REPORT ON GEOLOGICAL SURVEY OF THE SULTANATE OF OMAN

(SUR AREA)

PHASE III

MAY 1983

JAPAN INTERNATIONAL COOPERATION AGENCY

METAL MINING AGENCY OF JAPAN

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PREFACE

The Government of Japan, in response to the request of the Government of the Sultanate of Oman, decided to conduct a geological survey for mineral exploration in the Sultanate of Oman, and commissioned its implementation to Japan International Cooperation Agency.

Considering its technical aspects, the agency sought collaboration of Metal Mining Agency of Japan to accomplish the task within a period of three years.

As for this current year, a survey team was formed consisting of 9 members headed by Dr. Haruo Kousaka, staff of Metal Mining Agency of Japan, and sent to the Sultanate of Oman between November 8 and December 28, 1982 to conduct the third phase of the project.

The survey has been accomplished under close cooperation with the Government of the Sultanate of Oman and its various authorities.

This report hereby summarized the results of the aforementioned undertaking.

We wish to express our heartfelt gratitude to the Government of the Sultanate of Oman and other authorities concerned for their kind cooperation and support extended to the Japanese survey team.

March 1983

Keisuke Arita
President
Japan International Cooperation Agency

Masayuki Nishiie
President
Metal Mining Agency of Japan

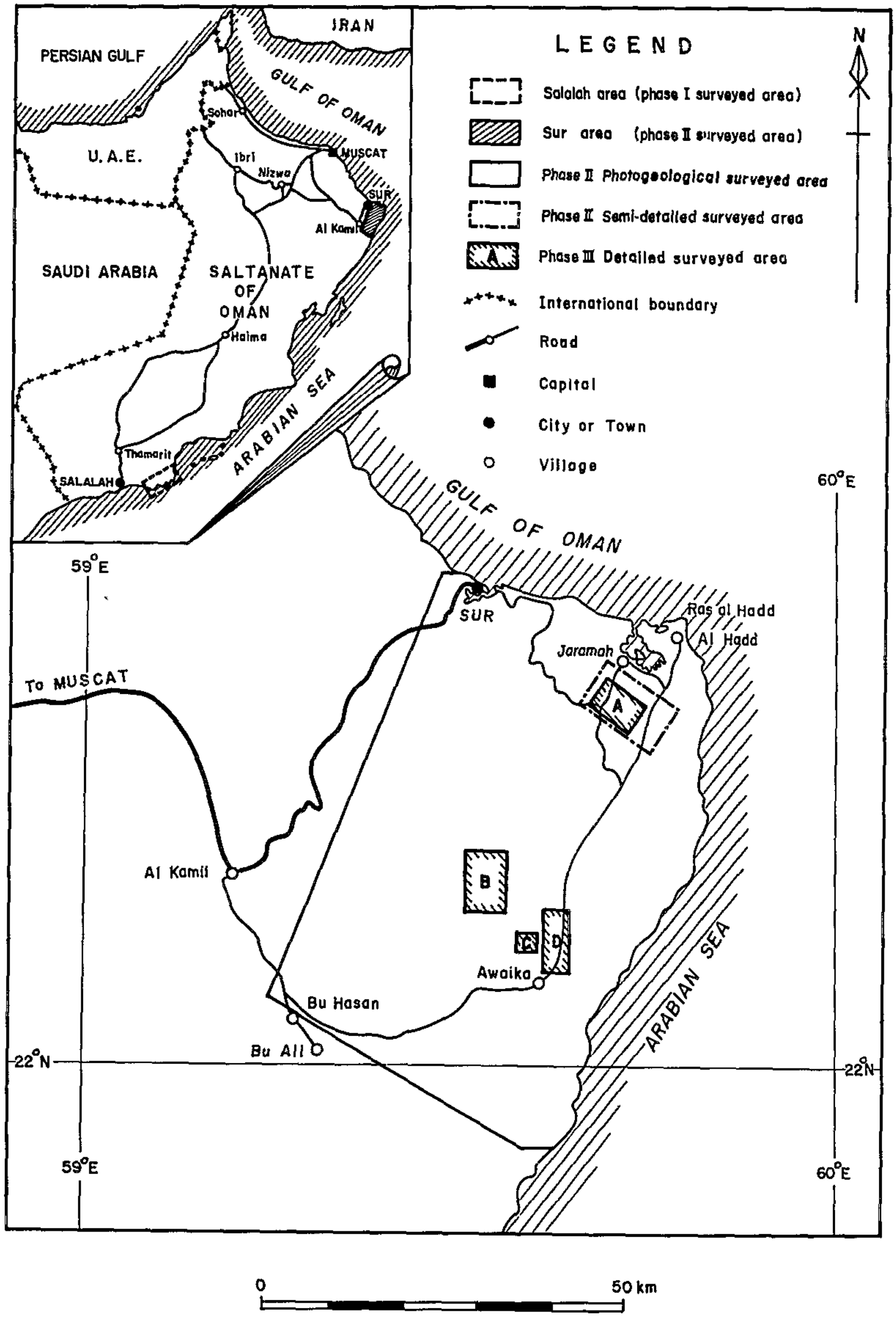

Fig. 1 Location Map of the Sur Area

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ABSTRACT

In the survey of the third year in the Sur area of the Sultanate of Oman, the geological survey, trenching survey and drilling survey were carried out to clarify the occurrence, scale and continuity of manganese ore deposits for evaluating the potentialities of ore deposits in the surveyed area.

The geology of the Sur area is composed of Precambrian basement rocks, Triassic to Early Cretaceous Halfa Formation thrusting over the basement rocks, Maastrichtian to Middle Tertiary Limestone Formation unconformably overlying the basement rocks and the Halfa Formation, and Quaternary sediments overlying all of them.

The geology of the area of this year consists of the Halfa Formation, Tertiary Limestone Formation and Quaternary sediments. The Halfa Formation consists of radiolarian chert, shale and limestone in this area, and is divided into the Upper, Middle and Lower Members.

In this survey, the structure of the Halfa Formation, showing very complicated structure by many folding and faults, was made clear by the subdivision of the Middle Member, which contains manganese ore deposits.

The situation of ore horizon also became clear.

Manganese ore deposits occurring in the alternating bed of reddish brown chert, muddy chert and shale are composed of several small discontinuous manganese beds or lenses accompanied with manganese nodular zone.

Ore outcrops are distributed throughout the whole area of the Middle Member of the Halfa Formation.

Most of the ore outcrops are small scale.

It is clarified by the drilling survey that the continuity in direction of dip side is discontinuous.

Total ore reserve in the surveyed area is 520,000 ton with average grade of 29.57% MnO_2, assuming that ore beds continue down to 30 meters below the surface.

As a result of discussion and evaluation based on the numerous basic data, although manganese ore deposits are recognized in the Sur area, it seems that the development of ore deposits is not profitable at the present time because of their small scale, thin bed type, low grade and sporadic distribution.

GENERAL INFORMATION

Chapter 1. Outline of the Survey

1–1 Details and Purpose of the Survey

The Government of Japan conducted the survey for mineral resources development plan by Japan International Cooperation Agency from March 15 to April 17 in 1979 in order to confirm the possibility of mineral resources in the Oman upon a request of the Government of the Sultanate of Oman. During the survey, preliminary surveys on geology and ore deposits were conducted in three areas such as Salalah, Sur and Batinah Coast, and as the result, Salalah and Sur areas were selected as promising areas to be continued the survey in future.

On the basis of results of survey, the both Government of Japan and Oman reached agreement for performing the basic survey for mineral resources exploration in the two selected areas from fiscal 1980 as the first year, and the Government of Japan consigned the execution of survey to Japan International Cooperation Agency (JICA) and Metal Mining Agency of Japan (MMAJ).

In July 1980, an agreement of the scope of work for this project has been signed by the two agencies and the Ministry of Petroleum and Minerals of the Sultanate of Oman, and the field survey of the first year was commenced in the Slalah area and of the second year was commenced in the Sur area.

The survey in the Salalah area, the southern part of the Sultanate of Oman, was carried out for three months from September 26 to December 25 in 1980. The results showed no existence of significant ore deposit to expect further exploration, except some very small copper showings were discovered. The survey of the second year, therefore has been suspended.

Based on this circumstances, the survey of the second year was conducted only in the Sur area, where manganese ore deposits had been known.

The survey of second year (phase II) was carried out for two months from October 23 to December 28 in 1981. As the result of survey innumerable manganese outcrops were newly discovered in addition to known manganese ore deposits, and three areas, where many manganese outcrops were found, were selected for further exploration works.

The purpose of survey (phase III) in this year was to clarify the occurrence, scale and continuity of manganese ore deposits for evaluating the potentialities in these areas.

1–2 Substance of the Survey

In order to attain the object mentioned-above, geological survey consisting mainly of investigation for ore deposits, were carried out in the four areas (area A, B, C and D) as shown in Fig. 1

Table 1 Outline of the Field Survey in Phase Ⅲ

	Survey Period	Name of Survey Area	Area	Amount of Survey Work	Number of Tested Samples (pcs)
Preparatory Survey	Nov. 8, 1982 ~ Nov. 14, 1982				
Geological Detailed Survey	Nov. 15, 1982 ~ Dec. 24, 1982	A B C D	25 km² 40 km² 5 km² 25 km²	Length of Survey Route 48.6 km 32.5 km 8.8 km 21.9 km	Chemical analysis of ore 207 Thin section 30 Polished section 15 X-ray diffractive analysis 14 Determination of fossil 20
Trenching Survey	Nov. 15, 1982 ~ Dec. 24, 1982	B		Length of Trench 375 m	
Drilling Exploration	Nov. 15, 1982 ~ Dec. 22, 1982	A		17 holes 300 m	Chemical analysis of ore 47 Polished Section 1 X-ray diffractive analysis 3
Withdrawing	Dec. 23, 1982 ~ Dec. 28, 1982				

and drilling survey were also carried out to clarify the continuity of outcrop which was the biggest manganese outcrop known in the area A. Furthermore, trenching survey was carried out in area B.

The geological survey was conducted in the four areas, 95 km^2 in total, to clarify the distribution, scale and continuity of the ore deposit, and relationship between ore deposits and host rocks. The survey routes have been planned before starting this survey based on the data of the previous works, and the survey was carried out along the survey routes, 111.8 km long in total, in the scale of 1:5,000.

The trenching survey, 375 m long, was conducted in the area B to clarify the continuity of manganese outcrop which had been found in last year and was 9 meters in maximum thickness. The field work was carried out from November 8 to December 24 in 1982 and the result of survey was compiled on the geological maps of 1:10,000 in scale and on the sketch map of 1:200 in scale.

The drilling survey was conducted in the area A to the outcrop which showed maximum continuity in this project area. The drilling survey was carried out from November 8 to December 28 in 1982 and the number of holes were 17 at eight locations and its total depth was 300 m.

Topographical maps of 1:5,000 in scale for the whole area were prepared in Japan before commencing the field survey. These topographical maps were produced from aerial photographs of 1:60,000 and 1:20,000 in scale.

The outline of field survey of this year is shown in Table 1.

The brief discussion and investigation for geological survey and drilling survey were carried out in the base camp by the survey members of Japan and Oman, and the results of the survey are reported to the Department of Minerals, Ministry of Petroleum and Minerals after the field works.

The detailed analytical works on the results of field work were conducted in Japan.

Various samples were taken away to Japan for chemical analysis and various investigations, and those results were compiled in this report.

1–3 Member of the Survey Team

The members participated in the survey for planning, negotiation and field survey are as follows:

(1) Planning and negotiation

Japan	Hiroshi Iwasaki	MMAJ
	Takahisa Yamamoto	〃

		Haruo Kousaka	MMAJ
	Oman	Mohammed H. Kassim	Ministry of Petroleum and Minerals
(2)	Field survey		
	Japanese survey team		
	Team leader	Haruo Kousaka	MMAJ
	Geological survey	Masahiko Nouno	MMAJ
		Akio Abe	"
		Yoshiaki Shibata	"
		Norifumi Ushirone	"
	Drilling survey	Yuji Narita	"
		Kyozo Obara	"
	Oman counterparts	Mohammed El Hassan Rogheim	Ministry of Petroleum and Minerals
		Cherian Zachariah	"
		Adil Mansoor Mahfoodh	"

1–4 Previous Works

The surveyed area is located in the eastern end of the Oman Mountains and forms a part of the Mountains as geologically.

The first geological investigation of the Oman Mountains was conducted by Carter (1850), and after that, a systematic survey was carried out by Lees (1928) over the broad areas. Many surveys and studies have been done since that time, and as for these sythetic survey and description K.W. Glennie et al (1974) is well-known.

According to the report, the geology of the Oman Mountains is roughly divided into (1) basement rocks of Precambrian to Cambrian, (2) autochthonous continental and neritic sediments of Pre-Permian and Middle Permian to Late Cretaceous, (3) allochthonous sediments of Middle Permian to Late Cretaceous and (4) Late Cretaceous to Tertiary sediments.

The allochthonous sediments (3) is considered to have been thrusted over the autochthonous sediments in the later stage of Cretaceous by the tectonic movement of Arabian plate initiated in Late Cretaceous.

Among these four geological units, (3) and (4) are distributed in the survey area.

The previous work in the surveyed area and its surroundings were reported by B.M. Reinhardt and K.W. Glennie (1969), L.E. Carlson (1973), and R.G. Coleman and E.H. Bailey (1974),

and those of the latest data were carried out by I.E. Elboushi and C. Zachariah (1979), JICA (1979) and JICA and MMAJ (1981).

Reinhardt and Glennie (1969) studied the relation between the manganese deposits in the area and the stratigraphy of the Oman Mountains, and explained that formation of the manganese deposits has been related to submarine volcanic activity.

Carlson (1973) also surveyed and clarified the manganese deposits concentrated in the northern part of the area, the structure and continuity of the ore-bearing formation, and described occurrence of manganese minerals.

Coleman and Bailey (1974) clarified the lithology of the hanging wall and foot wall of the manganese deposits, and carried out analysis of the ore.

Elboushi and Zachariah (1979) surveyed on the manganese deposits and variation of rock facies of the ore-bearing bed, and considered that formation of the manganese deposit has been related to submarine volcanic activity.

JICA (1979) conducted a preliminary survey for geology and ore deposits, and studied the characteristics of the host rocks, the occurrence of the ore deposits, and carried out identification of compositional ore minerals and its analysis.

JICA and MMAJ (1981) clarified the regional geology and its structure, and newly discovered innumerable manganese outcrops by the field survey and the interpretation of Landsat images and aerial photographs. The survey for geology and ore deposit was also conducted in the known ore deposits area and clarified the distribution, ore grade and occurrence of the ore deposits.

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Chapter 2. Outline of the Surveyed Area

2–1 Location and Access

The survey area of this year is about 150 kilometers southeast from Muscat, the capital city of the Sultanate of Oman, and also located in the southern end of the Oman Mountains, with Wahiba Sand on the southwest of the area. The survey areas are consist of four areas (95 km^2 in total) such as area A (25 km^2), area B (40 km^2), area C (5 km^2) and area D (25 km^2), as shown in Fig. 1.

As for the main town in the surveyed area and the surroundings, Sur is located at the northwestern end of the area, Bu Hasan and Bu Ali at the southwestern end. As for villages, Al Hadd is located at the northeastern part and Jaramah at the northern part of area A and Awaika is located at the southern part of area D. Among these, Sur is the largest town and the fishing port in the district.

The base camp for the field survey was established in Jaramah, the nearest village from area A.

A road is connected Muscut and base camp in Jaramah, 360 kilometers long, through Bid Bid, Ibra, Al Kamir and Awaika, and it takes eight hours to travel by vehicle.

Among the road, a pavement road is 260 kilometers long between Muscat and Al Kamir, and a gravel road is 100 kilometers between Al Kamir and Jaramah.

The surveyed area consists mainly of gentle hills and it is available to access to the whole area by four-wheel drive veicles.

2–2 Topography

The topography of the area well reflects the geological features which is characterized by flat land or gentle undulating low hill (50 to 150 meters in altitude) consisting of alternation of chert and shale, plateau or steep highland (the highest point 1,442 meters in altitude) with escarpement consisting limestone and terrace consisting conglomerate.

The area A and D are located in the gentle undulating low hill extending northwest to southeast and north to south respectively and the terrace are dominated in the area C and D.

2–3 Climate and Vegetation

The more than 80 percent of the country of the Sultanate of Oman is occupied with desert, and most of the country including the survey area belongs to arid climate.

Because of hot wind blown from Al Rub Al Khli Desert of Saudi Arabia, the temperature

rises above 40°C in summer season from May to October, and the temperature is high even in winter from November to April, although it is a little lower than summer. The difference of temperature between day and night times is great especially in summer.

The annual precipitation is very small, which is concentrated in January in the winter season, and when stream of wadi flows the lowland becomes mashland. The annual precipitation in Muscat is 100 millimeters in average and its variation is from 60 to 300 millimeters.

Because of desert area and arid climate, vegetation is extreamly poor and scanty of vegetation is observed along wadi and around oasis.

Chapter 3. General Discussion

Numerous basic data on geology and ore deposits were obtained in this phase survey. The following is general discussion of stratigraphy, geologic structure and the modes of occurrence, continuity and scale of the ore deposits which are important for evaluation of the manganese ore deposits. And also result of brief study for development of the ore deposits will be described.

3–1 Stratigraphy of the Halfa Formation

The stratigraphic sequence in the areas A, B, C and D, surveyed areas of this phase, is Triassic to Early Cretaceous Halfa Formation, Maastrichtian to Middle Tertiary Limestone Formation and Quaternary sediments in ascending order.

The Halfa Formation, which contains manganese ore deposits, consists of alternation of chert and shale with some limestone, and was divided into three members such as Lower, Middle and Upper Members. The Lower and Upper Members are shale predominant formations.

The Middle member is further subdivided into four members as follows;

Red alternating bed (Hmr) : alternating beds of reddish brown chert, pale brown to pale brown to pale reddish brown muddy chert and red-brown to brown shale.

White alternating bed (Hmw) : alternating beds of whitish gray chert and whitish gray shale.

Transitional alternating bed (Hmw) : alternating bed of whitish gray to pale pink chert and reddish brown to pale brown shale.

Shale bed (Hms) : Whitish gray to yellowish shale.

There is no evidence of volcanic activity in the Halfa Formation of the area but basaltic lavas and tuffs are found in the Tertiary Limestone Formation. Small scale basic intrusives are found in the Halfa and Limestone Formations.

3–2 Geologic Structure of the Halfa Formation

The Halfa Formation is characterized by development of folds and faults caused by the Late Cretaceous major thrust movement and the Middle Tertiary upheaval. The folding of the Halfa Formation consists of first to third order foldings and the formation shows a complicated structure with repetition of formations caused by combination of each order folding with faulting.

The directions of main folding axes are vary within each area. The E–W, NE–SW and

NW–SE directions are predominant in the area A, the NNE–SSW, NW–SE directions are dominant in the area B and the directions of N–S and NNE–SSW are dominant in the area C and D. The directions of some faults are parallel to the fold axes and others are oblique to them.

3–3 Occurrence of Ore Deposits

The manganese ore deposits are embedded in the Middle Member of the Halfa Formation, especially in the Red alternating bed. These ore beds lie parallel to the stratification of the host rocks of the Red alternating bed and folded with host rocks. Many outcrops of the ore deposits tend to dip steeply.

The ore deposits are composed of manganese beds and manganese nodular ore zone in general. A manganese bed comprise manganese minerals concentrated in layer, lenticular or finely disseminated form in compact, massive and highly siliceous layer, which looks like "black chert".

Manganese nodular ore zone are composed of manganese minerals concentrated in small nodular, thin lenticular, and or small grain form in the host rocks.

Ore minerals consist mostly of pyrolusite and a small quantity of manganite and cryptomelane are also found. Large quantity of quartz is associated with them.

The mineralogy and mineral assemblage in the deeper part may be the same as surface ores according to the microscopic observation and X-ray diffractive analysis of the sample from drilling cuttings.

3–4 Continuity of Ore Deposits

The ore deposits consist of several thin layered ore beds. Generally a thickness of a single ore bed shows less than 20 centimeters and strike length continues less than 20 meters. So that a continuity of a single layer of ore is rather low.

A downward continuity along dip became clear by percussion drillings. A ore bed which continue at least 30 meters downward from the surface was found by drilling. The ore bed which shows high continuity along strike has also high continuity to depth. On the contrary ore bed which shows low horizontal continuity has low continuity to depth in general. From these mode of occurrence, the ore beds are considered to be intermittent in both direction of strike side and dipside.

3–5 Scale of Ore Deposits

Numerous outcrops of ore deposits have found in Sur area by this survey. The total number of ore deposits is sixty, when restrict to deposits which has more than 20 meters in strike length and thicker than 15 centimeters.

The tonnage of ore reserves up to the depth of 30 meters from the surface is estimated. As the result of estimation, the largest ore body is outcrop No.159 in area B, where trenching survey was carried out, the tonnage is 155,601 tons averaging 34.94% MnO_2. The second one is outcrop No.110 in the area A, where drillings were put down, the reserves consist of 53,403 tons, averaging 23.01% MnO_2.

Number of outcrops and their reserves in each area are as follows.

Area	Number of Outcrop	Reserves (Tons)	Average Grade (MnO_2%)	(Mn%)
A	24	214,880	23.59	15.10
B	23	250,545	36.04	24.06
C	5	25,537	19.60	12.29
D	8	30,965	33.36	20.68
Total	60	521,927	29.57	19.92

As presumable from this table, the scale of each ore deposit is very small.

3–6 Consideration on the Development of the Ore Deposits

The development of the ore deposits in the Sur area may considered to be difficult because of their small scale and low grade. The followings are a brief mining plan and a rough estimation of mining costs of these ore deposits as if they are mined.

(1) The scale of operation

Total tonnage of ore reserves is estimated as 520,000 tons but if a simple surface mining method would be applied, minable ore reserves should be reduced to 5 meters portion below the surface, and they would be recalcurated as 86,000 tons.

If the mine life is supposed to be of 5 years, daily production rate would be 57 tons of ore (300 operation days a year). The personnel is 30 employees.

(2) Mining method

The application of a small scale of simple surface mining method may be suitable for development of these ore deposits because the total reserves are small, ore beds are thin, ore beds dip steeply, continuity of beds is low and they lie sporadically in the vast area.

