Chapter 4 Drilling Survey

4-1. Outline of the Survey

Locations of the drilling survey are illustrated in Fig.II-4-1. The drilling was assigned to the local contractor based at the Republic of South Africa. Geological logging was recorded onto logging sheets at a scale of 1:200. The mineralised portions of the drill cores were taken at where necessary for chemical assays. The thin sections and polished sections of typical rock facies and mineralisation were prepared for microscopic test. The altered or argillaceous parts were collected for X-ray diffractometry. Some of the mineralised portion with lead and zinc were analyzed for lead isotopes. All the cores were marked showing orientation direction and packed in steel-made core boxes and recorded on the colour photos. The core boxes were housed in the core depository of GSN. The coordinates of drill holes are shown as below and the location maps of drill holes are illustrated in Fig. II-4-1.

Table II －4－1 Coordinates of Drilling Holes

			LATITUDE			LONGITUDE		
	HOLE No.	FARM LAND	Deg.	Min.	Sec.	Deg.	Min.	Sec.
1	MJNM-1	Guinab 277	19	10	26.53 S	18	23	00.54 E
2	MJNM-2	Aris 283	19	12	01.57 S	18	17	19.88 E
3	MJNM-3	Christiana 705	19	16	15.81 S	18	02	30.42 E
4	MJNM-4	Cadix 678	19	14	36.11 S	18	04	27.52 E
5	MJNM-5	Vogelsang 284	19	10	00.86 S	19	21	42.01 E
6	MJNM-6	Guinab 277	19	11	11.57 S	19	22	48.53 E
7	MJNM-7	Aris 283	19	10	34.20 S	19	22	10.57 E
8	MJNM-8	Vogelsang 284	19	09	12.91 S	18	19	59.08 E
9	MJNM-9	Guinab 277	19	10	10.46 S	18	22	47.86 E
10	MJNM-10	Vogelsang 284	19	09	38.75 S	18	19	41.04 E
11	MJNM-11	Birkenhead 699	19	12	42.35 S	17	55	58.79 E
12	MJNM-12	Bombay 670	19	12	51.38 S	17	57	28.12 E

4-2. Method and Equipment

The percussion method was applied for the first 80 metres with Drill Master in the hole of MJNM-5 to MJNM-10 and thereafter the wire line method with L-44 rigs were used as well as the normal method with SECO-12.

