REPORT
ON
THE MINERAL EXPLORATION
IN
THE OTAVI MOUNTAINLAND AREA
THE REPUBLIC OF NAMIBIA

SUMMARY

MARCH [illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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PREFACE

In response to the request of the Government of Namibia, the Japanese Government decided to conduct a Mineral Exploration in the Otavi Mountainland Area Project and entrusted the survey to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The JICA and MMAJ sent a survey team to Namibia headed by Mr. Tetsuo Hatasaki from 4 August to 29 November, 1997.

The team exchanged views with the officials concerned of the Government of Namibia and conducted a field survey in the Otavi Mountainland area. When the team returned to Japan, further studies were made and the present report has been prepared.

We hope that this report will serve for the development of mineral deposits and contribute to the promotion of friendly relations between the two countries.

We wish to express our deep appreciation to the officials concerned of the Government of Namibia for their close cooperation extended to the team.

February 1998

Kimio FUJITA
President
Japan International Cooperation Agency

Hiroaki HIYAMA
President
Metal Mining Agency of Japan

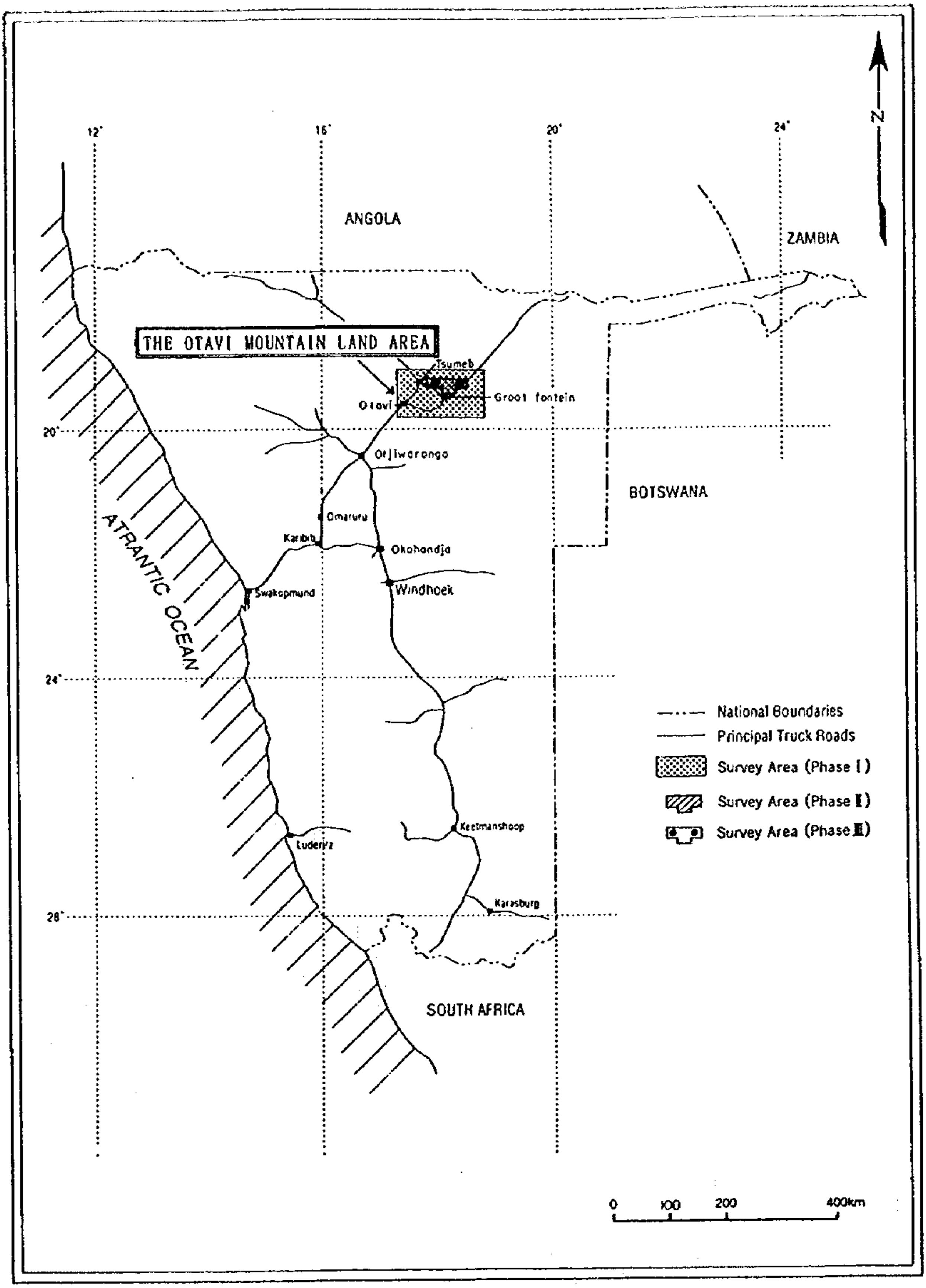

Fig. I - 1 - 1 Index map of the Otavi Mountain Land Area

Summary

This report summarized the result of a three-year mineral exploration project in the Otavi Mountainland Area of the Republic of Namibia. The objective of the project was to interpret the geological structure and to locate an ore deposit in this area. The Phase I survey consisted of research and compilation of the previous exploration data, geological survey and an aeromagnetic survey. The Phase II survey included an airborne electromagnetic survey and drilling. The PhaseIII survey consisted of follow-up by drilling.

On the basis of the result of the airborne geophysical survey, potential areas were selected and were flown in the airborne electromagnetic survey of the Phase II. Four holes were also drilled in the Phase II. The airborne electromagnetic survey delineated the targets to be drilled in the PhaseIII and eventually eight holes were drilled to test the subsurface mineralisation.

The drilling survey revealed that the area was underlain by the strata-bound lead and zinc mineralisation of low grade which was hosted within dolomite. The occurrence and ore grade are as follows.

Hole No.	Depth (Mineralized section)	Pb Assay	Zn Assay
MJNM-1	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 average grade of lead and zinc over 9.16 metres were 0.23% and 0.38% respectively. While, the hole of MJNM-9 is located 700 metres northwest of MJNM-1. The hole showed weak mineralisation less than 1%. The mineralisation more than 0.1% is as follows.

MJNM-9	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%

The average grade of lead and zinc over 5.24 metres were 0.04% and 0.20% respectively. The previous exploration and this survey indicated that the mineralisation was of so called the Mississippi Valley type and occurred extensively through the area but the mineralisation is deemed to be non-commercial.

In hole of MJNM-11 some dots of chalcopyrite and galena were observed. These are associated with an intensely fractured zone of dolomite. The chemical assays indicated a considerable concentration of copper, lead and zinc. The mineralized portions assaying more than 0.1 percent are as follows.

270.70m-270.75m(0.05m)	Pb=0.18%	(Cu=0.028%Zn=0.026%)
272.30m-272.50m(0.20m)	Pb=0.1%	(Cu=0.026% Zn=0.08%)

The metal ratios show the mineralisation is of Tsumeb/Kombat type and the follow up survey is recommended. The above results and interpretation led to the future recommendation including an airborne geophysical survey over the known ore deposits, amelioration of exploration model, ground geophysical survey and a proposal of new area.

CONTENTS

Figure		Page

Figure | Page

Table

Part I General Remarks

Part I General Remarks

Chapter 1 Introduction

1-1. Survey Area and Objective of the Survey

The Otavi Mountainland area is located in the north of the Republic of Namibia and is accessible from the capital, Windhoek through national route B1 taking five hours. The distance between the capital and Grootfontein and Tsumeb is 450 km and 426 km respectively. The area has been one of the most promising base metal provinces of the country producing copper, lead, zinc and vanadium. Two operation mines; Kombat and the new Khusib Springs and several dormant mines as well as many mineral deposits are situated in this area. The area has been in explored by several companies. Exploration mainly focused on the areas of outcrop where most of the deposits are located. However, exploration in areas overlain by calcrete and Kalahari sediments was minimal due to the difficulties in experienced in assessing the underlying geology. The depletion of ore reserves in the operating mines and the favorable geological setting of this area has necessitated the urgent appraisal of mineral potential and exploration in the eastern extension of the Otavi Mountain Land. The Government of Namibia, through the Ministry of Mines and Energy has thus requested the Japanese Government to conduct a proper exploration survey in this area by means of bilateral technical aid.

Initially the Japanese government embarked on the survey by conducting a high resolution geophysical survey as well as research and compilation of the previous exploration information. The second phase programme included airborne electromagnetic survey and drilling. The last phase concentrated on drilling survey to locate potential mineralisation using the result of two-year exploration.

1-2. Survey Method and Amount

The survey was conducted following the flow chart of exploration illustrated in Fig. I -1-2 and the flow chart of Extraction of potential areas. The survey method and amount for each phase are shown in Table I -1-1.

1-3. Period and Member

The survey period and member are shown in Table I -1-2.

Table I −1−1 Summary of Exploration Method and Work Record

Phase	Phase I	Phase II	Phase III
Period	1995.9.16 - 1996.3.1	1996.8.26 - 1997.2.28	1997.8.4 - 1998.2.27
Compilation of Previous Work	Geologic Map 5 sheets Satellite Image 2 Aeromagnetic Map 3 Bouger Gravitic Map 2 Literature 17 (Geology,Ore Deposit, Geophysics) Status of Mining 3 Status Map of License 2 Exploration Report 5		
Geology	Coverage : 12,600 km ²		
Airborne Geophysical Survey	Magnetic/Radiometric Coverage : 5,000 km ² Flight line : 25,034 L.km	Electromagnetic Coverage : 904 km ² Flight line : 4,895 L.km	
Drilling		4 holes 900 m	8 holes 2,320 m
Laboratory Test	Thin Section 10 Polished Section 20 Physical Property 30 (Magnetic Susceptibility Resistivity,Chargeability)	Thin Section 10 Polished Section 5 X-ray Diffractometry 5 Chemical Assay 30 (Au,Ag,Cu,Zn,Pb,Cd,Ga,V) Lead Isotope 7 Physical Property 40	Thin Section 20 Polished Section 10 X-ray Diffractometry 10 Chemical Assay 20 (Au,Ag,Cu,Zn,Pb,Cd,Ga,V) Homogenization Temperature and Salinity 10 Physical Property 50

Table I −1−2 Summary of Working Period and Member

Phase	Phase I	Phase II	Phase III
Period	1995.9.16 - 1996.3.1	1996.8.26 - 1997.2.28	1997.8.4 - 1998.2.27
Planning and Negociation	Ministry of Trade and Industry Koji Kuwayama Metal Mining Agency of Japan Kenji Nakamura Haruhisa Morozumi	Metal Mining Agency of Japan Kenji Nakamura Haruhisa Morozumi Katsuhisa Ohno Yoshiyuki Kita	Metal Mining Agency of Japan Tadashi Ito Hiroshi Shibazaki Yoshiyuki Kita
	Ministry of Mines and Energy/Namibia H.Shimutwikeni	Geological Survey of Namibia Gabriel I.C.Schneider Herbert Roesener Volker Petzel	Geological Survey of Namibia Gabriel I.C.Schneider Herbert Roesener Volker Petzel
Survey	Dowa Engineering Co.,Ltd Tetsuo Hatasaki Yoshiaki Karino	Dowa Engineering Co.,Ltd Tetsuo Hatasaki Yoshiaki Karino	Dowa Engineering Co.,Ltd Tetsuo Hatasaki
	Geological Survey of Namibia Herbert Roesener	Geological Survey of Namibia Herbert Roesener	Geological Survey of Namibia Herbert Roesener Volker Petzel