Ore beds are mined by a hydraulic braker and a backhoe type power shovel as a manner of

trenching along the ore beds to the depth of 5 meters.

Since ore bed is thin, crude ores which lifted up to the surface from the bottom by backhoe, may contain waste rocks. Therefore, waste rocks should be excluded by hand picking. The upgraded broken ores (Mn 20%) are heaped up by a loader as stock pile.

The personnel is composed of 8 workers for mining and 7 for hand picking and handling the ore.

(3) Transportation

There is no suitable facilities in the seashore of Sur area, although the area is close to the seaside. The ore may be transported by trucks to Mina Qaboos, 360 kilometers from the mine sites. 5 trucks and one loader will be used and 10 workers may be employed for this section.

(4) Management and service section

A total of 5 employees should be necessary for a mine office and a repair shop.

(5) Operation costs

The costs of mining and transportation are estimated based on the budget of the Rajmi Mine in the Sultanate of Oman, because the Rajmi Mine is similar to the mining plan of the manganese ore deposits in operational scale and mining method. The Rajmi Mine produces chromite ore by surface mining method using rock drills, loaders and trucks with about 30 employees. The Rajmi Mine, located in northwest of Sohar, is owned by the Government of the Sultanate of Oman.

(a) Budgetary costs of the Rajmi Mine

Mining costs : US$20/ton ore

including all costs of mine site with depreciation

Transportation costs : US$25/ton ore

truck transportation costs of about 300 km from the mine to Muscat, including ore handling costs at the port.

(b) Estimated mining costs of manganese ore

In case of mining down to the depth of 5 meters below the surface, the amount of waste rock is more than that of Rajmi Mine, because the shape of manganese ore beds is thin. Therefore, estimated mining costs of manganese ore may be more than US$20/ton ore.

(c) Estimated transportation costs

US$30/ton ore is applied, because transportation distance is about 360 km, 20% longer than

that of the Rajmi Mine.

(d) Total costs are therefore estimated more than US$50/ton ore.

(6) Price of ore

The price of manganese ore is not stable, but the recent price of manganese ore is around US$70/ton ore* in case of 48% Mn ore. Assuming the price of manganese ore is US$70/ton ore, the unit price (1% Mn price) is US$1.46/ton ore. The average grade of the manganese ore is about 20% Mn, so the ore price will be US$29/ton ore.

(7) Profitability

The price of ore is US$29/ton ore as mentioned above, and the estimated transportation costs are US$30/ton ore. Therefore, the price of ore can not cover the transportation costs. Furthermore, assuming the mining cost of the manganese ore deposits are similar to the costs of the Rajmi Mine, the total costs of mining operation are US$50/ton ore. Therefore, the development of the manganese ore deposits in the Sur area is not profitable at the present time.

As a result of the study of use of the ore, the manganese ore of the Sur area has no good electrical characteristics, so these ore can not use for dry cell batteries. And, these ore also is not available to steel industries and chemical industries because of high content of SiO_2.

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* Year Book of Ferroalloy (1982 in Japanese)

Manganese ore price (FOB) imported from Australia

1981	US$67.296/T (Mn48%)	US$1.402/T (Mn1%)
1980	US$65.28/T (")	US$1.36/T (")
1979	US$57.00/T (")	US$1.1875/T (")

Mining Journal (1982 Dec.)

Manganese ore price

	US$76.8/T (Mn48%)	US$1.60/T (Mn1%)

Chapter 4. Conclusion and Evaluation

As the results of surveys and studies in this phase, the following conclusions were obtained.

(1) The Halfa Formation, embedded by manganese ore deposits, consists of alternating bed of chert and shale, shale and limestone. The Formation can be divided into three members such as Lower, Middle and Upper Members.

(2) The situation of ore horizon became clear by subdividing the Middle Member of the Halfa Formation, which contains three to six ore beds.

The host rock of the ore horizon is the "Red alternating bed" of the Middle Member. The Red alternating bed consists of alternating beds of reddish brown chert, pale brown muddy chert and reddish brown shale.

(3) According to biostratigraphic study for radiolarian chert, the beds in the area A, B, C and D were almost correlated and it is clarified that the age of chert is from Tithonian to Aptian.

(4) Structure of the Middle Member also became clear by the study of the Red alternating bed and the White alternating bed.

(5) The geologic structure of the Halfa Formation is characterized by development of folds and faults, and directions of fold axes are slightly different in each area.

Principal folding axes : trend NW–SE, E–W, NE–SW in area A, NE–SW, NNE–SSW, NW–SE in area B, and N–S, NNE–SSW in area C and D.

(6) The ore horizons are croped out repeatedly caused by folding, so the ore deposits are widely distributed sporadically in the surveyed area.

(7) The ore deposits are comformed to the stratifications of alternating beds of chert and shale of the Red alternating bed and consist of several manganese beds with low grade nodular ore zone.

These ore beds have small scale of discontinuous bedded or lenticular form.

(8) Most of the ore deposits dip steeply. Continuity in dip direction of the ore bed is low in general.

(9) By the drilling survey it was confirmed that one ore bed extends to the depth 30 meters below the surface. But the dip-side continuity of the most ore beds is poor as same as the strike-side one.

(10) The ore consists of manganese oxide minerals with high contents of silica minerals (mainly quartz and chalcedony). Pyrolusite is a main ore mineral, and a little quantity of manganite and cryptomelane is also found.

(11) A grade of ore shows 20% to 40% MnO_2 (average 29.57% MnO_2, 19.92% Mn) in general with high SiO_2 content.

(12) Total ore reserves (assuming ore beds continue down to 30 meters below the surface) is 520,000 tons with average grade of 29.57% MnO_2.

(13) As for the development of manganese ore deposits in Sur area, it seems that the development of the mine is not profitable at the present time, because of their small scale, thin bed type, low grade, sporadic distribution and balance of estimated mining operation costs and ore price.

DETAIL DESCRIPTION

PART I GEOLOGICAL SURVEY

Chapter 1. Introduction

The purpose of this survey was to clarify the occurrence, scale and continuity of manganese ore deposits in four areas and to evaluate these ore deposits. These four areas were selected for further exploration works on the basis of the survey result in 1981.

The surveyed areas consist of area A (25 km^2), area B (40 km^2), area C (5 km^2) and area D (25 km^2) as shown in Fig. 1. The area A is located in 5 km south of Jaramah, the area B is located in 16 km northwest of Awaika, the area C and area D are also located in northwest and north of Awaika.

The surveyed areas consist of hill and terrace as topographically and the altitude is 50 to 100 meters.

The field survey was carried out along wadi and ridge and all the geological observation results were recorded on the route map of 1:5,000 in scale and all data were compiled on the geological map of 1:10,000 in scale.

In addition to the geological survey, trenching survey was also conducted in the area B and all data were compiled on the sketch map of 1:200 in scale.

As the results of this survey, the stratigraphy and geologic structure of Halfa Formation were more clarified, nevertheless poor exposure of the formation because of the areas were widely covered by Quaternary sediments. The occurrence, scale and continuity of the manganese ore deposits were also clarified in this survey.

Chapter 2. Geology

2–1 General Geology

The surveyed area is located in the southeastern part of the Oman Mountains and forms a part of the Mountains as geologically.

According to Glennie et al (1974), the geology of the Oman Mountains are divided into following group in ascending order, shown in Fig. I–1 and Fig. I–2, I–3.

(1) Pre-Cambrian to Cambrian basement

(2) Pre-Permian continental sediments

(3) Hajar Super Group comprised of Middle Permian to Late Cretaceous neritic sediments

(4) Sumeini Group comprised of Middle Permian to Late Cretaceous continental shelf sediments

(5) Hawasina Group comprised of Permian to Middle Cretaceous pelagic sediments

(6) Semail ophiolite of Permian to Late Cretaceous

(7) Neritic limestone of Maastrichtian to Middle Tertiary

Among these, the basement rocks, pre-Permian continental sediments, and the Hajar Super Group are autochthonous, and the Sumeini Group, the Hawasina Group and the Semail ophiolite are allochthonous formation overlying the above autochthonous sediments. The limestone of Maastrichtian to Middle Tertiary was deposited unconformably upon the autochthonous and allochthonous sediments.

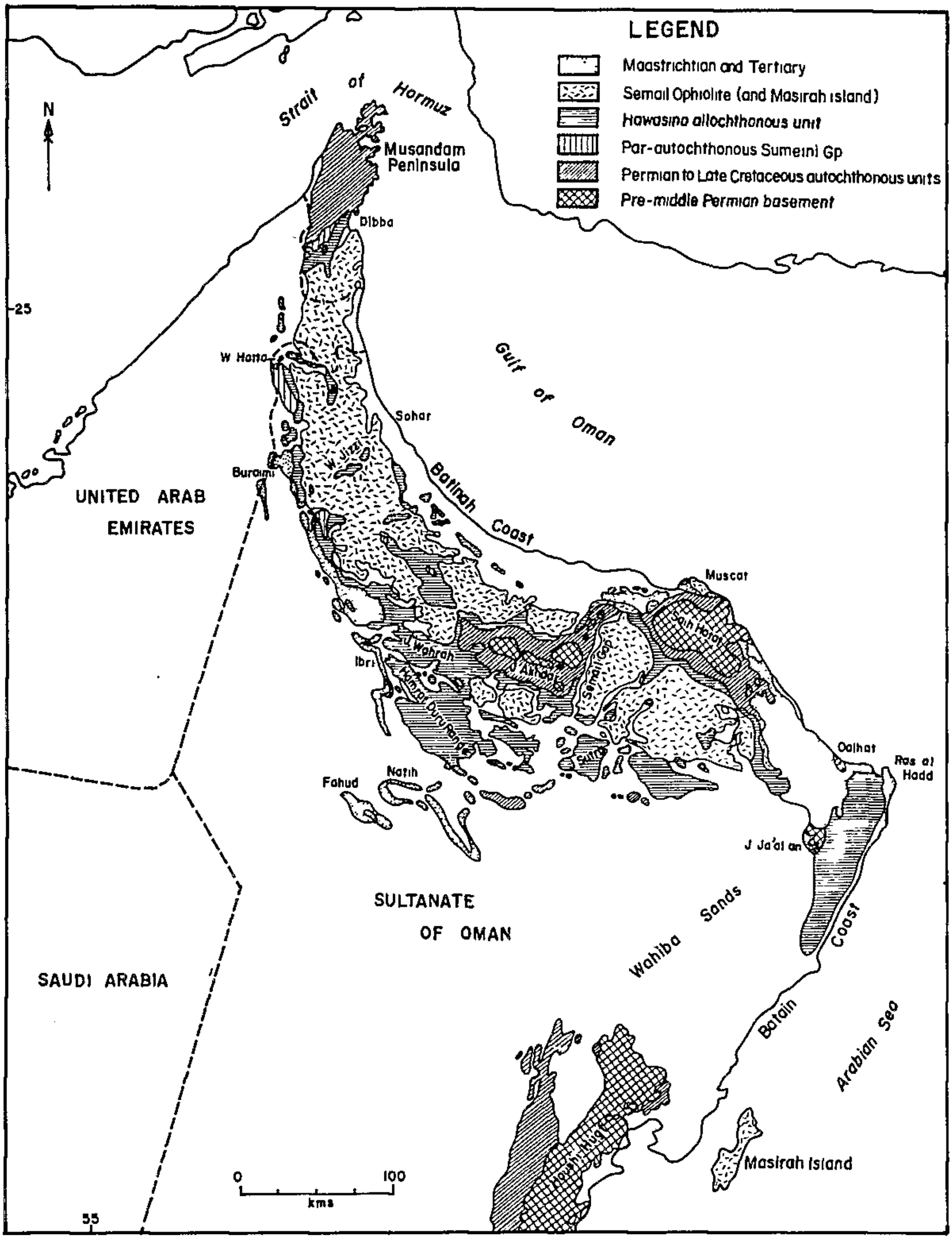
The general structure shown by those formations is a single curved anticline, having two remarkable culmination.

The Sur area is occupied by Pre-Cambrian basement rocks, Triassic to Early Cretaceous Halfa Formation of Hawasina Group, Late Cretaceous to Middle Tertiary Limestone Formation (hereinafter call Tertiary Limestone Formation), and these formations are covered by Quaternary sediments. Basic and acidic intrusive rocks are also recognized in this area (Fig. I–4, I–5).

The surveyed areas of this year, the area A, B, C and D, are occupied by Halfa Formation, Tertiary Limestone Formation and Quaternary sediments. Small scale of basic intrusive rocks are also recognized. The manganese ore deposits are embeded in the Halfa Formation (Fig. I–6, I–7, I–8, I–9, I–10). Halfa Formation, distributed each surveyed area, is composed of shale limestone and alternating bed of chert and shale.

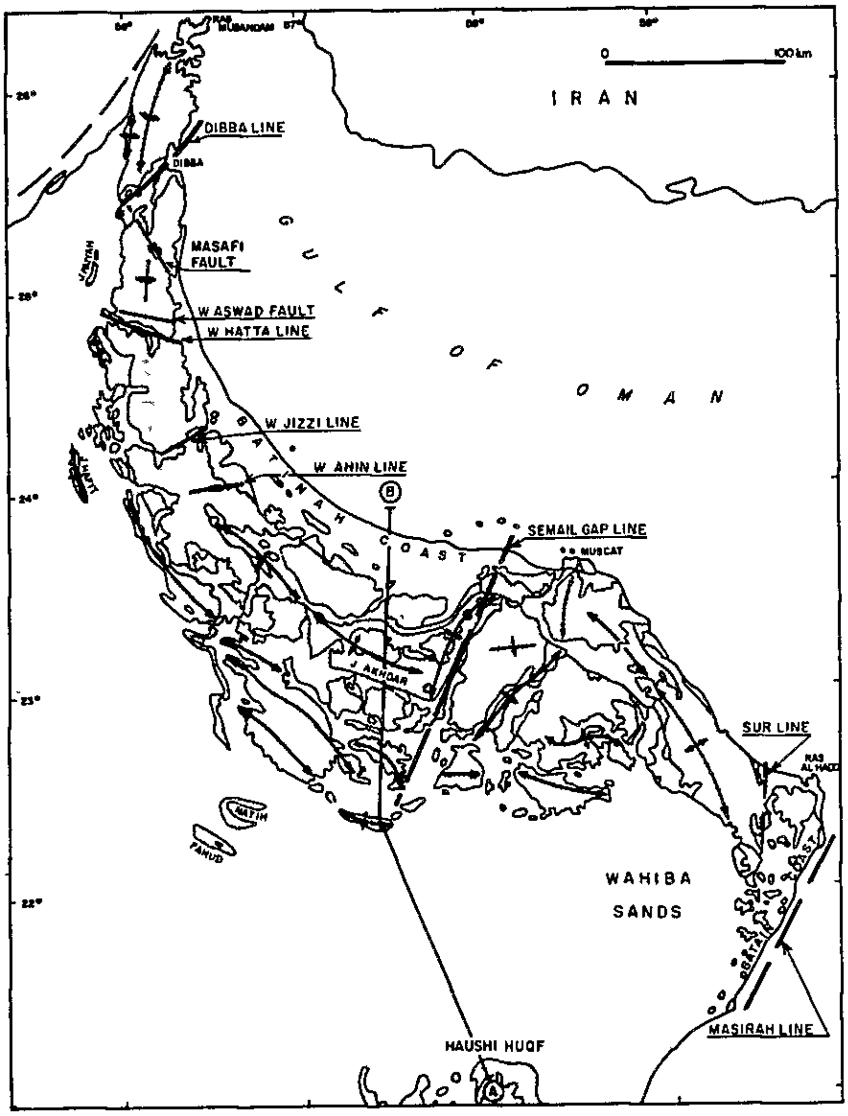
On the basis of result of survey in 1981, Halfa Formation was divided into three members such as Lower, Middle and Upper Member.

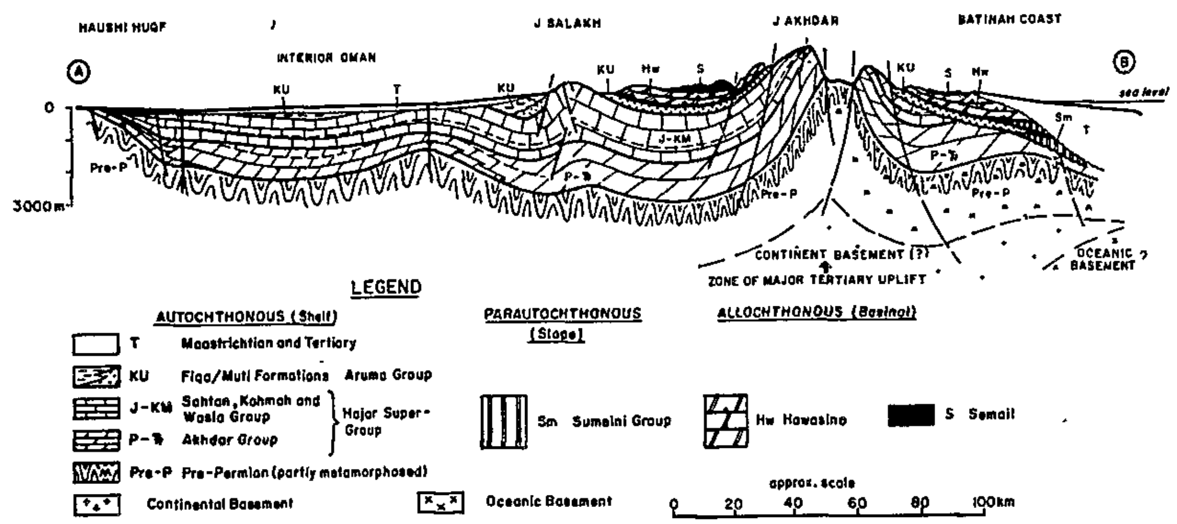
In the survey of this year, Middle Member which contains major manganese ore deposits is subdivided into Red alternating bed, White alternating bed, Transitional alternating bed and



(after K.W. Glennie et al, 1974)

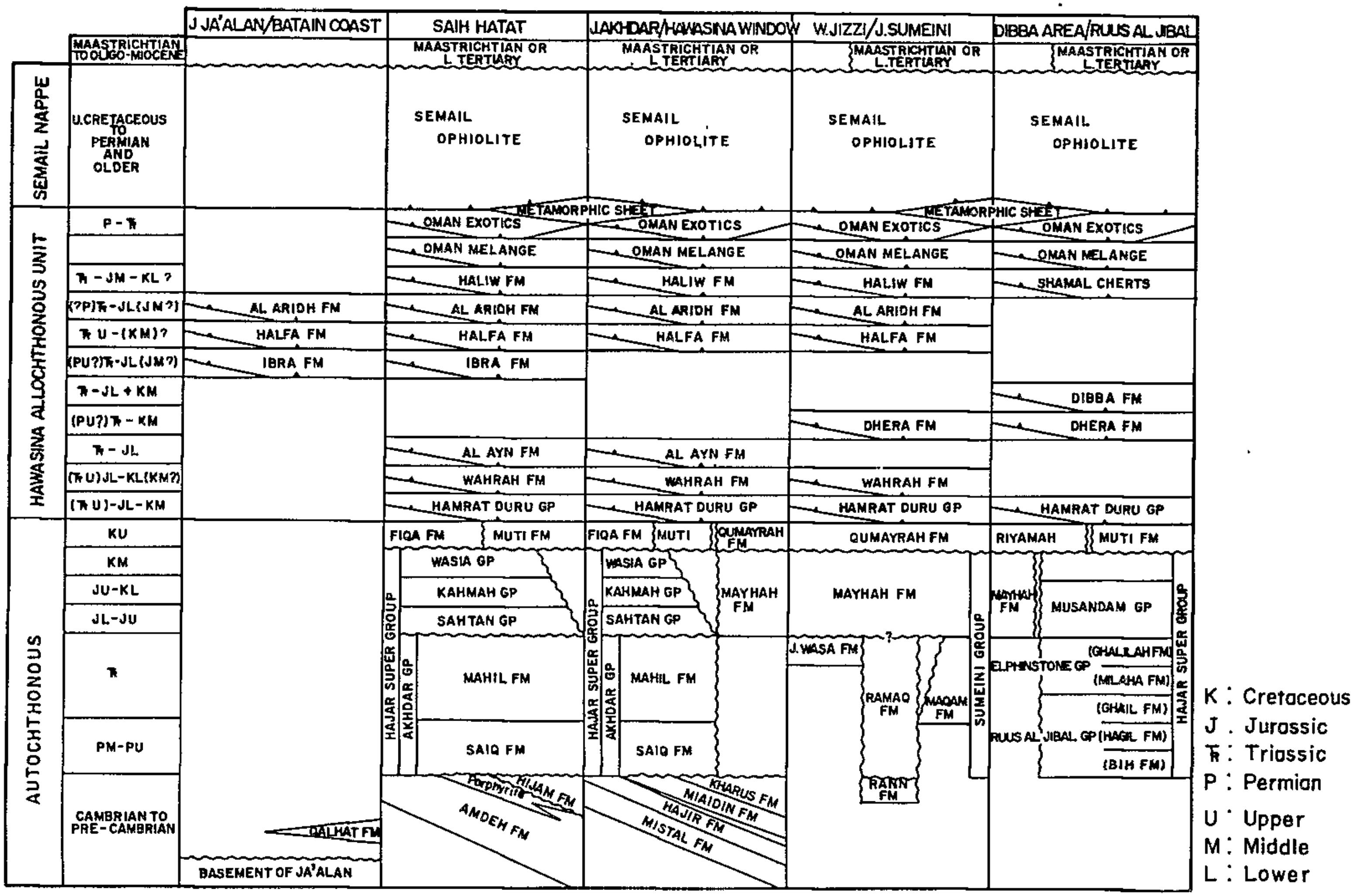
Fig. I—1 Geological Map of the Northern Oman





(after K.W. Glennie et al, 1974)

Fig. I—2 Geological Framework of the Northern Oman



(after K.W. Glennie et al, 1974)

Fig. I—3 Schematized Correlation of the Stratigraphic Units in the Oman Mountains