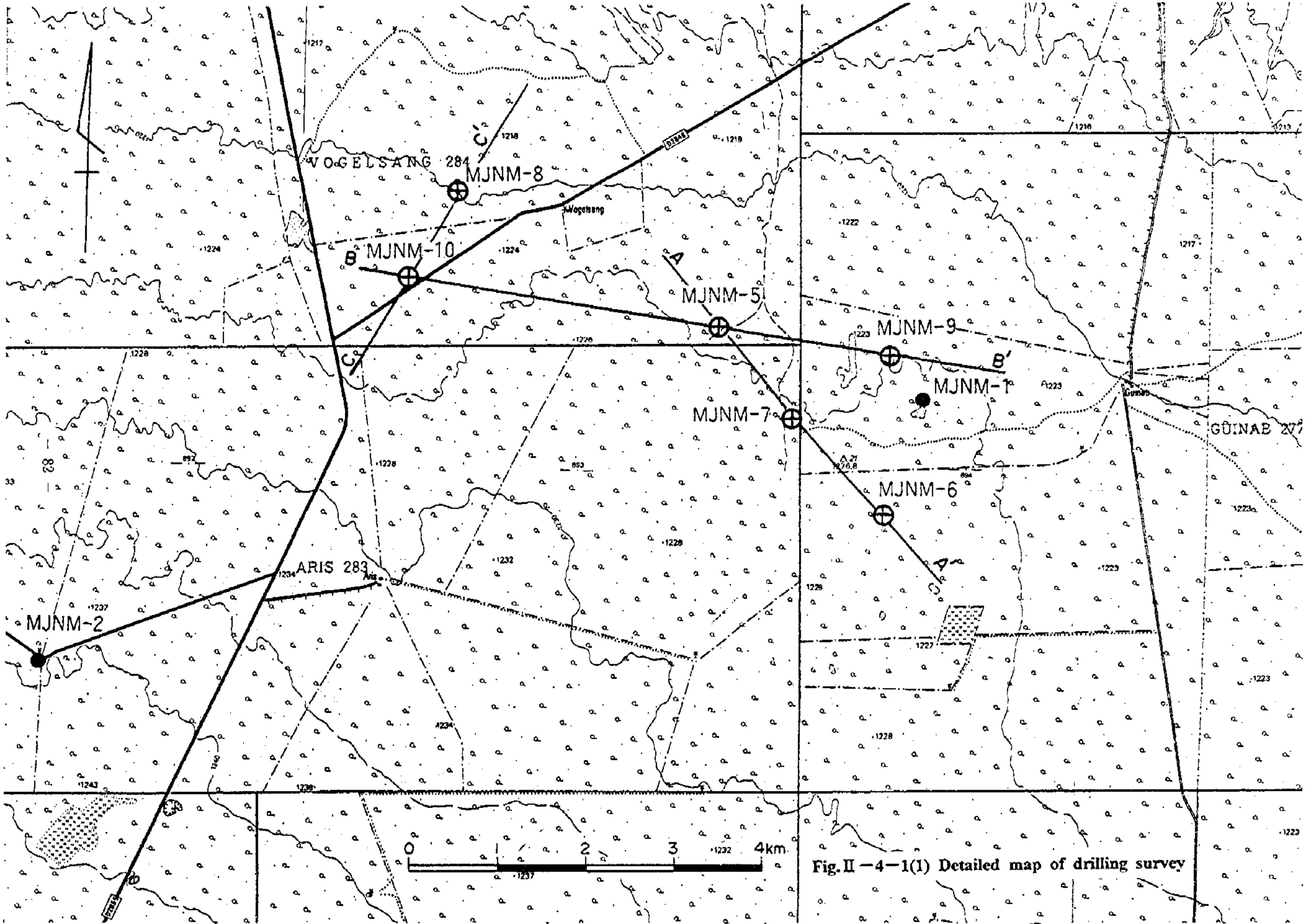


Fig.II −4−1(1) Detailed map of drilling survey

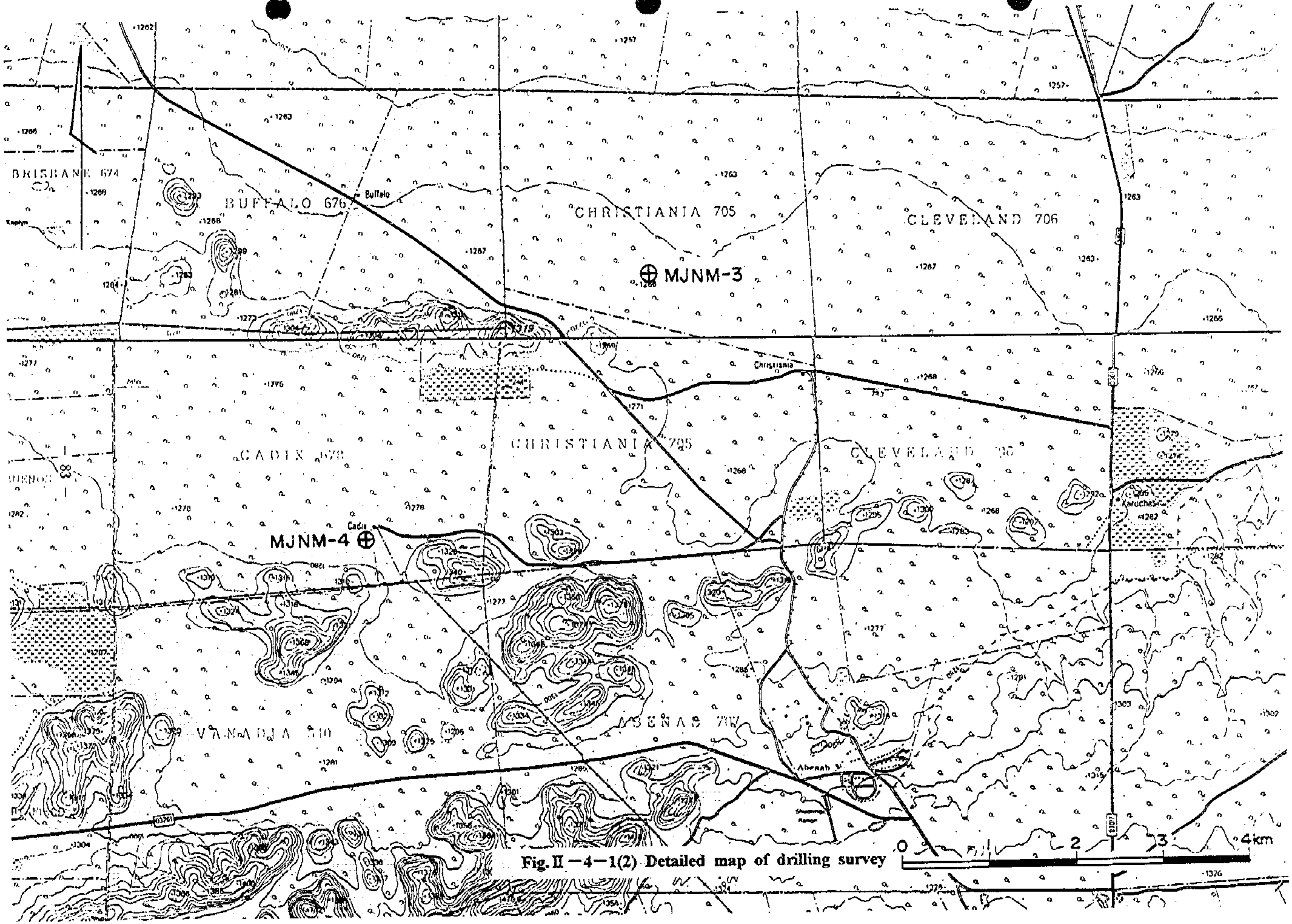


Fig. II −4−1(2) Detailed map of drilling survey

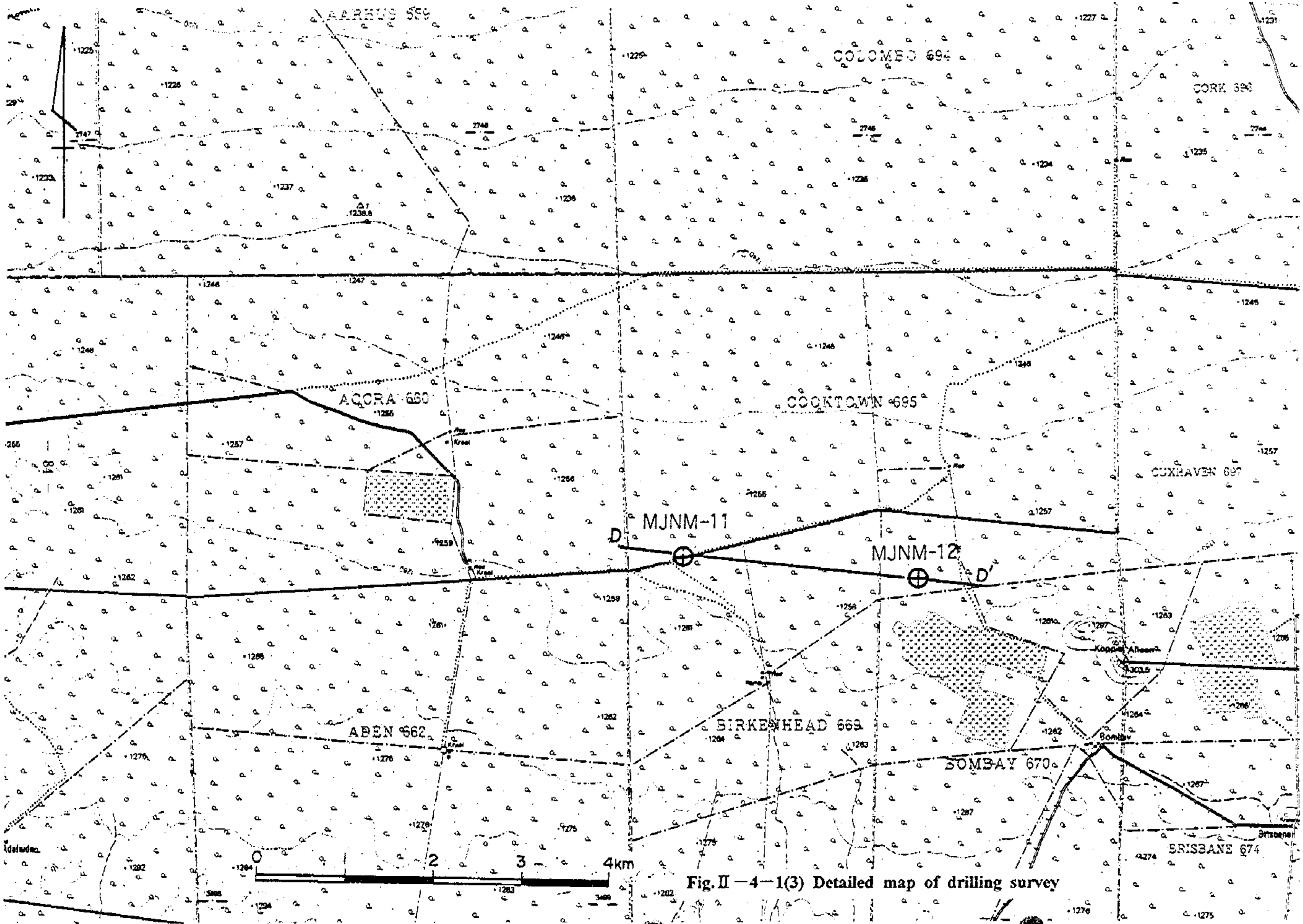


Fig. II —4—1(3) Detailed map of drilling survey

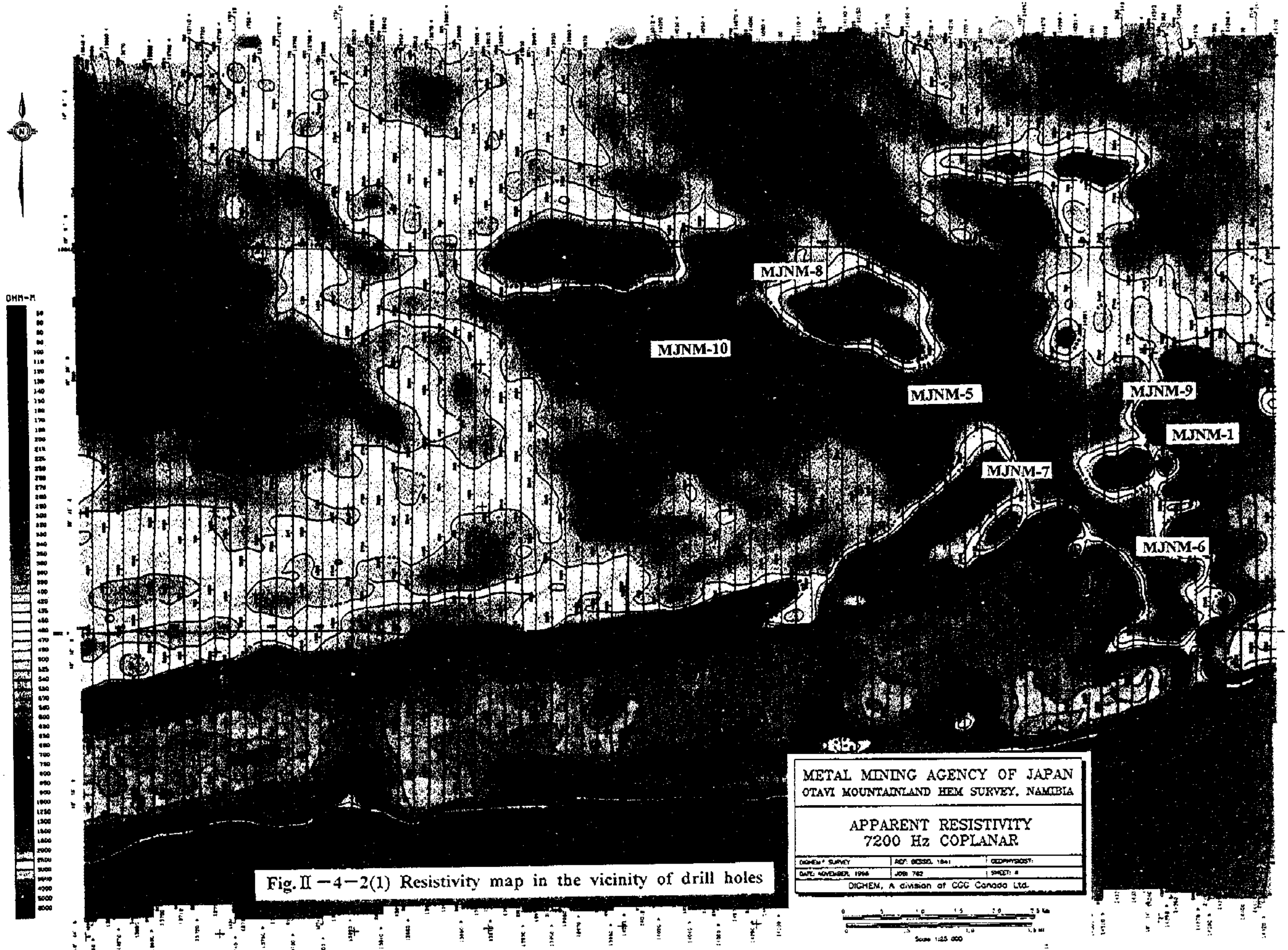


Fig. II −4−2(1) Resistivity map in the vicinity of drill holes

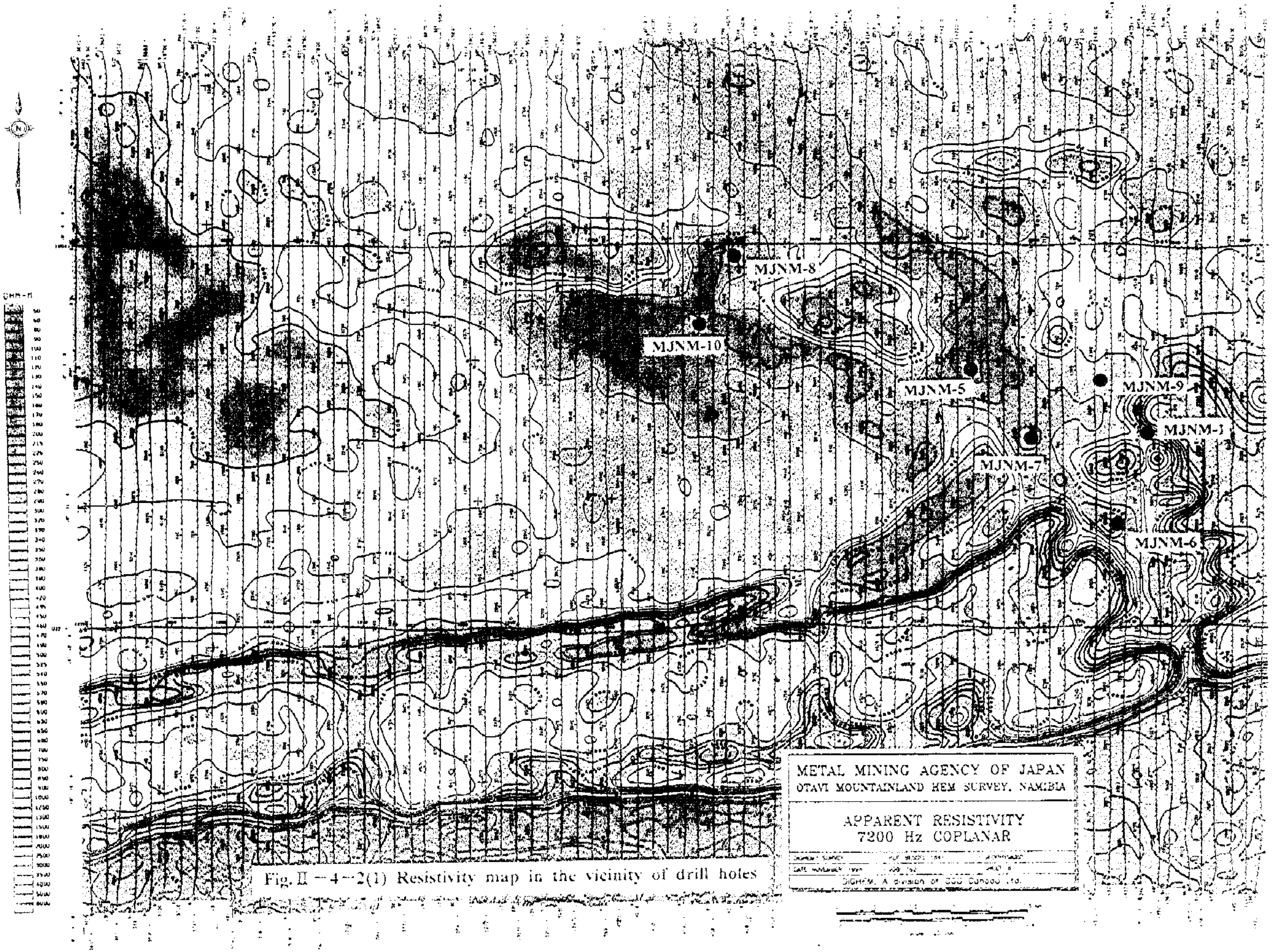


Fig. II−4−2(1) Resistivity map in the vicinity of drill holes

Fig. II −4−2(2) Resistivity map in the vicinity of drill holes

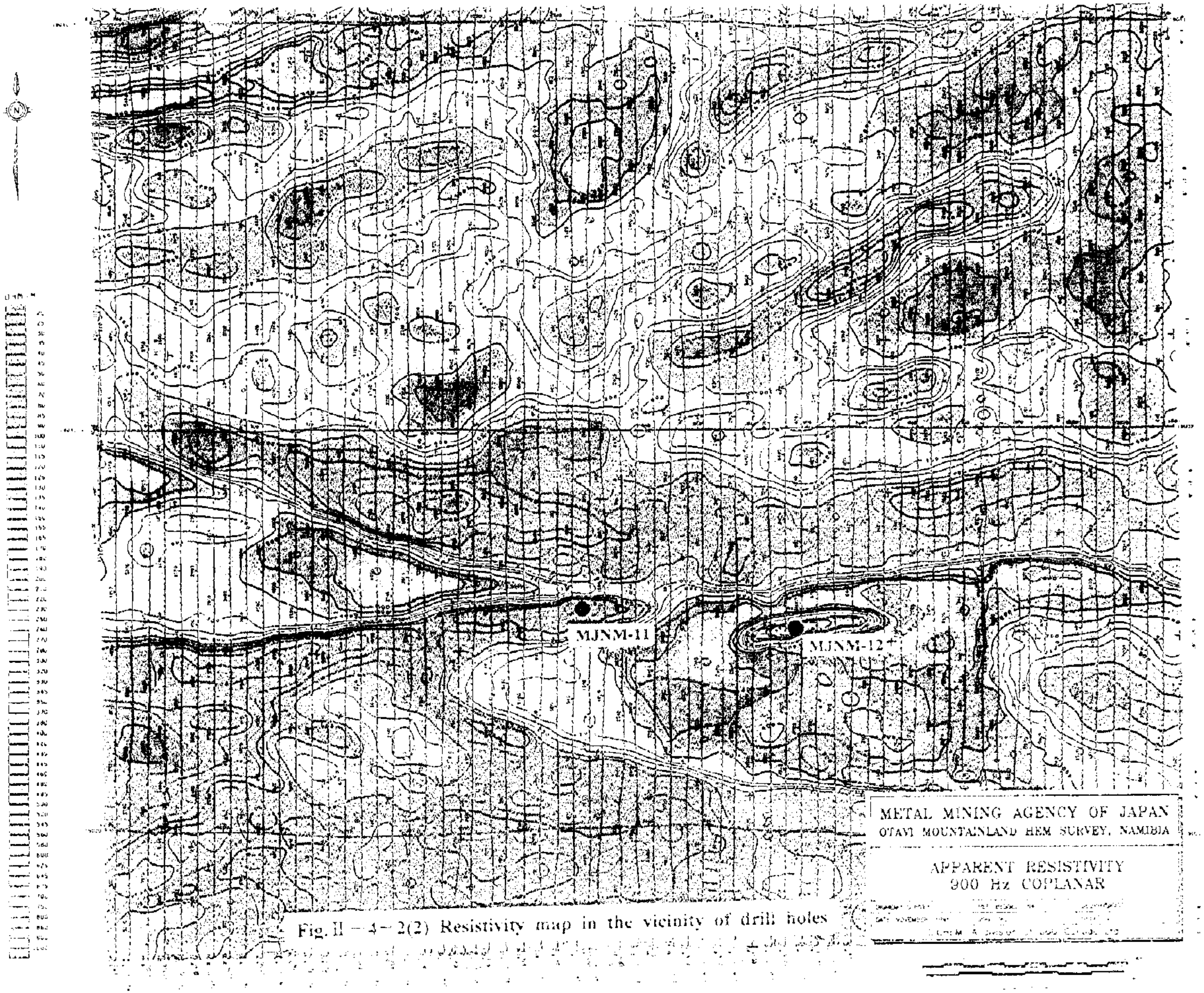


Fig. II−4−2(2) Resistivity map in the vicinity of drill holes

4-3. Result of the Survey

4-3-1. Geological logging

The geological explanation is given below based on the core logging and the result of microscopic identification of thin sections, polished sections and X-ray diffractometry are shown in Table II-4-2 through Table II-4-4.

MJNM-1

- 0.00m- 85.40m Calcrete

The calcrete is post-Tertiary sediment overlying unconformably over the dolomite of Damara system in the upper Proterozoic age, being pale brown and massive or stratified. The basal facies include gravels over 25 metres. From 50 metre to 30 metre deep, a rough size-grading of gravels is recognized. Local development of the cavities elongated parallel to the bedding plane may form an aquifer of groundwater.

- 85.40m- 300.08m Dolomite

The dolomite is greyish white to grey occasionally pale brown. The lithofacies are less variable except for the thin beds of chert some centimetre to ten centimetre thick over the formation and the beds of black to dark grey shale within the section from 92.40 m to 94.90 m and around 153.50 m deep. The dolomite is massive or well bedded where the bedding planes cross the hole at 60 to 80 degree. It reacts with chloric acid giving tiny bubbles. The stylolite develops over the massive facies from 210 m to 240 m deep. Grainstone which is composed of fine to medium-grained dolomite underlies the shale.

Oolitic dolomite occurring locally within the formation seems to have undergone silicification during the diagenesis stage. The small mound textures which seem to stromatolite were observed at around a depth of 296.0 m with oolitic texture. The formation could be correlated to T6 of the Tsumeb subgroup according to the lithological sequence.

A mineralisation occurs intermittently over 12 metres from 102 m to 114 m deep and from 212 m to 285m deep including principally sphalerite and galena in the form of pods, irregular network and dots associated with silicification in dolomite. The mineralisation is also restricted to the fine fractures at the proximity of the stylolite and is conformable to the bedding plane giving possible model of strata-bound type lead and zinc mineralisation.

Rare copper mineralisation includes a covelline-bearing dot at a depth of 92.60 m and a green copper mineral 285.50 m deep. Vanadium mineralisation basically overlaps the above-mentioned mineralisation and occurs filling the young fractures with the characteristically green to orange coloured showing.

MJNM-2

- 0.00m- 60.96m Calcrete

The calcrete is white to pale brown and includes a large number of breccias less than 5 centimetre in

Table II −4−2 Microscopic Identification of Minerals in Thin Section

Sample	Hole No.	Depth(m)	Rock Name	Constituent minerals											Accessory minerals									Sec. minerals					
				Qz	Pl	Kf	Hb	Mu	Cx	Bi	Cal	Dol	Ser	Chl	Sp	Mt	Zr	Ap	Tm	Lx	Ep	Hm	Op	Ser	Qz	Dol	Chl	Ep	Cal
100504			Biotite-hornblende granodiorite	◎	◎	○	○			○					△	△	+	△				△		△			△		
100603			Quartz with opaque mineral	◎									○					+	+				◎						
100605			Quartz hornblendite	△	○		◎								△	△		+						○				△	
100607			Micro quartz diorite	△	◎	△	○								+		+	+					△	○			△	△	
100608			Dolomite with calcite vein	△								◎																	◎
101308			Quartz-chlorite schist	◎	○								○	◎	△				+		△		○						
102103			Biotite-muscovite granite	◎	○	◎		△		△					△			+						○			△		
102106			Altered porphyrite	△	◎		◎													△		+		○			○	○	△
110601			Calcareous medium sandstone	◎	○	○					○		○				+		+				△						
110705			Dolomite	+								◎											△						
S-01	MJNM-1	141.00	Shale	△								◎										+							
S-02	MJNM-1	242.80	Sandy dol	△								◎										△			○				
S-03	MJNM-1	246.00	Dolomite									◎										△			○	○			
S-04	MJNM-1	212.00	Calcitizaiton									◎																	◎
S-05	MJNM-1	102.10	Oolite	◎								◎										△			◎				
S-07	MJNM-2	196.00	Chert	◎												△									○				△
S-08	MJNM-2	210.50	Dol/Shale	△								◎										△							
S-09	MJNM-2	218.40	Sandy dol	△								◎										△				○			
S-10	MJNM-4	113.20	Calc shale	△							○	○				△													
S-12	MJNM-2	182.39	Argil	◎												+	+	+						○					
T-01	MJNM-5	144.90	Oolite chert								△														◎				
T-02	MJNM-5	168.00	Dolomite									◎										△			△				
T-03	MJNM-5	219.30	Dolomite									◎													△	△			
T-04	MJNM-6	140.70	Dolomite									◎													○				
T-05	MJNM-6	250.70	Dolomite									◎																	△
T-06	MJNM-6	296.30	Dolomite									◎													△	△			
T-07	MJNM-7	133.50	Dolomite									◎																	
T-08	MJNM-7	139.10	Calcareous chert	△								△						+				△			◎				○
T-09	MJNM-7	163.90	Dolomitic shale	◎								◎						+						△		○			
T-10	MJNM-7	227.60	Dolerite		△				◎	△						○													
T-11	MJNM-8	140.00	Dolomite																						△	◎			
T-12	MJNM-8	188.70	Limestone	○							◎	○																	○
T-13	MJNM-8	230.75	Chert/Dolomite	◎								◎														○			
T-14	MJNM-8	261.70	Dolomite									◎														○			
T-15	MJNM-9	132.00	Dolomitic shale	△								◎												△					
T-16	MJNM-9	188.30	Chert	◎																						◎			
T-17	MJNM-9	243.40	Dolomite									◎													△				
T-18	MJNM-9	299.50	Dolomite									◎													△				
T-19	MJNM-10	83.80	Sandy calcrete									◎																	
T-20	MJNM-10	131.45	Oolite chert									○													◎				
T-21	MJNM-11	110.60	Arenite	◎																									

◎:abundant ○:common △:rare +:trace

Abbreviations

Qz:quartz Pl:plagioclase Kf:potassium feldspar Hb:hornblende Mu:muscovite Bi:biotite
Cal:calcite Dol:dolomite Ser:sericite Chl:chlorite Sp:sphene Mt:magnetite Zr:zircon Ap:apatite Tm:tourmaline Lx:leucoxene Ep:epidote Hm:hematite Op:opaque mineral Cx:clinopyroxene plagioclase

Table II −4−3 Microscopic Identification of Minerals in Polished Section

Sample No.	Locality or drill hole No.	Rock Name or Depth(m)	Sulphide & primary oxide												Hydroxide	
			Cp	Gn	Sp	Py	Cc	Bo	Nc	Cup	Dg	Cv	V	Mt	Fe	M
100401	Tschudi mine	Malachite-galena ore		○			△1)				+	+				○
100405	Bobos mine	Mottramite ore											●2)			
100407	Tsumeb West mine	Chalcocite ore				+	○				+	+				◎
100408	Tsumeb West mine	Chalcocite ore					●									
101104	Rodgerberg mine	Chalcocite-covellin ore					●1)					○				
102004	Harasib mine 1	Descloizite ore											●			
102005	Harasib mine 1	Fe-hydroxides-Cu-Sp ore			◎-○				◎4)						●3)	
102006	Harasib mine 2	Galena sphalerite ore		◎6)	○							△5)				
102010	Harasib mine 3	Chalcocite ore					●		+							
102501	Abenab mine	Sphalerite galena ore		◎-○	◎	△										
102505	Abenab mine	Galena ore		○	△7)	△				△		△-+				
102506	Abenab mine	Sphalerite galena ore	+	◎	●-◎	△									○	
102507	Abenab mine	Sphalerite pyite ore		◎-○	◎	◎-○						+				
110601	Kombat-W E80 14L	Secondary copper ore					○		△	◎						◎
110602-1	Kombat-W L15/1 No.5	Chalcocite cuprite ore			+		△		+	△					○?	
110602-2	Kombat-W L15/1 No.5	Fe-Mn ore					△									
110603	Kombat-W E80 14L	Chalcocite bornite ore					◎	◎8)								
110604	Kombat-W 16L/1 No.2	Galena Chalcopyrite ore	●-◎	●-◎	○			○				△				
110605	Kombat-W 16L/1 No.1	Chalcopyrite galena ore	●	◎-○		△	◎-○									
110701	Tsumeb Mine,L10No.1	Chalcocite covellin vein				+	◎-○		+			△				
P-01	MJNM-1	91.60		◎								○				
P-02	MJNM-1	112.30		●	◎							○				
P-03	MJNM-1	141.63		○	●							○				
P-04	MJNM-1	246.25		●	●	○						○				
P-05	MJNM-3	63.55											●			
P-01	MJNM-7	227.60												◎		
P-02	MJNM-8	227.80				●										
P-03	MJNM-9	232.07	+	+	○											
P-04	MJNM-9	241.87											○			
P-05	MJNM-9	242.90	+	◎	◎											
P-06	MJNM-9	243.15	○	○	◎	+										
P-07	MJNM-9	248.10	+	○	◎											
P-08	MJNM-9	251.40											○			
P-09	MJNM-10	269.10	+											○		
P-10	MJNM-11	270.70	+	+	+											

●:abundant ◎:common ○:poor △:rare +:trace

Abbreviations

Fe:Fe-hydroxides **M**:malachite **Bo**:bornite **Cc**:chalcocite **Cp**:chalcopyrite **Cup**:cuprite **Nc**:native copper

Dg:digenite **Cv**:covelline **Gn**:galena **Py**:pyrite **Sp**:sphalerite **V**:descloizite or mottramite **Mt**:magnetite

1)Frequently coexists with covellin.