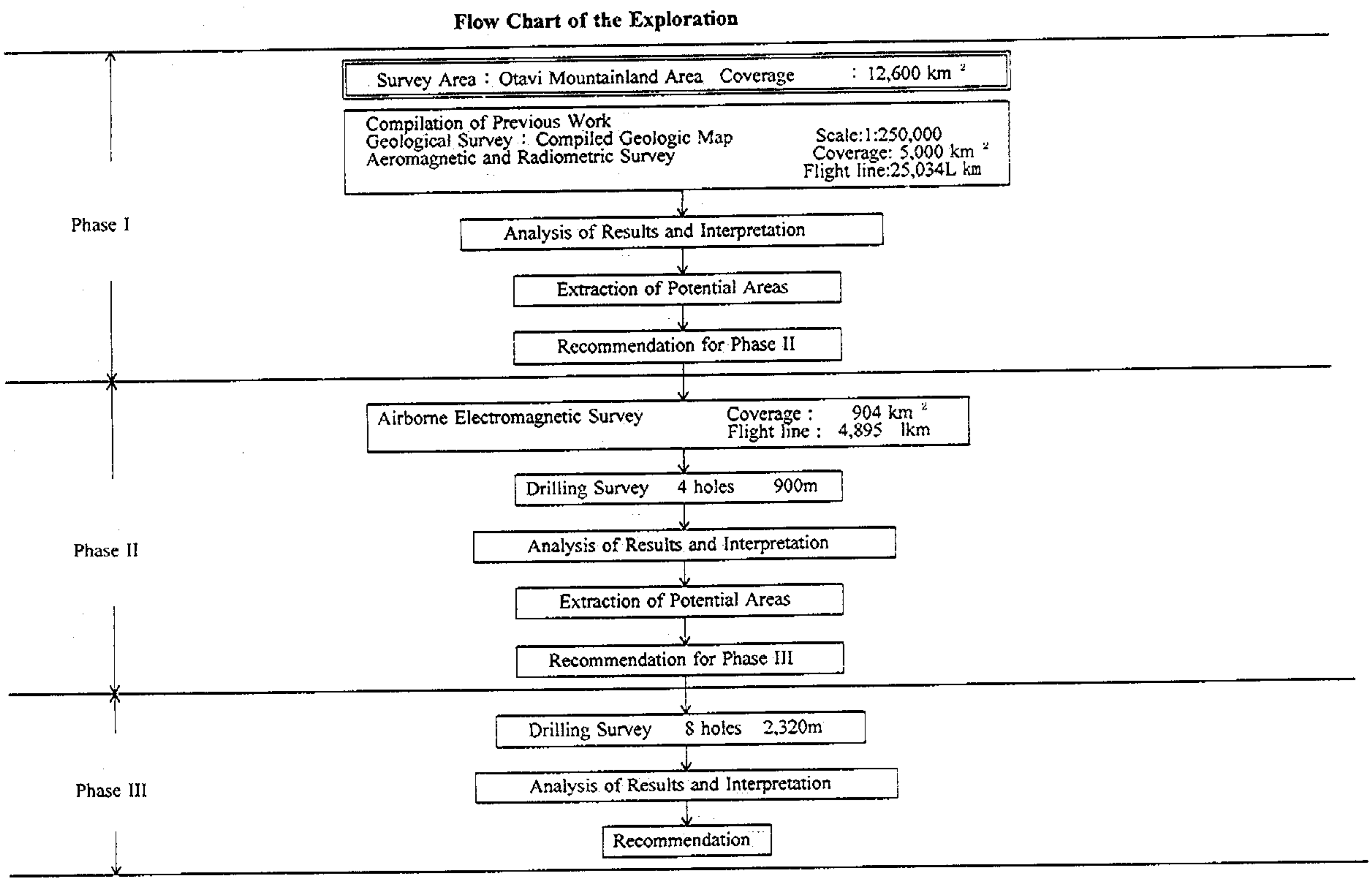

Fig. I −1−2 **Flow chart of exploration in the Otavi Mountain Land area**

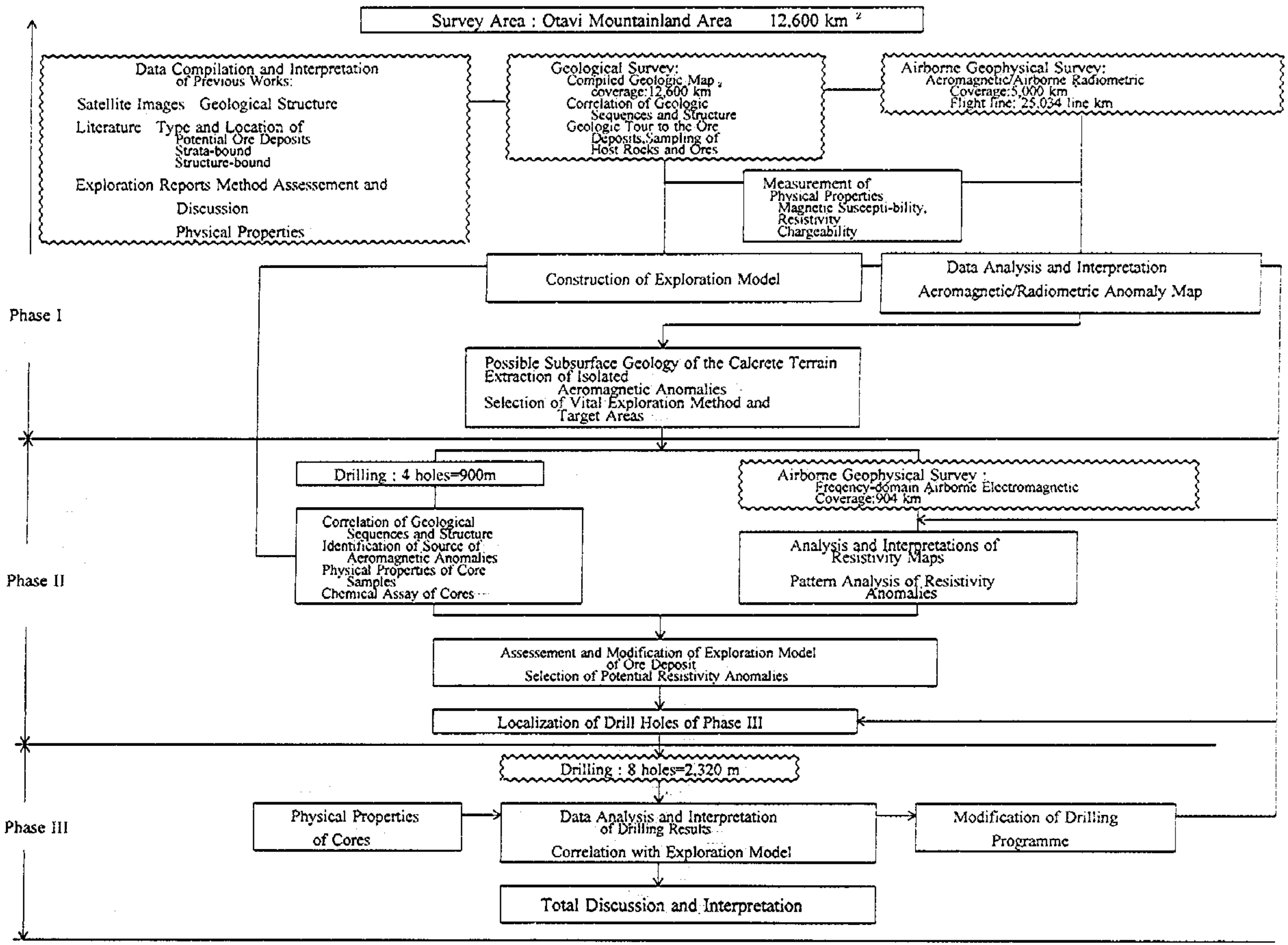

Fig. I -1-3 Flow chart of extraction of potential areas

Chapter 2 Previous Work

The history, current situation, economy, investment and law of mining in Namibia are detailed in Advertisement Supplement of Mining Journal(1992) and Namibia Foundation(1993).

Regional geologic maps on a scale of 1:1 000,000, 1: 500,000 and 1: 250,000 are available at Geological Survey of Namibia.

The survey area is situated in one of the most significant mining belts and includes the Tsumeb and Kombat Mines and a large number of publications are available on this area (A.F.Lombaard, A.Gunzel, J.Innes and T.L.Krüger, 1986),(Innes and R.C.Chaplin 1986). In addition the unpublished exploration open file reports that are submitted by mining companies are also available at Geological Survey. A Special Publication issued by the Geological Society of South Africa (1983) describes the geology of the Damara belt, of which the survey area forms the northern carbonate platform.

In Japan, the reports of project finding prior to Cooperative Exploration for Mineral Resources Development conducted by Japan Mining Engineering Center for International Cooperation(1992 a, b JMEC), are available.

Chapter 3 General Geology of the Survey Area

3-1. General Geology

There were five main periods of lithogenic activity and these are as follows.

Tertiary to Recent (<65 Ma)

Carboniferous to lower Cretaceous (345 to 120 Ma)

Namibian (1,000 to 570 Ma)

upper Mokolian (1,800 to 1,000 Ma)

Vaalian to lower Mokolian (2,100 to 1,800 Ma)

The oldest rocks occur within metamorphic complexes of Vaalian (2620 to 2070 million years) to early Mokolian age (Mokolian: 2070 to 1080 million years). These form a basement to younger sedimentary and volcanic successions, the oldest of which are of mid-Mokolian age and of limited regional extent. The next major phase of activity involved the formation of the Rehoboth-Sinclair magmatic arc and the Namaqua Metamorphic Complex during the late Mokolian. The Damaran orogenic phase is the third main event; it started with intracontinental rifting and sedimentation about 900 million years ago and lasted approximately 450 million years. Extensive peneplanation precede the fourth phase which was the deposition of the Karoo Sequence between the Carboniferous and early Cretaceous. Cretaceous to Recent deposits cover many of the older stratigraphic units. Lower cretaceous to tertiary sediments and minor volcanics which are probably underlain by Karoo Sequence rocks form a thick offshore succession.

The distribution of pre-Tertiary rocks divides the country roughly into three regions. the Damara Sequence covers most of the northern half of the country. The southern half is divided along an approximate north-south line into a western third, underlain by rocks older than about 600 million years, and an eastern two-thirds underlain largely by the Nama Group and Karoo Sequence: older rocks are exposed in the far south of the latter portion. Tertiary deposits of the Kalahari Sequence cover large areas in the eastern and northern parts of the country. Much of the coastal region is covered by sand seas, deflation lag deposits and fluviatile sediments of the Namib Desert.

3-2. Geological Structure

The survey area is situated within the Damara belt of Namibian age and is composed of granitic and metamorphic basement rocks of pre-Damara age, overlying clastic sediment and thick carbonate sediment of Damara age. This Damara sequence of the area was subject to several times of deformation to form multiple synclinorium and anticlinorium with east trending folding axis. Deformation of the primary folding axis has occurred under the east-west compressional stress during later deformation.

The fold structure and geometry of the basement complex are believed to be controlled by NE-SW or ENE-WSW trending faults within the basement.