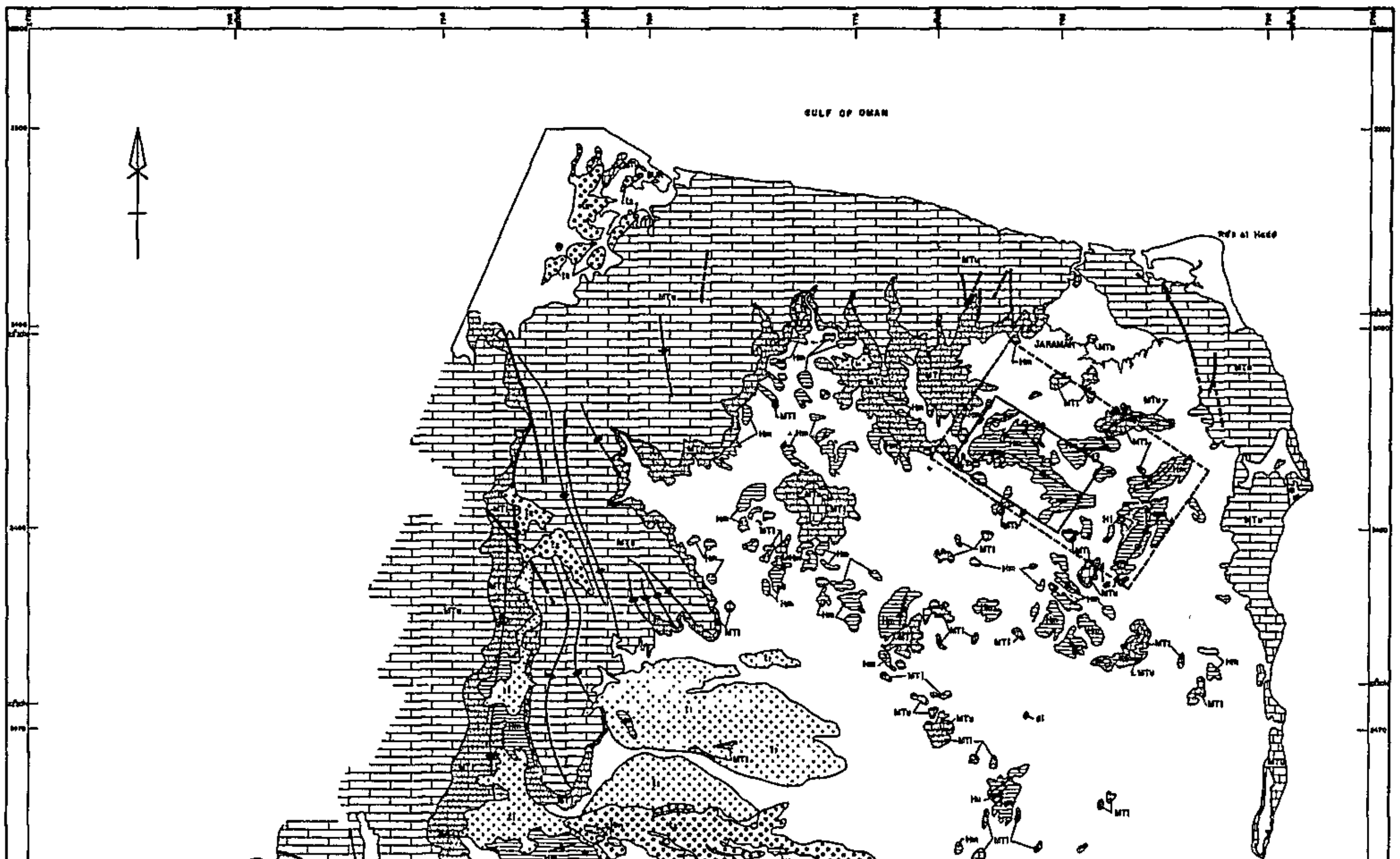


Fig. I—4 Geological Map of the Sur Area

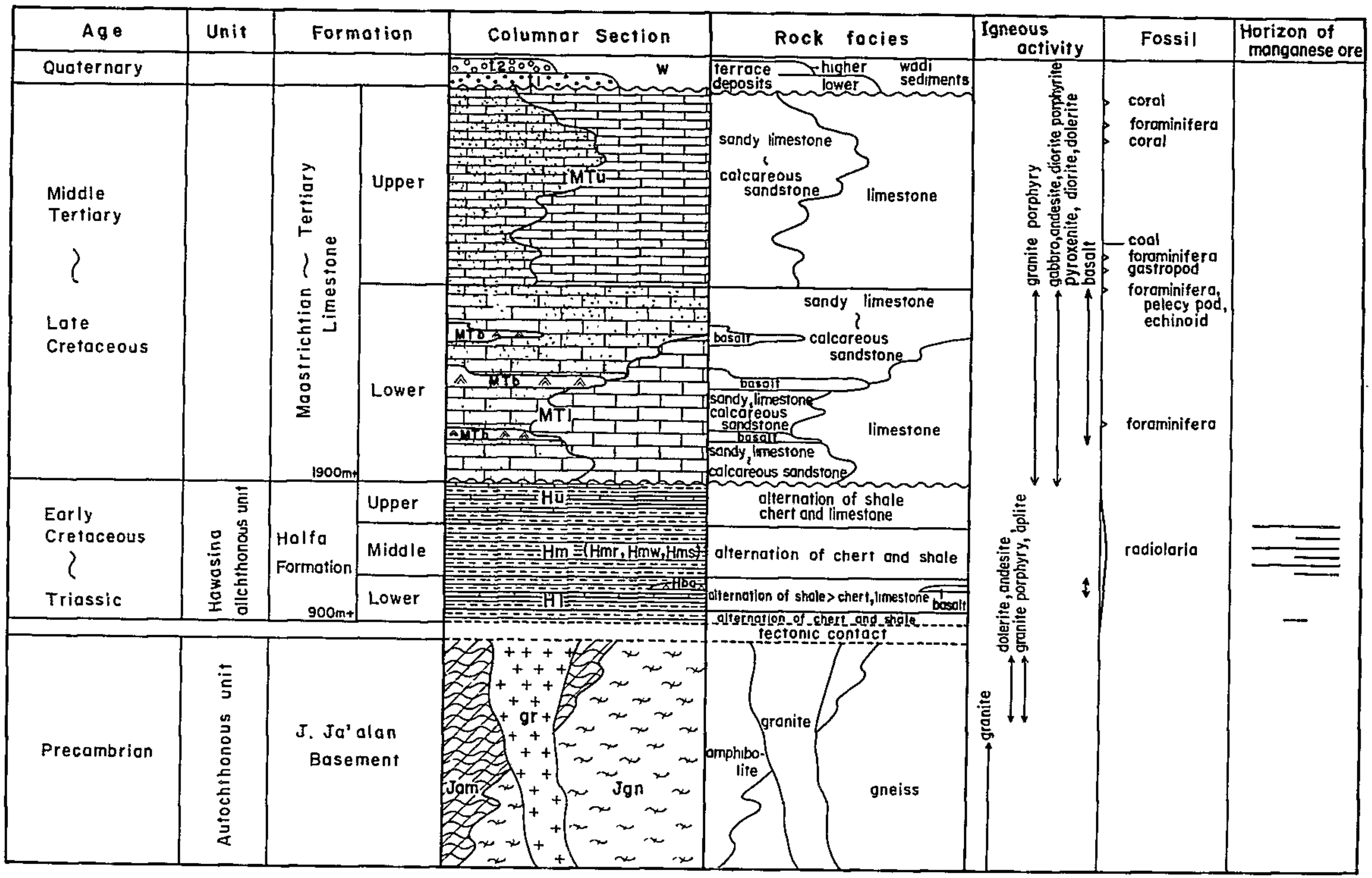
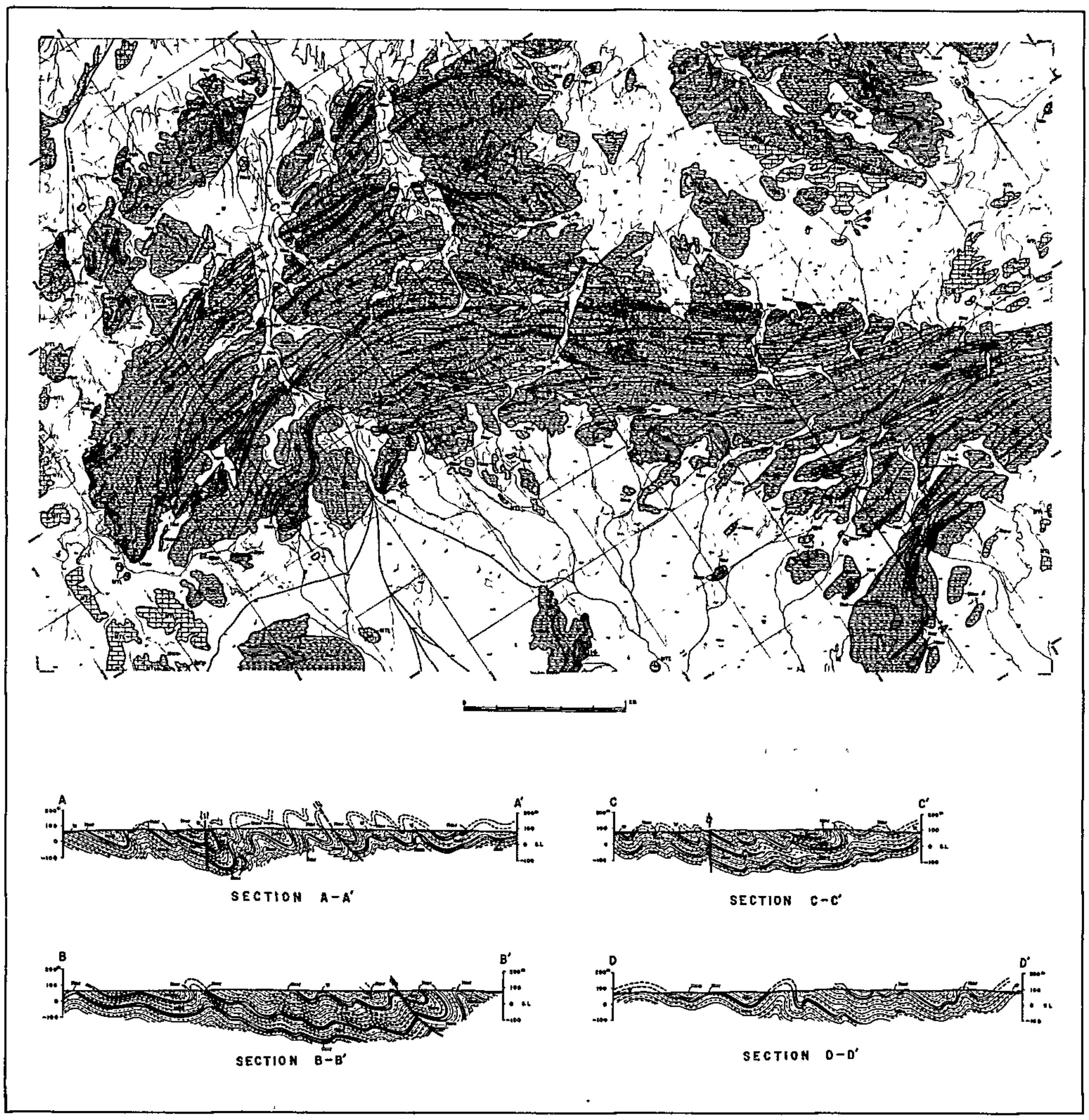


