67.5m: alternations of about 20–cm–thick, medium-grained sandstone and about 50–cm–thick, silty, fine-grained sandstone or siltstone.

67.5~71.3m: pinkish purple, massive, coarse-grained sandstone

71.3m ~ : alternations of 30–cm–thick, medium-grained sandstone and 5 ~10 cm thick siltstone.

Sandstone of the lower part of the Lower member is generally arkose and baddly sorted in the basal part, and the basal conglomerate includes subangular cobble~boulder of granitic rock which constitutes the underlying basement. Therefore, the constituent material of the basal part is thought to be derived from the adjacent basement.

The matrix of sandstone is mainly composed of carbonate material (Photomicrographs 33 · 34).

Jabal Shereef is a small prominent mountain standing about 170 m above the

peneplain, showing continuous exposure from base to top (Photo. 19).
Geological succession is as follows:

0 ~23.4m: mainly medium-grained sandstone, a layer 3.4-m-thick composed of abundant quartz grains and light-green gneiss pebbles at the uppermost.

23.4 ~ 43m: varicolored siltstone with intercalations about 15 cm thick, fine-grained sandstone, ripple mark on the upper surface of sandstone at 36.6m (Photo. 20) showing the direction of wave in N 50° E – S 50° W.

43~57m: mainly alternations of medium-grained sandstone and siltstone, partly alternations of fine-grained sandstone and siltstone, channel structure in coarse-grained sandstone at about 53 m with a thicker siltstone intercalation and coarser sandstone (Photo. 21).

57 ~ 70m: mainly siltstone with alternations of fine-grained sandstone and siltstone in the upper part.

70 ~ 82m: mainly massive, medium-to coarse-grained sandstone, alternations each about 10-cm-thick, fine-to medium-grained sandstone and siltstone in the middle part, cross bedding at 77m (Photo. 22).

82 ~ 89m: alternations of each about 50-cm-thick, fine-grained sandstone and siltstone.

89 ~ 108m: alternations of about 1-m-thick, medium-grained sandstone and 10 ~ 50-cm-thick, fine-grained sandstone or siltstone.

108 ~ 115m: massive, medium-grained sandstone with intercalations of about 20-cm-thick, fine-grained sandstone, siltstone and shale.

115 ~ 168m (summit) : alternations of siltstone and shale with intercalations of under 5-cm-thick, fine-grained sandstone.

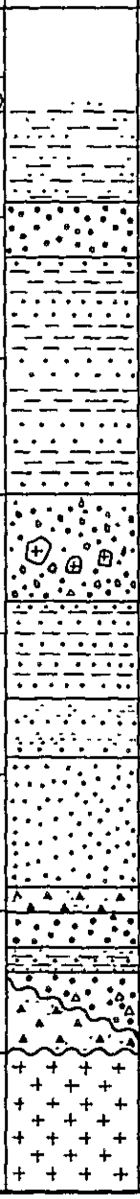
As mentioned above, medium-grained sandstone occupies the part from 0 m to 115 m and it is about a half of the whole. The upper part from 115 m is mostly composed of shale and siltstone. In this survey, the boundary between Lower and Upper members is tentatively decided at 115 m. The occurrence of channel structure and ripple mark shows that the formation is sedimented in shallow water under the influences of wave and running water.

Geological Structure

The Mirbat sandstone formation generally dips gently to NNW. Measured stride and dip of the Lower member show N10°~35°E strike and 40°NW dip at the base and 15°NW dip in the upper part, and those of the Middle and Upper members show N–S~N 40°E strike and 8°~15° dip. There is no remarkable fault or folding.

Stratigraphic Relationship

As mentioned already, the Mirbat sandstone overlies unconformably the Precambrian basement and underlies unconformably the Umm er Radhuma formation, and is thought to be Ordovician.