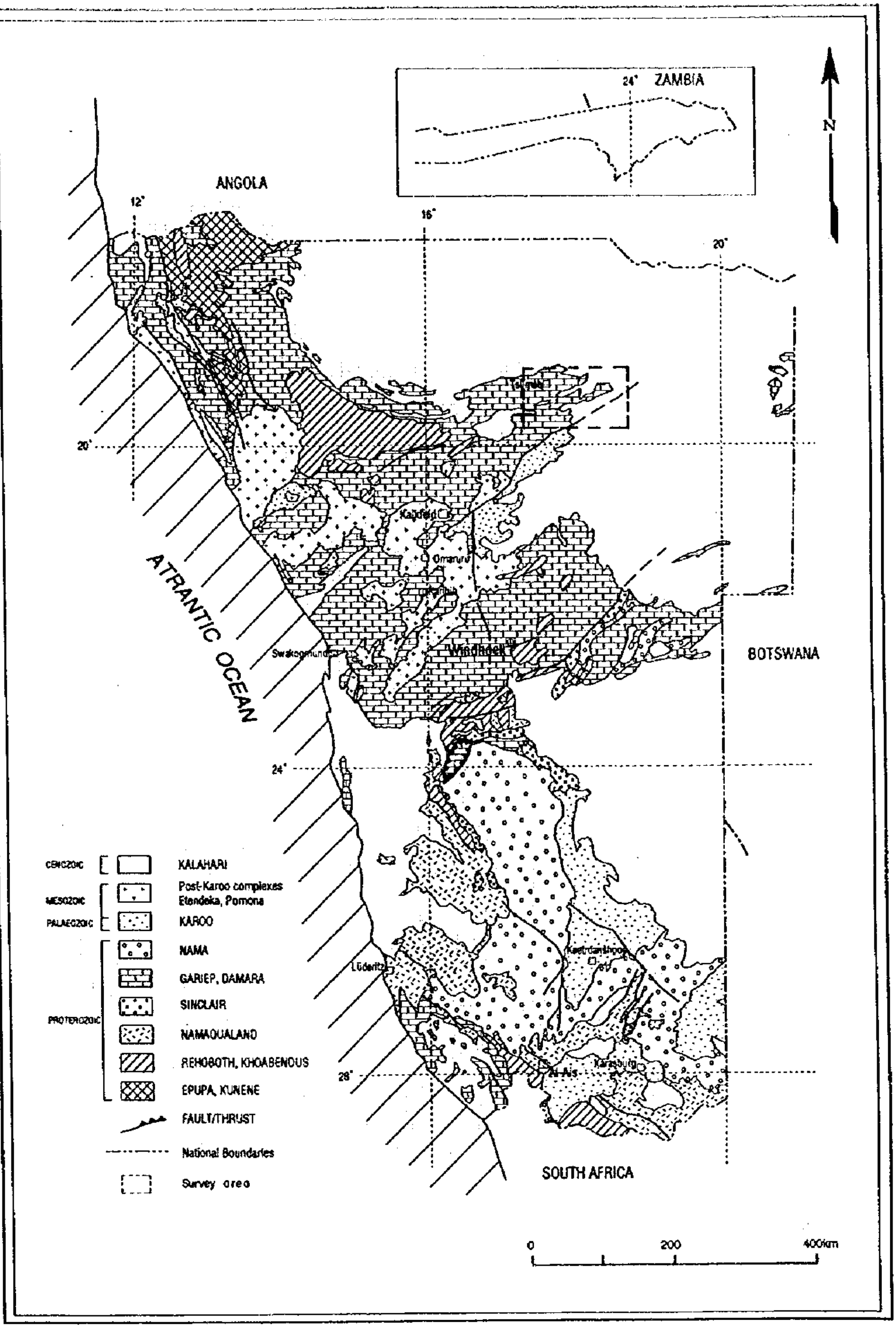

Fig. I −1−4 Geologic map of Namibia

3-3. Known Ore Deposit

Mineralisation in the survey area includes two broad types: the Tsumeb-type and the Berg-Aukas type. The Tsumeb type is characterised by complex sulphide ores containing Cu, Pb, Zn, Ag, As, Ge, Cd and Ga. The ore minerals occur in several loci: pipes, solution breccias, shear zones, dilation fractures etc.. These ore bodies are not stratabound and are generally confined to the upper Tsumeb Subgroup and appear to be related to the disconformity between the Tsumeb Subgroup and the Mulden Group.

The Berg Aukas type is similar to the Pb-rich Mississippi Valley type deposits. The sulphide ore contains Pb, Zn and V with little or no Cu. Enrichment of Ag, Ge, Ga and Cd is less than those in the Tsumeb type ore deposits. The Berg Aukas type deposits are generally confined to the Abenab Subgroup and the middle-lower part of the Tsumeb Subgroup. The mineralisation occurs in breccia bodies and may be stratabound or discordant. Brecciation and karst structures are important in the localisation of the ore bodies.

Chapter 4 Geography of the Survey Area

4-1. Location and Access

The survey area is located in the northeast of the republic of Namibia centered by Tsumeb and Grootfontein extending from 19° to 19° 47'30" south latitude and from 17° 20' to 18° 45' east longitude.

The area is situated 426 km north of Windhoek and is accessible by road (B1) from Windhoek via Otjiwarongo to Tsumeb. Air Namibia's is also flying from the Eros airport in Windhoek to Tsumeb.

4-2. Environment of the area

4-2-1. Topography and Drainage System

Namibia covers 820,000 square kilometers, more than twice the size of Japan. It is bordered by Angola, Zambia, South Africa, Botswana and the Atlantic Ocean.

The land is geographically divided into three zones; the forest zone in the northern part, the savanna zone of inland plateau, and the desert zone along the Atlantic Ocean. While the forest zone and the desert zone are of flat relief, the inland plateau is of high relief and mountainous.

The Otavi Mountainland is situated in the savanna zone. The geomorphology of the survey area is controlled by the underlying geology. The area underlain by basement complex show gentle relief, whilst the terrain consisting of the overlying Damara carbonate rocks show considerably rigid topography particularly at the axial cores of anticlinorium. The eastern part of the survey area is flat and covered by calcrete and recent sediments. The flat areas range in height between 1,200 metres and 1,600 metres. The highest peak in the mountainland is 2,155 metres above the sea level. The southwest corner of the survey area is the highest and flattens to the north and east. No well developed fluvial systems are present in the survey area.

4-2-2. Climate and Vegetation

The climate of the Namibia is between semi-arid and subtropical. The highest mean temperature for Windhoek are 23 degree centigrade in November and the lowest mean temperature is 17 degree centigrade in July. The annual average rainfall is 600 millimetres in the northern forest zone, 20 millimetres in the desert zone, and 350 millimetres in the inland plateau. The wet season is in summer (October to April) with rare winter rains occurring in the extreme south of the country. The temperatures at Tsumeb are 2 to 3 degree centigrade higher than in Windhoek while the annual average rainfall for Tsumeb is 572 millimetres.

The vegetation in Namibia is also variable. The forest zone is covered with broad-leaved trees. The inland plateau is spotted with stunted acacias while the desert zone is covered by scattered shrub and lichen.

4-3. Mining law and tax environment of Namibia

The basic concept of Namibian mining law includes the following two aspects. First, minerals are constitutionally the property of Namibia and, Inter alia, its people. Mining companies profit by developing and marketing the mineral wealth, whilst the in habitants benefit by direct and indirect job opportunities and through the establishment of support structures to service the industry. By taxing the profits of the mining industry, the government has the means to improve infrastructure, upgrade and expand its social programmes and provide healthy mining sector therefore positively affects the growth of the country and the well-being of its nation.

The Minerals Act,1992 empowers the Mining Commissioner in the Ministry of Mines and Energy to grant the following mineral licences.

(1) Non-exclusive prospecting license

The licence is granted to an individual or company to prospect and sample non-exclusively on land open to prospecting. Details of samples removed must be furnished to the Mining Commissioner. The validity of the licence is 12 months and is non-renewable.

(2) Reconnaissance license

This is designed primarily to provide an opportunity for broad-based regional airborne appraisals and surveys of mineral provinces. Only exclusive where deemed necessary and the licence has a validity of six months with a renewal of a further 6 months in exceptional circumstances.

(3) Exclusive prospecting license

This licence confers sole prospecting rights to areas of land up to 1000 km2 in extent for a specific mineral or group of minerals based on certain commitments by the applicant. The validity is three years with two renewals for two years and, under exceptional circumstances, for further periods.

(4) Mineral deposit retention license

The retention licences provide for the retention of rights to a discovery without obligation to mine which may be renewed subject to certain project assessment/review procedures.

(5) Mining license

Mining licences are issued, subject to the submission and approval of satisfactory environmental safe guard proposals, to applicants who demonstrate the necessary technical and financial capabilities to conduct a mining operation. The licence grants an exclusive right to mine for a predetermined period, initially up to 25 years with renewals of up to 15 years at a time.

(6) Mining claim

The claims are primarily designed for the small-scale miner or prospector and are restricted to Namibian citizens or Namibian owned companies who are holders of non-exclusive prospecting licences or, inexceptional circumstances, exclusive prospecting licences. The claim, measuring 600m by 300m must be pegged according to regulations, with a maximum of ten claims being allowed. Once pegged and registered, the holder has the exclusive right to prospect or mine in that area.. The initial validity is for three years which, where mining is taking place, can be renewed indefinitely for periods of two years at a time. However, without obligation to mine is limited to 6 months.

Tax is normally payable on income derived from within Namibia and sources deemed to be within the country, with special provisions applicable to dividend income remitted overseas or in respect of non-resident controlled companies. Taxable corporate income comprises gross income originating within Namibia, less exempt income and allowable deductions.

Registered companies in Namibia are provisional tax payers and must pay tax in advance twice yearly on estimates of profits and are then assessed on receipt of the annual tax return after which a final adjustment is made.

The mining fiscal regime today cites that direct taxes are profit-based and redemption of capital, exploration and development expenditure is allowed against taxable income. There is no ring-fencing of exploration or development expenditure in this case. The effective tax rate for foreign investors is increased by non-resident shareholders' tax of 10%. A provision for loyalty payments is aimed at greater domestic processing of minerals.

Calculation of the mining taxes is based on the ratio of profit to total sales ; the greater the profit in relation to turnover, the higher the tax rate. Corporate tax is payable at a rate of 35% by mining companies on taxable income arising from non-mining activities. Development capital expenditure is allowable against tax over three years and exploration expenditure is allowed in the year in which it is incurred. In the case of new mines both exploration and development are deemed to have been incurred in the first year of production, the latter is then written off over three years.

Chapter 5 Conclusion and Recommendation

5-1. Conclusion

This survey included a compilation of the previous work followed by geological mapping, an airborne geophysical survey and a drilling survey of total 12 holes. The survey concluded as follows and is discussed in details below.

1. Four drill holes were sunk targeting the aeromagnetic anomalies of Phase I for massive sulphide ore pipes of Tsumeb/Kombat type. One hole of which; MJNM-1 intersected low grade lead and zinc mineralisation in the form of dissemination and network.

The mineralisation showed average grade of 0.23% lead and 0.38% zinc over 9.16m. Within 9.16 metre, the mineralised portions showing more than 1 percent concentration, 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%

Whereas, eight drill holes were sunk targeting the airborne electromagnetic anomalies of Phase II aiming for massive sulphide ore pipes of Tsumeb/Kombat type.

One hole, MJNM-9, intersected low grade lead and zinc mineralisation in the form of disseminations and veinlets. The hole is located 700 metres northwest of MJNM-1 of Phase II. The mineral occurrence and host stratigraphic horizon may suggest that the mineralisation is an extension of that of MJNM-1 and it is subject to stratigraphic control.

Within a total of 5.24 metre intersection, the mineralised portions assaying more than 0.1 percent, 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%

2. In the hole MJNM-11, some dots of chalcopyrite and galena were recognized. These are associated with an intensely fractured zone within the upper Tsumeb subgroup. Chemical assays indicated a considerable concentration of Cu, Pb and Zn.