Fig. I —5 Schematic Geolegical Columnar Section of the Sur Area



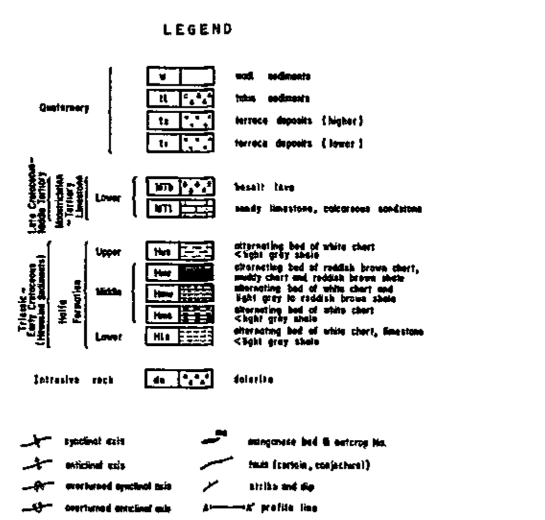


Fig. I—6 Geological Map of the Area A

Fig. I—7 Geological Map of the Area B

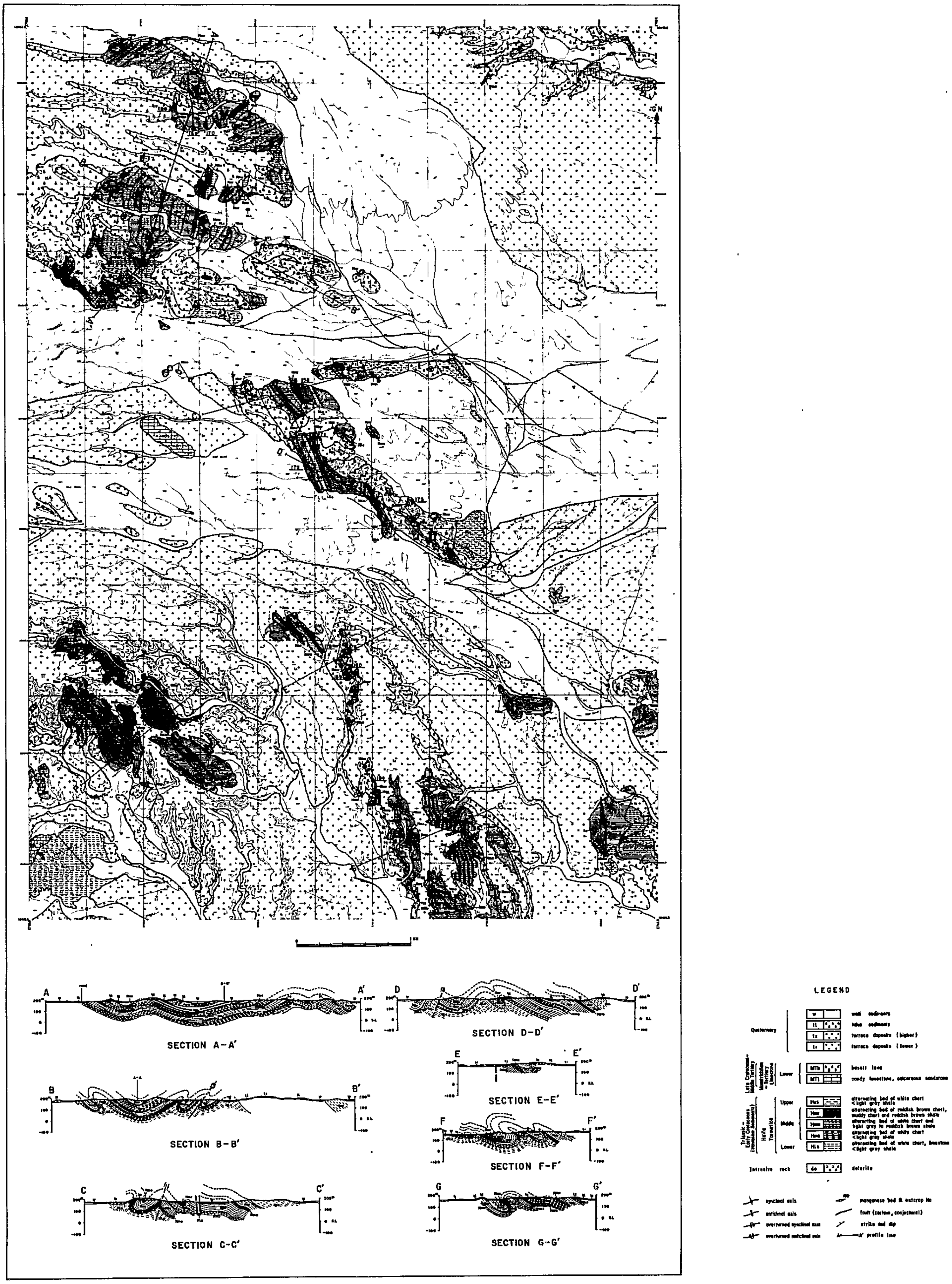


Fig. I—7 Geological Map of the Area B

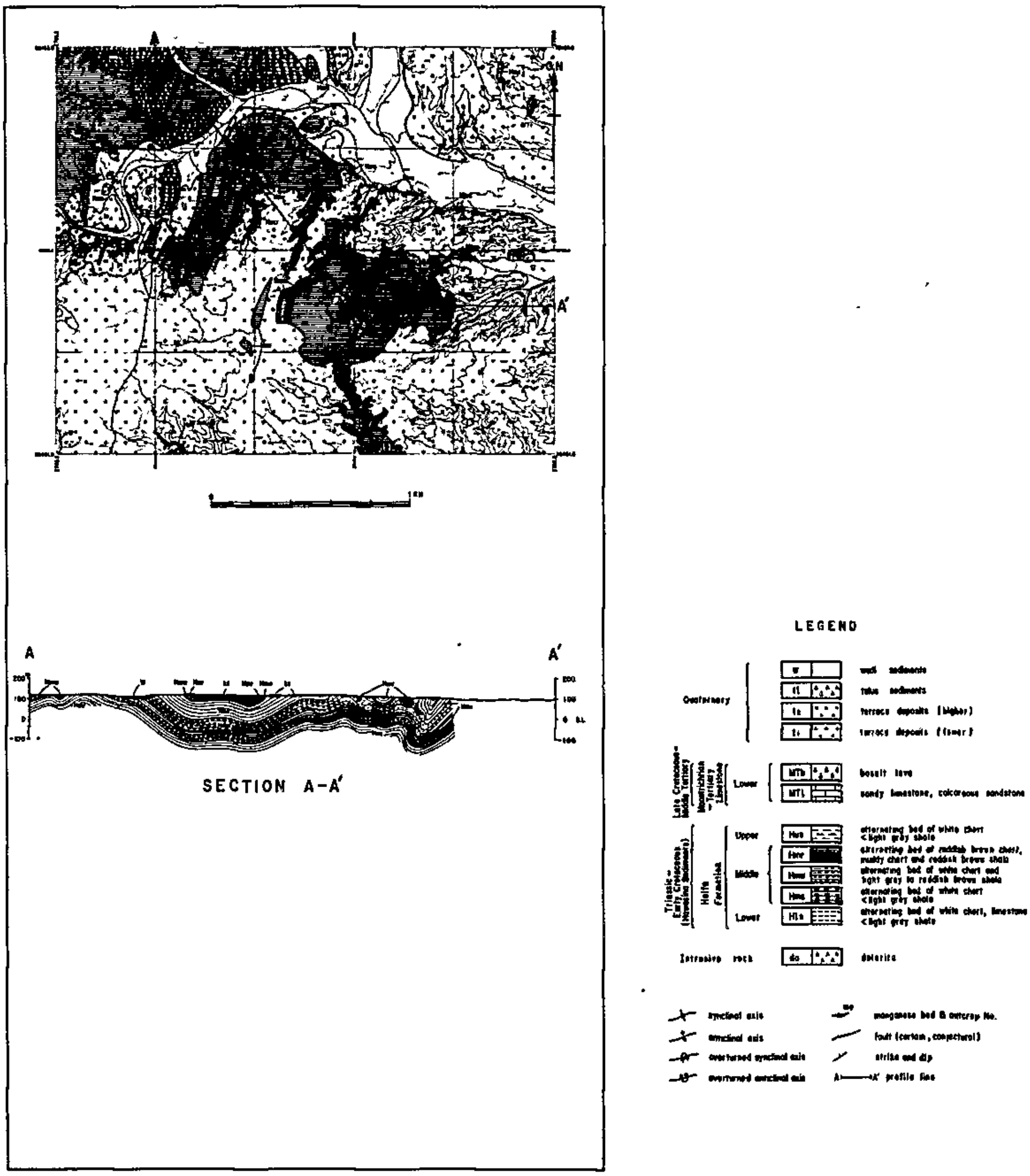


Fig. I—8 Geological Map of the Area C

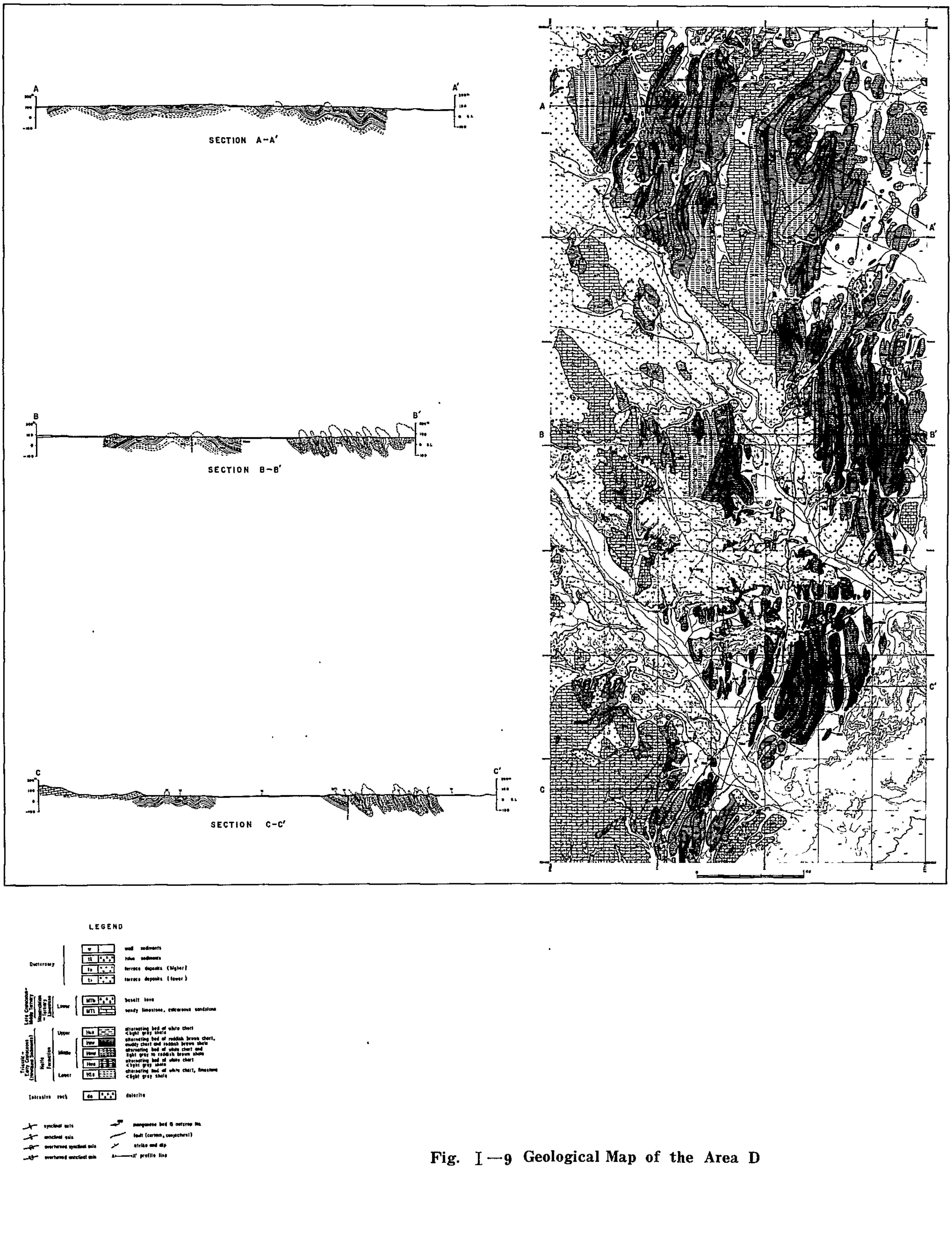


Fig. I—9 Geological Map of the Area D

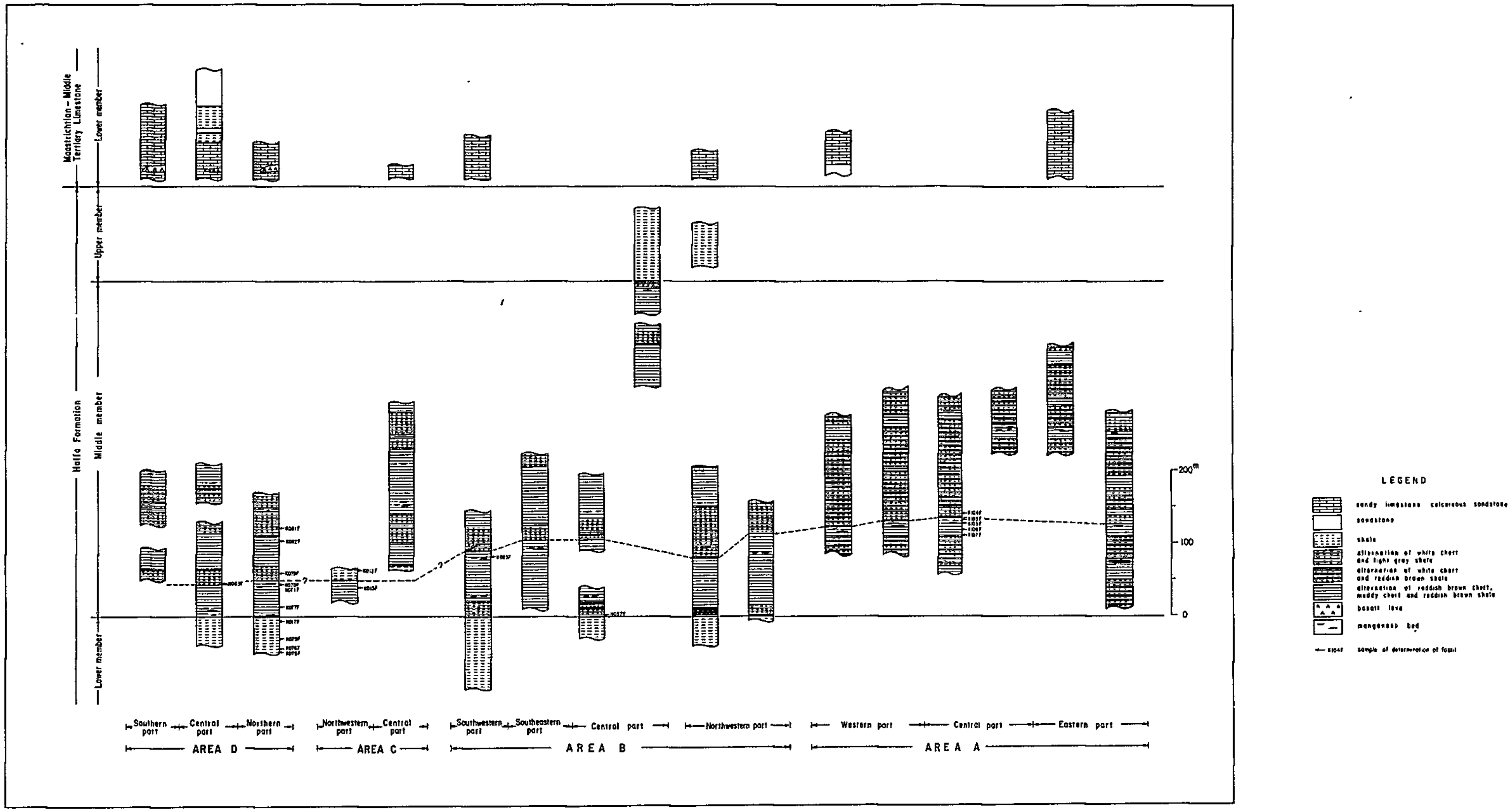


Fig. I—10 Geological Columnar Sections of the Surveyed Areas

Shale bed on the basis of its lithology and color. Red alternating bed consists of reddish brown chert and alternation of reddish brown to pale brown muddy chert and reddish brown shale, and chert exceeds shale in amount. White alternating bed consists of alternation of grayish while chert and shale and the quantitative ratio chert to shale is equivalent or shale is dominant in this bed. Transitional alternating bed consists of alternation of grayish white to pink chert and reddish brown to pale brown shale, and the quantitative ratio of chert to shale is almost equivalent in general, although one exceeds other in amount at some places. The relationship between Transitional alternating bed and White alternating bed is gradual change.

The rapetition of thin Red alternating bed can be observed in the area A and the repetition of thick Red alternating bed is recognized in the area B, C and D.

On the basis of previous works, it was defined that the Lower Member consists of shale and alternation of chert and shale, and the Upper Member consists of alternation of chert and shale, and limestone. However, limestone beds were also recognized in the Lower Member by the survey of this year. It is, therefore, difficult to classify these two member lithologically. The Lower and Upper member are divided on a basis of the Middle Member. The evidence which show the existance of volcanic activities is not recognized in the Halfa Formation.

Tertiary Limestone Formation overlying unconformably the Halfa Formation is exposed in the hill and lowland scatteringly. The Lower Member consisting mainly of sandy limestone, can be observed in the surveyed area of this year, but Upper Member is not exposed. Basalt lava and tuff are also recognized in this member.

Quaternary sediments covering the Halfa Formation and Tertiary Limestone Formation are widely distributed, especially 70 to 85 percents of the area B and C are covered by these sediments.

As for intrusive rocks, dolerite is recognized in the area B and D and pyroxenite in the area B. Among these intrusive rocks, dolerite in the area D intrudes into the Halfa Formation. Except this, the relationship between intrusive rock and the Halfa Formation is not clear because of these intrusive rocks are covered by Quaternary sediments.

Surveyed areas are reflected by thrust movement of Late Cretaceous age and upheaval movement of Middle Tertiary age and the geological structure of these areas are remarkably complecated by numerous folds and faults. In this survey, the Middle Member of Halfa Formation was subdivided into the Red alternating bed and the White alternating bed and these beds are traced in detail to clarify the geological structure. As the result of this survey, it made clear the second to third order fold structure and the complicated geological structure. The axis of main fold show E–W, NW–SE, NE–SW and N–S direction. The axis of fold show different direction in each

area, but generally NW–SE trend is dominant in the area A and N–S trend is dominant in the area B, C and D. The trend of fault show two direction, one is parallel and other is diagonal to the direction of fold.

2–2 Stratigraphy

2–2–1 Area A

The geology in the area A consists of the Middle Member of Halfa Formation, the lower Member of Tertiary Limestone Formation and wadi sediments in ascending order.

(1) Middle Member of Halfa Formation (Hmr, Hmw)

Distribution: This member is widely distributed in the whole area.

Lithology: This member is composed mainly of chert and shale and subdivided into two rock units on the basis of its lithology and color, such as Red alternating bed (Hmr), White and Transitional alternating bed (Hmw).

Red alternating bed (Hmr) comprises alternation of red, reddish brown and dark brown chert to muddy chert and reddish brown and pale brown shale.

The chert in this alternative bed gradually change to muddy chert. In general, the center part of single bed consist of chert and marginal part is muddy chert. The thickness of each chert and muddy chert bed is 2 to 20 centimeters and shale bed is one to 10 centimeters. Quantity of chert and muddy chert is dominant and the quantitative ratio of chert to shale is 2:1 to 10:1. Six units of Red alternating bed, at least, are recognized in this area and the thickness of each unit is 5 to 30 meters.

The manganese ore deposits occur in this Red alternating bed, and in the vicinity of the ore deposit the color of muddy chert and shale change to pale brown color.

The result of microscopic observation of chert in Red alternating bed is shown as follows;

Reddish brown chert (K106)

Reddish brown chert consists mainly of chalcedonic quartz and microcrystalline quartz. Clastic materials are not observed, large amount of spherical radiolaria and red colored lamina can be recognized in reddish brown chert. The diameter of spherical radiolaria is 0.1 mm in average and is 0.3 mm in maximum. A small amount of clay minerals (montmorillonite and sericite), opaque minerals and several quartz stringers are also recognized in this chert.

Pale brown muddy chert (K112)

Pale brown muddy chert consists mainly of chalcedonic quartz, microcrystalline quartz, a

little piece of clay mineral (montmorillonite) and calcite spot. Red colored lamina and black colored lamina formed by manganese minerals can be observed in this muddy chert. This muddy chert also contains spherical radiolaria, 0.3 mm in average diameter and 0.6 mm in maximum.

Red brown muddy chert (K113)

This muddy chert consists mainly of chalcedonic and microcrystalline quartz. Red colored lamina is clearly observed. This chert contains many spherical radiolaria and the diameter is 0.1 mm in average and 0.3 mm in maximum. A small amount of clay minerals (montmorillonite, kaolinite and sericite) are also recognized.

White alternating bed consists of white, pale yellow, grayish white and pale purple colored chert and shale. The thickness each bed is 2 to 20 centimeters. The quantity of shale in this bed is equal or dominant compare to chert. Manganese ore can not be recognized in this bed.

Because the distribution of White alternating bed is limited and gradually changes to Transitional alternating bed, it was difficult to divide these bed on the geological map. White alternating bed is usually distributed along Red alternating bed.

The result of microscopic observation of chert in White alternating bed is as follow;

Gray chert (K104)

Gray chert consist of chalcedonic quartz and a large amount of microcrystalline quartz also can be recognized. Lamina and spherical radiolaria are recognized. The diameter of the radiolaria is 0.01 mm in average and 0.3 mm in maximum. A little piece of clay mineral (sericite), opaque mineral and quartz stringer are also recognized in this chert

Transitional alternating bed consists of white to pink chert and reddish brown to pale brown shale. The thickness of each bed is 2 to 20 centimeters.

Although the quantitative ratio of shale to chert in this bed is different in some places but is almost equivalent in general. The thickness of the Transitional alternating bed including White alternating bed is 10 to 50 meters. In this alternating bed, lenticular manganese concentration less than 1 centimeter is rarely recognized.

The chert and shale which compose of the Red and White alternating bed were analized by X-rays fluorescence analysis method. As the result of this analysis, it was confirmed that the difference of color of the beds is due to the difference of Fe content and Red alternating bed contains more Fe than White alternating bed, as shown in Table A–7.

Stratigraphic relation: Although the Lower Member does not crop out, the relationship between Lower Member and this member is inferred to be a conformity.

Thickness: The estimated thickness is more than 400 meters in this area.

(2) Lower Member of Tertiary Limestone Formation (Htl)

Distribution: This member occurs in a small area of the western and eastern part of this area.

Lithology: This member consists of well bedded pale gray sandy limestone. The dark gray sandy limestone are also recognized in the western part of the area.

Stratigraphic relation: Although the contact between lower formation and this member is not observed in the surveyed area, the relation is inferred to be an unconformity.

Thickness: The estimated thickness is more than 90 meters.

(3) Wadi sediments

Distribution: The wadi sediments is distributed widely along the wadi and in the lowland of the area.

Lithology: Wadi sediments consists of sand and gravel.

2–2–2 Area B

The stratigraphy in the area B consists of the Halfa Formation, Tertiary Limestone Formation and Quartenary sediments. Because of the wide distribution of Quaternary sediments, the Halfa Formation occurs in the restricted area.

(1) Halfa Formation

The Halfa Formation in this area is divided into following Lower, Middle and Upper Member.

Lower Member (Hl)

Distribution: The Lower Member is distributed in the western and west side of central part of the area.

Lithology: The Lower Member consists mainly of shale and partially intercalates grayish white chert. The color of Lower Member is yellowish white, and black to blackish brown calcareous bed and calcareous nodule, 3 to 5 centimeters thick, are intercalated.

Stratigraphic relation: Although the lower formation does not crop out, the relationship between lower formation (Ibra Formation) and the Lower Member (Hl) is inferred to be tectonic contact (Glennie et al 1974).

Thickness: The estimated thickness of the Lower Member is more than 100 meters in the southwestern part of the area.

Middle Member (Hmr, Hmw, Hms)

Distribution: The outcrop in the area mainly belongs to the Middle Member.

Lithology: The Middle Member consists of the Red alternating bed, the White alternating bed and the Transitional alternating bed and the repetition of these bed is also recognized. The Red alternating bed consists of four beds and the thickness of the Middle Member is 30 to 90 meters. The Red alternating bed is more thick compare to the same bed in the area A. The manganese ore deposits are mainly occure in the Middle Member.

The results of microscopic observation of chert in the Red alternating bed is as follows;

Red brown muddy chert (G125)

Red brown muddy chert consists of chalcedonic and microcrystalline quartz. Red colored lamina, great amount of radiolaria and a little piece of clay mineral are observed.

Lens of yellow chert is recognized in the Red alternating bed. The result of microscopic observation of this chert is as follows;

Yellow chert (G124)

Yellow chert consists of microcrystalline quartz. Manganese minerals and limonite are observed and the yellow chert is strongly disseminated by limonite. Many quartz stringers are observed and the quartz stringer is cut by calcite stringer. Clastic material and radiolaria are not observed in the yellow chert.

The White alternating bed consists of four bed, and the thickness is 10 to 60 meters. Because the White alternating bed changes gradually to the Transitional alternating bed, both beds could not be divided on the geological map.

The results of microcopic observation of white chert in the White alternating bed is as follow;

Grayish White chert (G064)

Grayish white chert consists of chalcedonic and microcrystalline quartz. Weak lamina, radiolaria and a little piece of clay mineral are observed. Clastic material is not recognized.

The thickness of each alternating bed have not big difference, and the thickness of chert is 5 to 20 centimeters and shale is 1 to 15 centimeters. The Shale bed (Hms), in which thin chert bed is intercalated, is distributed in the southeastern part of this area. Shale bed which show same rock facis are also recognized in the area C, but it seems the horizon of the bed is different.

Stratigraphic relation: Middle Member conformably overlies the Lower Member.

Thickness: The estimated thickness of this member is about 300 meters.

Upper Member (Hu)

Distribution: The Upper Member is distributed in east side of central part and eastern part of this area.

Lithology: There is no difference of rock facies between Lower and Upper Member. The Upper Member consists of yellowish white shale.

Stratigraphic relation: The Upper Member conformably overlies the Middle Member.

Thickness: The estimated thickness is more than 100 meters.

The Lower, Middle and Upper Member are distributed in this area and the total thickness is estimated to be more than 500 meters.

(2) Lower Member of Tertiary Limestone Formation (MTl)

The Lower Member is the only exposed member in the Tertiary Limestone Formation in this area.

Distribution: Many small outcrops are observed in the whole area.

Lithology: The Lower Member consists mainly of sandy limestone and it contains medium to coarse quartz fragments. The color on the surface of this rock is dark brown to dark gray.

Stratigraphic relation: Although the relationship between the Halfa Formation and this member is not clear, the relationship is inferred to be an unconformity.

Thickness: The estimated thickness is more than 60 meters.

(3) Quaternary sediments

Quaternary sediments consists of sand and gravel covering more than 85% of the area, and are distributed as terrace and talus deposits.

The terrace deposits consist of the higher terrace and the lower terrace deposits. The higher terrace deposits is distributed at more than 210 meters in altitude in the western part and more than 185 meters in altitude in the eastern part. The lower terrace deposits is distributed at more than 175 meters in altitude in the western part and more than 163 meters in altitude in the eastern part of the area. Trenching survey was conducted for manganese ore deposit in the area where the higher terrace deposits are distributed. The thickness of the terrace deposits is 1 to 3 meters, and the deposits mainly consist of limestone gravel.

2–2–3 Area C

The stratigraphy in the area C consists of Middle Member of the Halfa Formation, Lower Member of the Tertiary Limestone Formation and Quarternary sediments in ascending order.

(1) Middle Member of Halfa Formation (Hmr, Hmw, Hms)

Distribution: The Middle Member crops out at the hill in central to northwestern part of the area.

Lithology: The Middle Member consists of the Red alternating bed, the White alternating bed and the Transitional alternating bed.

The Red alternating bed consists of muddy chert, 5 to 15 centimeters in thickness, and shale, 1 to 5 centimeters in thickness, and chert is dominant in the bed. Four Red alternating bed are recognized in the area and the thickness of each bed is 20 to 90 meters. The upper and lower margin, 5 to 10 mesters from the boundary, of the Red alternating bed show purplish gray color, and chert is dominant. The Red alternating bed changes gradually to the White alternating bed and also to shale bed. The manganese ore deposit occurs in the Red alternating bed. Two White alternating bed are distributed in the area and the thickness of each bed is 40 and 50 meters. The thickness of chert and shale in the White alternating bed is 2 to 20 centimeters and shale is dominant. Yellowish brown chert, 60 centimeters in thickness, is intercalated in the White alternating bed and rarely lenticular manganese ore, less than 5 centimeter in thickness, is recognized in this chert. Shale bed consist mainly of gray shale and the thickness is about 30 meters. The shale rarely intercalates white muddy chert, 10 centimeters in thickness, and organic material bearing black calcaseous mudstone, 3 to 10 centimeters in thickness.

Stratigraphic relation: Although the Lower Member does not crop out, the relationship between Lower Member and the Middle Member is inferred to be a conformity.

Thickness: The estimated thickness is more than 270 meters.

(2) Tertiary Limestone Formation (HTl)

Distribution: Tertiary Limestone Formation occurs in a small area of the eastern part of the area C.

Lithology: Tertiary Limestone Formation in the area C consists of pebble bearing pale yellowish brown sandy limestone in the lower portion and black porous tuffaceous limestone in the upper portion of the formation.

Stratigraphic relation: The relationship between the Halfa Formation and the Tertiary Limestone Formation is an unconformity.

Thickness: The thickness is estimated to be more than 20 meters.

(3) Quaternary sediments

Quaternary sediments of the area C consists of the higher terrace deposits, the lower terrace deposits, the talus deposits and wadi sediments. The terrace are composed of calccrete and

unconsolidated gravel, and the wadi sediments consists of unconsolidated gravel.

2–2–4 Area D

The stratigraphy in the area D consists in ascending order of the Halfa Formation (Lower and Middle Member), the Tertiary Limestone Formation and Quaternary sediments.

(1) Lower Member of Halfa Formation (Hl)

Distribution: The Lower Member of the Halfa Formation is distributed in the central to northern part of the area D.

Lithology: The Lower Member consists of yellowish white to pale purplish gray shale and intercalates grayish white chert. The lower portion of the member rarely intercalates pale pinkish siliceous limestone of 2 to 5 centimeters in thickness and this limestone is compact and hard.

The result of microscopic observation of the chert is as follow;

Grayish white chert (K075)

Grayish white chert consists of chalcedonic and microcrystalline quartz, and clay mineral (montmorillonite) is also recognized. Brown colored lamina and spherical radiolaria are observed. The diameter of the spherical radiolaria is 0.1 mm in average and 0.2 mm in maximum. Opaque mineral could not be observed.

Pale red chert (K076)

Pale red chert consists of chalcedonic and microcrystalline quartz. The alternation of white chert and pale brown chert is observed. The white chert consists of large amount of spherical radiolaria, and the pale brown chert contains clay mineral (montmorillonite) and poor radiolaria. The diameter of the spherical radiolaria is 0.08 mm in average and 0.2 mm in maximum.

Stratigraphic relation: It is not clear because the lower formation does not crop out.

Thickness: The estimated thickness is more than 150 meters in the area D.

(2) Middle Member of Halfa Formation (Hmr, Hmw)

Distribution: The Middle Member of the Halfa Formation is distributed in the whole area.

Lithology: Three Red alternating bed are recognized in the area D. Among these, the thickness of lower two beds is 40 to 50 meters each, and the thickness of the upper most bed is more than 30 meters. The Red alternating bed consists of the alternation of muddy chert and shale. The thickness of the chert is 2 to 10 centimeters and the shale is 1 to 10 centimeters, and the chert is

generally dominant. The manganese ore deposits are recognized in the Red alternating bed.

The result of microscopic observation of chert in the Red alternating bed is as follow;

Reddish brown muddy chert (K073)

Reddish brown muddy chert consists of chalcedonic and microcrystalline quartz. Red colored lamina is recognized. A little piece of clay minerals (kaolinite and sericite) are observed. Great amount of spherical radiolaria is recognized and the diameter is 0.15 mm in average and 0.4 mm in maximum. The stringer of manganese mineral, quartz and calcite are also recognized.

Three White alternating bed are identified in the area. The amount of chert and shale in the White alternating bed is generally equivalent. Two or three Transitional bed are recognized in the area and the thickness of each bed is 5 to 40 meters. The amount of chert and shale in the Transitional alternating bed is almost equivalent. The Transitional alternating bed change gradually to the White alternating bed and therefore, could not be divided on the geological map.

Stratigraphic relation: The Middle Member of the Halfa Formation conformably overlies the Lower Member.

Thickness: The estimated thickness of the Middle Member is more than 210 meters.

(3) Tertiary Limestone Formation

Distribution: The Tertiary Limestone Formation is distributed in the northern part and south side of central part of the area D.