2)Enhedral to subhedral,showing zoning texture. Primary ore mineral.

3)Locally showing colloform texture,occurs as acicular crystal.

4)Aggregate of very fine crystals

5)Occurs enclosing sphalerite grains.

6)No exsolution texture.

7)Coated with thin band of galena.

8)Crystal rims bordered by chalcocite.

Table II −4−4 Result of X-ray Diffractometry

No.	Well No.	Depth	Rock Name	Silicate Minerals / Clay Minerals: Montmollironite	Smectite	Chlorite	Sericite	Palygorskite	Talc	Quartz	Biotite	K-Feldspar	Albite	Carbonate Minerals: Calcite	Dolomite	Cerussite	Ore Minerals: Pyrite	Pyrrhotite	Magnetite	Brucite	Galena	Remarks
1	MJMN-1	89.0 m	Reddish argil			△		△		◎												
2	MJMN-1	112.3 m	Sillicification				△			◎					◎	△		?			△	
3	MJMN-1	257.4 m	Dolospar							◎					◎							
4	MJMN-3	63.1 m	Dolospar + Sp							?				△	◎							
5	MJMN-4	134.0 m	Sericitic dolomite	△		△	△		○	◎					◎							
X-1	MJMN-5	91.5 m	White argil					○		○												
X-2	MJMN-6	296.5 m	Calcareous dolomite												◎							
X-3	MJMN-7	157.0 m	Talc			△			◎	△												
X-4	MJMN-7	227.6 m	Dolerite			△					◎			○					△	○		+Chrysotile Lizardite
X-5	MJMN-7	262.7 m	Pink talc		△	△			◎						◎							
X-6	MJMN-8	230.8 m	Pyrite		△					○				○			○					
X-7	MJMN-9	113.3 m	Crackled dolomite			+				○				◎	◎							
X-8	MJMN-10	262.0 m	Dolerite		△	△								○			△					
X-9	MJMN-12	59.6 m	Mulden sandstone		△					◎		○	△									
X-10	MJMN-12	291.5 m	Pink talc						◎	○					+							

Abbreviation
◎:Abundant ○:Common △:Poor +:Trace

diametre. The breccia is commonly dolomitic showing grey to reddish brown. The calcrete between 25 m and 37 m deep includes elongated cavities where crystalline calcite occurs. The water circulation was encountered at a depth of 15.10 m.

- 60.96m-100.60m Dolomite

The formation is light grey and fine grained dolomite including white spots of dolospar and is intercalated with local lenses of chert and silicified oolite. The bedding planes are approximately parallel to the drill hole. A dot of green copper mineral is embedded in the thin bed of chert at a depth of 90.96 m.

- 100.60m- 204.95m Shale

The formation is black shale rarely intercalated with red chert. The shale is identified with calcareous shale because of a reaction with chloric acid. The angle between the bedding plane and drill hole varies from 10 to 20 degrees. The formation is fractured at around a depth of 111 m and 145 m to form argillaceous matter.

- 204.95m- 300.30m Dolomite

The formation is composed of dark coloured coarse to medium-grained sandy dolomite with argillaceous and conglomerate intercalations around 219 m deep.
At depth it changes to fine grained dolomite. An older crackled zone develops between 267.70 m and 285.25 m. The bedding planes run almost parallel to the drill hole. No mineralisation was recognized.

MJNM-3

- 0.00m- 12.00m Calcrete

The formation is grey to purplish brown and is sometimes stratified with vugs.

- 12.00m- 150.30m Dolomite

The massive facies are dominant with thin beds of chert. The dolomite from 74.60 m to 76.45 m, from 94.20m to 100.60 m and from 120.85 m to 128.50 m shows medium grained sandy facies. Remarkable stromatolitic texture is recognized at a depth of around 50 m. The angle between the bedding plane and drill hole varies from 60 to 85 degrees. Mineralisation includes a dot of green cupriferous mineral which is associated with dolospar filling the fractures within dolomite at a depth of 36.64 m and a large grain of sphalerite at a depth of 63.10 m as well as descloizite film at a depth of 63.55 m.

MJNM-4

- 0.00m- 5.58m Calcrete

The calcrete is composed of white argil and dolomitic gravels.

- 5.58m- 50.00m Dolomite

The formation is grey bedded or massive dolomite intercalated with black shale some ten centimetre thick and chert. The bedding plane gives 45 to 60 degrees with the drill hole. Orange-coloured mineralisation in veinlets at around a depth of 22 m is possibly vanadium.

- 50.00m- 117.00m Dolomite/Shale alternation

The formation is composed of bedded dolomite, sandy dolomite, black shale and chert. Within the dolomite with black carbonaceous stripes, a large number of vugs which vary from 0.5 to 1.0 centimetre in diametre characterize the formation.

- 117.00m- 150.60m Dolomite

The formation includes well bedded pale brownish grey dolomite with thin beds of black carbonaceous dolomite. The carbonaceous facies show stripe texture and are rich in vugs formed by dissolution. The formation is also characterized by pink coloured sericitic layers deeper than 133 m. The bedding plane gives 45 to 60 degrees with the drill hole. No mineralisation was encountered.

MJNM-5

- 0.00m- 83.00m Calcrete

This is a pale brown or greyish white pelagic calcareous sediment of concretion. The first aquifer was encountered at a depth of 6 metres and the aquifer 60 metre deep was the most important. In general the lower it goes, it shows mottled coloured and more pebbled. The upper part is unconsolidated sandstone with predominately quartz grains in red argillaceous matrix cut by steeply dipping white argillaceous veins. The argil was identified as palygorskite$(Mg,Al)_2[(OH,O)/Si_4O_{10}\}]$ which is of hydrothermal origin. The clay mineral occurs commonly in the Kalahari sand of holes. From 98.70m to 117m and from 134,50m to 144.60m it contains more pebbles of subangular form. In the lower part, the pebbles are oolite, chert and dolomite within calcareous matrix. The formations are post Tertiary sediments which are overlying the Proterozoic dolomite unconformably.

- 144.60m- 220.00m Dolomite

Karst cavities are present right beneath the unconformity. Sandy dolomite is intercalated with black dolomite and oolite characterizing the upper Tsumeb subgroup. Under the microscope the chert at a depth of 145m formed from calcareous weed that has been replaced by fine quartz. From 181m to 190m Karst cavities develop with reddish argil deposited in it. From 195m black dolomitic shale is predominant with almost horizontal bedding plane.

The dolomite is generally composed of a fine grained dolomite groundmass and coarse grained dolomite and quartz filling the pores, implicating dolomitization at diagenesis stage. Older fracturing and cavities were recognized without psammitic filling sediment of Mulden group, they are therefore believed to have formed later than ore formation.

MJNM-6

- 0.00m- 94.05m Calcrete

The upper part consists of greyish white or pale brown calcrete with reddish brown pebble-like mottles. From 75m pebble calcrete dominates, of which pebbles of mottled sand, black chert and sandstone are predominant. This is underlain by an argillaceous facies some 3 metres thick. The basal facies, three metres in thickness, overlying unconformity include dolomite and chert pebbles within an argillaceous matrix.

- 94.05m- 300.00m Calcareous dolomite

The characteristics of this formation is pale brick brown calcareous dolomite. This facies crops out in the vicinity of Abenab mine and therefore the formation is correlated to Abenab subgroup. It is intercalated with thin beds of reddish brown shale, chert and grainstone and is rich in vugs. The vugs are filled with coarse calcite, dolospar and quartz which may signify pervasive calcitization.

From a depth of around 240m a graded texture of dolomite occurs in which cycles from fine shale to coarse grainite are repeated. The beds are likely to dip less than 30° in the shale and grainstone. The formation is fractured at about 191m and 200m. No remarkable fracture zones were recorded except from those at a depth of 191m and 200m.

MJNM-7

- 0.00m- 88.25m Calcrete

The lower part consists of pebble calcrete. Rounded to subrouded pebbles of gneiss, greenstone and shale 3 to 5 cm in diametre, are embedded within a sandy matrix.

- 88.25m-237.90m Dolomite and black shale

Tsumeb subgroup starts with black sandy shale underlain by grey dolomite.

From a depth of 120m black calcareous shale alternates with grainstone. Talc argillization appears from 127m down. A pure talc bed is enclosed over two metres from 156m to 158m as well as intense talc argillization zone at depths of 192, 194 and 207m. X-ray diffractometry indicates weak peaks of chlorite and quartz associated with talc.

- 227.90m- 230.75m Dolerite

The dyke rock is dark green compact and is significantly magnetic. The upper contact with dolomite dips 45°, while lower contact dips 35°. The dip is almost coincident with that of beds of host rock. This rock is rich in altered yellowish brown pyroxene. The relict crystals have been fully serpentinized under microscope. X-ray diffractometry showed evident peaks of chrysotile and lizardite as well as biotite. The last is comparatively common but is not known whether this is of primary or secondary origin.

・ 230.75m- 300.00m Dolomite

The facies are uniform until around the depth of 260m where intense argillization is recognized. In part the talc shows a pink colour, suggesting it being manganiferous. X-ray diffractometry gave remarkable peaks of chlorite and smectite as well as talc. Between 270m and 300m black dolomitic shale and a fine sandy dolomite(packstone) associated with grey dolomite alternate every four to five metre.

MJNM-8

・ 0.00m- 128.00m Calcrete・Kalahari sand

In the upper part the formation is grey to pale brown and becomes mottled from 50m. From a depth of around 70m, it showed psammitic material within reddish argil. Pebble calcrete beds are intercalate from 90.40m to 91.50m, from 96.40m to 100m, from113.58m to 114.28m and from 118.60m to 128.00m.

・ 128.00m- 229.52m Dolomite/Shale alternate

The upper most two metres from the unconformity is dark grey porous dolomite which changes into fractured grey dolomite below. The fracture planes are filled with dolospar and calcite but are not associated with mineralisation. Such the crackled structure, which has a good potential for sulphide mineralisation is also recognized from 156m to 158m and from 161m to 162m.

In the lower part the grey dolomite is intercalated with black shale to black sandy dolomite(packstone) some tens centimetre to several metres thick.

From a depth of around 160m talc veins parallel to beds are present. Core logging showed that the beds dip 5 to 30° . Near the contact of dolerite dyke, a network mineralisation of pyrite occurs over 20cm. The diffractometric peaks of calcite, quartz and smectite as well as pyrite were detected. Under the microscope the limestone from 187m to 190m includes peloid and clastic calcite grains cemented by fine dolomite.

・ 229.52m- 230.75m Dolerite

The dyke rock intrudes into the host rock at an angle of 60° forming bleached zone 5cm in width. Pyrite network 5cm wide occurs at the footwall side.

・ 230.75m-300.00m Dolomite ・ Shale

Fine grained dolomite is predominant in this section where it is intercalated with sandy dolomite and black dolomitic shale. Talc argillization is remarkable in the fine dolomite. Microscopic identification showed white spots in the dolomite from 261.40m to 267.10m were coarse subhedral crystals of dolomite which suggest right lateral detachment.

MJNM-9

- 0.00m- 91.20m Calcrete・Kalahari sand

The lower part of calcrete consists of mottled pebbles from a depth of 50m. Kalahari sand occurs from 65m with black manganese stains and white argil identified to be palygorskite in the cracks.

- 91.20m- 165.00m Dolomite/Shale alternate

The beds of grey sandy dolomite dip 30° to 50°. The cavities and fractures that occur are filled with reddish breccias and the Kalahari sand over 2m under the unconformity. The dolomite is intercalated with brown shale less than two metre thick. The section from 113m to 118m and from 124m to 128m is fractured and filled with calcite and quartz. This old fractured zone has a good potential for mineralisation. The grainstone is occasionally intercalated with thin beds of chert.

- 165.00m- 300.00m Grainstone

Sandy dolomite with frequent lenses of chert dominates. The first sphalerite mineralisation is evident at a depth of 186m where it is associated with silicification. Further mineralisation of sphalerite and galena dots occur from 231m to 253.60m. A vanadium mineral, possibly descloizite, occurs in the cracks overprinting the mineralisation. Under microscope veinlets of secondary dolomite and quartz were observed. From around 280m the formation consists of a black facies, similar to the lithofacies in MJNM-2.

MJNM-10

- 0.00m- 117.95m Calcrete・Kalahari sand

The upper 91.85 metres from the surface consists of sandy calcrete and pale purple pebble bearing calcrete in descending order. Microscopic observation showed round clastic fragments of chert, andesite, dolomite and biotite schist embedded in fine calcareous matrix. From 91.85m the formation consists of psammitic sediment with characteristic of reddish argil.

- 117.95m- 259.90m Grainstone・Dolomitic shale

Dark grey to grey calcareous sandstone and black dolomitic shale predominate with flat flying chert and oolite. Microscopic identification revealed that the chert was originated from oolite and the weed was silicified. Stromatolitic texture was recognized at around 165m.

- 259.90m- 263.00m Dolerite

The upper and lower dips of the contact between dolomite and dolerite are steep anep and horizontal respectively. The dyke rock has dark green, medium to coarse magnetite and phenocrysts of altered pyroxene. X-ray diffractometry detected chlorite, smectite and calcite at 262m.

- 263.00m- 300.00m Calcareous sand・Black shale

Down from a depth of 270m the formation changes into light grey facies with intense talc argillization from particularly 270m to 280m.

MJNM-11

- 0.00m- 32.05m Calcrete

It is a greyish white pebble calcrete which is locally argillaceous at the intersection with the aquifer.

- 32.05m-174.00m Sandstone of Mulden group

The formation is dark green and pale cream medium grained sandstone with weathered brittle zone over 10m from the unconformity. The sandstone is well sorted, arkosic and the grey band and reddish band repeat alternatively.

Disseminated pyrite occurs parallel to the horizontal beds suggesting syndepositional origin. The pyrite mineralisation is limited to the grey facies and is weak or absent in the dark green and reddish purple facies.

The matrix is poor and the clastic minerals are poorly grinded. The clastic minerals of grey facies consist of quartz, microcline, muscovite, tourmaline and pyrite under the microscope. The cross bedding occurs over 1.4m at around 160m suggesting littoral or fluvial environment. The boundary of underlying Tsumeb subgroup is not obvious, however the non conformity was determined where calcareous sediment started.