The mineralised portions assaying more than 0.1 percent, are as follows.

270.70m-270.75m(0.05m)	Pb=0.18% (Cu=0.028% Zn=0.026%)
272.30m-272.50m(0.20m)	Pb=0.10% (Cu=0.026% Zn=0.08%)

The metal ratios of Cu, Pb and Zn show the mineralisation is of Tsumeb/Kombat type. This mineral showing could be derived from an potential ore deposit of moderate size and should therefore be explored in the future.

3. Pyrite mineralisation is commonly hosted in the sandstone of Mulden group but almost no copper content was assayed in the mineralisation. The copper content and syndepositional occurrence may explain that the pyrite was biogenic and was precipitated under a reducing environment. The pyrite mineralisation is believed to be the potential source of the low resistivity anomalies present at every frequency.

4. The interpretation of airborne electromagnetic anomalies with correlation to the result of drilling indicated that the Damara system and its subsurface structure extends throughout the area covered by calcrete. However, the drilling result showed inconsistency with the exploration rationale. The low resistivity lineaments traversing the geological trend were correlated to a swarm of dolerite dykes and their associated hydrothermal alteration zones. The observed resistivity values of core samples also supported the phenomenon. None of the spot anomalies coincided with Karst or solution breccias.

5. No sandstone of Mulden group was intersected in the area where it had been expected to occur as indicated by the previous maps and the current geophysical survey. A detailed investigation of the resistivity of the surface formation is thus essential for the interpretation of the deeper structure of geology.

6. The drill depth of 300 meters are believed to be adequate for correlation between the key depth of the resistivity profiles.

5-2. Recommendation for the future

Based upon the result of the survey and subsequent discussion and interpretation of all the data available, the following recommendation are made.

1. Airborne geophysical survey over the known ore deposits

The exploration rationale used in this project had been based upon the assumption that pipe like massive sulphide ore deposit should give a signal of a low resistivity anomaly and therefore these should be target of the drilling. Nevertheless, there seems to be an opposite effect that ground electromagnetic survey showed inconsistency of the ore deposit with low resistivity anomaly as seen at Khusib Springs. Therefore there is a need to restudy the geophysical response of the ore deposits themselves and ore controls. It is thus important to fly over the known ore deposit to collect the signature of ore control.

2. Restudy of exploration rationale

The exploration rationale used in this project should be thereby modified on the basis of the geophysical interpretation.

3. Ground geophysical survey and subsequent drilling

With the revised exploration rationale a detailed ground electromagnetic survey is recommended within the extracted area. The core samples of this project are available for interpretation of anomaly maps, and in particular the cores may provide more information of geophysical properties of the surface formation.

4. Follow-up exploration for MJNM-11 mineral showing

The minute mineralisation is recommended to be assessed using new exploration rationale and the result of ground geophysical survey and thereafter be drilled. In this case isotopic analysis of C14 and O18 of calcite and dolomite would be useful for delineate potential areas.

5. Exploration of a new area

For a new area to be explored, the broad area extending north of Tschudi ore deposit through northwest of Tsumeb mine is recommended. The area has no outcrop with thin calcrete being less than 100 metres thick.

Part II Details of the Survey

Part II Details of the Survey

Chapter 1 Compilation of Previous Work

A list of studied literature and list of mineral showing and previous exploration are shown in TableII-1-1 and TableII-1-2 respectively. A location map of previous exploration activity and location map of known mineral showings are illustrated in Fig.II-1-1 and Fig.II-1-2 respectively.

Table II－1－1 (1) Studied Literature of Previous Work

Documents and Information	Copy/Sheet
Geologic Map (1:500 000)	1
(1:100 000 edited by TCL)	2
(1:250 000 edited by TCL)	2
Satellite Image (Landsat TM 1:250 000)	2scenes
Aeromagnetic Anomaly Map (1:250 000 1916, 1918)	2
(1:1 000,000)	1
Burger Gravity Map (1:3 000,000)	1
Literature on Geology Economic geology and Geophysics	17
Current situation of mining	3
Mineral Grant Map (1:250000 Sheet 1918,1916)	2
Exploration Final/Progress Report (Open File/GSN) Grant No. 19 Company ETOSHA PETROLEUM CO. 150 ETOSHA PETROLEUM CO. 192 ETOSHA PETROLEUM CO. 193 ETOSHA PETROLEUM CO. 162 ETOSHA PETROLEUM CO.	5 Grants

1-1. Geology

1-1-1. Local Geology and Geological Structure

Compiled geologic map of the Otavi Mountainland is shown in Fig.II-2-1. The stratigraphic succession is shown in Table II-1-3.

The survey area covers the Northern Platform in the Damara orogenic belt and is characterized by thick carbonates overlying the basement complex of Vaalian to Mokolian period. The Damara sequence has been folded with eastern and northeastern-trending axis to form three synclinoriums and two anticlinorium.

Table II −1−1 (2) Studied Literature of Previous Work

Grant	Company name	Commodity	No.of document	Title of the document	Method	Date of issue
No. 19	ETOSHA PETROLEUM(PTY) LTD	Base metals		A Data Integration and Petroleum Evaluation of the Etosha		
				Basin Concession Namibia	general	1990/Jul
				Aeromagnetic Survey Acc Progress Report No.5	geophysics	1963/Jan
				Geologic Report on the Etosha Basin	geology	1980/Dec
				A Geochemical Comparison of Some Crude Oil from Pre-Orbo		
				Carbonate rocks	geochemistry	
				Seismic Interpretation Report in the Oponono & Ondangwa Area	geophysics	1991/Mar
				Aeromagnetic Survey Second Derivative	geophysics	
			M4613119	Etosha Petroleum Progress Report No.8		
				Gravity Profile West from Tsumkwee		
			M4613119	Bore Hole Magnetic Susceptibility data/ Hunting Surveys Ltd	seismic, aerogravity	1963/Jan
	OVERSEAS PETROLEUM & INVESTMENT COPORATION NAMIBIA			Annual Report June 1990-June 1991	aeromagnetic	
	ELAND EXPLORATION(PTY) LTD		M463193	Geochemical Anomaly Map		1970/Dec
			M463193	DDH Logging Scheet		
	ELAND EXPLORATION(PTY) LTD		M463193	IP method exploration	geophysics	1972/Nov
				Progress Report on Border Property District Grootfontein		
				first to third		
	ELAND EXPLORATION(PTY) LTD			Proton Magnetometer Survey		
192	ETOSHA PETROLEUM (PTY)LTD	Cu/Pb/Zn		Geochemistry and Airphoto interpretation		
193	ETOSHA PETROLEUM (PTY)LTD	Cu/Pb/Zn		Fluid Inclusions & Ore Genesis in the Otavi Mountains	geology	
				S.W.Africa by P.J.M.Ypma		
				Stream Sediment Samples, Eland Exploration		
				Gravity Map		
				Resistivity Survey on the Border Property	geophysics	
162	ETOSHA PETROLEUM (PTY)LTD	Cu/Pb/Zn		Trenching & Diamond Drilling		1968/1973/1976-79
				2nd Progress Report on Border Property		1970/Apr
				3rd Progress Report on Border Property		1970/Jul
				A Study of the Berg Aukas-type Pb-Zn-V Ore Deposit		
				Gold Fields Namibia		
150	ETOSHA PETROLEUM (PTY)LTD			Gravity Anomaly Map	geophysics	