Lithology: The Tertiary Limestone Formation consists of yellowish brown sandy limestone, gray to dark gray massive limestone, gray sandstone, pale greenish gray shale, dark gray basalt lava and tuff. The sandy limestone is fine grained, but partially coarse part and cobble are also recognized. The massive limestone contains foraminifera in some parts. The dark gray limestone is porous. The basalt lava is distributed in the eastern and southeastern part of the area D. The tuff is andesitic and basaltic tuff, and it contains angular chert fragment originated from the Halfa Formation. The tuff also contains pisolite.

The result of microscopic observation of basalt is as follow;

Basalt (K006)

Texture: Graphic porphyritic texture

Constituent minerals: Augite > Plagioclase > Opaque mineral.

As the secondary mineral, calcite, chlorite and epidote are observed. Phenocryst consists of graphic augite of 1 mm in size. Groundmass is comprised of plagioclase, euhedral opaque

minerals and augite. Augite phenocryst has been partially changed to calcite.

Stratigraphic relation: The relationship between the Halfa Formation and the Tertiary Limestone Formation is inferred to be an unconformity.

Thickness: The estimated thickness is more than 150 meters.

(4) Quaternary sediments

Quaternary sediments in the area D consists of the terrace deposits, the talus deposits and the wadi sediments. These sediments are comprised of sand and gravel.

2–2–5 Geological correlation and age of the Halfa Formation

Halfa Formation in the four survey areas of this Phase, consist of Lower, Middle and Upper Member, dominate folding structures and lack a obvious key bed, it is therefore difficult to correlate each survey area stratigraphycally.

Geological correlation between areas B, C and D are comparatively easy because the areas have Lower Member and thick beds of Red alternating bed and White alternating bed of Middle Member.

In the area A, there is only Middle Member which have six Red alternating beds without Upper and Lower Members, then geological correlation with areas B, C and D is quite difficult.

In the area where eastern neighbourhood of the area A, Lower Member crops out and lower Red alternating bed of the Middle Member thought to be correlate with Red alternating bed of the area B, C and D.

Radiolarian fossile were recognized in the 16 samples as shown in Table A–3.

Three groups of species of radiolaria can be observed as follows, and age of these groups were determined by correlation with zonage of Passagno (1977 a,b), Foreman (1973, 1977) and schaaf (1981).

Although each groups have a time range, and appearently overlap each other, the relationship of upper and lower can be recognized.

group 1: Berriasian ~ Valanginian

Eucyrtidium (?) ptyctum, Protunuma sp., Thanarla conica, Parvicingnla citae, P. spp., Setocapsa sp., Archaeodictyomitra apiara, Paronaellasp.

are observed characteristically.

group 2: Valanginian ~ Barremian

Archaeodictyomitra apiara, Pseudodictyomitra carpatica, Thanarla pulchra, Parvicingla boesii, Alievium sp., Mirifusus sp.

are observed having a transitional characteristics of group 1 and group 3.

group 3: Barremian ~ Aptian

Cecrops septemporatus, Archaeodictymitra lacrimula, Eucyrtis tenuis, E. micropora, Alievium helenae, Sethocapsa trachyostraca, thanala pulchra.

are observed characteristically.

K077 and K106 are typical samples of group. K077 is reddish brown tint chert collected from foot wall side of the outcrop No.160 in the area D, and K106 is brown chert collected from appearently hanging wall side of the outcrop No.110 in the area A. Typical samples of group 2 are K013, K071, K081, K082, K103 and H003.

K071, K081 and K082 are red chert, grayish white chert and red chert collected from haying wall side of the outcrop No.160 in the area D.

Although these samples are distributed from the bottom to upward K071, K082 and K081, age of these samples are shown similar epoch, therefore, a stratigraphical repetition can be considered.

K103 is red chert from the appearently foot wall side of the outcrop No.110 in the area A, and H003 is White alternating bed in the area D.

Typical samples of group 3 are K078, K093 and K104. K028 is chert in the White alternating bed collected from hanging wall side of the outcrop No.160 in the area D. K093 is red chert collected from the outcrop No.159 (trench No.3) in the area B.

K104 is chert in the White alternating bed collected from appearently foot wall side of the outcrop No.110 in the area A.

Furthermore, K012 and H037 are samples of Thitonian ~ Berriasian.

K012 is chert in the shale bed in the area C, H037 is chert in the White alternating bed of the lowest portion in the area B.

In the K075, K076 and K107, radiolarian fossils were recognized but these fossils can not be classified into the groups abovementioned because of bad preservation. As the mentioned above, chert samples in the survey area show the age from end of the Jurassic (Tithonian) to early Cretaceous (Aptian).

The second Red alternating bed (group 1 and 2) from the bottom in the area A is thought to be correlated with the lowest Red alternating bed (group 1 and 2) in the areas C and D. Although rock facies of the lowest Red alternating bed in the area B is appearently correlate with the second Red alternating bed of the area A and the lowest Red alternating bed of the area C and D, radiolarian fossil of K093 is correlated with the lowest White alternating beds of the area A and D.

The outcrop No.110 is embedded in the second Red alternating bed in the area A, and the outcrop No.159 and No.160 are embedded in the lowest Red alternating bed in the area Band D.

Two horizon of the Red alternating bed embedding main ore deposits are thought to be distributed in the area.

2–3 Intrusive Rocks

Intrusive rocks in the area are dolerite, andesite, basalt and pyroxenite.

Dolerite was discovered in the area B and D. Although the dolerite of the area B is recognized in the talus sediments as small outcrop having indistinct relation with the Halfa Formation, the dolerite of the area D is observed as dyke rocks, intruded in the Tertiary limestone trending N20°W with width of 20 centimeters, and a small outcrop of trachyandesite dyke or sheet is covered by the Quaternary sediments.

The results under the microscopic observation are as follows.

Trachyandesite (H014)

Texture: trachytic texture

Constituent minerals: plagioclase, opaque, calcite and chlorite are observed. Carlsbad twin of the plagioclase is dominant and complex twin of albite-carlsbad can be observed. An = 40%, as the secondary mineral calcite and chlorite are recognized.

Basalt dyke is observed intruding the Halfa Formation in the area D.

The rock facies of the basalt show green color, compact and aphanitic, and trend N–S to NNE–SSW with width of 1 ~ 5 meters.

The rock has chilled margin pyritized part. A small outcrop of Pyroxenite is recognized in the area B, showing holocrystalline texture.

The results under the microscopic observation are as follows.

Pyroxenite (K150)

Texture: Equigranular texture

Constituent minerals: orthopyroxene (hypersthene) > clinopyroxene (augite) > olivine

serpentine and calcite are secondary minerals. Euhedral orthopyroxene crystal are 1 ~ 2 mm in size and subhedral clinopyroxene are 1 mm in size. Small amount of euhedral olivine, 0.4 mm in size, are also observed. Exsolution lamella can be observed in orthopyroxene and a part of cleavage is replaced with calcite. Serpentine replace a part of clinopyroxene crystal and interstice of crystals, and almost olvines are replaced.

The relationship between this rock and Halfa Formation is not clear because the talus sediments unconformably overlie this rock.

2–4 Geologic Structure and Geological History

Geologic structure in the Sur area is characterized by a large-scale thrust movement in Late Cretaceous and upheaval movement which formed the Middle Tertiary foldings. The geological structure of the Halfa Formation which is distributed as the main geological unit in the Sur area, is remarkably complicated by numerous folds and faults.

The Halfa Formation is mainly distributed in the surveyed area of this year. The geologic structure of the Halfa Formation is slightly different in each area as mentioned below.

2–4–1 Area A

The Halfa Formation in the area A is complexly folded and faulted. The fold structure is divided into three different order such as 1) 100 to 500 meters wave length, 2) 1 to 3 meters wave length, and 3) several centimeters wave length.

1) is the main folding structure and the axis of the fold show NW–SE direction in the central part of the area A. The fold is overturned and closed fold. The axis of the fold planges to south. Among the fold structure of 2), the open folds were recognized, and the axis of the fold structure intersect at right angles to the axis of fold structure of 1). The fold structure of 2) was frequently observed in the field. The fold structure of 3) is small scale accompanying the fold structure of 2).

The numerous small scale faults are observed in the area A, but the most of them are too small to mapped on the geological map. The trend of faults are generally oblique to the axis of the folds, however, some fault show similar trend of the axis of the folds. ENE–WSW and NW–SE trend faults are dominant and NNE–SSW and E–W trend faults are also recognized.

2–4–2 Area B

The axis of main folds shows NE–SW and NNE–SSW direction in the northern part and NW–SE in the central to southwestern part of the area B. In the southern to southeastern part of the area B, the axis of the fold shows different direction such as E–W, NW–SE, and NE–SW. NNE–SSW direction fold structure contributes to form the basin structure and E–W trend weak fold structure is recognized in the basin.

Thrust fault which shows similar direction of the axis of the fold and the general strike of the formation is recognized. NE–SW trend small fault in the southwestern part and NW–SE trend small fault in the northwestern part of the area are also recognized.

2–4–3 Area C

The axes of main fold structure in the area C trend to N–S and NNE–SSW. Small fold structures are also recognized and the axis of the fold trends to NNW–SSE and NNE–SSW.

Small scale faults are recognized. As rather large scale fault, E–W trend fault is observed in the western part of the area C.

2–4–4 Area D

The axes of fold show N–S to NNE–SSW direction and the wave length is 50 to 100 meters or more. Among these folds, the folds in the eastern to southern part of the area D are overturned fold and dipped to east. The remarkable NE–SW direction fold is recognized in the northeastern part of the area and it planges to northeast. The repetition of the bed is recognized because of the fold structure.

Fold structure is also recognized in the Tertiary Limestone Formation and the directions are similar to the direction of the fold in the Halfa Formation.

As the remarkable fault structure, NE–SW trend faults are recognized. The other small scale faults show N–S and E–W trend.

The trends of the intrusive rocks show N–S to NNE–SSW which are main structure trend in the area D.

2–4–5 Geological history

The outline of the geological history of the Sur area including the surveyed area is described in the following, with reference of the history of structural development of the Oman Mountains reported by Glennie et al (1974).

From Permian to Triassic, the area on the northeast of the Sur area was under the shallow sea, where coral limestone formed, and basic volcanic activity took place in the same period.

In Triassic period, the calcareous neritic sediments (Ibra Formation) was formed around the limestone. Further subsidence of this area during the period from Late Triassic to Early Jurassic and the Hawasina basin was formed. Deposition of the Halfa Formation initiated at that time, and a forming ridge and submarine volcanic activity took place in the period. Untill Middle Cretaceous, the characteristic sediments (Hawasina Group), showing sedimentary environment, were formed in the Hawasina basin.

The Halfa Formation is one of the formation of the Hawasina Group and consists of pelagic sediments such as chert and shale. Submarine volcanic activity took place in the period of deposition of the Halfa Formation, and it is presumed that the manganese ore deposits was related to

the volcanic activity. Radiolaria fossil evidence suggests that the manganese ore deposit formed in Late Jurassic to Early Cretaceous. After that, from Late Cretaceous to the final stage of Cretaceous, major thrust movement took place and the Hawasina Group over the autochthonous Arabian platform, and further the ophiolite thrusted over the Hawasina Group. This thrust fault seems to have caused severe folding and faulting in the Halfa Formation. From Latest Cretaceous to Middle Testiary, the area was under the neritic sedimentary environment, and thick limestone was formed.

Upheaval movement after Middle Tertiary formed gentle foldings and faults.

Chapter 3. Manganese Ore Deposits

3–1 General Description

The emplacements of manganese ore deposits has been reported. The previous phase's survey added many new manganese ore outcrops and made it clear that the manganese deposits are widely distributed in the whole Sur area.

The ore deposits generally occur as ore zones of several manganese beds embedded mainly in the Red alternating beds of the Middle Member of the Halfa Formation. The individual ore bed is small in scale and intermittent, however, the ore bed zone is, in place, traceable over a distance of 1,500 m.

The manganese minerals are mainly pyrolusite, with very small amounts of cryptomelane and manganite.

The average ore grade is 29.57% MnO_2 indicating the ores are of low grade.

In the Middle Member, 3 to 6 ore-horizons are found being repeated by folding. The ore deposits is considered to be of layered volcanogenic sedimentary deposits.

In this phase, detailed mapping for the ore outcrops in 4 areas where ore deposits are abundant, trenching survey for the lateral extension of an ore outcrop in the area B, and drilling survey for the subsurface extension of the outcrops in the area A were conducted. The results obtained are described hereafter. The results of the drilling survey will be stated later.

3–2 Distribution of Ore Deposits

The manganese ore deposits in the Sur area show a widely scattered distribution occurring in the almost every part where the Middle Member of the Halfa Formation underlies.

However, the areas where the ore deposits occur relatively in abundance are the objective areas of this phase. In particular, numerous ore outcrops were found in the area A, 5 km south of Jaramah, and in the area B, 16 km northwest of Awaïka.

The number of the major ore deposits surveyed in this phase comes to 60 as listed in Table I–1.

The distribution of the ore deposits in the whole Sur area is shown in Fig. I–4, Plate I–5. The distribution in each area is shown in Fig. I–6, I–7, I–8, and I–9, respectively.

3–3 Ore Horizon

In this phase's survey, the Middle Member of the Halfa Formation where the manganese ore deposits are abundant were subdivided into Red alternating beds, White alternating beds, Transi-

Table I—1 List of Manganese Outcrops

(Area A)

Outcrop No.	Location		Strike dip	Lateral Length (m)	Average Thickness (m)	Mode of Ore	Host Rock	Ore Sample No.	Average Grade	
	Latitude	Longitude							MnO$_2$(%)	Mn(%)
56	N2482	E781	E–W 85S~85N	50	0.30	layer	muddy chert/ shale	A068 A069	19.95	12.84
59	N2482	E781	N65W 65~70N	150	0.20	do	do	A009 A014 A012	21.17	13.55
60	N2482	E781	N65W 85S~60N	80	0.15	do	do	A016 A018	27.26	17.98
64	N2482	E780	N80W~E–W 55~65S	140	0.20	do	do	A070 A071	27.83	18.12
68	N2484	E780	N70E 25S	150	0.40	do	do	D026A D030A D028A D032A	21.17	13.98
69	N2481	E780	N80E 90	300	0.61	do	do	F056A~F058A F060A, F061A	19.69	12.87
71	N2481	E780	N80E 55N	350	0.50	do	do	H070A~H076A H078A, H079A F063A~F068A H081A~H084A	24.70	15.21
72	N2481	E780	N45E 60N	140	0.30	do	do	F074A~F076A	30.79	20.12
73	N2483	E780	N30W 50S	250	0.90	do	do	D034A	19.83	12.61
76	N2481	E770	N85E 80W	300	0.45	do	do	F077A~F080A	13.24	9.07
95	N2483	E779	N50W 45S	350	0.85	do	do	D039A~D042A D044A, D047A D049A	19.40	11.66
110	N2485	E778	E–W/75N N45W/30S	1510	0.60	do	do	B107A~B116A C063A~C074A F088A~F095A H085A~H143A	26.68	17.29
114	N2482	E778	N25W 70N	70	0.85	do	do	C047A~C049A	17.71	11.50
116	N2482	E777	E–W 50S	430	0.43	do	do	B137A B140A B139A	16.18	10.33
117	N2484	E777	N80W 55S	500	0.29	do	do	B141A~B145A	19.94	12.84
120	N2485	E777	E–W 60S	50	0.62	do	do	A029A A032A A031A	12.26	8.01
121	N2485	E747	N75E 70~80N	140	0.30	do	do	A034A A038A A036A A039A	16.65	10.73
123	N2484	E777	N75W 40S	650	0.34	do	do	B043A~B045A B120A~B124A	31.57	20.39
124	N2483	E777	N65E 70S	65	0.40	do	do	B136A	58.15	36.74
132	N2484	E777	N30~60E 70N	160	0.30	do	do	A043A~A045A	11.95	7.68
133	N2483	E777	N40E 70N	200	0.24	layer lens	do	B103A B106A B105A	19.35	12.43
136	N2485	E776	N70E 80S	500	0.84	layer	do	D054A D058A D055A D061A D063A D067A D066A	23.67	15.00
140	N2484	E776	E–W/50S N50E/55N	500	0.47	do	do	J087A~J107A B092A B096A B095A B098A~B101A J073A~J075A	27.68	17.54
142	N2484	E776	N45E 50S	300	0.29	do	do	B084A~B086A B091A	26.59	17.51

(Area C)

Outcrop No.	Location		Strike dip	Lateral Length (m)	Average Thickness (m)	Mode of Ore	Host Rock	Ore Sample No.	Average Grade	
	Latitude	Longitude							MnO_2(%)	Mn(%)
161	N2452	E767	N50W/40S N5W/65S	250	1.35	layer	muddy chert/ shale	J024A E076A J025A	13.90	8.71
188	N2452.5	E766.5	N12E/74S N5E/60S	70	0.50	do	do	H023A H028A	46.54	29.69
189	N2452.5	E767	N75W 23S	70	0.25	do	do			
190	N2452	E766.5	N30E 80S	80	0.30	do	do	H029A	47.07	29.68
191	N2451	E767	folded	100	0.30	do	do			

(Area D)

Outcrop No.	Location		Strike dip	Lateral Length (m)	Average Thickness (m)	Mode of Ore	Host Rock	Ore Sample No.	Average Grade	
	Latitude	Longitude							MnO_2(%)	Mn(%)
160	N2456	E771	N–S 80E	250	0.95	layer	muddy chert/ shale	K004A K050A~K052A K053aA K054A K053bA K055aA K0556A K55cA K060A~K064A E037A	40.77	25.58
192	N2456	E771	N–S 55E	110	0.50	do	do	K056A K057bA K057aA K058aA K058bA K059A	45.91	28.18
193	N2454.5	E770.5	folded	40	0.20	do	do			
194	N2453.5	E769	N60E 45S	100	0.30	do	do	H011A	20.35	12.60
195	N2452	E770.5	folded	50	0.25	do	do			
196	N2452.5	E771.5	N5E 85S	230	0.15	do	do			
197	N2452.5	E771.5	N15W~N10E 78E	260	0.25	layer lens	do			
198	N2448	E770	N–S~N10E 60W	250	0.20	layer	do			

tional alternating beds, and shale beds according to their lithology and characteristic tones. In this mannar the ore horizons were clearly distinguished.

The ore horizons are the Red alternating beds except the White alternating beds that embeds small-scale manganese lenses at a place in the area C. The Red alternating beds consist of reddish brown chert, reddish brown to light brown muddy chert, and reddish brown shale. The beds around manganese ore beds are in most cases of alternating beds of light brown chert and shale. The chert beds which are the constituent of the alternating beds generally grade into muddy chert. In a chert bed, the central part is pure chert but the marginal part is muddy chert. In the muddy chert laminations are characteristically developed. Under the microscope, the muddy chert has laminations where hematite is densely banded and the chert includes rare clay minerals. Excepting these characteristics, no remarkable difference in mineral composition is observed between the chert and muddy chert. In the Red alternating beds, chert beds are dominant when compared with those in the shale beds. The accumulating type of these cherts (or muddy cherts) and shales is considered to be of the "triple layered type" or "laminated type" proposed by Iijima (1982). The upper or lower sequence of the Red alternating beds is the White alternating beds or Transitional alternating beds. In most cases the White alternating beds occur neighboring to the Red alternating beds.

The Red alternating beds, the ore-embedding sections, occur in 6 horizons ranging their thickness from 5 to 30 m in the area A. In the areas of B, C and D, they occur in 3 to 5 horizons ranging their thickness 20 to 90 m.

The apparent tone difference between red chert and white chert is due to the difference of iron content. In addition the difference of frequency of included radiolaria fossils is recognized by microscopic studies. From above-mentioned facts it is considered that the two-type chert beds are formed in different sedimentary environment to each other.

3–4 Scale of Ore Deposits

Numerous manganese ore deposits are distributed in the Sur area. In this phase, the major ones consisting of ore beds of over 15 cm thickness and of over 20 m length were listed up in Table I–1. About these ore deposits in the Sur area, particularly in the areas of A, B, C and D, a preliminary calculations of the ore reserves were undertaken based on the following assumption.