Member (Total thickness)	Lithology (Thickness)	Radioactivity (μR/Hr)	Remarks
Lower member (80m) (77.5m)	buff and gray alt of m s.s (30cm thick) and sls (7m+)	•75.0m 12~16(sls) •71.0m 12~16(m ss.)	
(70m)	purple c. arkose ss (3.8m)		•N25°E NW15°
(60m)	blackish gray alt of m ss. (20cm thick) and silty ss or sls (50cm thick) (17.5m)	•62.0m 9~12(sls) •52.5m 6~8(m.ss.)	•N20°E NW18°
(50m)	gray c.~m. ss. rarely with subangular granite cobbles (7.5m)	•45.0m 6~(m.ss.)	•N20°E NW35°
(40m)	gray~buff sls. with thin m. ss seams (7m)	•38.0m 6(m ss)	well-bedded N10°E NW20°
	buff alt of m and f. ss (4m)	•32.5m 9(f ss)	•N30°E NW22°
(30m)	gray~buff m arkose ss rarely with f ss inter (9.5m)	•27.5m 5(m ss) •23.0m 5(m. ss)	•N35°E NW40°
(20m)	congl with c ss (2m)		
	c. ss. (2.2m)		
	alt of massive m ss. and f ss (2m)	•16.5m 15(sls)	29-A-103
(10m)	buff c ss with granite boulders (5.0m) congl (1~3m)	•13.0m 6(m ss) •10.5m 5(congl)	29-A-101 (Matrix of congl)
Pre-C. (0m)	quartz diorite (10m+)	•5.0m 5	intrusive rock of Precambrian basements

Abbreviations

sandstone	: ss	coarse-grained	: c	alternation	: alt
siltstone	: sls	medium-grained	: m	intercalatios	: inter.
mudstone	: ms	fine-grained	: f.		
shale	: sh.				

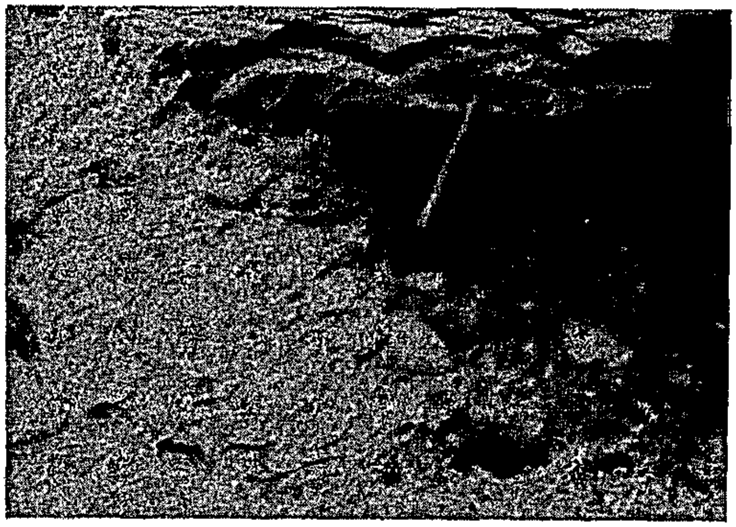
Fig. 15 Geologic columnar section showing radioactivity of the Mirbat sandstone on the left bank of Wadi Marsham

Member (Total thickness)	Columnar section	Lithology (Thickness)	Radioactivity (μR/Hr)	Remarks
Upper member	(168m) (160m) (150m) (140m) (130m) (120m)	buff ~ gray alt of sls and sh with 5cm thick f ss (53m+)	•144.6m 11 (sls.) •140.7m 11 (") •134.0m 12 (") •126.2m 12 (") •123.0m 14 (") •117.8m 10 (")	
Middle member	(110m)	(7m) massive m ss with f. ss., sls and sh (20cms) inter	•113.2m 12 (") •108.2m 9 (m.ss)	
	(100m) (90m)	buff ~ gray alt of m ss, f. ss., sls and sh. (19m)	•105.6m 13 (sls) • 98.6m 15 (") • 93.3m 10 (m ss.)	•N15°E W14° •N30°E NW8°
		buff-gray 10cm± alt of f ss and sls (7m)	• 87.6m 12 (sls)	
	(80m)	(4m) buff massive m ss with f ss and sls	• 81.8m 9 (m ss.)	
		(4m) buff alt of m ss, f ss and sls	• 75.0m 6 (")	•N40°E NW12° cross bedding
	(70m)	(4m) buff massive m. ~ c ss	• 70.3m 5 (")	
		(7m) buff 20~30cm alt of f. ss and sls.	• 66.7m 10 (f ss) • 64.0m 11 (sls.)	•N35°E NW15°
	(60m)	(6m) buff sls with f ss inter.	• 58.0m 14 (sls)	
		(4m) buff alt of m ss and sls	• 56.0m 14 (sls) • 55.0m 8 (m.ss.)	channel structure
	(50m)	(4m) buff 10cm alt. of sls and f. ss.	• 52.0m 11 (sls) • 51.5m 8 (m.ss)	
	(40m)	(6m) buff 30~60cm alt of m ss and sls	• 43.4m 8 (m ss.)	•N30°W SW12°
	(30m)	buff, gray, white, purple sls with 15cm± f. ss inter. (19.6m)	• 36.6m 10 (f.ss) • 28.0m 10 (sls.)	ripple mark •N-S W10°
	(20m)	(3.4m) buff m ss with pebbles	• 21.0m 10 (m ss)	•N25°W SW10°
	(10m)	buff massive m. ss with 20~30cm thick f ss inter. (12m)	• 14.0m 10 (m ss) • 9.8m 14 (sls)	•N6°E W8°
	(0m)	(8m) buff massive m ss with 70 ~ 80cm thick f. ss. inter.	• 2.5m 15 (f.ss.)	•N60°E W10°