No.	Mine/Mineral Occurrence	Location	Host rock・Formation・Geological Setting	Mineralisation	Element・Metallic Ore Mineral	Exploration	Mine Development/Production	Reference
1	Uitsab	Uitsab654	dolomite Elandshoek F.	N~NW-trend shear zone	V-Cu-Pb・Gn, Cer, Pm		Open pit 800t	Willemse et al 1944
2	Gross Otavi	Baltika515	Otavi Syncline, dolomite Huttenberg(Hb) F.	①Solution-Collapse breccia ②N-S trend fissure-filling ③Sand sack	V-Cu・Sp, Sm V	Discovered 1931	1931-1942 Conc 5820t V205:9%	
		Ardvord518	Fractured Chert Hb F./Phl contact	69-110m subsurface	Pb Cu-V		Ore 157,000t Pb:5.85% Cu:1.54%, Ag:15g/t	Tsumeb Corporation1993
		Auros595 Sonneneu757	dolomite Maieberg F.	Stratabound mineralisation 2km long Dissemination	V-Cu-Zn±Pb Pb			
	Gross Otavi			Calcitisation/Brecciation			1939-1941 Exp Ore 571t Cu:36.8% Smelt Ore 1428t Cu:12.8% V-Conc 95t Cu:17%	Worst 1973 Tsumeb Corporation1978
3	Abenab West	Abenab707	Brecciated dolomite (Abenab Subgroup)Auros F.	Unconsolidated clay NE trend karst fracture 220-380m PbZn sulphide+V 1m thick 180m strike showing:20m thick strata extension 15m Pb+Zn=2% Zinc reef eastward	V-Zn・Descloizite ・Wil, Cer		1939-1958 ~1952 Gravl Conc 25412t Pb:58%, V205:5% Flot Conc 5939t Pb:51%, V205:13% 1952-1958 Sulphide ore 51582t	Verwoerd 1957
	Okarundu pipe	2.5km west of Abenab	brecciated limestone	Calcite coating	V・Ds			
4	Abenab		faults at Ls/Dol Maieberg F.	Red clay within breccia pipe 425m subsurface	V・Ds	Discovered 1920	1922-1948 Ore 1.36Mt Conc 56600t V205:18.5% 1947 Production ceace	Verwoerd 1957
5	Berg Aukas	Berg Aukas593	north margin of Berg Aukas Syncline lowest dol. Gauss F.~Berg Aukas F.	NE fissure Solution Cave	V-Pb-Zn・Ds, Mottramite ・Pb Zn sulphide Secondary:Ds, Wil	1957~Commenced exploration	1967-1975 Ore 1.60Mt Pb:4.04%, Zn:16.77% V205:0.93% 1977 Reserve 1.65Mt	Ihirian 1973 Paverd 1975
6	Tsumeb West	2.5kmSW of Tsumeb	breccia zone and faults crossing Tsumeb Syncline quartzitic sandstone pipe (QSP)	matrix mineralised	Cu・Cc, Mal+Py	1947-1978 drilling 31974m	1910-1912 Ore 742t Cu:9.7% 1990 Ore 52964t Reserve 1.16Mt Cu:1.88%	Ferreira, Zwanziger1971, rawle1972, blaine1973 Gold Fields Namibia1990, 1991 Tsumeb Corporation Ltd 1978 Veldsman1977
7	Tschudi	Tschudi461 Uris481	Southern rim of Tschudi Syncline/arenite, quartzite base of Mulden Group NW trend post-ore fracture	Strike 2500m long, 420m down, Supergene Cu sulphide 4~5m high above 18 dol. sulphide dominant from 80m deep	Cu・Mal, Cup, Az, ±Cc, Co	Discovered 1968	Reserve 5.7Mt Cu:0.72% Ag:11g/t	Venter1976
8	OtjikotoII prospect	13km west of Tsumeb	Slip & shear zone/axial plane, Huttenberg F.	strike 70m, dips 60-70° N	Cu-Zn・Mal, Co, Az, Cr, Cu-Pb-As, Cup	geochem CuPb anomal	1929 Cu ore mined	
9	Alt Bobos Karavatu Tonnesssen Uris	Uris481 Uris481 Bobos544 Tsumore	Flow breccia zone & calcitization QSP, southern rim of Tschudi Syncline dolomite Huttenberg F. NW breccia zone Sand sack type:breccia zone, dolomite Elandshoek F. Huttenberg F.	Cu sulphide 3km long disseminated Vanadiferous clay, Fe-Cu cement	V-Cu-Zn・CuDs, Gn, Cc, Sp	drilling in 1970's Pb<8.4% Zn 3.0% over 0.7~12m	Grade of Conc. V205:18.75%, Pb:45.57% Cu:9.99%, Zn:4.12% Karavatu+Uris 1919-1943 Conc 5234t V205:11.87%	TCL1978 Schneiderhohn1921 Schwellnus1945 Veldsman1977
10	Asis Ost	2km east of Kombat	Brecciated calcitized dolomite	Disseminaion, blebs, veinlets post-ore NE-trend fault	Cu・Bo (primary) Cc, Gn, Mal V	1910-1915	Cu Pb Ore 600t 1974-1976 Ore 34913t Cu:1.26%, Pb:0.25%	Gold Fields Namibia 1990
11	Guchab Mine		E-W, NE trend fracture	Strike 1.5km long 150-300m wide Cu:calcitisation silicification	Cu・Mal, Co, Plancheite, Dioptase	1893 Investgation 1900 OMEG Exploration 1955-1975 778m drilled	1908-1911 Exp.ore 2540t	TCL1978
12	Schlangental Prospect	west of Guchab		ENE trend/jasperoid			Exp.ore 5.5t Cu:8% Pb:26.1%, V205:10.8% Conc 30.5t Cu:3.3%, Pb:11.7% V205:4.7%	TCL1978
13	Rodgerberg Mine			S.A Guchab	Cu・Dioptase		1924-1927 Exp.ore 6800t Cu:10% Exp.ore 1980t Cu:38%	TCL1978
14	Deutsche Erde Area Deutsche Erde Magestolz Elefantenberg Ondjondjo Elefantenberg Nord		North rim Elefantenberg Syncline, Base Abenab Subgroup Nosib schist Lower Tsumeb Subgroup	10-50cm×30m Cu anomaly strike 850m Pb+Zn anomaly 8000m long Cu:100-259ppm	Cu・ Cu-Pb-Zn	1975 Soil geochem.		Mueller 1975
15	Neuwerk prospect	NW of Neuwerk507	S rim Neuwerk Syncline, Askevold F. (epidosite) Nosib-Abenab Subgroup contact Sil.Ls/Schist Nosib-Abenab Subgroup	Cu:>200ppm 4km long Silicification table type Cu dep. 150m long	Cu・Bo, Cp, Cc, Mal ・Cp	Trench 100m Drilling assay Cu:0.5m 0.41%, 5.0m 0.18% 5 holes drilling Cu:2.8% 170000t 4.0m×100m×150m	1973, 52m dig shaft	
16	Otaviberg South Area		Dol&Ls Abenab Subgroup/ Nosib schist contact	Geochem. anomaly	Cu・Mal, Bo, Cc, Cp	Soil geochem. 8 holes drilling 1968 Askevold South Cu:1.2% 300000t		Rawle & Lee1972
17	Finsterbergen Prospect	43km SW of Tsumeb	Shear zone paral.to bedding upper Tsumeb Subgroup, NE fracture	70m long Cu:0.33%, Pb:0.07%, Ag:10g/t		Soil geochem		Fereira, Zwanziger1971
18	Olifantsfontein Area South ridge Pickaxe Tiger Tunnel Butterfly Dogleg Hambone		Harasib-Olifantsfontein Syncline, Elandshoek F. Flow breccia Ls./Dol contact Maieberg F. Quartz & dolospar vein along EW fault	Patchy Qtz & clast-supported mineralisation breccia	Pb-Zn-Cu・Gn, Sp, Sm, Zc, Co, Mal +Ds	Trench Diamond drill 17 holes Percussion 109 holes		King 1990
19	Nosib Mine	Nosib valley	Shear breccia zone at Nosib/Otavi Group contact	sericite, chlorite	Pb-Zn-Cu-V・Cc, Sp, Gn+Ds	Discovery 1915	~1920 production developed down to 120	
20	Nosib BlockIII	Nosib BlockIII655	Brecciated dol. Elandshoek F. Gauss F., mid.Auros F.		Pb-Zn	Diamond drill assay 1~6m wide Pb:0.1~8.0% Zn:0.1~5.7%		
21	Nosib Block648	Harasib I	Karuchas zone, Elandshoek F.		Pb-Zn-V・Gn, Sp		Shaft, Open pit, Adit V Ore 18450t, Pb:7%, Zn:13.5%	Paverd 1976
22	Driehoek768 Gauss46	15km N Kombat	Dolomite Abenab Subgroup	Dissem lens Pb:2.4%, Zn:3.10%	V-Pb-Zn			
23	Border prospect	Toggenburg591	Brecciated massive dol. lower Tsumeb Subgroup	340° oriented joints control	Cu-Pb-Zn・Sp, Gn±Cp, Tet, Py	Drilling estimate Reserve 30Mt cut off at Pb+Zn:5.8%		Klugman1969, 1970

Gn:Galena Cer:Cerussite Pm:Pyromorphite Sp:Sphalerite Wil:Wilemite Ds:Descloizite Cc:Chalcocite Mal:Malachite Py:Pyrite Cup:Cuprite Az:Azurite Co:Covelline Cr:Chrysocolla Sm:Smithonite Tet:Tetrahedrite Zc:Zincite