Table I—2 Ore Reserve of Manganese Outcrops

(Area A)

Outcrop No.	Lateral Length (m)	F_1	Thickness (m)	F_2	Dip Side Length (m)	Specific Gravity	Ore Reserve (t)	Average Grade MnO_2(%)	Contents MnO_2(t)	Number of Samples
56	50	80	0.30	80	30	3.00	864	19.95	172.4	2
59	150	80	0.20	80	30	3.04	1,751	21.17	370.7	3
60	80	80	0.15	80	30	3.15	725	27.26	197.6	2
64	140	80	0.20	80	30	3.16	1,698	27.83	472.6	2
68	150	80	0.40	80	30	3.04	3,502	21.17	741.4	4
69	300	80	0.61	80	30	3.00	10,540	19.69	2,075.3	15
71	350	80	0.50	80	30	3.10	10,416	24.70	2,572.8	10
72	140	80	0.30	80	30	3.37	2.717	30.79	836.6	3
73	250	80	0.90	80	30	3.00	12,960	19.83	2,570.0	1
76	300	80	0.45	80	30	2.87	7,439	13.24	984.9	5
95	350	80	0.85	80	30	3.01	17,193	19.40	3,335.4	7
110	1,510	80	0.60	80	30	3.07	53,403	23.01	12,288.1	121
114	70	80	0.85	80	30	2.96	3,381	17.71	598.8	3
116	430	80	0.43	80	30	2.94	10,437	16.18	1,688.7	3
117	500	80	0.29	80	30	3.01	8,379	19.94	1,670.8	4
120	50	80	0.62	80	30	2.87	1.708	12.26	209.4	3
121	140	80	0.30	80	30	2.95	2,378	16.65	395.9	4
123	650	80	0.34	80	30	3.24	13,747	31.57	4,339.9	5
124	65	80	0.40	80	30	3.85	1,921	58.15	1,117.1	1
132	160	80	0.30	80	30	2.86	2,635	11.95	314.9	2
133	200	80	0.24	80	30	3.00	2,764	19.35	534.8	2
136	500	80	0.84	80	30	3.08	24,837	23.67	5,878.9	26
140	500	80	0.47	80	30	3.16	14,258	27.68	3,946.6	10
142	300	80	0.29	80	30	3.14	5,245	26.59	1,394.6	3
						A Total	214,880	22.67	48,708.2	

(Area B)

Outcrop No.	Lateral Length (m)	F_1	Thuckness (m)	F_2	Dip Side Length (m)	Specific Gravity	Ore Reserve (t)	Average Grade MnO_2 (%)	Contents MnO_2 (t)	Number of Samples
155	50	80	0.65	80	30	3.45	2,153	41.11	885.1	1
158	150	80	2.37	80	30	3.41	23,275	39.78	9,258.8	4
159	590	80	4.15	80	30	3.31	155,601	34.94	54,369.1	52
168	70	80	0.60	80	30	3.31	2,669	34.56	922.4	1
169	50	80	1.30	80	30	3.45	4,306	41.47	1,785.7	1
170	50	80	0.70	80	30	4.04	2,715	65.94	1,790.3	1
171	100	80	0.25	80	30	3.57	1,714	46.99	805.4	1
172	350	80	0.45	80	30	3.58	10,820	47.16	5,105.5	2
173	40	80	0.80	80	30	3.29	2,021	34.07	688.6	1
174	10	100	0.70	80	24	4.19	563	71.29	401.5	1
175	40	80	0.20	80	30	3.10	476	24.74	117.8	1
176	30	80	0.30	80	30	3.54	612	45.14	276.1	1
177	20	100	0.15	80	24	3.24	187	31.72	59.3	1
178	50	80	0.70	80	30	2.97	1,996	17.48	348.9	1
179	30	80	0.05	80	30	3.19	92	28.79	26.6	1
180	20	100	0.20	80	24	4.61	354	85.14	301.4	1
181	60	80	0.40	80	30	3.33	1,534	35.44	543.8	1
182	130	80	0.28	80	30	4.18	2,921	71.49	2,088.5	1
183	40	80	0.70	80	30	3.31	1,779	34.94	621.7	2
184	370	80	1.30	80	30	3.13	28,906	26.50	7,660.1	6
185	100	80	0.45	80	30	3.34	2,886	36.42	1,051.0	2
186	40	80	0.30	80	30	3.08	710	23.49	166.8	1
187	110	80	0.30	80	30	3.55	2,249	45.54	1,024.2	2
						B Total	250,545	36.04	90,298.6	

(Area C)

Outcrop No.	Lateral Length (m)	F_1	Thickness (m)	F_2	Dip Side Length (m)	Specific Gravity	Ore Reserve (t)	Average Grade MnO_2(%)	Contents MnO_2(t)	Number of Samples
161	250	80	1.35	80	30	2.90	18,792	13.90	2,612.1	2
188	70	80	0.50	80	30	3.51	2,359	46.54	1,097.9	2
189	70	80	0.25	80	30	3.0	1,008	19.0*	191.5	
190	80	80	0.30	80	30	3.58	1,650	47.09	776.7	1
191	100	80	0.30	80	30	3.0	1,728	19.0*	328.3	

C Total 25,539 19.60 5,006.5

(Area D)

Outcrop No.	Lateral Length (m)	F_1	Thickness (m)	F_2	Dip Side Length (m)	Specific Gravity	Ore Reserve (t)	Average Grade MnO_2(%)	Content MnO_2(t)	Number of Samples
160	250	80	0.95	80	30	3.44	15,686	40.77	6,395.2	15
192	110	80	0.50	80	30	3.55	3,748	45.91	1,720.7	6
193	40	80	0.20	80	30	3.0	460	19.0*	87.4	
194	100	80	0.30	80	30	3.02	1,740	20.35	354.1	1
195	50	80	0.25	80	30	3.0	720	19.0*	136.8	
196	230	80	0.15	80	30	3.0	1,987	19.0*	377.5	
197	260	80	0.25	80	30	3.0	3,744	19.0*	711.4	
198	250	80	0.20	80	30	3.0	2,880	19.0*	547.2	

*estimated grade

D Total 30,965 33.36 10,330.3

A,B,C,D Total 521,927 29.57 154,343.6

Bases of ore reserves calculation

Length: the ore deposits are the ore bed zones composed of several intermittent ore beds. The length means the strike-side elongation of the ore bed zones. Here, considering the discontinuity of the ore beds the adapted length values equal to the 80% values of the original ones.

Thickness: This means the average thicknesses of the ore beds. Considering the lenticular forms of the ore beds the thickness values adapted equal to the 80% values of the original ones.

Depth: The ore beds are inferred to extend 30 m in their dip side. The ore reserves were calculated within a range of 30 m below surface. In the cases of those ore beds less than 30 m long, their depths were reduced.

Specific gravity: With an assumption that the ores are composed of pyrolusite (S.G.5.1) and quartz (S.G.2.65) a graph that shows the relation between ore specific gravity and ore grade in MnO_2 was made by plotting the calculated values. The specific gravity of each ore were obtained from this graph.

The method of ore reserves calculation is explained in Fig. A–6.

The results of the ore reserves calculation about each ore deposit are shown in Table 1–2. The ore reserves in each area are as follows:

	Number of ore deposits	Ore reserves(T)	Average grade (%MnO_2, %Mn)	
Area A	24	214,880	23.59	15.10
Area B	23	250,545	36.04	24.06
Area C	5	25,537	19.60	12.29
Area D	8	30,965	33.36	20.68
Total	60	521,927	29.57	19.92

The total ore reserves of the 4 areas are approximately 520,000 tons of an average grade of 29.57% MnO_2 (19.92% Mn). When compared the ore reserves in each area, those of the area A and B reach a 41% and 48% of the total ore reserves showing that the manganese deposits are concentrated in those two areas. Among the ore deposits, the largest one is the outcrop No.159 (155,601 tons, average grade 34.94% MnO_2) in the area B that was surveyed by the trenching. The second one is the outcrop No.110 (53,403 tons, average grade 23.01% MnO_2) in the area A that was confirmed by the drilling survey. The ore reserves of these two deposits are as large as 40% of the total ore reserves. In contrast, mosts of the ore deposits are small in scale showing the ore reserves of less than 5,000 tons. Here, the ore reserves of the outcrop No.110 was calculated taking into account the results of the drilling survey.

Regarding the ore grade of each ore deposit, the maximum is 85% MnO_2. However, this deposit is a small one of the ore reserves of 354 tons. An ore deposit of over 5,000 tons ore reserves locally shows an maximum grade of 40.77% MnO_2, but the whole average grade is as low as 29.57% MnO_2.

In this phase, the ore reserves were calculated within the range of 30 m in dip side below surface. The manganese deposits in the Sur area are considered to be generally composed of numerous, small-scaled, low-grade ore beds.

3–5 Major Ore Outcrops

Among many ore deposits the major ore deposits are described hereafter in their mode of occurrence, scale, continuity, and ore grade.

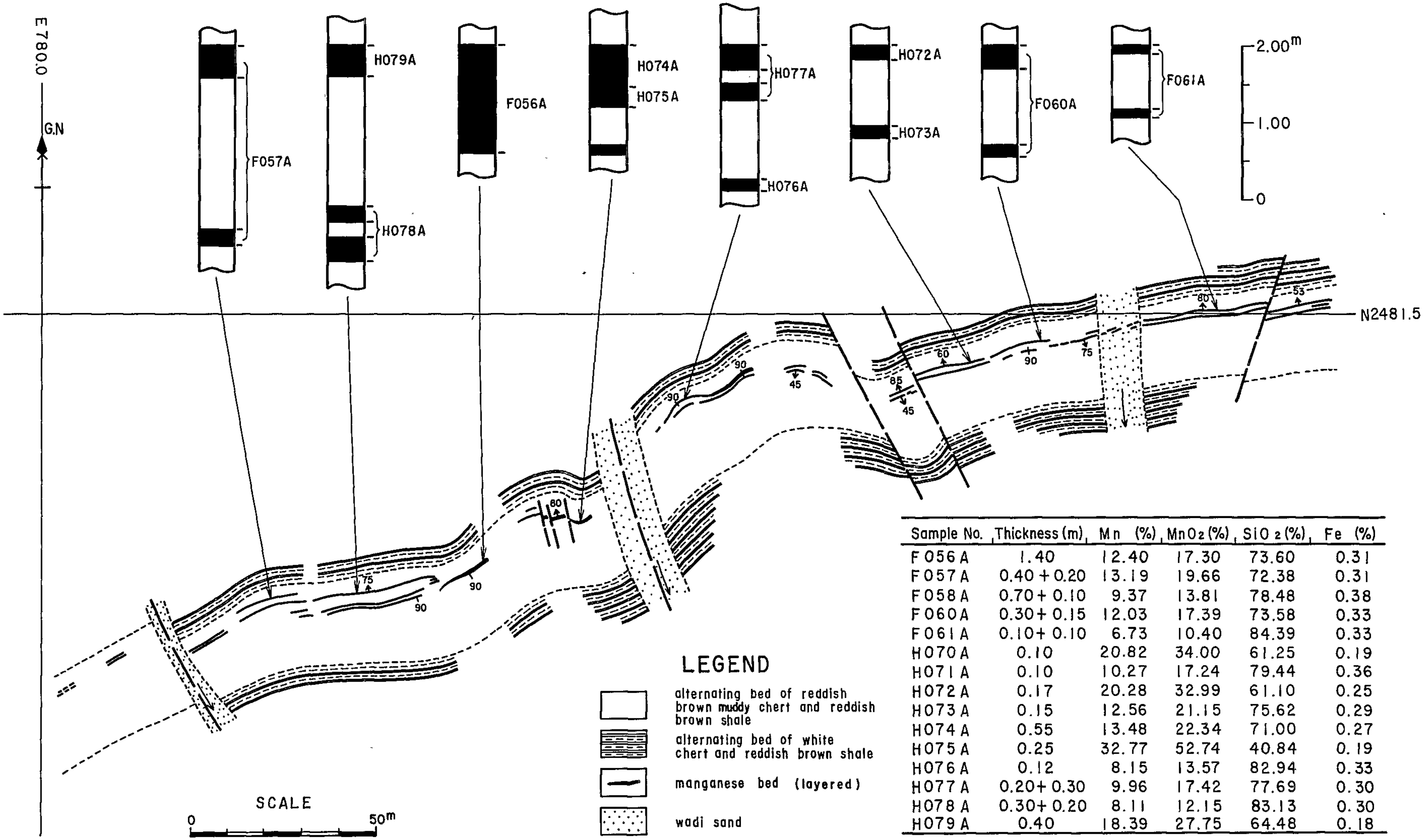
3–5–1 Outcrop No.69

The outcrop No.69 is located in the southeastern part of the area A. The outcrop consists of two manganese beds embedded in the Red alternating beds that strike N70°E and dip 55° to 90°N. (Fig. I–11) shows their mode of occurrence and distribution. The upper ore bed is 10 to 140 cm thick and 10 to 50 m long. The lower one is 10 to 30 cm thick and 10 to 50 m long. The two beds are generally intermittent. They are embedded in the uppermost part of the Red alternating beds. The beds are cut by minor faults of NNE–SSW and NW–SE systems. Ore reserves calculation of this outcrop attained the following figures: ore reserve = 10,540 tons (strike-side length = 300 m, average thickness = 0.61 m, dip-side length = 30 m), average ore grade = 16.69% MnO_2 (12.87% Mn).

3–5–2 Outcrop No.71

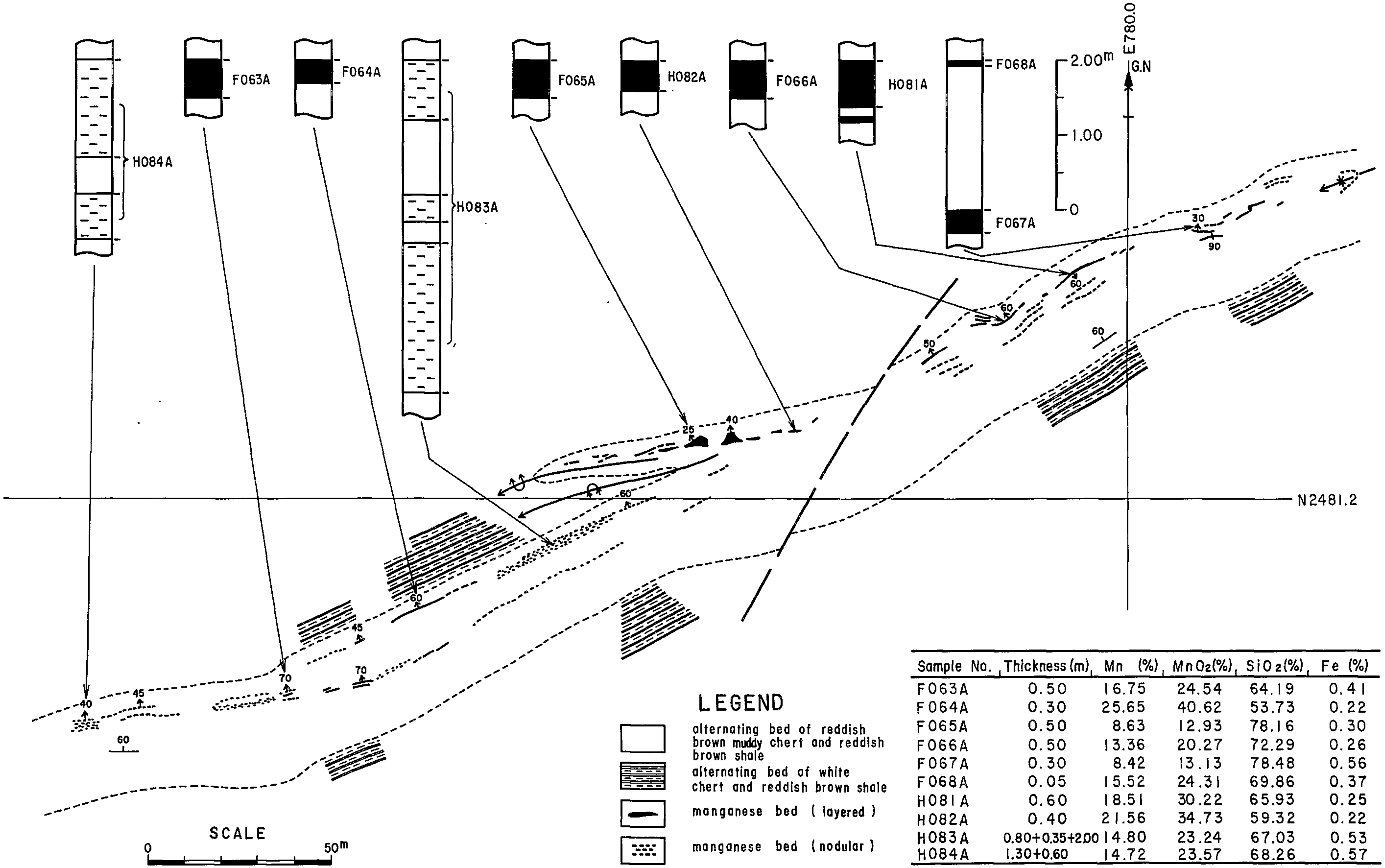
The outcrop No.71 is located in the area A and is 150 m south to the outcrop No.69 (Fig. I–12). The outcrop trends ENE–WSW and dips 35° to 60°N. This outcrop consists of two or three ore beds embedded in the Red alternating beds. Individual ore bed is 5 to 50 cm thick and 10 to 15 m long. Around the ore beds the nodule zones where lenticular or spot-like manganese concentrations are recognized are widely developed. The ore grades are variable from 8.42 to 25.65% Mn and 12.93 to 40.62% MnO_2.

The ore reserves calculation gets the following figures: ore reserve = 10,410 tons (strike-side elongation = 350 m, average thickness = 0.50 m, dip-side elongation = 30 m), average ore grade = 24.70% MnO_2 (15.21% Mn).



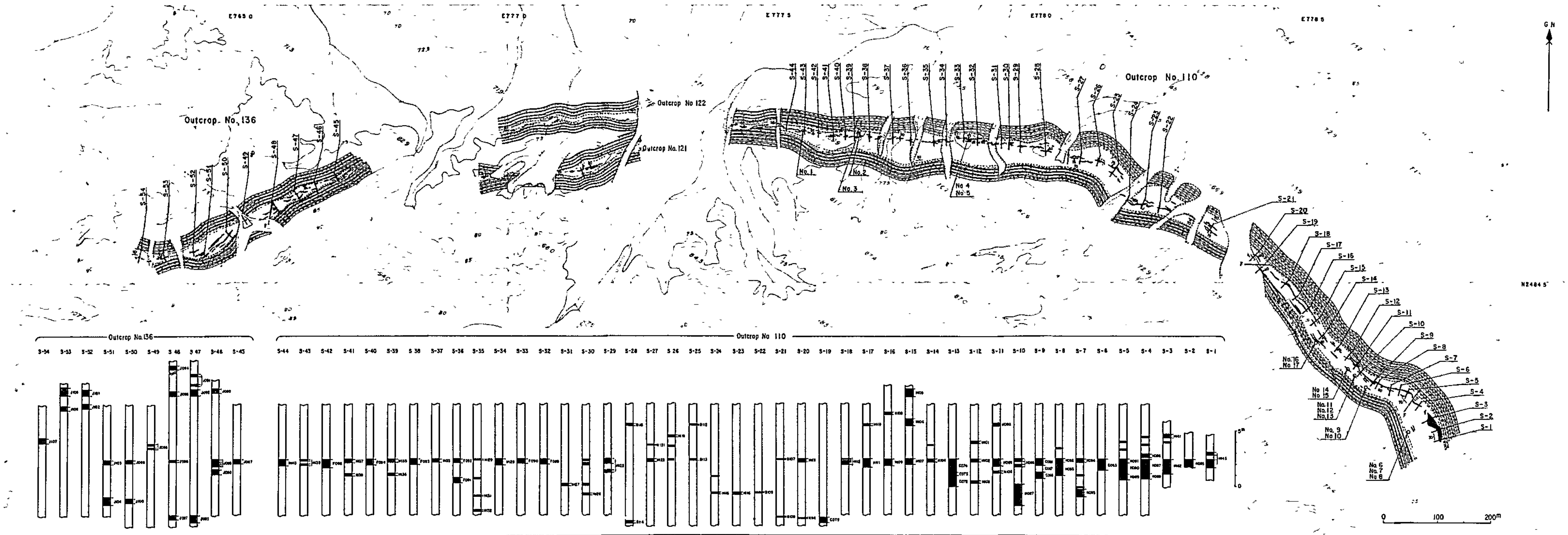
Sample No.	Thickness (m)	Mn (%)	MnO_2 (%)	SiO_2 (%)	Fe (%)
F056A	1.40	12.40	17.30	73.60	0.31
F057A	0.40 + 0.20	13.19	19.66	72.38	0.31
F058A	0.70 + 0.10	9.37	13.81	78.48	0.38
F060A	0.30 + 0.15	12.03	17.39	73.58	0.33
F061A	0.10 + 0.10	6.73	10.40	84.39	0.33
H070A	0.10	20.82	34.00	61.25	0.19
H071A	0.10	10.27	17.24	79.44	0.36
H072A	0.17	20.28	32.99	61.10	0.25
H073A	0.15	12.56	21.15	75.62	0.29
H074A	0.55	13.48	22.34	71.00	0.27
H075A	0.25	32.77	52.74	40.84	0.19
H076A	0.12	8.15	13.57	82.94	0.33
H077A	0.20 + 0.30	9.96	17.42	77.69	0.30
H078A	0.30 + 0.20	8.11	12.15	83.13	0.30
H079A	0.40	18.39	27.75	64.48	0.18

Fig. I—11 Geological Sketch Map of the Manganese Outcrop No. 69



Sample No.	Thickness (m)	Mn (%)	MnO2(%)	SiO2(%)	Fe (%)
F063A	0.50	16.75	24.54	64.19	0.41
F064A	0.30	25.65	40.62	53.73	0.22
F065A	0.50	8.63	12.93	78.16	0.30
F066A	0.50	13.36	20.27	72.29	0.26
F067A	0.30	8.42	13.13	78.48	0.56
F068A	0.05	15.52	24.31	69.86	0.37
H081A	0.60	18.51	30.22	65.93	0.25
H082A	0.40	21.56	34.73	59.32	0.22
H083A	0.80+0.35+2.00	14.80	23.24	67.03	0.53
H084A	1.30+0.60	14.72	23.57	68.26	0.57