- 174.00m- 300.00m Dolomite・Oolite chert・ Black shale

Stylolite texture characteristically comes in the formation of Tsumeb subgroup. Fine grained grey dolomite dominates with intercalation of oolitic chert less than 1m thick. From a depth of 260m, dark grey dolomite, grainstone and black dolomitic shale. The formation from 275m to 290m is seriously broken and red argil precipitated on the crackled planes. This is possibly fault fractured zone.

The mineralisation of copper oxide and vanadium mineral occurs in a minute vugs at 269.90m. The calcite veins occurring between 270.70m and 270.75m is mineralized with copper sulphide. Another vanadium and copper oxide mineral was recognized at 272.40m.

MJNM-12

- 0.00m- 16.60m Calcrete

The upper half is pebble calcrete less than 5cm in diametre and the lower half is argillaceous to fine sandy calcrete. Siliceous conglomerate lies at the base.

- 16.60m-135.60m Sandstone of Mulden subgroup

Less weathered zone of the formation shows dark green to light grey medium to coarse grained sandstone. The coarser facies is mostly reddish purple. The dissemination bands of pyrite predominantly occurs within light grey facies. The mineralisation underlies parallel to the sandstone beds which dip 20° to 30°. Cross bedding was recognized at a depth of 116m. The contact of the underlying Tsumeb subgroup is not definite from a view point of lithofacies and looks like transitional. X-ray diffractometry gave remarkable peaks of quartz, smectite, albite and potash feldspar for a specimen at 60m.

・ 135.00m-219.70m Dolomite・Black shale

The formation is dark grey or black, fine grained dolomite with sandy dolomite. Down from 272m black dolomitic shale dominates and alternates with fine sandy dolomite and grey dolomite. No sulphide mineralisation was recognized. From 258m semi-transparent pink coloured talc alteration are embedded within the beds.

4-3-2. Mineralisation

The result of chemical assays is shown in Table II-4-5. The mineralised cores were quartered using diamond blade and cut into samples more than 5 centimetre long. Each sample was prepared for chemical assay of eight elements including Au,Ag,Cu,Pb,Zn,Cd,Ga and V. The result is shown in the geological column sections as well as Fig.I-1-10. The analytical methods were atomic absorption method for Au,Ag,Cu,Pb Zn and Cd using Hitachi Z-6000 and Z-8100 (flameless) and absorbance optical density method for Ga and V. Detection limit for Au and Ag is 1 ppb whereas that for Cu,Pb,Zn,Cd,Ga and V is 1 ppm.

The cumulative length of the mineralised cores of the hole MJNM-1 reaches to 9.16 metres, while the cumulative value of the mineralised lengths by assay values amounts to 2.125 metre ・ percent(m・%) for Pb and 3.461 m・% for Zn totaling 5.586 m・% for Pb+Zn. Of the assayed samples, the mineralised sections which gave more than 1 % are as follows.

111.58m-111.69m(0.11m)	Pb=1.45%	
112.30m-112.62m(0.32m)	Pb=4.52%	Zn=1.58%
245.75m-246.25m(0.50m)		Zn=1.76%
246.25m-246.65m(0.40m)		Zn=2.28%

The mineralized dolomite is indicated in Fig. II-4-6.

Sulphide mineralisation was also recognized in the hole of MJNM-9,MJNM-11 and MJNM-12. The cumulative length of the mineralised cores of MJNM-9 reaches to 5.24 metres, while the cumulative value of the mineralised lengths by assay values amounts to 0.22 metre ・ percent(m・%) for Pb and 1.08 m・% for Zn totaling 1.29 m・% for Pb+Zn. Of the assayed samples, no mineralised sections gave more than 1 % and the sections with more than 0.1% are as follows.

234.10m-234.50m(0.40m)		Zn=0.58%
242.60m-243.35m(0.75m)	Pb=0.17%	Zn=0.83%
248.10m-248.64m(0.54m)		Zn=0.31%

Pyrite mineralisation intersected by MJNM-11 and MJNM-12 is hosted within the sandstone of Mulden group. No significant concentration of Au and Cu was assayed in this mineralisation but the dolospar and calcite veinlets embedded in dolomite of MJNM-11 indicated a significant concentration of Cu,Pb and Zn.

Table II –4–5 Result of Chemical Assay

Chemical assay (ppb for Au and ppm for others)

Sample No.	Hole No.	From (m)	To (m)	Width(m)	Au	Ag	Cu	Pb	Zn	Cd	V	Ga
A-01	MJNM-1	101.86	102.26	0.40	<1	2.18	14	1710	851	4	<1	4
A-02	MJNM-1	104.01	104.41	0.40	<1	0.50	6	154	107	<1	<1	49
A-03	MJNM-1	104.41	104.66	0.25	<1	0.50	30	605	244	1	<1	42
A-04	MJNM-1	106.70	107.00	0.30	<1	0.50	4	99	35	<1	<1	12
A-05	MJNM-1	110.81	110.94	0.13	<1	0.20	4	85	35	<1	<1	25
A-06	MJNM-1	111.09	111.29	0.20	<1	1.49	7	374	139	2	<1	42
A-07	MJNM-1	111.58	111.69	0.11	<1	7.06	12	14500	1420	5	<1	7
A-08	MJNM-1	112.30	112.62	0.32	<1	19.00	59	45200	15800	32	<1	<1
A-09	MJNM-1	113.94	114.15	0.21	<1	0.60	5	161	43	<1	<1	16
A-10	MJNM-1	123.88	124.08	0.20	<1	0.30	8	136	226	<1	<1	28
A-11	MJNM-1	141.55	141.93	0.38	18	0.79	25	267	909	15	<1	27
A-12	MJNM-1	143.70	144.00	0.30	<1	0.89	9	150	3500	12	<1	13
A-13	MJNM-1	157.25	157.88	0.63	<1	0.70	8	128	49	<1	<1	12
A-14	MJNM-1	158.08	158.78	0.70	<1	0.70	3	69	67	<1	2	11
A-15	MJNM-1	211.57	211.77	0.20	<1	2.10	8	102	302	2	1	13
A-16	MJNM-1	211.91	212.08	0.17	<1	1.80	11	147	998	5	<1	27
A-17	MJNM-1	213.00	213.15	0.15	<1	2.90	13	605	5710	21	<1	57
A-18	MJNM-1	217.15	217.30	0.15	<1	0.80	8	86	55	<1	<1	12
A-19	MJNM-1	222.60	222.85	0.25	<1	2.00	32	156	2300	10	1	7
A-20	MJNM-1	223.07	223.67	0.60	<1	0.80	22	165	3160	15	<1	9
A-21	MJNM-1	242.76	242.97	0.21	<1	5.49	16	4280	179	3	<1	31
A-22	MJNM-1	245.75	246.25	0.50	<1	4.00	29	1990	17600	46	1	8
A-23	MJNM-1	246.25	246.65	0.40	13	4.57	20	781	22800	74	<1	13
A-24	MJNM-1	246.92	247.17	0.25	2	1.69	13	172	6110	24	1	2
A-25	MJNM-1	258.95	259.50	0.55	<1	3.48	19	353	7610	29	1	30
A-26	MJNM-1	263.20	264.04	0.84	<1	1.39	6	539	137	<1	1	36
A-27	MJNM-1	268.10	268.20	0.10	<1	0.79	4	114	49	<1	1	20
A-28	MJNM-1	271.50	271.58	0.08	<1	7.25	18	4960	183	1	<1	13
A-29	MJNM-1	273.64	273.69	0.05	<1	5.46	7	4870	33	<1	<1	13
A-31	MJNM-1	185.93	186.07	0.14	1	0.60	5	85	72	<1	<1	13
A-1	MJNM-9	170.57	170.62	0.05	<1	0.80	6	811	320	<1	20	<1
A-2	MJNM-9	186.31	186.39	0.08	9	0.95	10	11	32	<1	7	<1
A-3	MJNM-9	231.63	232.20	0.57	9	0.20	9	100	14	1	18	<1
A-4	MJNM-9	232.20	232.55	0.35	4	0.20	6	122	56	<1	8	<1
A-5	MJNM-9	233.36	233.46	0.10	24	0.20	5	95	42	<1	5	<1
A-6	MJNM-9	234.10	234.50	0.40	2	0.50	12	322	5810	15	5	<1
A-7	MJNM-9	234.73	234.82	0.09	13	0.95	10	560	108	<1	21	<1
A-8	MJNM-9	235.30	235.55	0.25	<1	0.20	6	49	114	<1	<1	<1
A-9	MJNM-9	241.87	242.60	0.73	<1	0.50	9	142	250	1	34	2
A-10	MJNM-9	242.60	243.35	0.75	<1	1.25	18	1660	8300	36	2	2
A-11	MJNM-9	243.35	244.00	0.65	<1	0.50	5	288	95	<1	7	<1
A-12	MJNM-9	245.75	246.15	0.40	<1	0.65	13	269	142	<1	27	2
A-13	MJNM-9	248.10	248.64	0.54	26	0.50	9	275	3130	14	3	1
A-14	MJNM-9	248.79	248.93	0.14	12	0.50	5	176	416	3	17	1
A-15	MJNM-9	249.52	249.65	0.13	87	0.20	7	75	71	<1	17	2
A-16	MJNM-9	251.35	251.45	0.10	<1	0.50	12	182	541	31	18	1
A-17	MJNM-11	110.55	110.65	0.10	<1	0.05	7	11	25	<1	32	6
A-18	MJNM-11	270.70	270.75	0.05	<1	2.95	283	1760	260	4	208	1
A-19	MJNM-11	272.30	272.50	0.20	<1	0.95	270	1100	807	11	167	2
A-20	MJNM-12	86.18	86.23	0.05	<1	0.35	6	15	13	<1	27	7
A-21	MJNM-12	118.48	118.53	0.05	<1	0.05	14	6	16	<1	<1	4

270.70m-270.75m(0.05m) Pb=0.18%

272.30m-272.50m(0.20m) Pb=0.10%

More than a half of Au assays are less than detection limit and the values over 1 ppb of Au came from the samples in which Pb and Zn are concentrated. The silver assays show a positive correlation with Pb assays. The copper assays are invariable regardless of Pb and Zn assays. The relation between Pb and Zn is obscure. The one group shows considerably obvious relations while another group show deviant relations. Cd assays are definitely proportional to Zn content. Comparison with Tsumeb ore which contains 3% Zn with 400 ppm Cd in average, may indicate that the core samples show lower Cd content for Zn assays than Tsumeb ore. Gallium is less than detection limit for more than a half of the samples and for others very low. Vanadium assays are also low compared to the mineralisation of MJNM-11.

No characteristic structures such as karst breccias and sand pipes which may host Tsumeb and Kombat-type ore deposits, were intersected by MJNM-1 hole. The mineral assemblage may also suggest that the mineralisation is of different type from that of Tsumeb and Kombat. Detailed observations of the mineralised sections of cores and the microscopic texture of the thin sections revealed that the lead and zinc minerals are associated with fine chalcedonic quartz which has formed in separate stages. It is thus believed that the mineralisation is of classic Mississippi Valley-type which implies mineral precipitation at comparatively low temperature during diagenesis.

Sketches of the mineralised sections are shown in Fig.II-4-3. The sketches indicate that galena and sphalerite has occurred filling microfractures subparallel to the stylolitic planes near by. The microfractures transecting the stylolitic planes are rare and intermittent. It is therefore suggested that the mineralisation is approximately restricted to a specific stratigraphic horizon or lithofacies.

The occurrences related to the strata-bound MVT are hosted by dolomites of the Gauss Formation, Abenab Subgroup through to the Huttenburg Formation of the Tsumeb Subgroup, most frequently within the Elandshoek Formation of middle Tsumeb Subgroup. Combined lead and zinc ore grade of the occurrences varies less than 5 to 10 %. In the recent years only one prospect reached to the ore reserve estimate and feasibility study but gave negative result for development.

However, the previously known MVT mineral occurrences zone includes Khusib Springs copper ore deposit which has been recently developed. From a view point of mineral assemblage of chalcocite, tetrahedrite, chalcopyrite and pyrite the deposit is obviously different from MVT ore deposit which features fissure filling or disseminated lead and zinc minerals. Therefore, in the survey area, the copper ore deposits could have formed overlapping or neighbouring to the MVT ore deposits.

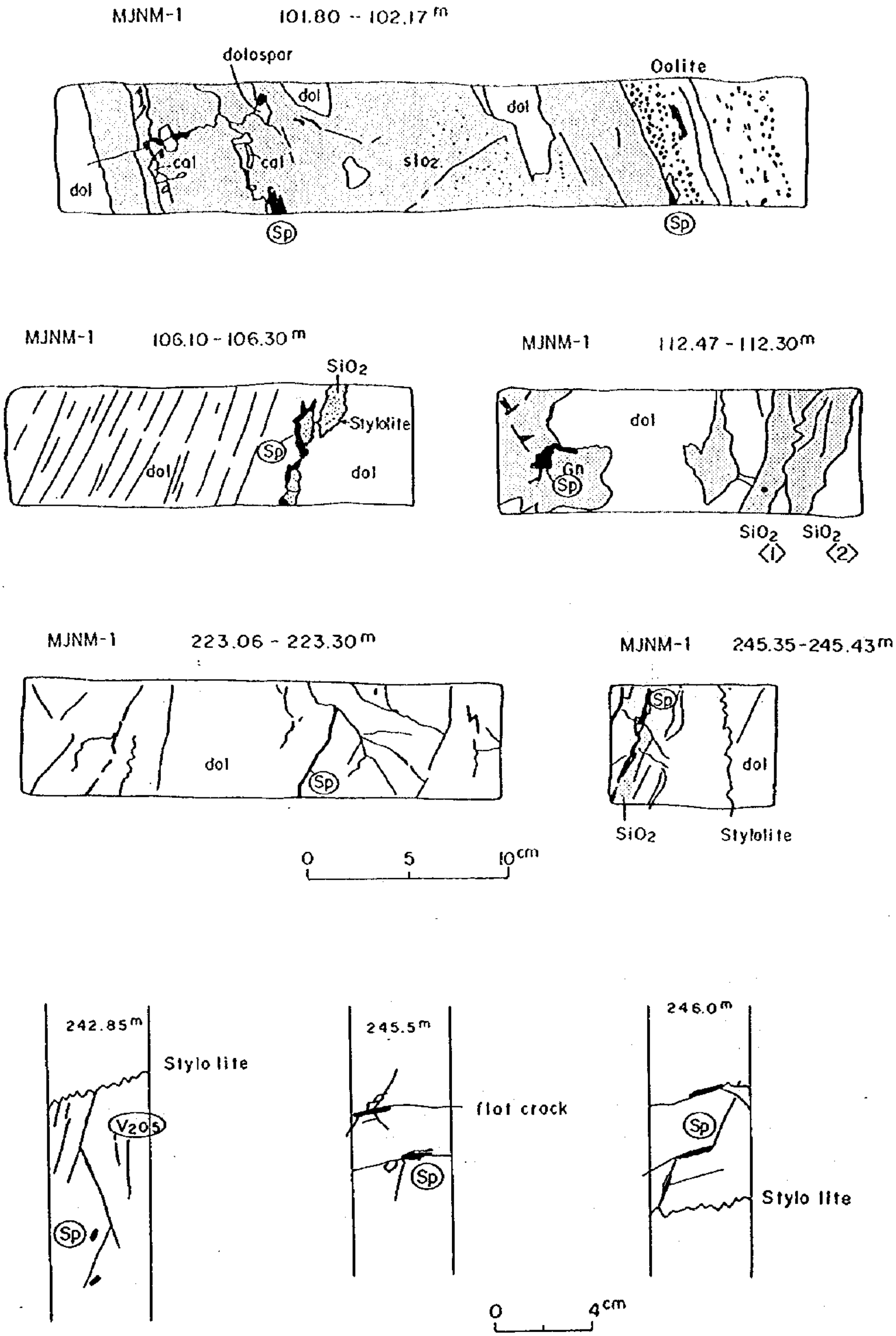


Fig. II −4−3 Sketch of mineralized cores

4-3-3. Homogenization temperature and salinity of fluid inclusion

Histograms of the homogenization temperatures of core samples are shown in Fig. II -4-6. Ten thin sections were prepared for the measurement out of silicified dolomite associated with lead and zinc mineralisation of MJNM-9. The occurrence and form of the fluid inclusions including two phases were examined and the homogenization temperature and salinity was determined.