Table II-1-2 Mineral Showings and Previous Exploration

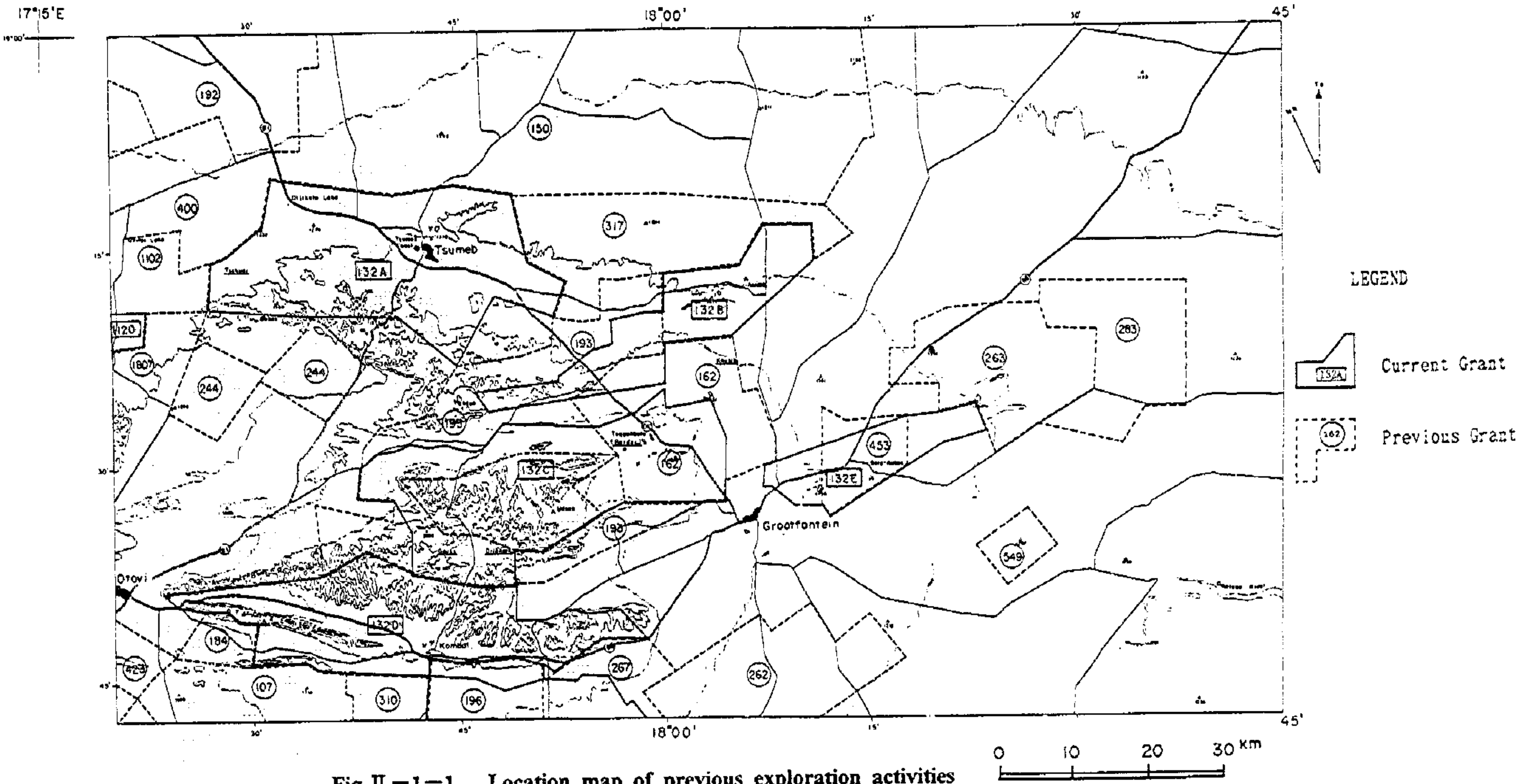

Fig.II－1－1　Location map of previous exploration activities

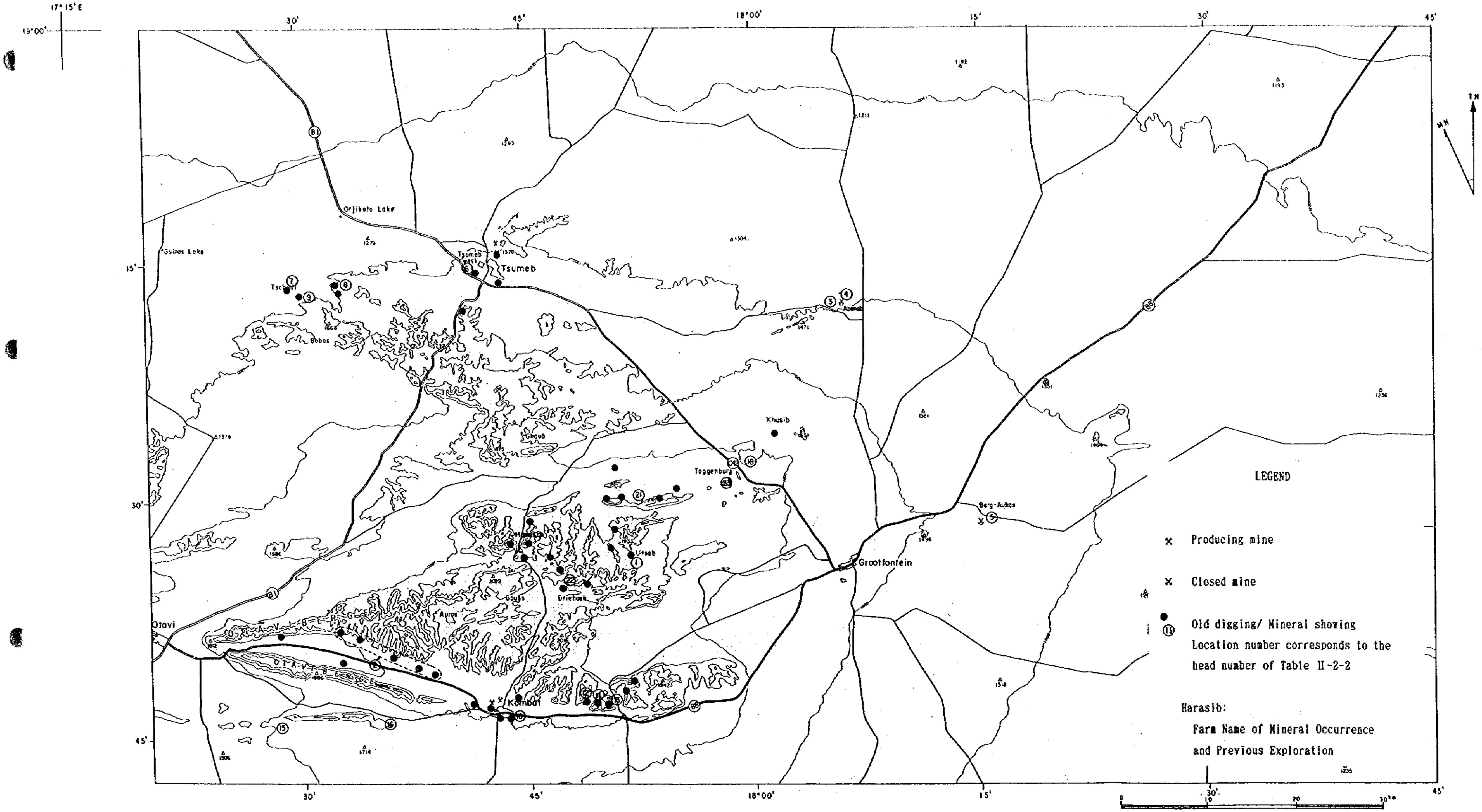

Fig. II—1—2 Location of known mineral showings

Table II − 1 − 3 Stratigraphic Succession in the Otavi Mountain Land Area

Sequence	Group	Subgroup	Formation	Informal Lithozone	Lithology	Average thickness (m)
Damara	Mulden		Kombat and Tschudi		Kombat Formation: slate; sub-arkose and pebbly sandstone near base Tschudi Formation: feldspathic sandstone, sub-greywacke; argillite and conglomerate interbeds in basal portion	> 700
			Disconformity			
	Otavi	Tsumeb	Hüttenberg	T8	Dolomite, bedded light to medium grey; oolitic chert and stromatolite layers near top	240
				T7	Dolomite, bedded dark grey; limestone, shale and chert interbeds	300
				T6	Dolomite, bedded light grey; abundant chert; stromatolite interbeds in lower part	300
			Elandshoek	T5	Dolomite, bedded and massive light grey	1 200
				T4	Dolomite, massive light grey	
			Maieberg	T3	Dolomite, thinly bedded light and dark grey	180
				T2	Limestone, bedded light and dark grey	700
			Chuos	T1	Tillite, quartzite, shale, minor dolomite and limestone	200
			Disconformity			
		Abenab	Auros		Dolomite, bedded and massive light to medium grey; limestone, marl, shale, oolite and stromatolite interbeds	350
			Gauss		Dolomite, massive light to dark grey; local oolite and stromatolite interbeds	750
			Berg Aukas		Dolomite, laminated and massive light and dark grey; black limestone, shale	550
			Disconformity			
	Nosib		Varianto		Quartzite, conglomerate, arkosic mixtite, dolomite, ferruginous shale	
			Askevold		Phyllitic agglomerate, tuff; epidosite	750
			Nabis		Feldspathic quartzite, arkose, conglomerate	
			Unconformity			
Grootfontein Basement Complex					Granite, gneiss, mafic schist	

(1) Grootfontein Basement Complex

The main rock type is coarse-grained gneissose to porphyritic hornblende-biotite granite. Local dioritic phases and crosscutting veins of aplite are present. The granite is probably younger than associated schist, quartzite, calc-silicate rock, hornblende gneiss and amphibolite. Minor amphibolite dykes cut the granite. Previous aeromagnetic surveys suggest the existence of a large poorly exposed basic intrusive body in the Grootfontein area.

The Damara sequence overlying the Grootfontein Basement Complex is classified into four group and subgroups as follows.

(2) Nosib Group

The Nosib Group outcrops mainly to the south and west of Otavi Mountains. In these areas it consisting of quartzite, conglomerate, arkose sandstone and basic volcanics now epidosite and chlorite schist.

(3) Otavi Group Abenab Subgroup

The Abenab Subgroup is sub divided into the Berg Aukas, Gauss and Auros Formations. These formations are dominated by dolomite intercalated with limestone and shale. The dolomite is light grey to dark grey bedded or massive and stromatolitic in places. The Abenab Subgroup occurs in a narrow band along the rim of anticlinoria commonly hosting ore deposits.

(4) Otavi Group ,Tsumeb Subgroup

The Tsumeb Subgroup is documented in detail because most of the known mineralisation is hosted by this subgroup. It is over 3000 metre thick and is divided into the Chuos, Maieberg, Elandshoek and Huttenberg Formations. T.C.L geologists further subdivide the Tsumeb subgroup into lithozones termed T1 to T8. The Maieberg and the Elandshoek Formation are subdivided lithologically into T2, T3 and T4, T5 respectively where as the Huttenberg Formation is subdivided into the T6, T7 and T8 lithozones.

The Chuos Formation at the base of the Tsumeb Subgroup, is about 200 metre thick and is composed of tillite, quartzite accompanied by subordinate dolomite and limestone. The Maieberg Formation has a thickness of about 900 metres and consists of light grey to dark grey limestone in the lower part and dolomite in the upper part.

The Elandshoek Formation is composed of bedded and massive dolomite reaching 1,200 metres in thickness. The Huttenberg Formation is chiefly composed of light to dark grey bedded dolomite with subordinate oolitic chert, black shale and limestone. Stromatolitic beds occur in the lower part and the uppermost part. The average thickness of this formation is 840 metres.

(5) Mulden Group/Kombat Formation and Tschudi Formation

This group consist essentially of arenious sediments, outcropping close to the axial part of synclinoriums which extend to the east and west of Tsumeb and within the Otavi Valley.

The Tschudi Formation of Mulden Group in the vicinity of Tsumeb includes conglomerate, feldspathic sandstone, greywacke and shale, whereas in the Otavi Valley, the Kombat Formation of Mulden Group consist mainly of silt and slate with a coarse-grained sandstone at the base. Psammitic sediment also fill mineralised karst developed within the Tsumeb Subgroup. These sediments were termed "Pseudo-aplite" or "Feldspathic sandstone" and some controversy with regards to their origin exists. However, it is likely that these are arenaceous sediment of the Mulden period.

(6) Karoo Formation

Sedimentation of continental arenaceous sediments and basic volcanic activity occurred from late Paleozoic to Cretaceous. Although there is no exposure of the formation in the area, previous aeromagnetic survey indicated subsurface basalts in the northeast of the survey area. A dolerite dyke was intersected by drilling to the west of Tsumeb.

(7) Kalahari Formation

The Kalahari Formation consist of sand and calcrete deposited during the Cretaceous to Tertiary periods. In the northeast of the survey area, satellite images indicate the existence of paleo sand dunes of the Kalahari Desert. The calcrete is generally white to pale brown in color and calcareous sandstone are blanketing the older rocks particularly in the eastern half of the survey area.

(8) Geological Structure

Fold structures prevailing the area are commonly symmetric open fold with an overturned syncline limb in the Otavi Valley. Generally the fold axis trend easterly or east-northeasterly. A northwest trending fold in the west of the area may suggest that the area was subjected to two deformation periods.

Northeast-trending faults occur in the Kombat area as well as west of Tsumeb. In the Tsumeb area these are accompanied a dyke swarm.

Several northeast-trending faults are mapped in the Otavi Mountainland, but difficulties are experienced in tracing these on satellite images.

1-2. Ore Deposit

Tsumeb

From then to 1990, some 24.60 million tons of ore had been mined which produced 1.7 million tons of copper, 2.8 million tons of lead and 0.9 million tons of zinc. In 1979, the ore reserves were calculated at 3.50 million tons with an ore grade of 4.27 percent Cu, 7.02 percent Pb, 1.19 percent Zn, and 100g/t Ag. The continuous operation of Tsumeb mine over hundred years resulted in the depletion of ore reserves and the mine was close in 1996. At present the smelters of copper and lead are operated feeding the ore concentrates from the Kombat and the Khusib Springs for copper and from the Rosh Pinah for lead.

(1) Geological Setting and Ore Deposit

The Tsumeb Mine is the largest known concentration of base metals within the Otavi Mountainland. It is a polymetallic (lead, copper, zinc, silver, vanadium, cadmium, arsenic, antimony, germanium, tin , tungsten) pipe like deposit, hosted within folded dolomite of the of the Otavi Group. The configuration and dimensions of the Tsumeb deposit varies from a gently-dipping, narrow, tabular lens, 130 metre long and 10metre thick, to a near-vertical, predominantly plan-elliptical, pipe-like body up to 200 metre long and 100 metre across. The pipe has been traced by underground diamond drilling to a vertical depth of 1800 metres. The pipe structure is located within the axial zone of a complex fold structure. The boundary of the pipe is generally defined by the distribution of mineralisation, dolomite breccia, feldspathic sandstone (also termed pseudo-aplite), rock alteration and arcuate shears and fractures. Internal brecciation varies in intensity with the nature of the adjacent rock types.

(2) Ore Mineral

Mineralisation was synchronous with waning tectonism. The ores are of the epigenetic, hydrothermal, replacement and fracture filling type. The main ore minerals are galena, tennantite, sphalerite, chalcocite, bornite, and enargite, together with widely distributed, but erratic sulphides and sulphosalts of Ge, Ga, V, Sn and W. Massive ores are concentrated on the periphery of the deposit and in places as mantos in adjoining bedded dolomite. In the deeper part disseminated and stringer ores contribute to the metal content. The gangue minerals are calcite, quartz, dolomite and subordinate barite and fluorite.

(3) Ore genesis

Several models of ore formation have been proposed. A dewatering model and variations of it is generally accepted as the ore forming process. In this model hydrothermal brines are generated from the compaction of trough sediments. These fluids leach metals from the sedimentary pile and move as saline metalliferous fluids with a temperature between 100° C and 250° C via rift-grabens, growth faults, unconformities and other basement fractures to the carbonate environment at the basin margin.

Kombat

As of June, 1995 the assured and inferred ore reserves amounted to 3.8 million tons with ore grade of 2.75 percent Cu, 1.48 percent Pb and 25.5 g/t Ag. Currently the monthly production involving 612 employees varies from 35,000 ton to 40,000 tons with ore grade of 2.6 percent Cu, 1 percent Pb and 24 g/t Ag.

(1) Geological Setting and Ore Deposit

The ore deposits are hosted in dolomite of Huttenberg Formation, Tsumeb Subgroup at the northern limb of Otavi Valley synclinorium. Chalcocite and copper carbonates occupy fractures in dolomite and are disseminated in lenses of feldspathic sandstone adjacent to a disconformable contact between dolomite and overlying slate. Mineralisation is spatially associated with a regional disconformity between dolostone and younger slate.

The sulphide ores of Kombat deposit are of epigenetic hydrothermal and fracture-filling and metasomatic replacement type. The mineralisation is controlled by the geometry of the feldspathic sandstone and fracture cleavage in dolomite. The massive ore is oblique to bedding and with depth horse-tails into thready, stringer type and disseminated mineralisation.

(2) Ore Mineral

The important primary minerals include bornite, chalcopyrite, galena and pyrite with subordinate amount of sphalerite and tennantite. The secondary minerals are chalcocite, malachite, covelline, digenite, cuprite, cerrucite, native copper and native silver.

(3) Ore Genesis

The origin of the Kombat ores is a contentious issue. However, certain facts are apparent and these are described below.