Abbreviations are same as those of Fig. 15

Fig. 16 Geologic columnar section showing radioactivity of the Mirbat sandstone at Jabal Shereef

Photo. 17 Basal conglomerate of Mirbat sandstone formation (29–A–101)

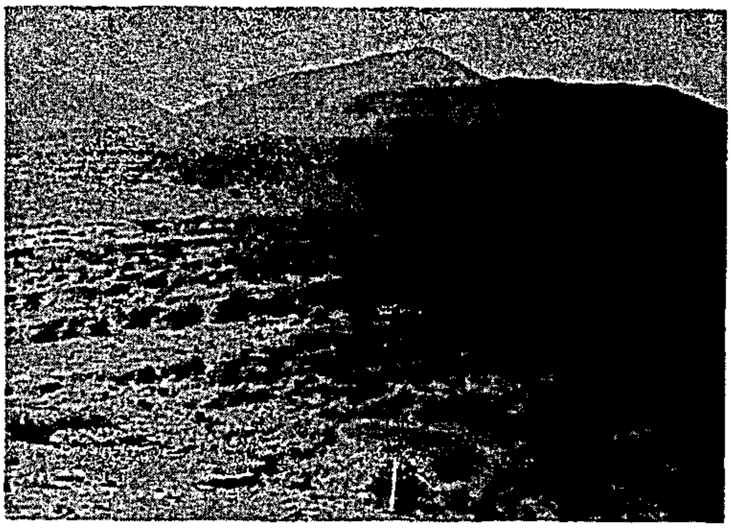


Basal conglomerate is composed of subangular and subround Precambrian muscovite-quartz diorite gravels up to boulder size and sandy matrix. The matrix consists of grains of abundant quartz diorite, quartz, plagioclase, muscovite and matrix of carbonate.

Ptoto. 18 The Lower member of Mirbat sandstone formation (22–10)

Coarse-grained, arkose sandstone of the uppermost part of the Lower member.

Photo. 19 Jabal Shereef



Jabal Shereef is composed of largely the Middle member of the Mirbat sandstone formation which consists of alternations of sandstone and siltstone and/or shale. The uppermost part of about 53 meters is composed of the Upper member.

Photo. 20 Ripple mark

Ripple mark is present on medium-grained sandstone of the Middle member on the slope of Jabal Shereef.

Photo. 21 Channel structure

Channel structure is present in massive medium-grained sandstone of the Middle member on the slope of Jabal Shereef.

Photo. 22 Cross-bedding

Channel structure is present in massive medium-grained sandstone on the slope of Jabal Shereef.

2–6–3 Cretaceous – Tertiary System (Umm er Radhuma formation)

The formation gently overlies the Precambrian basement and the Mirbat sandstone formation unconformably.

Most of the formation is distributed in the upper part of the north escarpment, forming a tableland of Jabal Samhan, at over about 1,000 m in altitude (Photos. 23. 24). It also overlies the Precambrian basement on Jabal Nuss, Jabal Habarit, etc. in the eastern part with continuous distribution from 500 m to 900 m in altitude. Furthermore, it is narrowly distributed as outlier on the upper part of Jabal Musayrah at over 200 m in altitude and of Jabal Qinqari at over 50 m in altitude. The Umm er Radhuma formation has very gentle dip.