The average values of samples fall into the area from 130℃ to 159℃. The number of datum is not enough though, there seems to be a rough trend of higher homogenization temperatures at the deeper mineralisation within the interval of 15m. The mean value of 146.6 ℃ is comparable to that of typical Mississippi Valley Type ore deposits (D.L.LEACH et al 1993)which varies from 75 to 200℃ and is lower than the temperature of the important phase of mineralisation at Tsumeb which varies from 230 to 250℃.

The mean value of 14.59 wt% eq.NaCl for salinity is also comparable to that of common Mississippi Valley Type ore which varies from 10 to 30 wt% when the samples with erratic small value are excluded. Meanwhile that of Tsumeb ore varies from 2 to 7 wt% and obviously different from those of MJNM-9. That resulted in the conclusion the mineralisation of MJNM-9 may have formed under diagenetic environment as Mississippi Valley Type ore.

4-3-4. Stratigraphical correlation

The formation of the holes were correlated to the standard stratigraphic sequence based upon the criteria and the result of the logging. The result is illustrated in Fig. II -4-5.

MJNM-1 is predominantly composed of light grey sandy dolomite intercalated with thin beds of chert. The formation is poor in shale and therefore was assigned to T4. The lead and zinc mineralisation of low to medium grade is reported to be hosted within T4 and T5 in the exposed area.

In the hole of MJNM-2, the beds dip steeply covering only a part of the succession, however the geology showed an alternation of dolomitic shale and sandy dolomite, which may suggest T3.

MJNM-3 is characterized by dolomite intercalated with chert and evident stromatolitic texture and was therefore correlated to lower T6.

MJNM-4 showed an alternation of black dolomitic shale and bedded porous dolomite, which may lead to the correlation to T8.

MJNM-5 was correlated to T7 because dark grey fine grained dolomite dominated. But the upper formation than 195m could be assigned to T8.

MJNM-6 is pale brick coloured calcareous deeper than 131 metre and therefore unique. The formation was correlated to Abenab subgroup according to the type locality.

MJNM-7 was correlated to T7 because of well laminated dolomite intercalated with shale beds. A part of black shale cores gave smell which is characteristic of lagoonal sediment of T7 orT8.

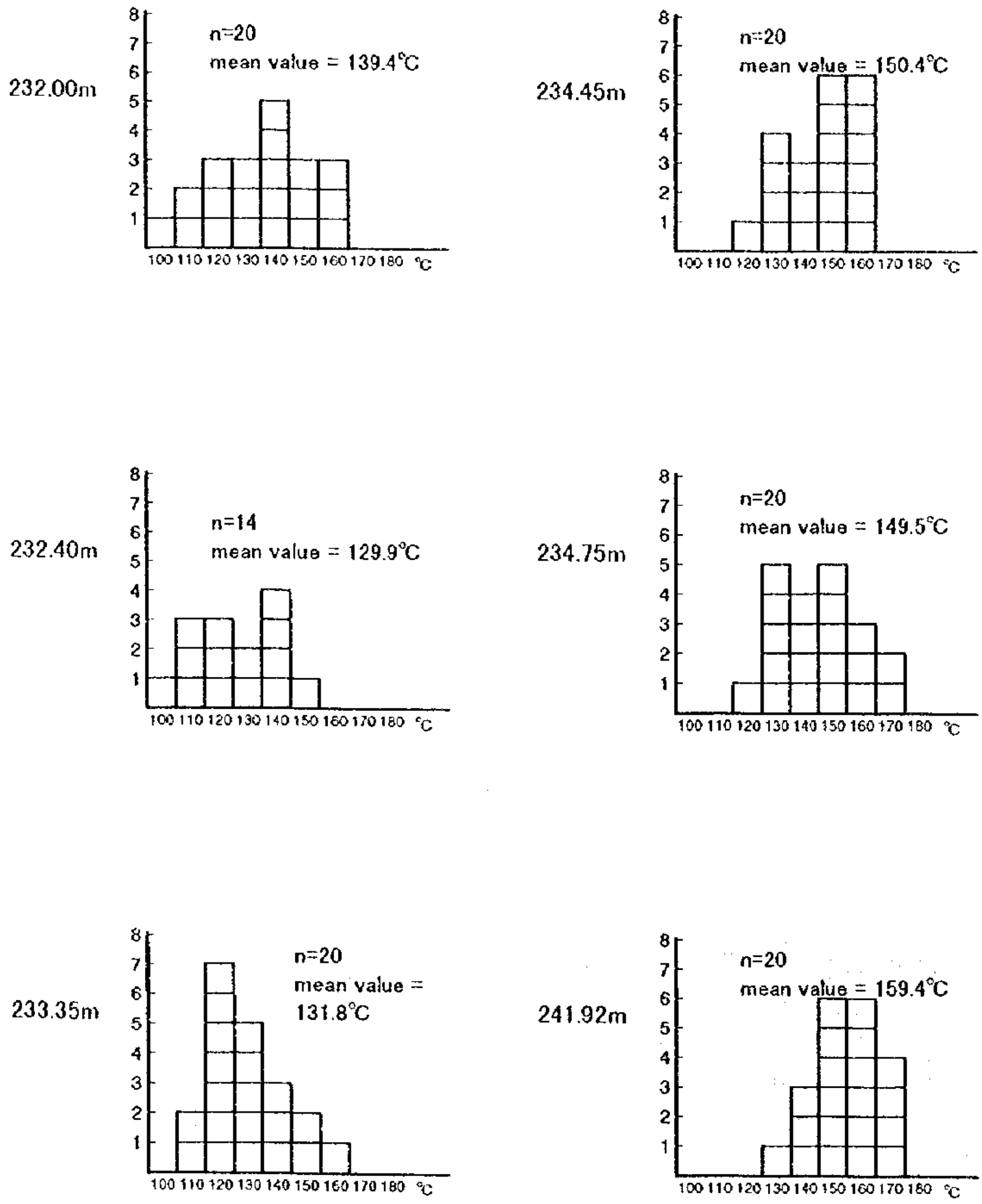


Fig. II −4−4(1) Histogramme of homogenization temperature

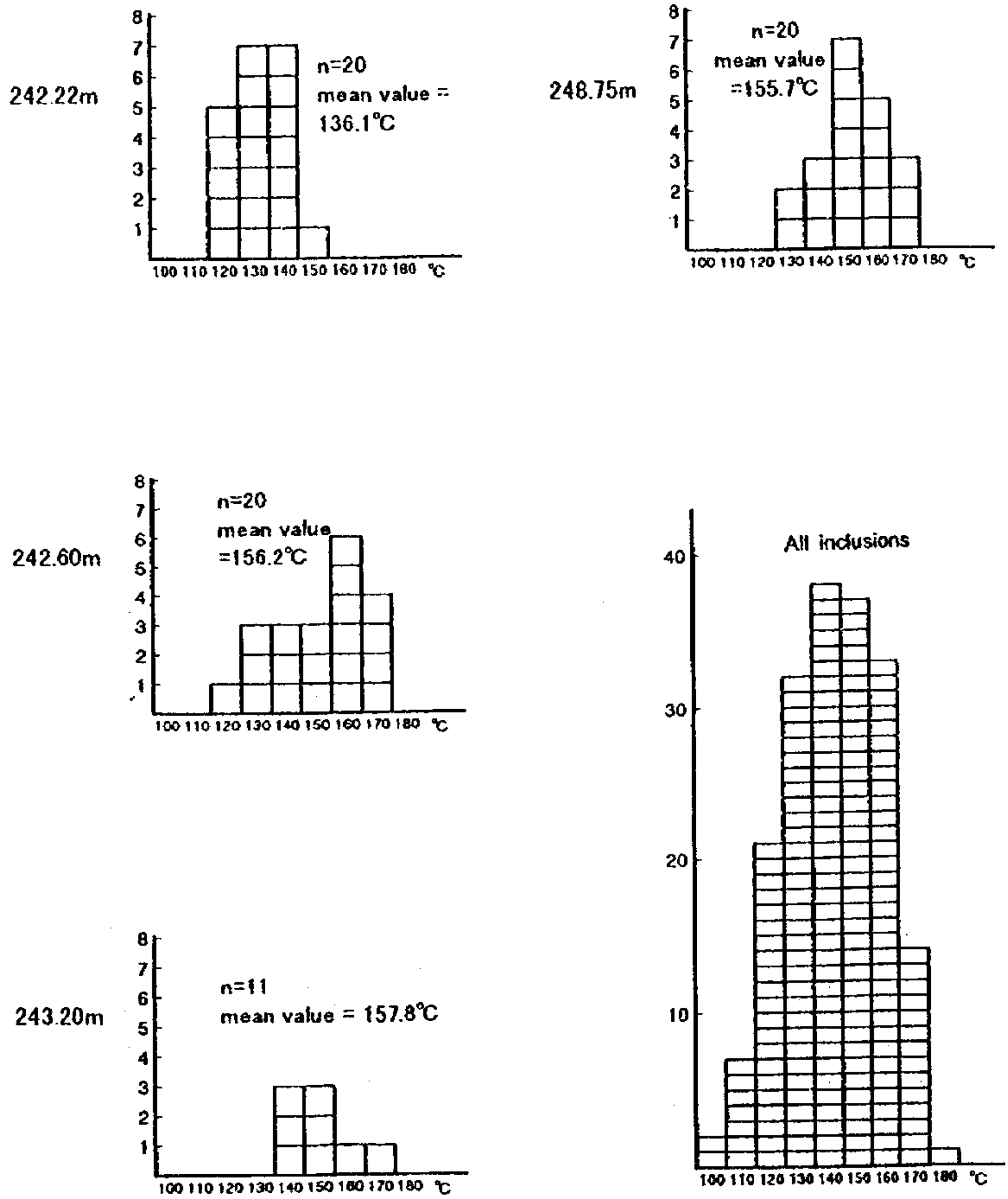


Fig. II −4−4(2) Histogramme of homogenization temperature

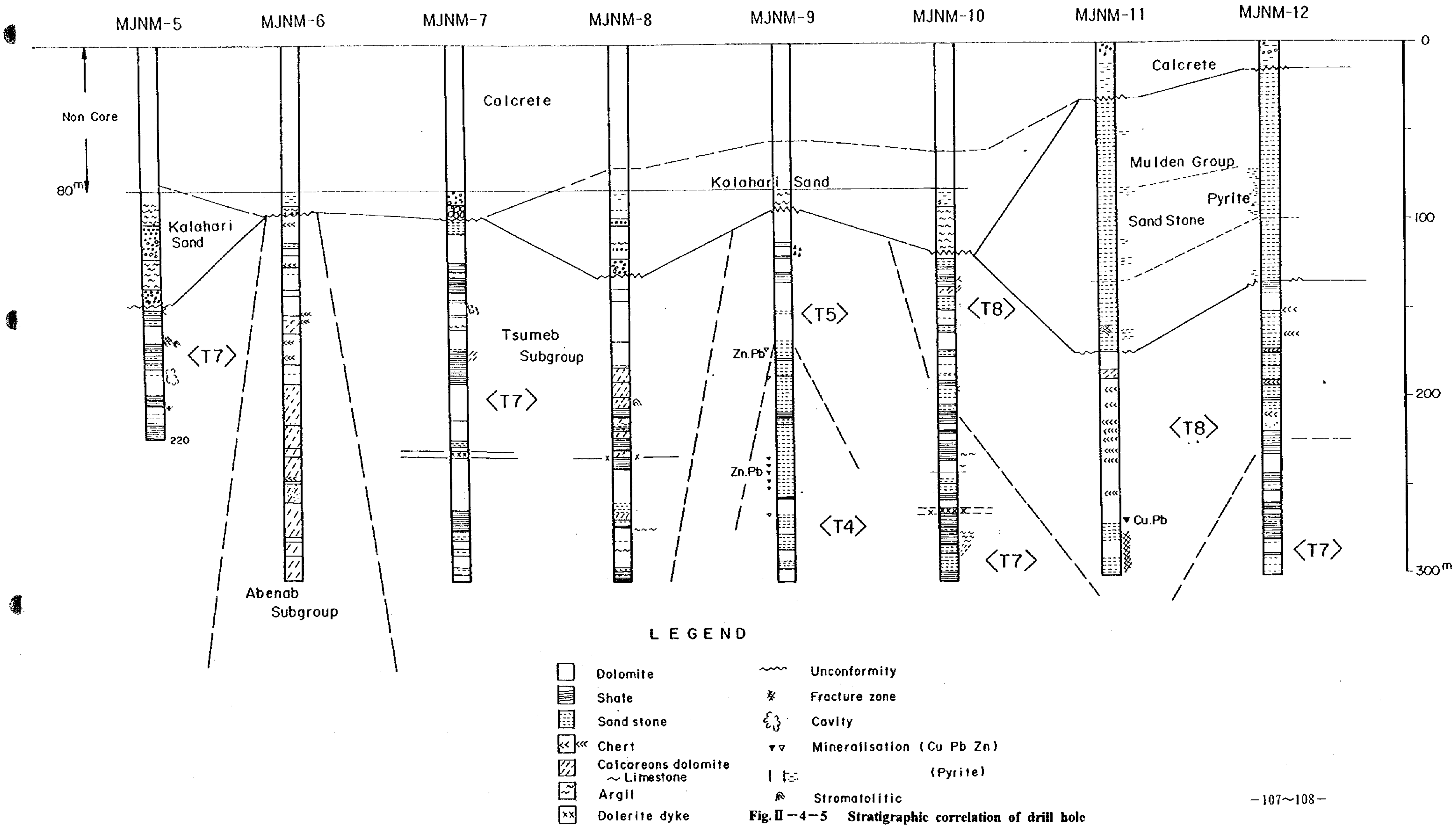


Fig. II—4—5 Stratigraphic correlation of drill hole

MJNM-8 showed similar succession to that of MJNM-7 and therefore correlated to T7.

MJNM-9 encountered medium grained sandy dolomite dominantly deeper than 170m and so was assigned to the upper T4 where transgression started towards T5. The formation upper than 170m which hosts old fractured zone is possibly correlated to T4 as well as the upper formation.

MJNM-10: black facies predominate at a depth greater than 200m and was identified as the same position with MJNM-7. The shallower part was correlated to T8 based upon characteristic stromatolitic texture at around 163m.

MJNM-11 was assigned to T8 because of the multiple thin beds of chert and intercalation of oolite within the dolomite deeper than 174m.

MJNM-12: The formation deeper than 220m is different from that of MJNM-11 and is characterized by black dolomitic shale. Therefore

it was correlated to T7 and the upper formation than 220m to T8.

4-3-5. Geological structure

The geological structure was introduced as illustrated in Fig. II-4-6 as a result of the stratigraphic correlation of the holes drilled in the east of the survey area combined with overall geological structure indicated by airborne geophysical survey.

In the drilling profile along NW-SE parallel to the low resistivity trend, the formation underlying the calcrete seems to form a synclinorium of which axis runs near MJNM-5 and the basement may underlie at a shallow depth 2.5km south of MJNM-6. The sequence of the lower Tsumeb subgroup from T1 to T6 forms the south wing of the syncline between MJNM-6 and MJNM-7. There could be T8 under the calcrete unconformity between MJNM-5 and MJNM-7. Many cavities revealed in MJNM-5 may be related to the proximity of the synclinal axis. In other words these cavities may have formed by the ground water circulating through fractures which develop in the vicinity of the axial part. The dolerite of MJNM-7 is running parallel to the direction of the profile.

In MJNM-5 the Kalahari sand was recognized between calcrete and Damara carbonate and seems to extend north from MJNM-5. Fig. II-4-6 indicates the geological structure along WNW-ESE profile where the holes of MJNM-10, MJNM-5 and MJNM-9 are involved. This profile suggests that Kalahari sand commonly underlies the calcrete and that the sequence from T4 to T8 forms a monoclinic structure dipping west. The apparent dip of the formation between MJNM-5 and MJNM-10 seems to be small along this direction.

In the profile along NNE-SSW direction passing the hole of MJNM-10 and MJNM-8, it seems that MJNM-10 is located at the north wing of the syncline whose axis runs easterly passing around MJNM-5, while MJNNM-8 is located at a local anticline. These two holes intersected dolerite dykes at the almost same depth, however the aeromagnetic anomaly map indicates the dolerite dykes are separately running parallel to the NW-SE direction.

The hole of MJNM-2 is believed to be located at the south wing of the synclinorium extending easterly where a fault of E-W trend runs in parallel and this may result in the steeply dipping beds of the hole.

The holes of MJNM-3 and MJNM-4 in the central part the survey area , are located at the north and south wing of the same synclinorium.