The copper-lead ores are envisaged as epigenetic, hydrothermal and metasomatic replacement and fracture fill deposits introduced into structurally favorable loci under conditions of initially high oxygen activity and relatively low sulphur activity. It is envisaged that the selective calcitization of dolomite by ground waters percolating in paleokarst features or in multiple fold hinges may have created ductility contrast resulting from high strain and that subsequent strain concentrated in the more ductile calcitized dolomite. The calcitization is possibly concomitant with the development of an associated S_3 axial plane cleavage.

The ubiquitous association of sandstone with mineralisation indicates that sandstone aquifers provided conduits. Equilibration of the hydrothermal fluids with dolomite may have altered the pH ,lowered the activity of oxygen and increased the sulphur activity until sulphides were precipitated.

Estimated age of upper part of the Mulden Group indicates 550 to 560 Ma for age of mineralisation provided that being contemporary with deposition of the Mulden Group. Lead isotopic age using galena from the Kombat Mine suggests 550 to 600 Ma. Syntectonic model may imply the age of mineralisation of 554 to 570 Ma which were obtained from granitoids of the second tectono-thermal Damara episode. This theory finds support in a metamorphic Rb/Sr age for pelites of the Mulden Group.

Abenab

This used to be one of the largest vanadium mine in the world. The ore deposit consists of the Abenab pipe occurring in brecciated dolomite and the Abenab West ore body which is a long narrow zone of deformation and associated bedding-parallel faulting. In the former reddish argil, coarsely crystalline calcite and descloizite formed interstitially within the dolomite breccia. The pipe hardly persist at depth more than 425 metres below the surface. In the latter, galena and unconsolidated clay containing descloizite occur filling solution cavities formed along faulted breccia zone. The fault zone stretches over 730 metres, is 6 metres wide and dips at 45 ° to 70 °.

Ore minerals from the upper portions are fine grained descloizite, cerussite, willemite and galena of which first three are of secondary supergene origin. Meanwhile in depth sphalerite, galena predominate with a lesser amount of descloizite.

Berg Aukas

The ore bodies are embedded in dolomite of the Berg Aukas and Gauss Formation on the northern limb of the Berg Aukas syncline. Ore minerals are sphalerite, galena, pyrite and the secondary minerals including descloizite. Some ore bodies are concordant to the east-striking beds and others occur in the solution cavities controlled by north to south striking fractures. Total output until closure in 1978, amounted to 1.6 million tons.

Tschudi

The mineralisation includes chalcocite, malachite, chrysocola and azurite, occurring in the fractures of basal quartzite of the Tschudi Formation. The occurrence may suggest that the primary mineralisation was subject to supergene diagenesis to disperse into permeable cleavages of sandstone.

An inclinal shaft has been completed by TCL but subsequent mine development is pending. Ore reserve of 9 million tons at a grade of 0.6 percent copper are reported. Because of the low grade of ore the SXEW method for copper recovery is considered.

Khusib Springs

Ore production was started in 1996 at a monthly rate of 8,000 tons with a copper grade slightly higher than that of Tsumeb.

The ore deposit consists of two ore lenses comparatively rich in copper, lead and silver lying about 20 metres below surface extending 70 metres by 120 metres and varying between 3-16 metres wide.

Most of the ore deposits in this area are similar to Mississippi Valley Type ore deposits and a summary of the characteristics is given below.

(1) There is an apparent absence of related igneous activity.

(2) The occurrence in limestone or dolomite in the relatively tectonically stable regions of continental platforms near the edges of relatively large sedimentary basins;

(3) The presence of possible evaporites in the basins at some distance;.

(4) They have low temperature of formation.

(5) The dominant lead-zinc mineralisation with the exception of Tsumeb where copper is dominant;

(6) Shallow depths of many of the ore bodies;

(7) The relationship to faulting and/or unconformities (Kombat, Abenab, Rietfontein)

(8) The ore bodies are tabular lodes parallel to bedding or as fracture or joint fillings and in solution cavities and collapse breccias associated with paleokarst topography.

The forming temperature of ore over 200 °C for the primary sulphide minerals may suggest that the ore forming process would be different from that of the Mississippi Valley type ore deposit together with predominance of copper over lead and zinc.

The mineralisation episode including karsting process is followed as below based upon the description of known ore deposits.

(1) Formation of fold zone within the nearly horizontal carbonate succession. Ductility contrast of carbonate and a culmination within the structure may have predetermined the loci of ore deposits.

(2) Solution collapse breccias were formed by meteoric water circulation between paleoaquifer and paleosurface. Where the paleo aquifer intersected fractured axial zone of folding, subterranean solution extended far upward into the succession with the dark dolomite breccia accumulated in the cavity.

(3) Below the aquifer, downward continuation of carbonate solution was also controlled by the permeable structural discontinuities.

(4) Influx of arenaceous sediments of the Tschudi Formation took place into the cavernous conduit to form plug-like body of feldspathic sandstone. Arenite and some argillaceous material became admixed in parts with the downward moving constituents of the dark dolomite breccia.

(5) Regional folding intensified cleavage and fracturing of dolomite. The permeability of the eventual pipe locus was thereby significantly enhanced.

(6) The first hydrothermal fluids effected host rock alteration, solution or fracturing. Further folding caused foliation and shearing of the lower part of the dark dolomite breccia along which local injection of feldspathic sandstone was also resulted.

(7) Metal-bearing hydrothermal fluids ascended into the sandstone pipe overlapping the alteration. These metalliferous fluids were of moderate salinity and the reaction with sulphate-bearing seawater played a role in inducing ore deposition chiefly wit

1-3. Interpretation of Photogeology

Since late 1960's the fracture density of the Etosha basin has been calculated using aerophotos on a scale of 1:10,000, 1:36,000 and 1:72,000. The photogeology is effective for structural analysis in areas of scarce vegetation as is the case in the Otavi Mountainland where the formation and lineaments are easily traced.

1-4. Geochemical Exploration

Soil geochemical exploration is most commonly in the survey area. Samples were taken from a spacing of 400 m to 500 m by 100 metres and were analysed for Pb, Zn, Cu and V.

In 1975 Eland Exploration Co. located high grade Pb-Ag mineralisation through geochemical prospecting in east of farm Driehoek.

1-5. Geophysical Exploration

In the 1960's to 1970's, Oil and gas exploration has been aggressively undertaken in the concession over the Etosha basin situated north of latitude 20° south. In this exploration programme, aeromagnetic survey and vibroseis seismic survey had been undertaken. For exploration for mineral deposit, gravity survey and IP method electric survey were locally used in addition to aeromagnetic surveys.

1-5-1. Aeromagnetic survey

In Grant 150, total aeromagnetic data at one kilometer line spacing was acquired by Etosha Petroleum Co. and other companies. The survey revealed that northeasterly trending magnetic lineaments of the Tsumeb area coincide with a dolerite dyke some 150 metres wide. The depth of basement was also estimated from the aeromagnetic anomalies.

1-5-2. Ground magnetic survey

In the exploration programme of Grant 150 the ground magnetic surveys were carried on along the main roads within the survey area.

1-5-3. IP method electric survey

On farm Driehoek within Grant 193, northwest of Grootfontein, Eland Exploration Pty Ltd. conducted IP surveys of time domain pole-dipole method to define the target for drilling. The results are as follows.

1) The weathered zone is about 5 metres thick.

2) Specific resistivity of host rock is around 15,000 Ωm (that means IP method is favorable for mineral

exploration)

3) The IP values of surface layer and host rock are more or less 4 msec.

4) Some of the IP anomalies recognized possibly resulted from the known Pb mineralisation (3.5 msec anomaly against less than 2 msec BG value)

5) Some anomalies have possibly resulted from electrode effect however, checking is needed with other information.

6) Comparatively high IP anomalies of surface layer may be derived of polarized argil.

7) IP method was not effective for detecting the Cu mineralisation of less than 2 percent Cu at depths of 50 feet.

8) Thin bed of argillaceous shale may disturb the anomaly interpretation because it gives lower resistivity than host dolomite and high IP value.

The survey concluded that the IP method was considered not to be favorable for evaluation of mineral potential.

Other geophysical surveys such as gravity, seismic, specific resistivity and artificial thermoluminescence were also previously used.

1-6. Drilling Exploration

From 1969 to 1970 two drill holes sunk in the Border property of Grant 193 intersected six mineralised zones with grades between 1 and 2.3 % Zn and ranging in thickness between tens of centimetres to ten metres. On Grant, 162 ten drill holes of up to 130 metres in length encountered secondary Cu mineralisation, basic dykes as well as calcrete thicknesses of up to 5 metres. On the Border property an additional 48 holes were drilled to a average depth of 180 metres. These holes intersected the mineralized zones over 6 metres in thickness with a average grade of 3.608 percent of combined Zn and Pb and an ore reserve of 5,440,000 short tons.

In 1974 some, 7 holes totaling 1068.65 metres were drilled on Driehoek East. These holes were followed up by an additional 11 holes in 1975. Seven holes intersected a mineralised zone over some 30 metres thick with an average grade of 1 to 2.5 percent Pb and 2 to 6 percent Zn.

In the following year 6 holes totaling at 559.41 metres were drilled on Driehoek North. Three of six indicated mineralisation over one to 18 metres in thickness. The grade of this was recorded as ranging between 1 to 7 percent combined Pb and Zn.

1-7. Feasibility Study

Etosha Minerals Co. did a feasibility study on the Border property and came to the following conclusions:.

Grade: 5.833 % (Pb 1.814% + Zn 4.019%)

Ore reserve: 30 million tons

Production rate: 10,000 tons/day

Duration: 10 years

Return : 25 %

and favourable effect of silver content by increase of Pb/Zn ratio to the feasibility was needed for the start of mine development.

1-8. Status map of Grants

The Grant map as of 1995 is illustrated in Fig. II -1-1. In terms of the Minerals Bill, all mineral rights are vested in the state and minerals production can only be under Government. Grant types comprise reconnaissance, exclusive prospecting, mining and mineral deposit retention grant.

In Fig. II -1-1, No. 132A, 132B, 132C, 132D, 132E, 1120, 1415, 1425, 1501, 1622 and 1655 are the current Grants. All the above mentioned grants except for No. 1120 are held by T.C.L. These grants cover most of the area with Damara Sequence exposures and known mineralisation. The areas to the north and east are not covered by any grants as exploration in calcrete covered areas is difficult.

Chapter 2 Geological mapping and sampling

During the 1995 field programme, the survey team familiarised themselves with the local geology by comparing field observations to existing geological maps that were prepared by various institutions. Rock samples were collected and these were used for the measurement of a set of the geophysical properties which are necessary for the interpretation of aeromagnetic data.

Out of more than 150 samples collected, 10 samples were selected for thin section, 20 samples for polished section whereas 30 samples were selected for geophysical tests. Ore samples were collected from the Tsumeb and the Kombat mines as well as old diggings and mining sites. Mining at Tsumeb was nearing an end and this had resulted in difficulties in obtain high grade as well as a diversity of samples.

The compiled geologic map is illustrated in Fig. II-2-1 and the result of microscopic identification of thin sections and polished sections are shown in Table II-4-2 and Table II-4-3 respectively.

2-1. Basement Complex

The basement rocks of Pre-Damaran age are exposed mainly to the west of Grootfontein and along the main route C-42 running between Tsumeb and Grootfontein. Granitic rock of the basement include biotite-muscovite granite comprising porphyritic pink microcline and biotite-hornblende granodiorite. These rocks have a moderate magnetic susceptibility. Other than the granites, psammitic metamorphic rock, quartzite, amphibolite schist and mica schist constitute the basement complex. The quartzite contains a considerable amount of hematite which could cause magnetism.