Fig. I—12 Geological Sketch Map of the Manganese Outcrop No. 71



Outcrop No.	Section No.	Sample No.	Width (cm)	Mn(%)	MnO2(%)	SiO2(%)	Fe(%)
110	S-1	H131	95	27.69	38.14	54.24	0.26
	S-2	H085	70	34.86	55.14	27.16	0.11
	S-3	H141	76	16.13	28.69	64.35	0.22
		H142	135	20.41	44.98	47.05	0.19
	S-4	H088	56	24.84	39.51	53.55	0.26
		H087	30	14.57	30.27	76.19	0.23
		H086	30	28.31	44.16	46.47	0.17
	S-5	H089	50	30.07	46.87	34.40	0.16
		H090	100	21.69	33.79	61.36	0.19
		H091	15	19.01	31.00	61.19	0.32
	S-6	C061	100	18.12	43.95	46.97	0.26
	S-7	H095	70	17.86	26.38	64.66	0.25
		H094	30	30.80	56.20	36.65	0.10
	S-8	H093	120	13.43	21.17	73.28	0.27
		H092	70	41.39	65.09	27.83	0.01
	S-9	C066	60	15.92	31.13	72.16	0.21
		C067	60	23.19	30.69	71.65	0.36
		C068	50	10.35	14.99	73.87	0.36
	S-10	H097	100	15.76	25.77	67.65	0.30
		H098	50	17.86	27.52	69.61	0.32
110	S-11	H100	20	15.17	23.73	65.75	0.26
		H099	55	18.94	30.93	64.54	0.22
		H098	20	20.84	32.30	61.16	0.30
	S-12	H103	28	15.90	24.13	68.74	0.25
		H102	27	12.77	19.33	72.96	0.30
		H101	23	6.36	17.34	81.79	0.28
	S-13	C072	100	7.15	11.11	74.63	0.64
		C073	30	10.86	26.62	76.57	0.40
		C074	120	4.76	6.70	85.66	0.43
	S-14	H104	30	21.00	33.40	51.05	0.22
	S-15	H107	53	21.13	33.64	58.12	0.25
		H106	60	9.67	15.69	79.25	0.33
		H105	70	12.24	21.03	70.96	0.30
	S-16	H109	60	13.69	23.97	70.40	0.37
		H108	18	15.07	23.86	69.01	0.10
	S-17	H111	55	14.16	23.35	70.61	0.27
		H110	15	9.16	17.93	83.27	0.27
	S-18	H112	27	13.07	19.02	75.52	0.33
	S-19	C075	10	6.41	9.29	85.80	0.62
	S-20	H114	13	15.75	24.46	70.54	0.29
110	S-20	H113	26	13.63	19.57	75.65	0.27
	S-21	H164	11	26.65	41.84	46.75	0.49
		H167	4	22.63	34.40	56.07	0.35
	S-22	H109	8	9.22	10.74	83.72	0.49
	S-23	H116	27	11.96	21.08	73.06	0.45
	S-24	H118	11	11.65	18.45	74.01	0.79
	S-25	H111	11	14.97	23.24	69.95	0.41
		H112	16	15.41	23.19	70.47	0.49
	S-26	H119	26	15.16	25.61	71.25	0.34
	S-27	H122	21	14.05	21.51	71.14	0.55
		H121	6	12.47	22.07	72.11	0.46
	S-28	H116	12	27.31	37.15	51.00	0.22
		H115	20	13.67	19.63	74.05	0.34
	S-29	H125	55	9.35	14.02	80.69	0.67
136	S-30	H126	35	6.16	10.87	81.34	0.38
	S-31	H127	35	13.38	20.46	76.30	0.32
	S-32	F088	35	14.85	22.65	69.25	0.32
	S-33	F090	48	11.40	16.30	75.18	0.36
	S-34	H128	58	26.57	41.17	45.64	0.24
	S-35	H132	32	17.32	27.45	65.04	0.45
110	S-35	H131	9	21.57	36.42	49.72	0.25
		H129	31	6.16	12.39	81.58	0.31
	S-36	F091	35	15.95	26.55	66.18	0.89
	S-36	F092	45	9.47	14.20	79.15	0.27
	S-37	H133	24	18.16	30.18	65.81	0.17
	S-38	F093	50	7.22	10.60	76.65	0.45
	S-39	H136	17	19.78	30.61	61.64	0.47
		H135	28	13.32	19.27	76.19	1.00
	S-40	F094	50	9.79	14.50	75.55	0.11
	S-41	H138	16	21.77	32.77	60.20	0.37
		H137	17	11.77	18.31	74.78	0.11
	S-42	F095	75	16.86	26.40	65.50	0.37
	S-43	H139	24	16.09	24.90	69.69	0.38
	S-44	H130	52	20.06	31.38	67.70	0.71
136	S-45	J087	38	17.94	30.10	66.97	0.27
	S-46	J090	65	16.76	25.97	68.56	0.23
		J089	37	18.16	28.98	65.36	0.29
		J088	38	15.17	24.35	70.93	0.38
	S-47	J093	56	21.63	34.35	59.33	0.53
		J092	45	25.27	39.66	53.77	0.35
136	S-47	J091	16	12.55	20.13	71.46	0.52
	S-48	J097	28	13.60	21.42	72.90	0.30
		J096	20	24.60	38.74	54.58	0.30
		J095	41	15.21	23.42	69.66	0.30
		J094	21	12.97	20.25	74.14	0.33
	S-49	J098	31	7.64	12.40	84.13	0.32
	S-50	J100	42	20.21	31.07	65.17	0.23
		J099	21	29.50	46.21	48.36	0.21
	S-51	J104	62	16.24	25.95	65.82	0.33
		J103	35	18.01	29.08	65.50	0.39
	S-52	J102	33	17.40	26.11	67.44	0.22
		J101	62	12.98	20.15	71.97	0.21
	S-53	J106	35	31.72	38.15	58.55	0.28
		J105	70	14.37	23.05	72.98	0.33
	S-54	J107	42	16.86	25.37	65.75	0.33

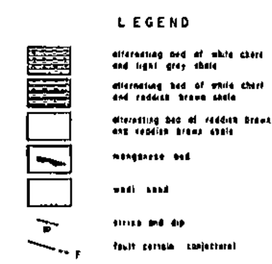


Fig. 27 Geological Map of the Drilling Area (Manganese Outcrop No. 110, No. 136)

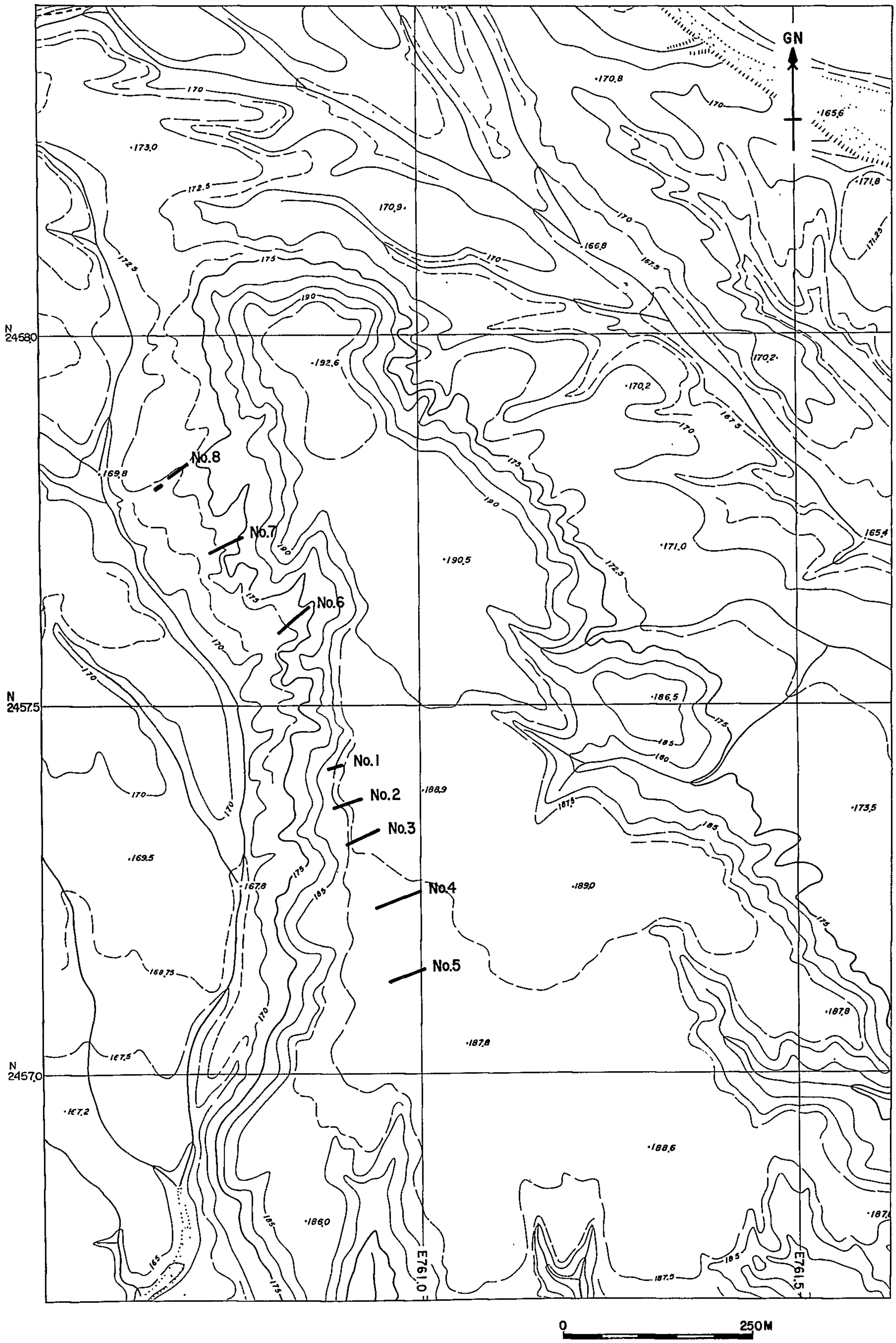
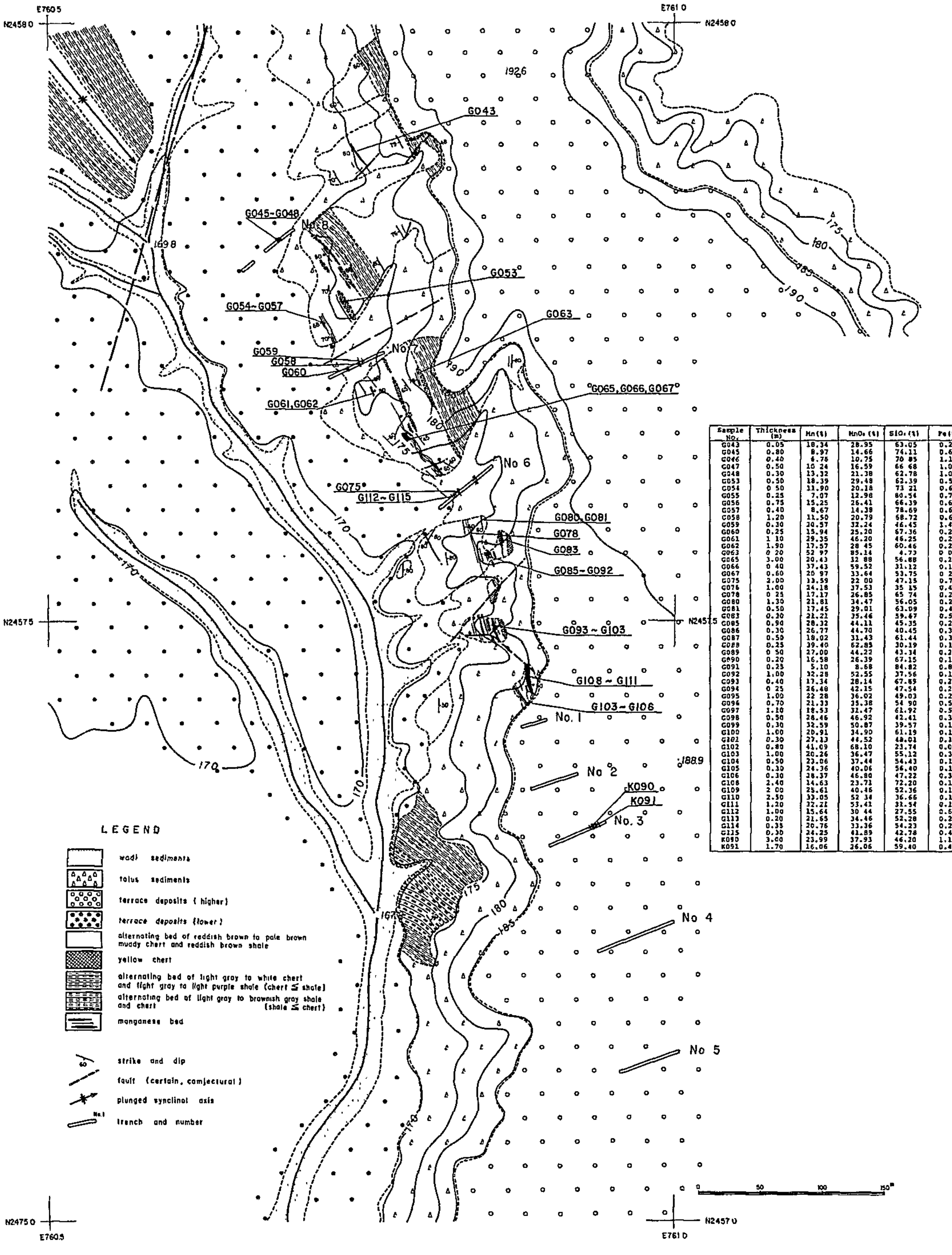


Fig. I —14 Location Map of the Trenches



Sample No.	Thickness (m)	Mn(%)	MnO_2 (%)	SiO_2 (%)	Fe(%)
G043	0.05	18.34	28.95	63.05	0.27
G045	0.80	8.97	14.66	74.11	0.60
G046	0.40	6.76	10.75	70.85	1.16
G047	0.50	10.24	16.59	66.68	1.00
G048	0.30	13.32	21.38	62.78	1.04
G053	0.50	18.39	29.48	62.39	0.53
G054	0.50	11.90	20.18	73.21	0.63
G055	0.25	7.07	12.98	80.54	0.79
G056	0.75	15.25	26.41	66.39	0.63
G057	0.40	8.67	14.38	78.69	0.68
G058	1.20	11.50	20.79	58.72	0.66
G059	0.30	20.57	32.24	46.45	1.46
G060	0.25	15.94	25.20	67.36	0.25
G061	1.10	29.35	46.20	46.25	0.20
G062	1.90	17.57	28.45	60.46	0.27
G063	0.20	52.97	85.14	4.73	0.07
G065	3.00	20.43	32.88	56.88	0.25
G066	0.40	37.43	59.52	31.12	0.11
G067	0.60	20.97	33.64	53.75	0.24
G075	2.00	13.59	22.00	47.15	0.74
G076	1.00	24.18	37.53	35.15	0.45
G078	0.25	17.17	26.85	65.74	0.22
G080	1.30	21.81	34.47	56.05	0.22
G081	0.50	17.45	29.01	63.09	0.41
G083	0.30	21.21	35.46	59.47	0.52
G085	0.90	28.32	44.11	45.35	0.20
G086	0.30	26.77	44.70	40.45	0.34
G087	0.50	18.02	31.43	61.44	0.31
G088	0.25	39.40	62.85	30.19	0.10
G089	0.50	27.00	44.22	43.34	0.20
G090	0.20	16.58	26.39	67.15	0.19
G091	0.25	5.10	8.68	84.82	0.81
G092	1.00	32.28	52.55	37.56	0.11
G093	0.40	17.34	28.14	67.69	0.25
G094	0.25	26.48	42.15	47.54	0.20
G095	1.00	22.28	36.02	49.03	0.22
G096	0.70	21.33	35.38	54.90	0.56
G097	1.10	18.53	31.47	61.92	0.58
G098	0.50	28.46	46.92	42.41	0.37
G099	0.30	32.59	50.87	39.57	0.19
G100	1.00	20.91	34.90	61.19	0.17
G101	0.30	27.13	44.52	48.01	0.10
G102	0.80	41.09	68.10	23.74	0.06
G103	1.00	20.26	36.47	55.12	0.30
G104	0.50	23.06	37.44	54.43	0.19
G105	0.30	24.36	40.06	56.40	0.17
G106	0.30	28.37	46.80	47.22	0.33
G108	2.40	14.63	23.71	72.20	0.17
G109	2.00	25.61	40.46	52.36	0.15
G110	2.50	33.05	52.34	36.66	0.13
G111	1.20	32.21	53.41	31.54	0.17
G112	1.00	15.64	30.44	27.55	0.65
G113	0.20	21.65	34.46	52.28	0.27
G114	0.35	20.76	33.36	54.23	0.20
G115	0.30	24.25	41.89	42.78	0.48
K090	3.00	23.99	37.93	46.20	1.14
K091	1.70	16.06	26.06	59.40	0.41

Fig. I—15 Geological Map of the Trenching Area (Manganese Outcrop No. 159)

Sample No.	Thickness (m)	Mn (%)	MnO2(%)	SiO2 (%)	Fe (%)
K004	0.60	18.17	29.28	66.76	0.30
K050	0.25	30.22	48.82	41.96	0.16
K051	0 25	12.77	20.15	72.80	0.37
K052	0.50	15.55	24.73	69.46	0.27
K053a	0.33	30.11	48.30	45.02	0.18
K053b	0.35	14.02	22.90	70.46	0.28
K054	1.40	18.92	30.89	64.51	0.25
K055a	0.70	16.68	26.38	69.17	0.25
K055b	0.60	31.56	49.96	43.27	0.16
K055c	1.70	28.17	45.59	43.55	0.18
K056	0.17	29.00	46.22	46.55	0.16
K057a	0.25	36.75	59.63	34.11	0.13
K057b	0.30	19.48	30.86	57.87	0.27
K058a	0.80	25.73	42.63	45.88	0.14
K058b	0.20	23.36	37.89	47.99	0.21
K059	0.29	39.39	64.05	26.22	0.90
K060	1.50	32.24	51.75	36.27	0.15
K061	1.10	40.62	61.12	31.90	0.15
K062	0.20	15.45	24.45	67.01	0.34
K063	0.40	19.03	30.55	58.91	0.34
K064	0.15	6.83	11.02	82.26	0.51

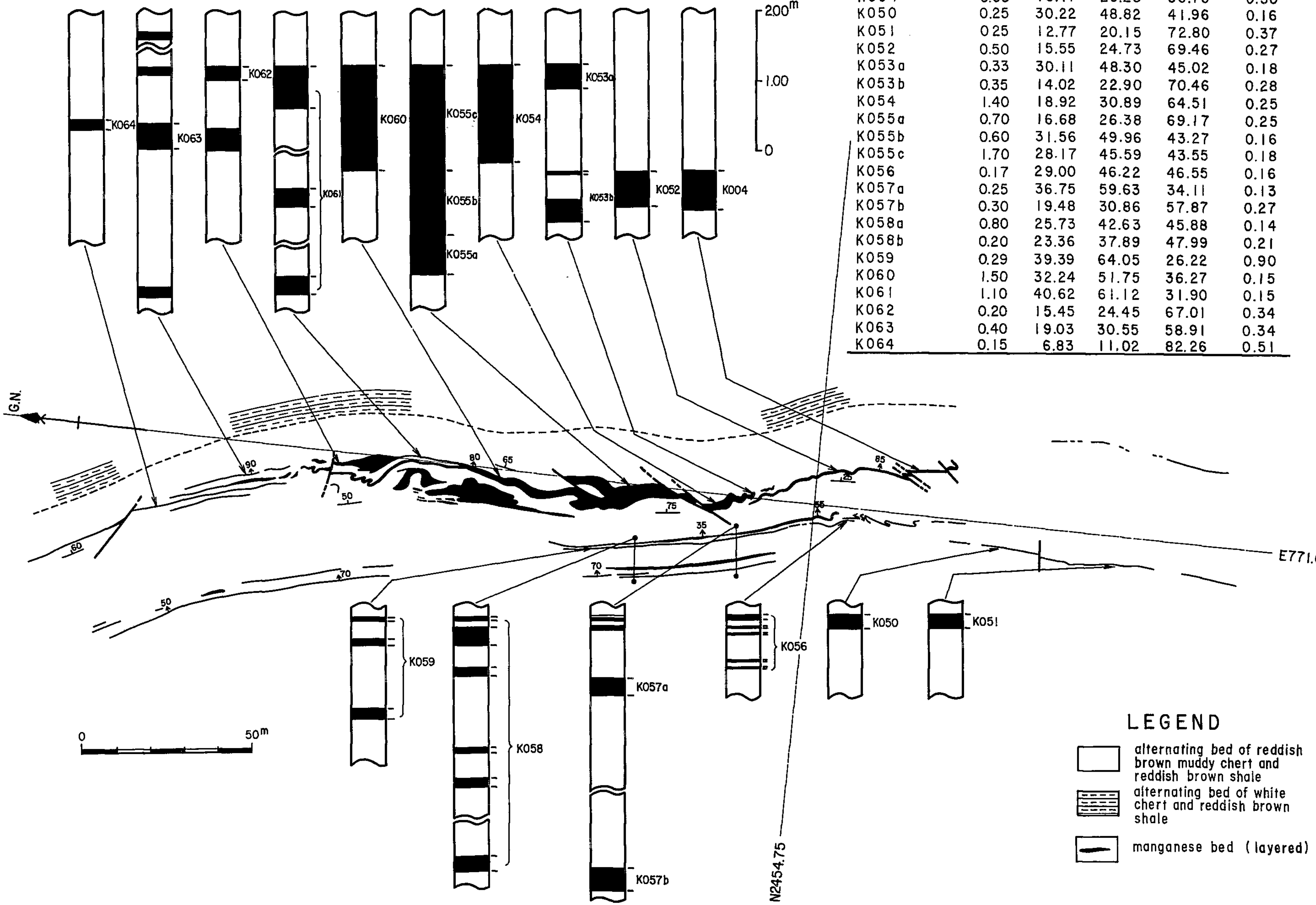


Fig. I—16 Geological Sketch Map of the Manganese Outcrop No. 160

3–5–3 Outcrop No.110

The outcrop No.110 is located along the hills, 75 m to 90 m in elevation, in the central to western part of the area A. The ore beds lie in the Red alternating beds. The alternating beds trend N45°W and dip 30° to 80°S in the eastern part while strike E–W and dip north in the central to western part (Fig. I–13). The alternating beds are merely gentle-waved in the eastern part while in the central to western part, as shown as in Fig. I–13, the beds are generally inclined to north showing small antioclinal and synclinal structures whose axes are pararell to the strike of the alternating beds. The alternating beds and ore beds are cut by faults of NE–SW system. The outcrops are variable in their scale; maximum thickness is 2 m but generally 10 to 20 cm; maximum elongation is 100 m but in most cases less than 10 to 30 m. The number of ore beds, their thickness and elogation are relatively developed in the eastern part. The nodule zones are frequently found in the neighboring part of ore beds. The host-rock Red alternating beds show reddish brown to light brown tone and is predominated by muddy chert. The Red alternating beds are bounded by the White alternating beds to the north and by the Transitional alternating beds to the south. The northern boundary is clear while the southern one is somewhat transitional.

By the drilling exploration to investigate the subsurface extentions of the outcrops, a ore bed was confirmed at the depth of 24.70 m in the drill hole No.9 that was conducted in the eastern part. This result clearly shows that the ore bed, here, extends at least 30 m in dip side. However, when considered the encountered depths in the remaining drill holes, most ore beds are estimated to be discontinuous in dip side as well as in strike side.

The calculation of ore reserves of the outcrop No.110 gave the following figures: ore reserves = 53,403 tons (strike-side length = 1,510 m, thickness = 0.60 m, dip-side length = 30 m), average grade = 23.01% MnO_2 (14.96%). The results of the drilling exploration will be described later.

3–5–4 Outcrop No.136

The outcrop No.136 is located in 900 meters west of the outcrop No.110 in the area A. Many small-scale outcrops, 10 to 30 cm thick and 5 to 50 m long, are embedded in the Red alternating beds that strike N60°E to N70°E and dip north. These outcrops occur in more than two horizons (Fig. I–13). In the outcrops many small-scale anticlines and synclines are observable.