The geological structure in the west of the survey area was interpreted as follows on the basis of stratigraphical correlation of MJNM-11 and MJNM-12.

It had been believed that this area was located at a local anticline between two large synclinal structure from the image interpretation and airborne geophysical anomaly map. Nevertheless, the sandstone of Tschudi formation of Mulden group was intersected over more than 100 meters below the calcrete. Therefore, this area was interpreted to be included within the broader synclinorium.

In the lower part of MJNM-12, back facies of dolomite predominate, whereas the upper part consists of grainstone and chert as MJNNM-11 do. That translates gently dipping structure to the west as a whole in the E-W profile. It is uncertain where in the broad synclinorium the area is situated.

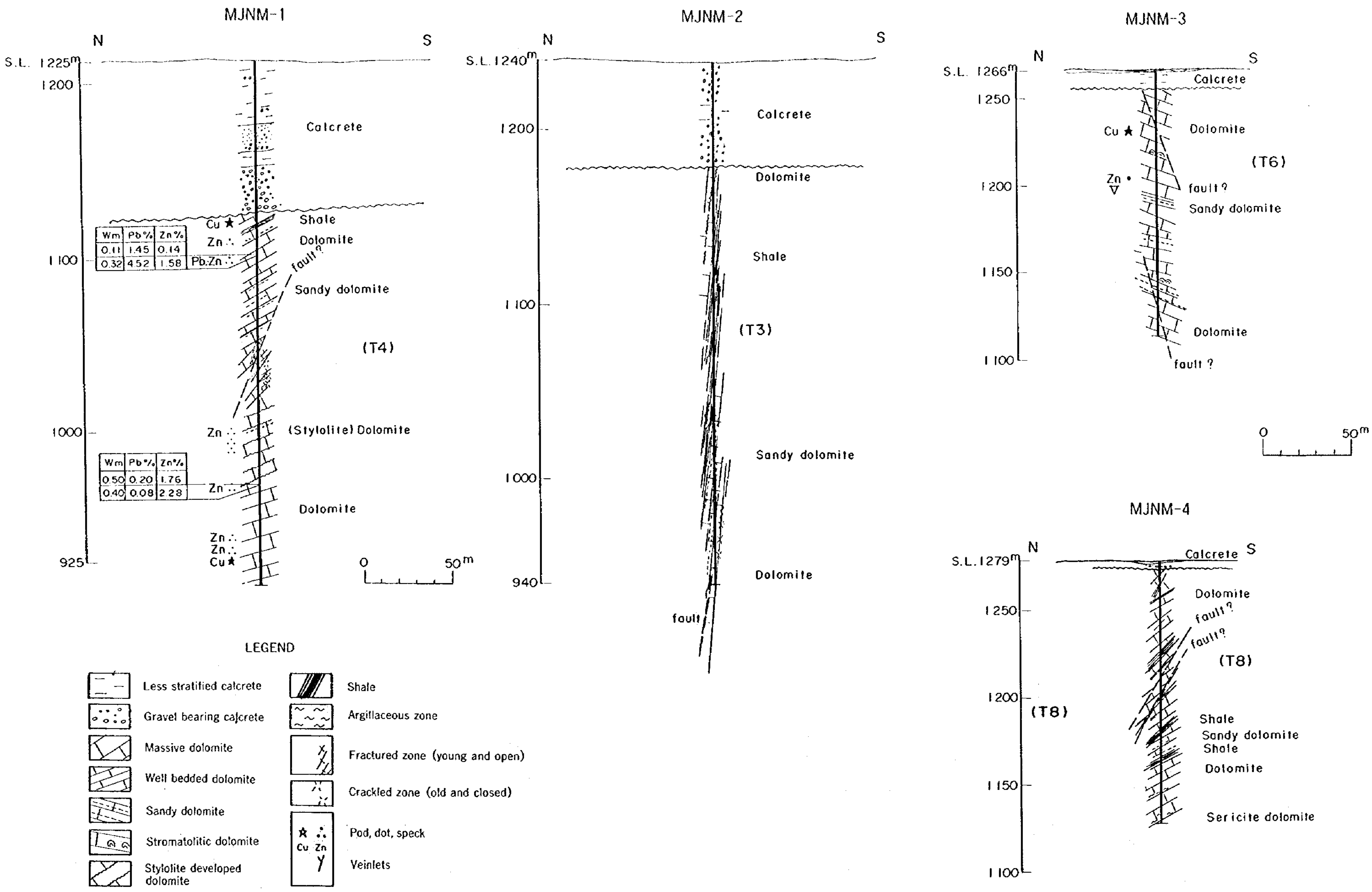


Fig. II—4—6(1) Geological cross section of drill hole

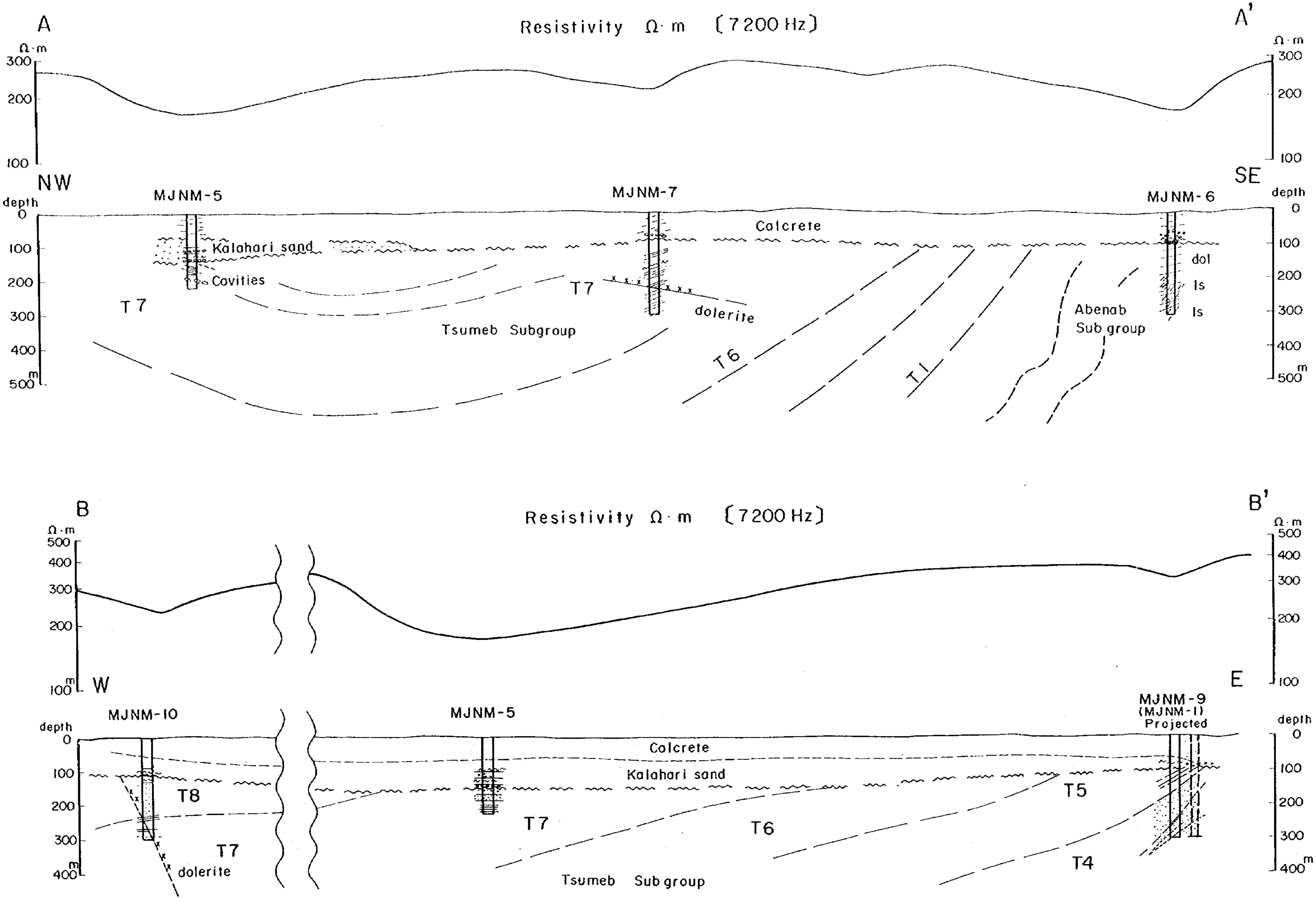
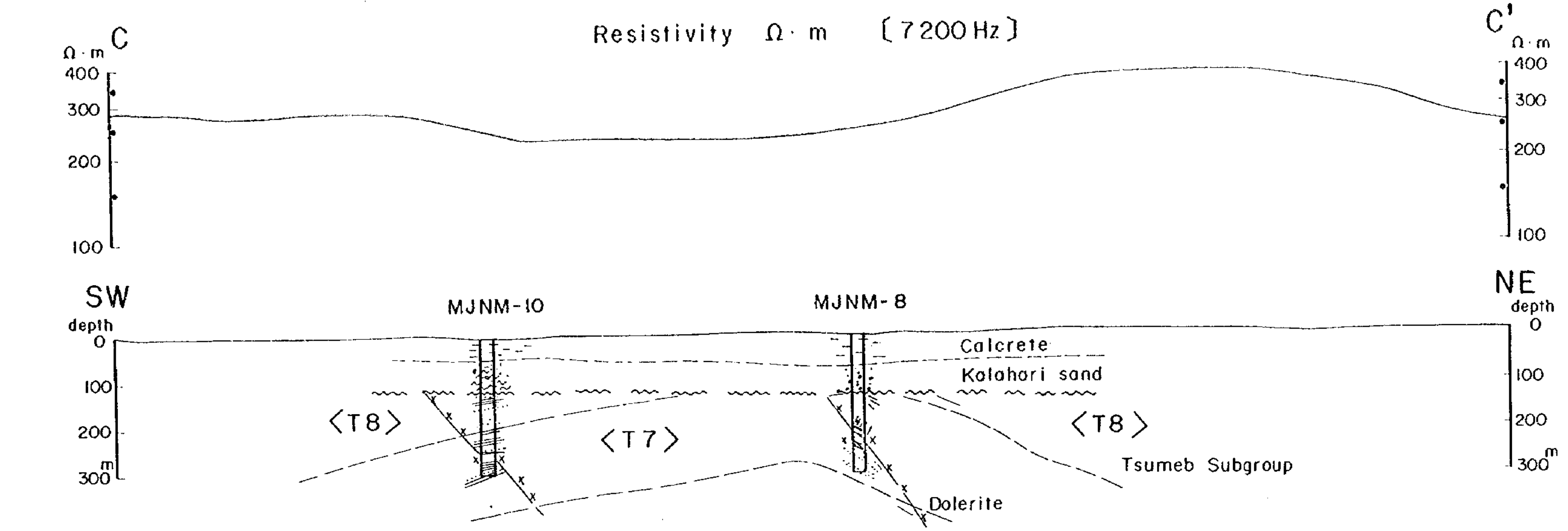


Fig. II −4−6(2) Geological cross section of drill hole



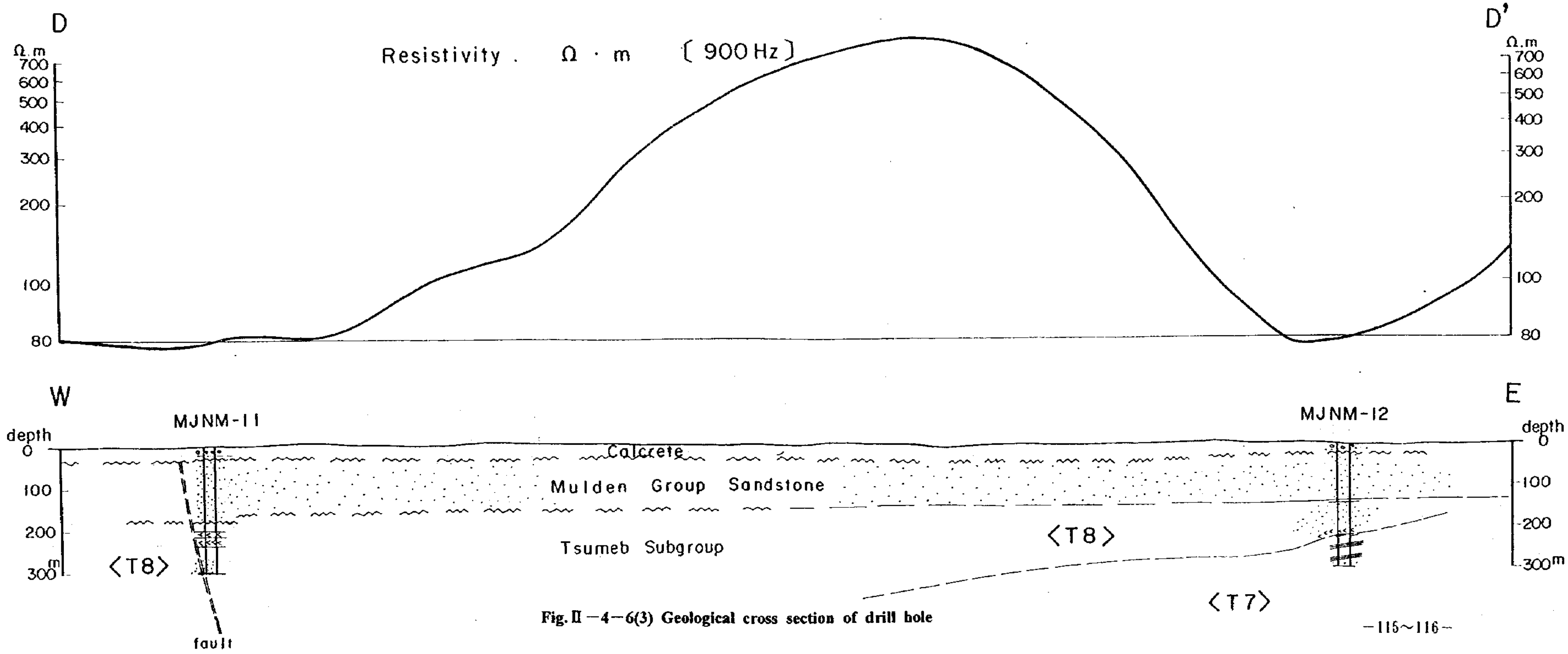


Fig. II—4—6(3) Geological cross section of drill hole

Chapter 5 Physical Properties

5-1. Objective and Number of Samples

The samples to be measured included rock samples of the main formations and ore specimens from the known deposits in the Phase Ⅰ. In the Phase Ⅱ and Ⅲ the core samples were used for physical properties. The properties included magnetic susceptibility, resistivity and chargeability. The number of the samples is 993 for magnetic susceptibility and 134 for resistivity and chargeability.

Time domain method was used for induced polarization and resistivity.

Inhomogeneity in a micro scale of the properties and off-situ measurement of samples may cause imperfect reproductivity of the observed values however, the properties are thought to be quite important giving approximate trends and a guide to the interpretation of the survey and hence to geophysical exploration programme of Phase Ⅱ.

5-2. Equipment and Sample preparation

(1) Magnetic susceptibility

Magnetic susceptibility meters used are compact and light KAPAMETER and BISON. Capability is shown in Table Ⅱ-5-1. KAPAMETER is highly sensitive and is designed for both measurement in the field as well as in the laboratory. In the case of laboratory it requires big samples therefore Bison-type magnetometer was used for small samples. The measurement was followed by correction by surface and geometrical conditions of samples and by conversion of susceptibility values into those of SI unit. (1 SI=4 π cgs)

(2) Resistivity and IP(Chargeability)

The equipment used is shown in Table Ⅱ-5-1. The samples for polarization and resistivity measurement were trimmed into cube each approximately five-centimetre long and were submerged in the water for about one day prior to the measurement. All samples except for drill cores were measured in three dimensions. The sampling time and interval to mid-point versus channel number are shown as follows.