The metasediments strike between N 40° to N 70° and dip steeply south. Basic dykes intrude into the metasediments at a direction of N 20° and the aplite dykes strike N 80° The basic dykes may be slightly younger than the basement complex because of the absence of distinct mineral orientation common to basic schists. No field evidence of dykes intruding Damara sequence rocks was found. The non-granitic basement rocks have a characteristic magnetic heterogeneous pattern.

2-2. Damara and Karoo/Kalahari system

Overlying the basement are Damara Sequence Rocks. The basal Nosib Group rocks consist of sedimentary and volcanic lithologies and occurs to the south of the Otavi Mountains. They contain weak chalcopyrite mineralisation. The Nosib Group rocks are overlain by the Otavi Group, which is divided into the Abenab and Tsumeb Subgroups. The Chuos Formation marks the base of the Tsumeb Sub Group and consists of tillite, quartzite, shale, minor dolomite and limestone. Except for the Nosib and Chuos Formations, the Damara Sequence largely consist of thick carbonate rocks with low magnetic susceptibility.

Dark grey massive dolomite, silicified oolitic dolomite, chert and calcareous sandstone of the

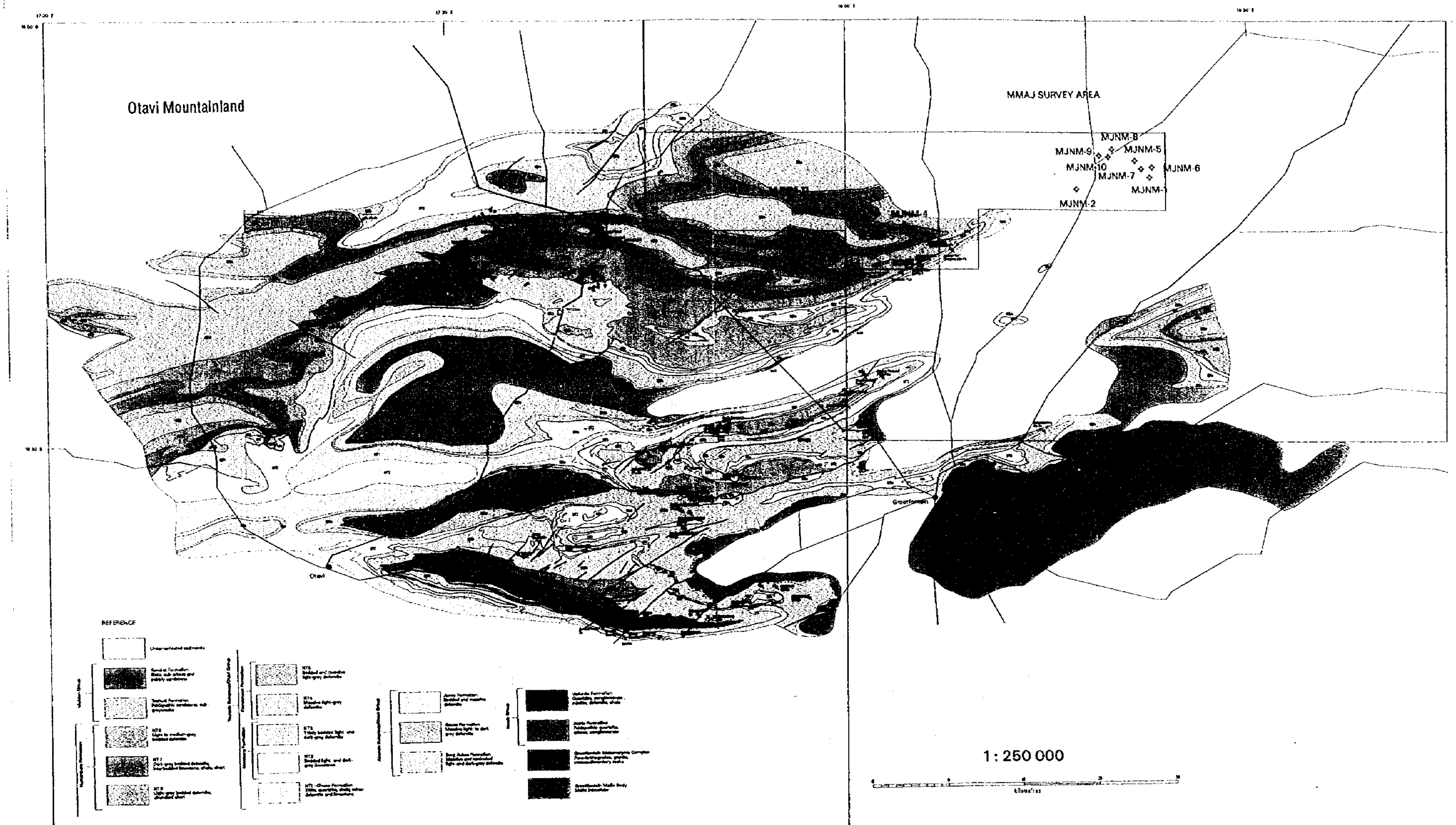

Fig. II－2－1 Compiled geologic map

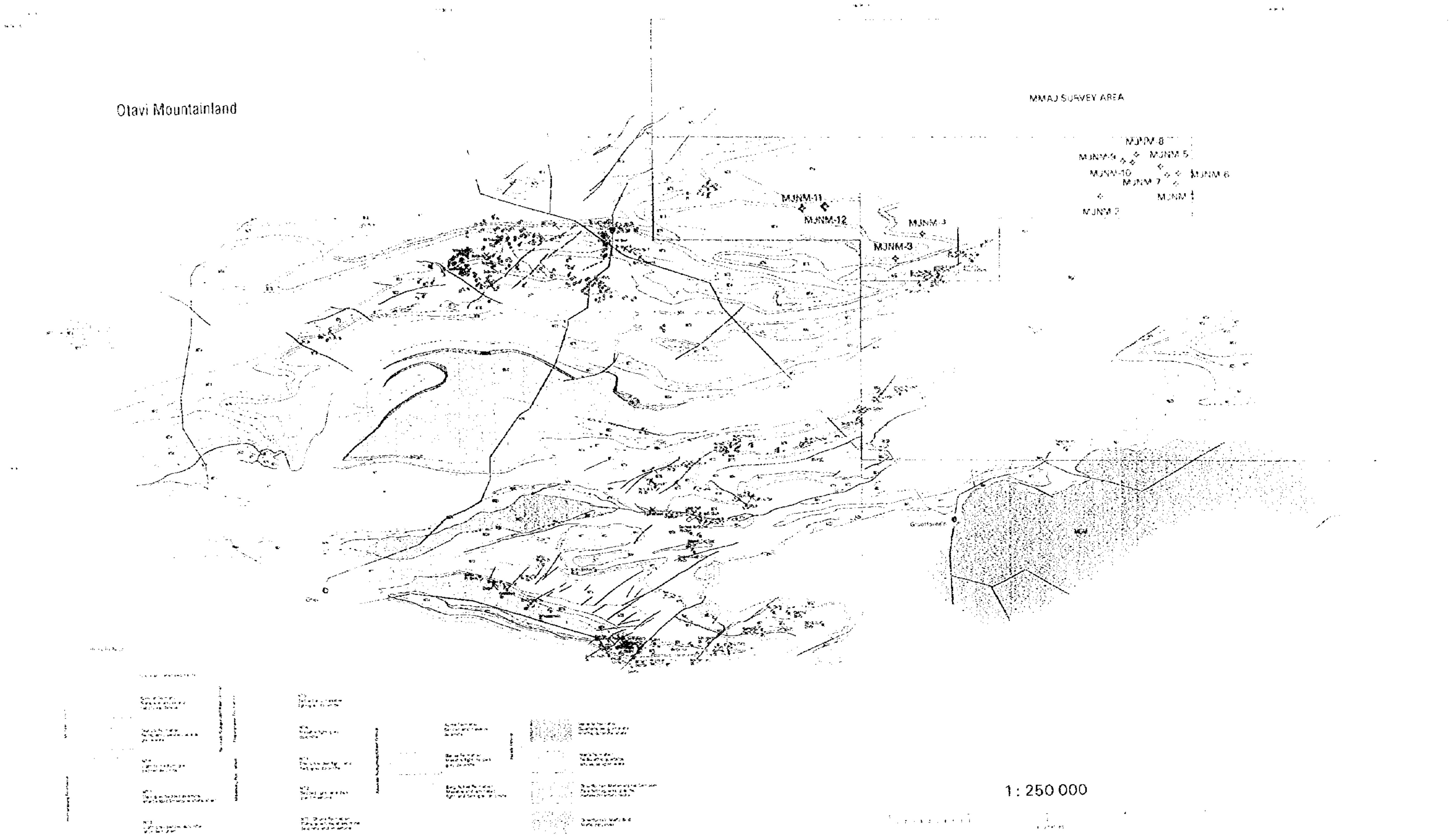

Fig. II－2－1　Compiled geologic map

uppermost facies of the Tsumeb Subgroup are exposed to the south of Tsumeb. The Mulden Group unconformably overlies the Otavi Group. Black calcareous shale and well bedded sandstone are exposed along the road cut to the east of Tsumeb could be correlated to the basal lithofacies of the Tschudi Formation of the Mulden Group.

The black phyllite of the Elandshoek Formation with a strike of N55° E to N65° E dipping 60° north, northwest of Grootfontein. Crenulation cleavage with a strike of N75° E dipping steeply south are present in this area. A calcrete cover overlies the Damara Sequence in the central and southern part of the area covered by the aerogeophysical survey.

Gently undulating Kalahari dunes with an easterly trend occur in the northeastern and eastern part of the survey area. These are clearly visible on the Landsat TM image.

2-3. Faults and Lineaments

Structural features like faults and bedding within the basement show northeast and east-northeast-trends. The mapping indicated predominant NNE-SSW and ENE-WSW trending fractures with subordinate NNW-SSE and WNW-ESE trends within the Damara system.

2-4. Mineralisation

Vanadiferous minerals were identified in a high grade ore from the dump of closed Bobos mine. It is aggregate of coarse-grained dendritic crystals associated with calcite. The mineral is believed zincian Mottoramite from assayed zinc of 3 to 5 percent. The oxidized ore from the Tsumeb West contains commonly chalcocite as well as secondary malachite, it encloses quite few inclusion and shows less anisotropic compared to that from epigenetic hydrothermal veins or Kuroko type ore deposits of Japan suggesting being of primary hydrothermal origin under moderate to high temperature condition.

The ores from the Abenab mine are rich in sphalerite and galena with lesser amount of copper sulphide which is of classic Mississippi Valley Type. Native copper, usually occurs as the secondary mineral in the oxidation zone though, is hosted within chalcocite in minute inclusions here.

The high grade ore from the Kombat mine is composed of galena, chalcopyrite, sphalerite and chalcocite with small amount of covelline and pyrite. Chalcopyrite shows no exsolution texture presented by minute stars of sphalerite and cubanite. In the disseminated feldspathic sandstone, cuprite with native copper and malachite predominate indicating mineral assemblage of oxidation zone.

At Harasib old diggings, the ore is accompanied by intense quartz network and silicification zone. The ore mineral is black to dark green and of dendric form as that of Bobos. Under the microscope it shows anisotropic property and sometimes rainbow-coloured internal reflection. Such mineral is identified to be cupriferous descloizite taking its Zn assay of 10 to 20 % into account. The mineral assemblage of ore is thus so variable that it may suggest that the ore had been formed under variable condition and not have been affected evenly by post ore events such as diagenesis and thermal alteration.