At the 22–3 point, 10 ~ 20-m-thick limestone conglomerate including angular~ subangular cobble~boulder is distributed overlying the Precambrian muscovite-biotite-quartz diorite. In the conglomerate, several tens-m-thick, reddish-purple, fine-grained sandstone is intercalated, which consists of subangular quartz grains and matrix of spherical limonite and irregular, tiny grains of silicate minerals under the microscope (Photomicrographs 35. 36). Calcareous foraminifera, *Rotaria* sp., is identified in the limestone and it suggests netric and oceanic environment.

2–6–4 Quaternary sediments

1) Raised beach sediments

The sediments are distributed mainly on the plateau at 100 ~ 200 m in altitude from near Mirbat to near Juffa Camp and partly on the lowland near the coast. It is poorly sorted and composed of gravel, sand and silt as well as shell.

2) Beach sand and aeolian sand

The Beach sand is distributed at Mirbat and its western side and western side of Jabal Musayrah. The aeolian sand dune develops near Wadi Anshayr east of Mirbat.

3) Gravel and sand on Wadi bed

The Wadi sediments are distributed on the main wadi beds of several tens~several hundreds meters in width and are mostly composed of coarse-grained sand and gravels up to boulder size. Because of insufficient stream, sorting is very bad and fine fraction is very rare.

2–7 Age Determination

Age determination by K–Ar method has been carried out on the samples of each rock type as fresh as possible. The result is shown in Table 6.

No. 25–1–1 is a scarcely altered garnet bearing muscovite-biotite gneiss sample belonging to the Juffa gneiss. No. 28–A–109 is a hornblende gneiss sample belonging to the Juffa gneiss in which volume of hornblende is about 70 % and plagioclase is strongly sericitized and epidotized. No. 22–6 is a muscovite-biotite granodiorite sample belonging

Photo. 23 Umm er Radhuma formation (near 22–2)

The Umm er Radhuma formation (well-bedded part) uncomformably overlies the Precambrian basement rock and make a near-vertical escarpment of Jabal Samhan.

Photo. 24 Umm er Radhuma formation

A typical topography of the near-horizontally bedding Umm er Radhuma formation on Jabal Samhan, from helicopter.

to quartz diorite~granodiorite intrusives in which some crystals of plagioclase and biotite are altered to sericite, chlorite and epidote. No. 27–A–105 is fresh perthite in pegmatite. No. 22–2 is a hornblende adamellite sample collected from the stock mentioned already and is partly altered to sericite and chlorite. Accordingly, No. 25–1–1 and 27–A–105 are thought to show exact ages but the other three are thought to show younger ages than true ages owing to their alteration though it is obsecure that the alteration happened simultaneously, immediately after or fairly after the formation of each rock. Age and standard deviation σ are given as result of calculation as shown in Table 4. An empirical error of age is 5% in the laboratory where this experiment is carried out, and this value corresponds approximately to about two times σ in this case.

The result is as follows taking into consideration on each error

No. 25–1–1	734.7 ± 36.7 million years
No. 28–A–109	662.8 ± 33.1 million years
No. 22–6	640.2 ± 32.0 million years
No. 27–A–105	576.7 ± 28.8 million years
No. 22–2	537.5 ± 26.9 million years

Taking each error in consideration, Nos. 25–1–1 and 28–A–109, Nos. 28–A–109 and 22–6 and Nos. 27–A–105 and 22–2 seem to have been formed simultaneously. If Nos. 25–1–1 and 28–A–19 were simultaneously metamorphosed to gneiss judging from the gradual transition between the two types of gneisses, then age of the metamorphism is thought to be around 700 million years. Geological succession of these Precambrian rocks based on the field observation is quite concordant with the result of age determination.

The boundary between Precambrian and Paleozoic is said to be 564 million years and the result of age determination of the adamellite stock shows 537.5 ± 26.9 million years. If an error of 26.9 million years is taken into consideration, the age of the stock may belong to Precambrian.

The oldest Precambrian age shown in Saudi Arabia is 1,200 million years (Defour, 1975), and the Eastern granite group in South Yemen has an age renge of about 600 ~ 640 million years based on Rb–Sr method of biotite from two samples (Brown and Jackson, 1960). In comparison with these ages, the result on the Precambrian basement in the Salalah area is thought to give an appropriate range of age.

2–8 Mineral Deposits

Data on the mineral deposits in the area are very scanty and only some descriptions on copper, lead, iron etc. without exact locations are available up to the present.

The survey was carried out for the metallic minerals and uranium as main subject.