Channel No.	4	5	6	7	8	9	10	11	12	13	14
Width(msec)	20	40	40	80	80	140	140	230	230	360	360
Mid-Point(")	60	90	130	190	270	380	520	705	935	1230	1590

Table Ⅱ—5—1 Specifications of Equipment for Measurement of Physical Property

Equipment	Maker	Type	Specifications	No
IP Transmitter	IRIS Instrument	IP-L Time domain O.S.C.	Output:1μA-100μA max10V	1
IP Receiver	SCINTREX	IPR-12 Multichannel rec.	Input:8ch 14 windows Range:50μV-14V	1
Electrode		Platinum		1
Magnetometre	Bison	Model-3101A	Sensitivity:1×1E-6 cgs, Range:0.00-999 ×1E-3 SI	1

5-3. Results of Measurement

5-3-1. Magnetic susceptibility

Magnetic susceptibility by the formation and lithological facies is shown in Fig. II-5-1. The mean value in the figure signifies the geometric mean. Based upon the figure and the aeromagnetic anomaly maps, the following aspects were indicated.

(1) Magnetic susceptibility of the rocks of the area is as follows in diminishing order.

Karoo dolerite, Grootfontein Metamorphic Complex, Mulden Group sediment, Otavi Group sediment

(2) The susceptibility of calcrete is relatively low indicating that the calcrete is magnetically less disturbing layer for deeper sequences regardless of its thickness.

(3) Karoo dolerite coincides with northeast trending linear structure. A swarm of lineaments of mid-central part of the area are interpreted as dolerite dykes.

(4) Next to Karoo dolerite, is ranked the basement rock which may provoke high magnetic anomaly in the south of the area.

(5) The Damara sequence is significantly low compared to the first two and hence magnetically transparent however, dolomite of Tsumeb Subgroup shows such a low magnetic susceptibility that it may present an obscure contrast against the shale and sandstone of Mulden group which are slightly higher than that. Paleokarst where ore deposit may occur, could thereby be extracted.

(6) Chalcocite and iron oxides show a comparatively high magnetic susceptibility among ore minerals indicating a slight higher susceptibility than the Mulden sandstone.

When such an ore is hosted somewhat massively within a sediment with extremely low magnetic susceptibility, a weak and small but discernible magnetic anomaly could be formed.

The magnetic features of the hole MJNM-1 to MJNM-4 are studied together with small magnetic anomalies in the magnetic compilation and interpretation map.

MJNM-1: The susceptibility is comparatively high at the lower part of calcrete and upper part of dolomite just underlying the unconformity where the higher the susceptibility may be, the more cores are reddish. The cores show brecciation and veinning with matrix of reddish material resulted from comparatively abundant iron oxides.

The susceptibility is low at the other lower dolomite facies and the mineralised sections giving 0.01 to 0.02×10^{-3}SI. Therefore the small magnetic anomalies could be originated from iron oxides embedded around 70 to 90 metre deep.

MJNM-2: Higher susceptibility values come from surface calcrete and shales at around 150 and 180 metre deep as well as lower dolomite however, no notably high values were observed. The isolated magnetic anomaly or magnetic lineament in the vicinity of the hole possibly resulted from subsurface shale which has comparatively high susceptibility.

MJNM-3: The calcrete is thin but has slightly high magnetic susceptibility. The susceptibility is almost low in the underlying dolomitic formation, in which the fractures filled with small amount of iron oxides, it is high. But origin of the magnetic anomaly could not be detected because of discontinuous high susceptibility.

MJNM-4: The overlying calcrete shows higher magnetic susceptibility compared to the other formations. Local magnetite grain 1 m/m cubic in size causes remarkably high susceptibility in particular. The magnetic minerals included in calcrete are thus believed to result in the aeromagnetic anomaly.

The magnetic susceptibility of the representative lithofacies of the hole from MJNM-5 to MJNM-12 were studied as follows.

MJNM-5: The susceptibility of Kalahari sand is high compared to that of Tsumeb subgroup.

MJNM-6: The susceptibility is low all over the hole, that of calcrete is comparatively high. The dolerite dyke gave obviously high at a depth of 227.40 m and less altered from resistivity

MJNM-7: The rate is high in calcrete compared to other formations. The dolerite at a depth of 227.40m is believed to be less altered from high resistivity. The magnetic susceptibility was the highest of all samples and suggested that it could be a prominent source of magnetic anomaly even though it is thin and if it is continuous.

MJNM-8: The same said as MJNM-7. The susceptibility of dolerite at a depth of 229.5m was lower than that of MJNM-7 but is distinguishable from the host rock. The lower resistivity than MJNM-7 may indicate advanced weathering. The low susceptibility may be caused by oxidation of magnetic minerals.

MJNM-9: The rate is comparatively high in calcrete as the holes mentioned above. The dolomite of Tsumeb subgroup at a depth of 120m showed higher susceptibility compared to other dolomites.

MJNM-10: The same said as MJNM-8. Reddish shale beds showed high susceptibility as much as surface calcrete. Iron oxides included could be a source.

MJNM-11: Sandstone of Mulden group gave high susceptibility. The sandstone includes a couple of facies, of which upper pink facies and middle white facies gave high susceptibility and grey facies lower compared to the formers. The mineralised sandstone with pyrite at a depth of 84m showed low susceptibility.

MJNM-12: The highest susceptibility value was acquired from mineralised sandstone at a depth of 86.2m in the hole. The value stays in the same order with that of calcrete.

5-3-2. Resistivity and IP value(Chargeability)

Average resistivity and IP value by lithofacies for all samples are shown in Table II-5-2. Fig. II-5-2 and Fig. II-5-3 show resistivity and IP values by formation or lithofacies respectively. Each of IP and resistivity value is in principle a geometric mean of three dimensional observed values. IP values are recorded from channel M4 to M14. For the remarkably anisotropic samples, three dimensional values are shown in the same table. The channel number 12 which is used most commonly as a standard was used for data interpretation.

The correlation between resistivity and chargeability(IP) was figured from the observed values(Fig. II-5-4). The figure was divided into three resistivity zones and four IP zones using thresholds for interpretation. The observed values and the relationship between resistivity and chargeability led to the following discussion.

Resistivity A and B could be a exploration target but sometimes may be disturbed by low resistivity of shale when duplicated. In a practical survey the IP II is the most common range within which some shale and sandstone of Mulden Group are included causing exploratory disturbance.

The shale of Damara sequence and the ore (Chalcopyrite) are strongly anisotropic as suggested and the shale shows considerably lower values of resistivity parallel to the bedding compared to vertical being as large as one forth to one tenth.

In the case of ore specimen, chalcopyrite from the Kombat mine shows remarkable anisotropic property. This specimen consists of massive chalcopyrite and hosting sandstone half-and-half showing low resistivity and high IP when the current is introduced to the mineralizing extension, and on the contrary high resistivity as some tens times as the former when the current crossing the boundary ore-sandstone. Generally, the more intensely a specimen is mineralized with sulphide, the lower resistivity and the higher IP may show.

The dolomite containing free carbon, hence showing high IP was anticipated, is attributed to the above-mentioned III zone and is thought to give disadvantage to the IP method for sulphide exploration.

The resistivity values were studied because the resistivity anomalies were targets for drilling survey of Phase III. The characteristics of resistivity by hole is mentioned below.

MJNM-5: The value of Kalahari sand, a new member of this phase, is low as much as 68 Ω·m. The

Table II −5−2 Mean Value of Magnetic Susceptibility, Resistivity and IP Value

Average of Geophysical Properties					
Formation	Rock name with Lithological description	sum	Magsus. *1E-3SI	Resistivity Ω·m	IP(M12) mV/V
	Calcrete (Massive)	13	0.05	1,212	0.79
Kalahari group	Calcrete (Pebble,brecci.clay rich)	6	0.07	304	2.24
	Sandstone	3	0.18	114	2.86
Karoo sequence	Dolerite(fresh)	4	33.29	9,544	9.37
	Dolerite(altered)	2	28.97	61	3.61
	Sandstone	13	0.22	6,976	3.77
	Pseudo aplite	2	0.04	5,209	2.48
Mulden group	Pyrite mineralized sandstone	2	0.06	185	18.38
	Shale,Phyllite	6	0.31	6,400	10.64
	Chert	1	0.05	-------	-------
	Sandstone	3	0.02	1,571	0.74
	Shale & Phyllite	16	0.05	2,977	1.46
	Chert	4	0.03	15,043	1.89
Tsumeb subgroup	Dolomite(massive)	41	0.03	6,077	0.77
	Dolomite(clay,sericite,talc,brec.)	11	0.03	1,637	1.65
	Sphalerite & Galena dissemi.	3	0.02	3,784	2.26
	Talc	4	0.04	1,095	2.34
	Sandstone	7	0.10	12,293	5.46
Abenab subgroup	Shale & Phyllite	6	0.11	4,042	1.54
Nosib group	Dolomite	4	0.04	5,171	2.55
	Limestone	7	0.02	11,710	0.62
	Schist	2	0.38	---------	---------
	Schist	5	1.22	2,625	2.46
Grootfontein Comp	Granirte,Gneiss	7	3.09	2,526	4.92
	Mafic rocks	4	2.07	---------	---------
	Chalcopyrite ore	4	0.98	405	67.97
Kombat mine	Chalcopyrite-Bornite-Galena	6	0.13	68	418.29
Tsumeb mine	Galena-Sphalerite	8	0.06	456	207.24
Other mine	Malachite ore	2	0.26	90	250.00
	Vanadium ore	3	0.06	9,766	1.25
	Fe-Mn ore	1	2.51	---------	---------