The calculation of ore reserves of the outcrop attained the following values: ore reserves = 24,763 tons (strike-side length = 500 m, thickness = 0.84 m, dip-side length = 30 m), average grade = 23.67% MnO_2 (15.00% Mn).

3–5–5 Outcrop No.159

The outcrop No.159, discovered by the previous phase's survey, is exposed at the western cliff of the higher terrace in the southern part of the area B. (Fig. I–15).

In this phase a trenching exploration was conducted to confirm the extensions of the ore beds both to the north and to the south. The trenching were planned in the areas where terrace deposit and wadi sediments are distributed. Practically 8 trenches (375 m length in total) were digged: 5 trenches at 50 to 100 m interval on the terrace and 3 trenches at 100 m interval in the wadi area (Fig. I–14, Plate I–3).

The ore deposit, composed of many manganese ore beds, is embedded in the Red alternating beds which strikes N–S to N40°W and dip 50°N.

In the main part of the outcrop 11 ore beds are recognized. These beds are continuous and traceable in a distance of 440 m to the north from the terrace cliff. The southern extension is estimated to be more than 150 m because two ore beds were confirmed in the trench No.3. The maximum thickness of the ore beds is 3 m and the maximum length is 50 m. The ore beds are remarkably irregular in thickness along their extensions. In addition to the Red alternating beds that embed these many ore beds, another upper Red alternating beds are found being separated by thin White alternating beds.

In this Red alternating beds only small-scale manganese beds are found. Along the contact of the lower Red alternating beds and White alternating beds, yellow lenticular chert (yellow siliceous rock) beds are recognized. In some of those beds manganese minerals are included.

In some cases manganese layers are found along the contact of the yellow chert and the Red alternating beds. These yellow chert beds thicken more than 3 m in place. The genesis of these yellow chert beds is not yet clearly explained.

In regard to the geological structures around the ore deposit, the sequences generally strike NW–SE and dip southeast with slight waving. There are several fault of NW–SE and NE–SW systems. These fault give the ore beds some dislocations.

The ore reserves within the area from the trench No.3 to No.8 are estimated as follows: ore reserves = 155,601 tons (strike-side length = 590 m, thickness = 4.15 m, dip-side length = 30 m), average grade = 34.94% MnO_2 (21.48% Mn).

The ore reserve of the deposit is the largest one in the Sur area.

The southward extension of the outcrop No.159 was not completely proven because some of trenches could not penetrate the thick (over 3 m) terrace deposit. However, judging from the geological structure and successions, the manganese beds are estimated to continue to those of the outcrop No.184, embedded in the Red alternating beds, at the southern cliff of the same terrace.

3–5–6 Outcrop No.160

The outcrop No.160 is located in the northeastern part of the area D. The outcrop consists of 1 to 4 ore beds embedded in the Red alternating beds which generally trend N–S and dip 50° to 80°E. The maximum thickness of ore bed is 1.7m, but the thickness is variable from place to palce. In contrast, the strike-side length attains 120 m with a good continuity (Fig. I–16).

Although small-scale folds are observable near the ore beds, the general structure is monoclinic with eastward dipping. Minor faults of NE–SW and NW–SE systems are locally recognized.

At the footwall of the ore beds belonging to this outcrop another two ore beds occur. Those were newly numbered as the outcrop No.192.

The ore reserves calculated are as follows:

No.160: ore reserves = 15,686 tons

(strike-side length = 250 m, thickness = 0.95 m, dip-side length = 30 m)

average grade = 40.77% MnO_2 (25.58% Mn).

No.192: ore reserves = 3,748 tons

(strike-side length = 110 m, thickness = 0.50 m, dip-side length = 30 m)

average grade = 45.91% MnO_2 (28.18% Mn)

3–6 Manganese Ore

The manganese ore is classifiable into layered ore and nodular ore from the mode of concentration of manganese minerals. The manganese minerals are composed of mainly pyrolusite. Minor amounts of cryptomelane and manganite are also recognized.

The layered ore is so-called manganese bed and is the main component of ore deposits. In this case manganese minerals concentrate as thin layer, lens, or dissemination in bedded, compact, massive black siliceous part (black chert in another term). In the black siliceous part very fine-grained manganese minerals are concentrated as dissemination or thin layer. The manganese concentrations, in the thicker ore beds, become 10 to 15 cm thick at the both boundaries. In the layered ore, in places, quartz segregation veins are developed as network. The colloform texture is also observable in some layered ores.

The results of microscopic observations of polished ore section are as follows:

Sample No. G058

Some laminations are observable. The black siliceous part is a mixture of pyrolusite and argillaceous material. The manganese-concentrated part consists of coarse-grained pyrolusite. The grain size is not uniform. Pyrolusite in the quartz-rich part is characteristically coarse-grained. Radioralia fossils are rich in the fine-grained part.

Judging from the cleavage characteristics, some or most part of pyrolusite is probably pseudomorph after manganite.

The nodular ores are those which occur in the Red alternating beds neighboring to the layered ore. Manganese minerals concentrate as thin lenses or pellets. The lenticular concentrations are generally 0.5 to 2 cm thick and 3 to 10 cm long. The lenses show generally irregular shapes along their strike side; amoebic shapes are obserbable in some cases.

The results of microscopic observations of the nodular ore are as follows:

Sample No. K069

The nodule is composed of outer shell and inner core. The outer shell consists of an aggregation of minute crystals of pyrolusite, 0.5 to 1μ in diameter. Radiolaria fossils are abundantly included and some of those are replaced by calcite. The aggregation of pyrolusite includes irregular aggregation of minute quartz and calcite and is penetrated by veinlets of those two minerals. The inner core is an aggregation of relatively coarse-grained (10 to 20μ in diameter), euhedral or subhedral pyrolusite. Radiolaria fossils are not observable. The coarse-grained crystals and the lack of radiolaria were probably caused by recrystallization of pyrolusite.

In addition, coarse-grained manganese minerals are sometimes recognized with quartz filling cracks of the Red alternating beds. The manganese minerals are generally recrystallized pyrolusite probably formed in a process of diagenesis.

The results of microscopic observations are shown in Table A–2. Again in this phase, manganese and gangue minerals were identified by X-ray powder diffraction. The results are almost same as those of the previous phase as shown in Table A–4. Pyrolusite, minor cryptomelane, and minor manganite were detected. Quartz and calcite were detected as gangue minerals. From a ore sample collected by the drilling exploration a weak X-ray peak of rhodochrosite was detected.

As described above, the results of microscopic studies of chert, the host rock, show that chert has no recrystallized texture because the chert is composed mainly of chalcedonic quartz and microcrystalline quartz. The alteration minerals are minor montmorillonite and sericite. The chert has no alteration minerals which might indicate high-grade metamorphism. Consequently, the genetic process of the manganese minerals are considered as follows:

The most parts of manganese minerals and gangue minerals are pyrolusite and quartz, respectively. Although there are some variations in crystal form, grain size, and texture, these valiations can be easily understood as a result of diagenesis of siliceous sediments and manganese oxides. In this case, colloidal or amorphous siliceous material and amorphous manganese oxide or cryptocrystalline pyrolusite (or manganite) were contemporaneously deposited to be a part of

the Middle Member of the Halfa Formation. The siliceous sediments (opal A) was transformed to quartz through the phases of opal C and T while the manganese dioxide was changed into minute pyrolusite. In the high-grade part where argillaceous materials were poor, crystal growth of pyrolusite was advanced. Moreover, the crystal growth of pyrolusite was accelated in and around the cavities and segregated quartz veins.

3–7 Chemical Analysis of Ore

In this phase 207 ore samples were analyzed for Mn, MnO_2, SiO_2, and Fe. The results are shown in Table A–5.

In the drilling survey, 47 samples of manganese ore were analized. The results are shown in Table A–6.

The results of analysis of 254 samples are mentioned as follow.

Maximum value and minimum value are below.

Mn: from 1.74% to 52.97%

MnO_2: from 2.89% to 85.14%

SiO_2: from 4.73% to 86.93%

Fe: from 0.01% to 6.28%

As the result of the calculation of ore reserve, the average grade of manganese is 19.92% Mn, 29.57% MnO_2. There is relatively large gap between maximum and minimum value. Because the concentrating parts of manganese mineral show lenticular or spotted form, the distribution of manganese grade has no tendency. The manganese grade of the nodular ore is less than 10% MnO_2.

SiO_2 content is high in general, because the ore is composed of large amount of quartz.

Fe content is less than 0.5% in general, but the nodular ore have more than 1.0%, especially in the sample of drilling cutting, because the nodular ore contains red chert.

Manganese coefficient (Mn/Fe) ranges from 1.54 to 4129. In the sample of drilling cutting, manganese coefficient ranges from 1.54 to 45.1.

Degree of oxidation (Mn/MnO_2) shows small range, from 0.51 to 0.77. Regularity about the degree of oxidation is not recognized between each outcrops. And also, any tendency was not recognized from surface to deeper part of the drilling cuttings.

3–8 Electrical Characteristic of Ore

A dry cell test was conducted to check the electrical characteristic of the ores from the Sur area. By this test the electrical characteristic of the ore was proven as described bellow. The chemical

analysis of the tested sample is also shown below.

This test is a 2Ω continuous dischargeability test as UM-1 type. The sample used is described below.

Tested sample:

The tested sample is the manganese minerals separated excluding chert from the ore samples collected from the ore outcrops distributed in the Sur area.

The weight of the sample is approximately 1 kg and the sample was pulverized under 200 mesh. Chemical analysis of the tested sample is below.

Results of chemical analysis

H_2O	0.32%
MnO_2	90.05%
Insoluble by HCl	4.42%
SO_4	0.18%
Fe	1,233ppm
Pb	13ppm
Cu	826ppm

The testing method is as follows:

The sample was mixed with acetylene black and electrolyritic solution (30% $ZnCl_2$) in a ratio of 50%, 8.3%, and 41.7%, respectively. The mixed paste was molded as UM-1-type dry cell using a hand press. The electromotive force of the model was measured as holding time of given voltage with 2Ω discharging resistor at 20°C.

The results are as follows:

Continuous dischargeability with 2 Ω resistor (UM-1 type)

	Short circuit current	Open circuit voltage	Closed circuit voltage	Dischargeability 1.1V	1.0V	0.9V
Sample	4.7A	1.568V	1.34V	30 min.	62 min.	105 min.
Reference	5.0A	1.639V	1.41V	53 min.	111 min.	171 min.

The reference values are of the manganese ores which are normally used for dry cell.

By the test it was proven that although the manganese ores from the Sur area are poor in impure materials, it is not so suitable to dry cell because the dischargeability is about 55% of normal battery-grade manganese ore.

PART II DRILLING SURVEY

Chapter 1. Introduction

Based on the results of the previous phase's survey, drilling survey was conducted to confirm the subsurface continuation of the manganese outcrop No.110, the largest outcrop in the area A.

In this survey, as shown in Fig. II–1, 17 drill holes were conducted at 8 drilling sites; 12 holes at 5 sites in the eastern part of the outcrop No.110 and 5 holes at 3 sites in the western part.

All drill holes were driven by percussion method. The operation started on November 9 and finished on December 26 in 1982, achieving a total drilled length of 300.00 m. by 17 drill holes.

The geology of the drill holes was complied as cutting logs on a scale of 1:200 through observations of cuttings collected by every 1 m length. When ore beds were encountered, the cuttings were collected by every 0.5 to 1 m length to be analyzed for Mn, MnO_2, SiO_2, and Fe. In total 47 ore samples were analyzed. The results are shown in Table A–6.

The details of the drilling operation and its results are described hereafter.

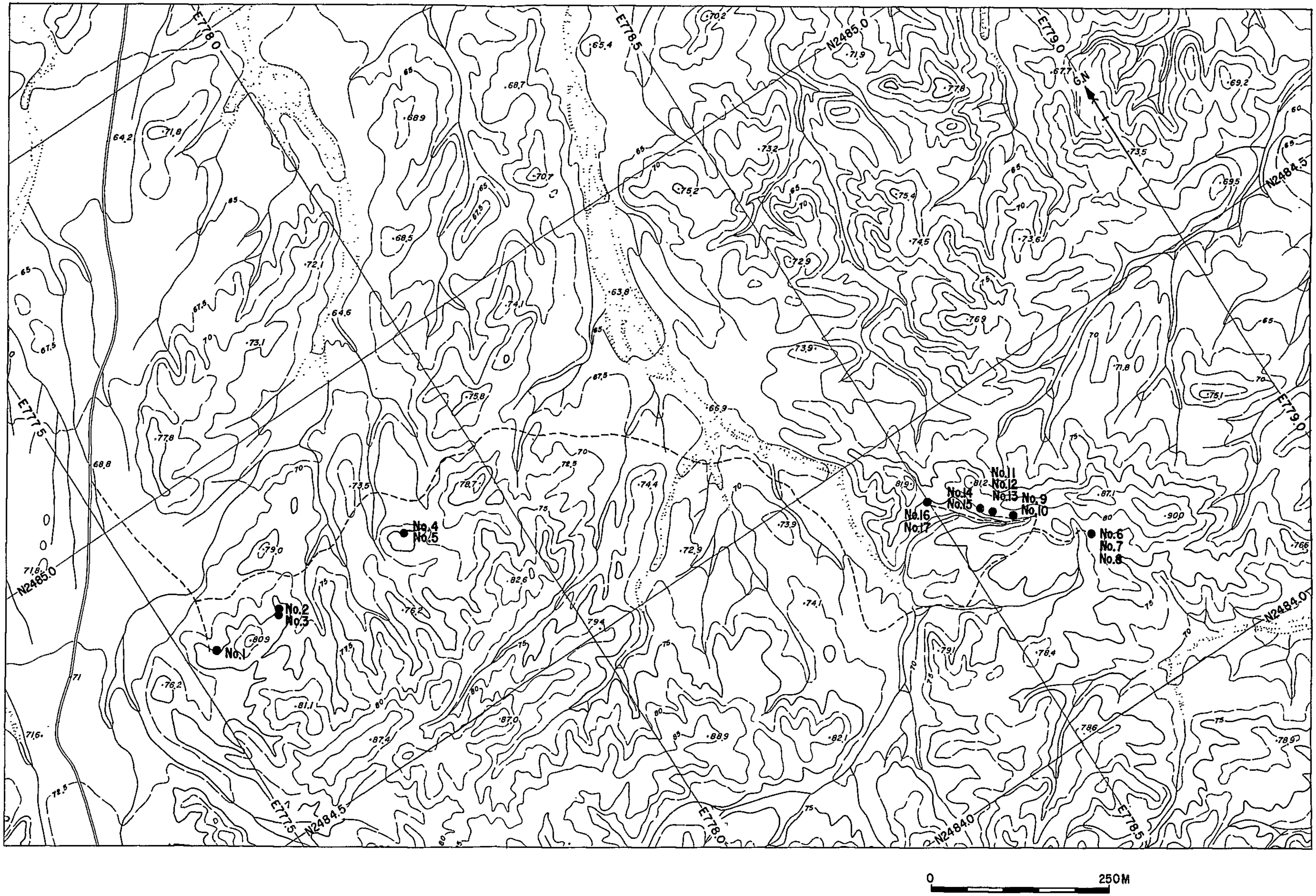


Fig. Ⅱ—1 Location Map of the Drill Holes

Chapter 2. Drilling Method and Drilling Machine

The drilling method adapted in the operation is percussion method. Practically, a large-caliber down-the-hole drilling machine was used according to the geological conditions of the survey area. The geology of the drilling area is composed of chert-dominant and fracture-rich alternation of chert and shale.

The types and specifications of the equipments used are shown in Table II–1.

Table Ⅱ—1 Drilling Equipment and Consumed Materials

A. Drilling Equipment

Article	Model	Specifications	Quantity
Drilling Machine	Model "THS-70" (Tone Boring Co.)	Capacity : 150 m/m, 150 m Dimension : Height 1,390 mm Length 1,770 mm Width 1,125 mm Weight (without Power Unit) : 950 kg	1 set
	Swivel Head	Spindle speed : 50, 100, 200 r.p.m.	1 set
	Hoist	Type : Planetary Gear Type Capacity . 1,800 kg	1 set
	Oil Pump	Type : Gear Type, Variable Delivery Capacity : 26 ℓ/min Pressure : Max. 70 kg/cm² Ord 20 kg/cm²	1 set
Power Unit	Model "F2L912" (Mitsui Deuts Co.)	Diesel Engine : 4 Cycle Air-cool Revolution : 1,800 r.p.m. Related power : 25.5 P.S.	1 set
Drill Rods		BW x 3.0 m BW x 1.5 m BW x 1.0 m	20 pcs 3 pcs 3 pcs
Down-the-Hole Hammer	AH-80 (Acker Drill Co.)		2 sets
Drilling Tools			1 set
Engineering Tools			1 set
Compressor	375 Sulliscrew	Rotary screw 375 CFM	1 set

B. Consumed Materials

Article	Specification	Unit	Quantity
Diesel oil	Engine	ℓ	2,730
Turbine oil	Compressor	ℓ	75
Gasoline	Jeep	ℓ	500
Grease	Machine	kg	10
Down-the-hole hammer	85φ	set	1
Chuck spanner		pce	1
Jug		pce	1
Sling wire	12 m/m, 13 m	pce	1
Iron wire	No. 10	kg	60
Waste cloth		pce	10
Pipe	2" x 5.5 m	pce	1
Cement		pack	3
Hammer bit	85φ	pce	9

Chapter 3. Drilling Operation

3–1 Preparatory Works

The drilling machine and materials were transported from Muscat to the temporal disloading point near the drilling area by a heavy truck through a 360-km-distance in 8 hours approximately.

Removing of the machine in the drilling area was done by a wheel loader (JCB type-3, backhoe-mounted), pickup truck and man power.

The drilling area is located in 5 km south to the base camp. It took 15 minutes by motor vehicle.

The ground levelings of drilling sites were done by JCB wheel loader. The superficial bedrock was generally loosened by weathering, therefore, it was necessary to strip the loose part off more than 1 m deep.

3–2 Moving Operations

Although a dirt road was available from the base camp to the unloading point, there was no road in the drilling area where low hills, 75 to 90 meters in elevation, and wadis are developed.

Therefore an access road, 3 m wide and 1,800 m long, was newly constructed from the unloading point to the eastern end of the outcrop No.110, connecting all drilling sites.

On the occasion of moving the drilling machine from a site to another site it was necessary to dismount the engine unit. The separated 2 units were transported by JCB wheel loader and pickup truck.

3–3 Drilling Conditions

According to the geological conditions, percussion method was adapted as the drilling method.

The work progress of each drill hole is shown in Table II–2.

3–4 Sampling Media of Cuttings

When cuttings recover, a collector were set around the hole to gather cuttings. The size of cuttings is normally less than 1 mm in diameter and the maximum size is 3 mm. Cuttings were collected by every 1-m-length in the country rock part and by every 0.5- to 1-m-length in the ore part. Sampling of cuttings of the ore part was, for assaying, undertaken with special care.

Table II—2 Result of Drilling Operation

Hole No.	Periods	Direc-tion	Incli nation	Drilling		Number of drilling shift		Number of worker		Working Hours						
				Bit size	Drilling length	Drilling	Total	Engineer	Assistant	Drilling	Hoisting & others	Sub total	Installation& dismounting	Haulage	Road construction & others	Total
				m/m	m	shift	shift			hour	hour	hour	hour	hour	hour	hour
1	24 Nov.~ 26 Nov.	–	90°	85	15.5	5	15	15	30	7.45	19.15	27.00	18.00	18.00	9.00	72.00
2	27 Nov.~ 28 Nov.	–	90°	85	18.3	2	5	5	10	10.20	9.40	20.00	1.00	3.00	–	24.00
3	29 Nov.~ 30 Nov.	–	90°	85	20.0	3	4	4	8	9.30	4.00	13.30	4.30	–	–	18.00
4	1 Dec.~ 2 Dec.	180°	75°	85	14.0	1	3	3	6	6.15	1.45	8.00	3.40	4.00	–	15.40
5	2 Dec.~ 3 Dec.	–	90°	85	14.5	1	2.5	2.5	5	7.00	1.40	8.40	4.50	–	–	13.30
6	4 Dec.~ 5 Dec.	–	90°	85	17.0	1	3	3	6	7.10	2.20	9.30	2.45	3.00	–	15.15
7	5 Dec. 6 Dec.	60°	75°	85	18.0	3	4	4	8	13.20	4.10	17.30	–	–	–	17.30
8	6 Dec. 7 Dec.	240°	80°	85	21.0	3	4	4	8	14.15	4.05	18.20	0.30	–	–	18.50
9	8 Dec. 10 Dec.	55°	75°	85	24.7	4	6	6	12	22.10	3.20	25.30	1.00	6.20	–	32.50
10	12 Dec. 13 Dec.	–	90°	85	19.0	2	3	3	6	10.40	0.50	11.30	3.30	–	–	15.00
11	13 Dec. 14 Dec.	260°	75°	85	21.0	3	4	4	8	13.25	1.15	14.40	1.20	3.20	–	19.20
12	14 Dec. 15 Dec.	–	90°	85	16.5	2	3	3	6	10.05	1.05	11.10	1.30	–	–	12.40
13	15 Dec. 16 Dec.	240°	85°	85	15.5	2	3	3	6	9.45	1.15	11.00	2.00	–	–	13.00
14	17 Dec. 18 Dec.	55°	75°	85	19.0	2	4	4	8	10.30	1.30	4.00	2.00	4.00	–	20.00
15	18 Dec. 19 Dec.	–	90°	85	15.0	2	3	3	6	8.40	1.20	10.00	3.00	–	–	13.00
16	20 Dec. 21 Dec.	60°	75°	85	19.0	3	5	5	10	12.30	2.15	14.45	1.00	3.15	6.00	25.00
17	21 Dec. 22 Dec.	–	90°	85	12.0	1	2	2	4	6.40	0.20	7.00	3.00	–	–	10.00

3–5 Withdrawing Operations

On completion of the No.17 drill hole, the drilling machine and derrick were disjointed and packed with wood frames. The drilling equipments such as drilling machine, compressor and other parts were transported to Muscat by a heavy truck. All of the samples of cuttings were stored at the Mineral Department, Ministry of Petroleum and Minerals. The withdrawing work finished on 24th of December, 1982.