Sample total = 200

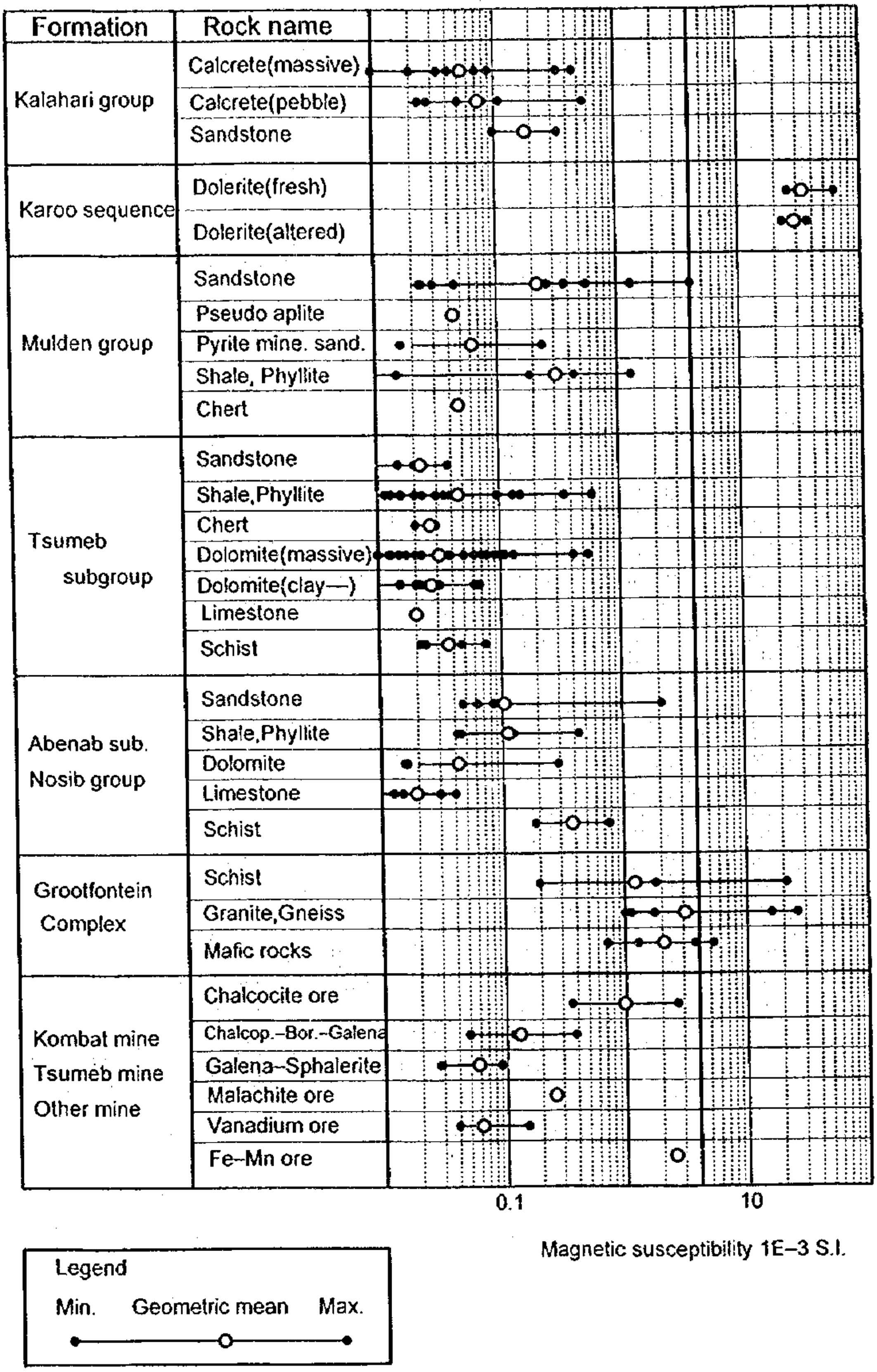


Fig. II－5－1　Distribution of magnetic susceptibility by lithofacies

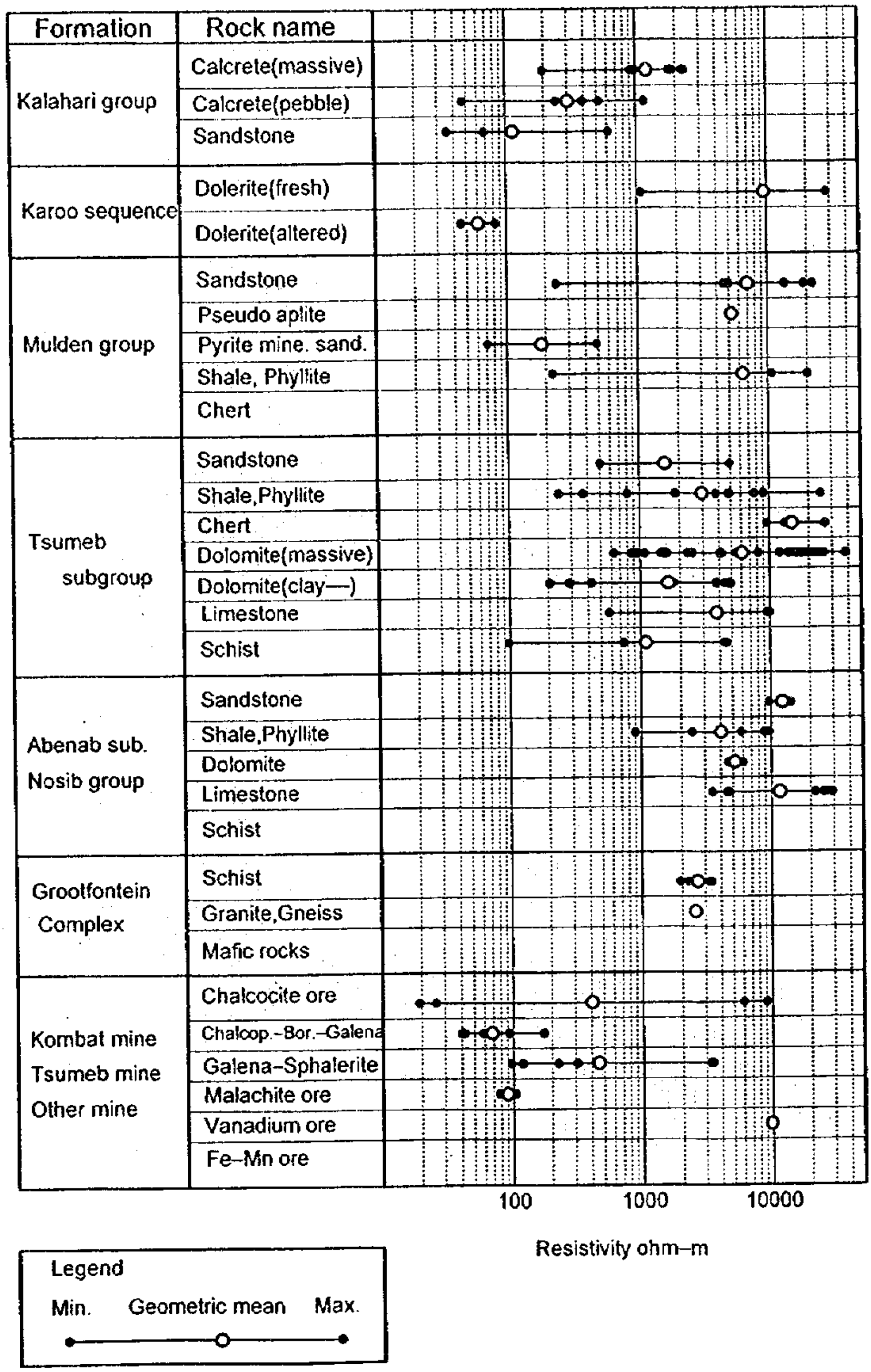


Fig. II −5−2 Distribution of resistivity by lithofacies

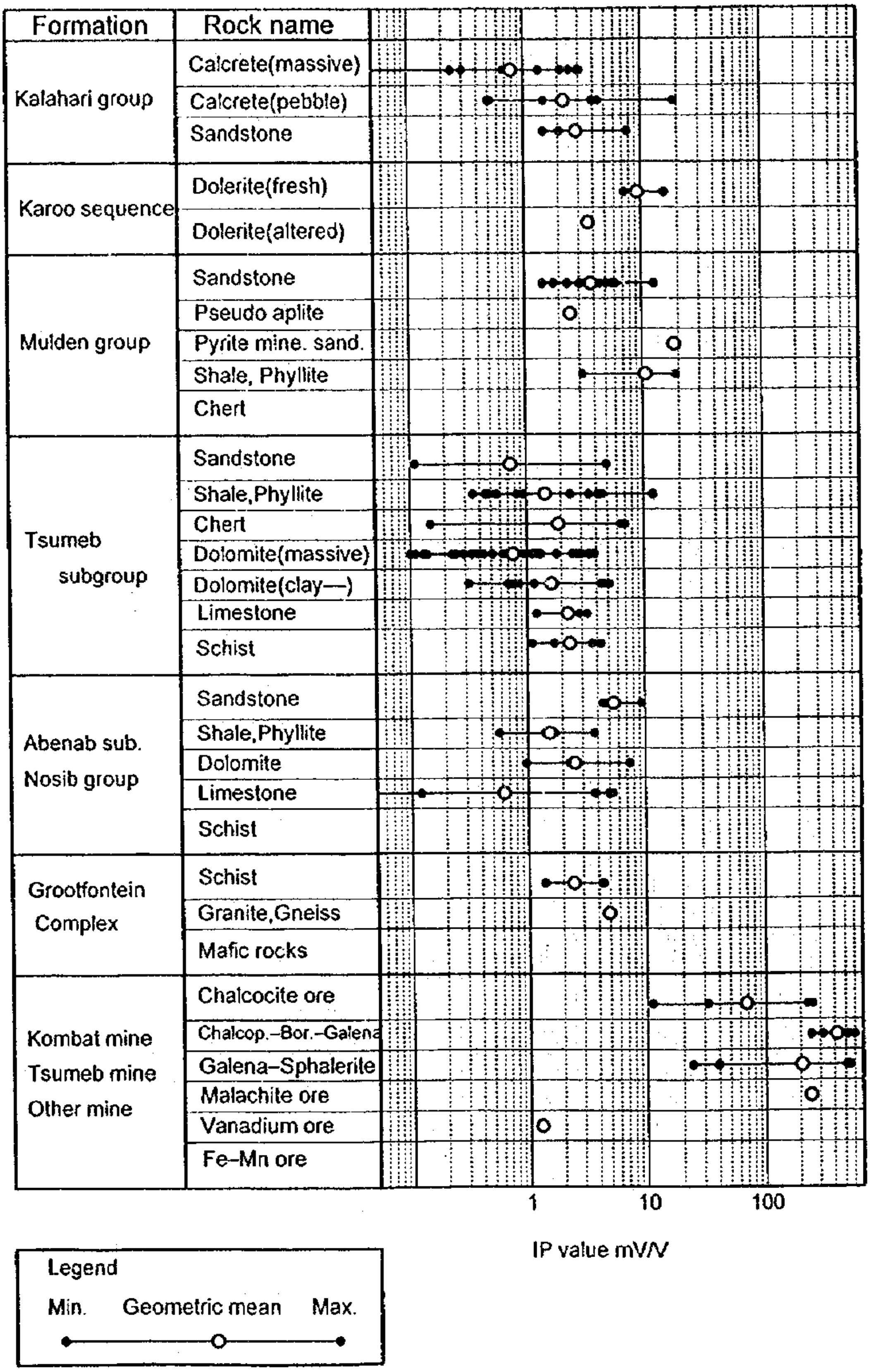
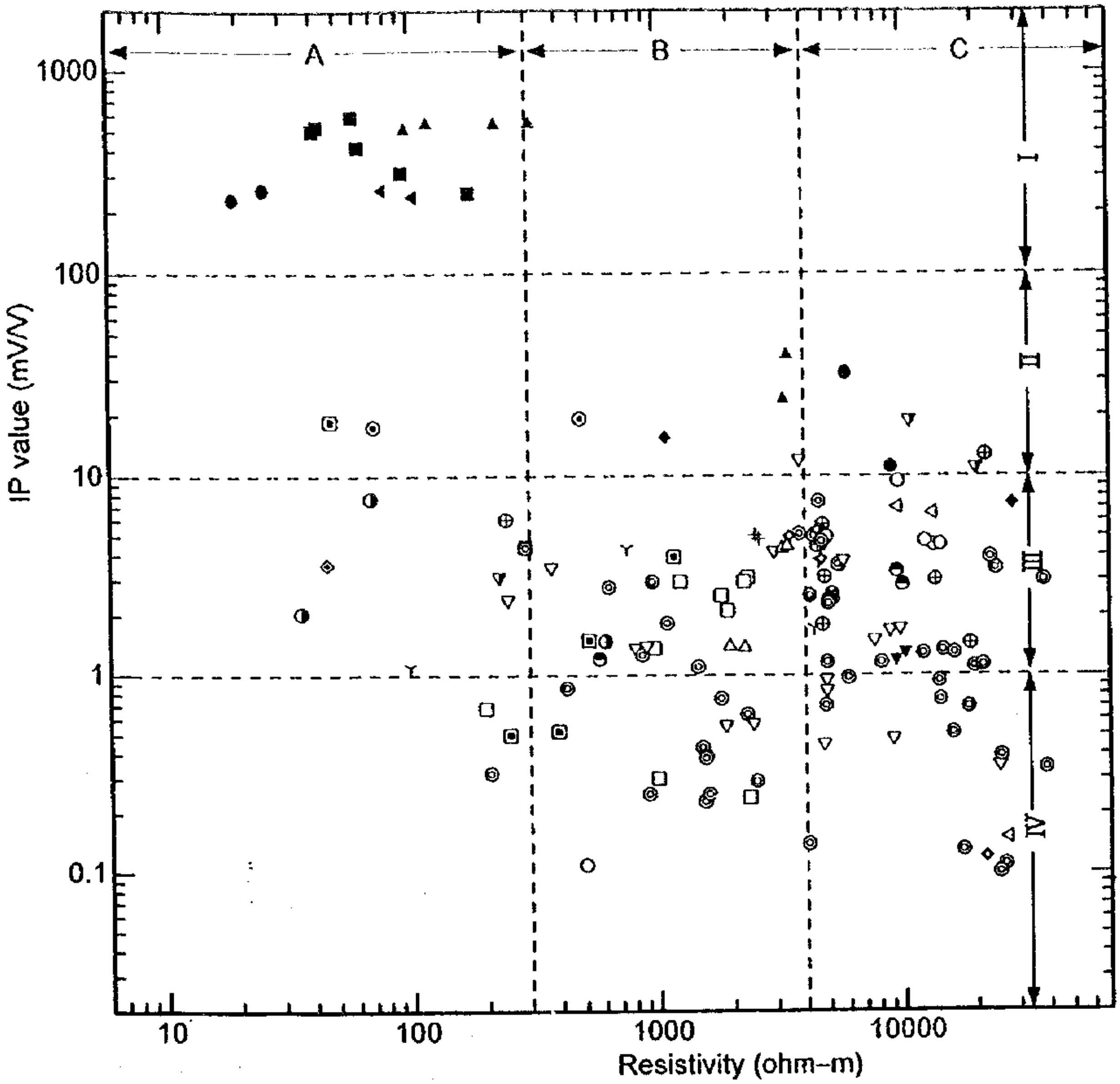


Fig. II −5−3　Distribution of IP value by lithofacies



Legend

Formation	Mark Rock name	Formation	Mark Rock name
Kalahari group	□ : Calcrete(Massive)	Tsumeb, Abenab subgroup	○ : Sandstone
	▣ : Calcrete(Pebble,clay rich)		▽ : Shale,Phyllite
Karoo sequence	◑ : Sandstone		◁ : Chert
	◆ : Dolerite(fresh)		⊚ : Dolomite
	◈ : Dolerite(altered)		⊖ : Sphale. & Galena dissemi.
Mulden group	⊕ : Sandstone	Nosib group	Y : Talc
	⊗ : Pseudo aplite		◇ : Limestone
	⊙ : Pyrite mineralized sand.	Tsumeb,Kombat mine ore	● : Chalcosite ore
	▽ : Shale,Phyllite		■ : Calcopyrite–Bornite–Galena
Grootfontein complex	△ : Schist		▲ : Galena–Sphalerite ore
	+ : Granite,Gneiss		◀ : Malachite ore
			▼ : Vanadium ore

Fig. II −5−4 Relationship between resistivity and IP value

number of samples is few though, this could be one of the probable source of low resistivity.

MJNM-6: Argillaceous calcrete at a depth of around 89m showed extremely low value less than 50Ω·m. The underlying Tsumeb subgroup indicated high values more than 3000Ω·m The argillized calcrete is believed one of the sources of low resistivity.

MJNM-7: Talc argillization zones intersected at 157.2m and 215.6m gave low values as much as 100 to 300Ω·m and are deemed to be a source for low resistivity.

MJNM-8: Surface calcrete, dolerite and talc zones showed low values and believed to be sources for low resistivity.

MJNM-9: Surface down to a depth of 120m and Tsumeb subgroup gave values. The kalahari sand was of the lowest resistivity of 35Ω·m of all samples measured.

MJNM-10: The kalahari sand of this hole gave comparatively high value but still low compared to other rock types. Dolerite at a depth of 261.8m gave low value as much as 45Ω·m possibly because of weathering.

MJNM-11: Mineralised sandstone with pyrite at 84.3m gave considerably low value of 71Ω·m. The underlying Mulden group and Tsumeb subgroup all showed high values larger than 4000Ω·m. A source of ellipsoidal anomaly of low resistivity is of question. It could be a mineralised sandstone near surface.

MJNM-12: Mineralised sandstone lying shallower than 120m, sandstone and shale beds of Mulden group gave low values indicating potential sources for low resistivity.

5-3-3. Discussion

(1) Magnetic susceptibility

1)The resistivity by lithofacies is arranged in descending order as follows.

Dolerite > Grootfontein Metamorphic Complex > Chalcocite > Sandstone of Mulden formation > Kalahari sand > Sandstone and Shale of lower Damara system and Chalcopyrite-Bornite-Galena > Calcrete and Tsumeb subgroup, other facies and ores.

2)Magnetic characteristics of the surface layer : The shallower the magnetic source lies, the stronger the anomaly may be. Since the samples of calcrete gave low magnetic susceptibility the calcrete was believed to be negligible for the deeper formations and this is supported by the mean value of the all samples. However, some core samples of calcrete which gave slightly high susceptibility could be a weak anomaly as well as Kalahari sand and the sandstone of Mulden group. Therefore, these formations could be unfavourable for deeper exploration using magnetic method.

3)Source of magnetic lineament: The susceptibility of dolerite is the largest of all lithofacies and forms a remarkable contrast to the surrounding rocks so, even if it occurs as a thin dyke, it may give a distinguished lineament of magnetic anomaly. The lineaments of NE-SW trend and NW-SE trend are possibly originated from dolerite.

4)Delineation of shallow-seated basement terrain: The basement may give a strong magnetic anomaly when it is shallow-seated. Strong anomalies with short wave length which may be resulted from the basement, extend in the south of Phase I survey area and in the southeast of Phase II and III survey area.

5)Contact of the Mulden group: Magnetic anomaly map mostly shows the subsurface information of such high susceptible formations as dolerite and basement because of the difference in its intensity between these formations and other sediments. But the magnetic image processing map gives curved magnetic lineaments conformable to the known geological trends which are believed to indicate the contact of the Mulden group and the Tsumeb subgroup.

6)Targeting using magnetic susceptibility of chalcocite: In conclusion of Phase I it was believed that a sulphide ore can be delineated because it could be hosted in dolomite with weaker susceptibility than that of chalcocite and manganese ore. The isolated small magnetic anomalies therefore were selected for drilling in the Phase II but no sulphide ore was encountered and the anomalies were believed to be originated from incoherent magnetic susceptibility of surface formations. It is most likely because of the significant deviation of the susceptibility of the samples from the surface lithofacies and that of Kalahari sand is sufficiently large. But it still could be sometimes an exploration rationale.

(2)Resistivity and IP

Zone	Range	Characteristics
Resistivity A	Less than 300 Ω·m	A massive sulphide ore and argillaceous minerals are grouped in this zone. Phase III survey indicated some of Kalahari sand, calcrete, shale, and mineralized sandstone with pyrite are included here. These could be an obstacle to mineral exploration.
Resistivity B	300 to 4,000 Ω·m	Disseminated ore mineral, argillaceous shale and porous rock are commonly grouped in this zone. Drilling survey revealed that various lithofacies were of low resistivity and thus in the practical exploration the extent of such lithofacies should be taken into account.
Resistivity C	More than 4,000 Ω·m	The characteristics of resistivity and IP value which are useful for mineral exploration in the survey area are summarized below.

IP I	No less than 100mV/V	A massive sulphide is included in this zone. The ore samples from Tsumeb and Kombat mine are plotted here. No samples other than the ores include.
IP II	100 to 10mV/V	This zone is most common for practical IP survey and is characterized with disseminated ore as well as pyrite mineralized sandstone, dolerite, calcrete, some of Mulden shale and mineralized dolomite with MVT type ore. The lithofacies other than ore could be a significant noise for exploration.
IP III	10 to 1mV/V	Weakly mineralized zone and argillaceous formation are assigned to this zone. The most of the samples are grouped here. The survey area is believed to be of comparatively high background of IP value.
IP IV	Less than 1 mV/V	This low IP zone includes surface massive calcrete, some of the dolomite, dolomitic shale and chert of Tsumeb subgroup. The argillaceous calcrete of core sample gave high IP values. This zone is favourable background for an exploration using IP method.

(3) Possible source of low resistivity anomaly

Many cores of calcrete from a depth of 100 meters and Kalahari sand gave less than 100 Ω·m indicating such formations could be a potential source of broad low resistivity zone delineated in the anomaly map. Some of the dolerite and talc argillaceous zones associated with it gave less than 50 Ω·m and may also result in the low resistivity lineament.

Mineralised sandstone with pyrite of MJNM-11 showed low values of 71 Ω·m giving good contrast with hosting sandstone of Mulden group and therefore is believed to be an important source of low resistivity window centred by this hole.

With regard to shale, while black facies of dolomitic shale gave some 1000 Ω·m being as high as the hosting sandstone and dolomite, green facies in the Mulden group and brown shale gave low as much as several hundred Ω·m. Such shales as the latter two may result in the elongated low resistivity zone parallel to the geological trend.

(4) Study of exploration method

Some sulphide ores from the known ore deposits showed some 10 Ω·m of resistivity in Phase I. Since such an ore is embedded within a sandstone or dolomite with some 1000 to some tens thousands Ω·m, the resistivity method had been deemed to be effective for Tsumeb·Kombat type ore deposit. But the drilling survey of Phase III revealed less resistive facies and conductive ground water at a shallow depth and that is expected to be a barrier for resistivity method for extraction of underlying low resistive mineralisation. In addition, some shale and dolerite with alteration halos could be a source of resistivity anomalies. That would not necessarily explain that resistivity method is the only most effective method, however the method is considered to be useful if the less resistive formation is previously known.

For a search of a subsurface structure and a concealed ore deposit thereby, the resistivity survey is inevitable as well as magnetic survey in the non exposed area.

With regard to IP, because of very high IP value of ore IP method is useful when the IP values of host rock is small enough, but practically dolerite and accompanying argillacous alteration zone, some shales of Damara system and surface group showed a comparatively high IP value, so those could be an obstacle to ore exploration.

When IP method is used, the survey area should be well extracted prior to it using TDEM method, magnetic survey and preliminary drilling because practical efficiency of IP survey is quite low.