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

PHASE I

MARCH, 1986

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 16 September to 16 November, 1995.

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.

March 1996

Kimio FUJITA
President
Japan International Cooperation Agency

Shozaburo KIYOTAKI
President
Metal Mining Agency of Japan

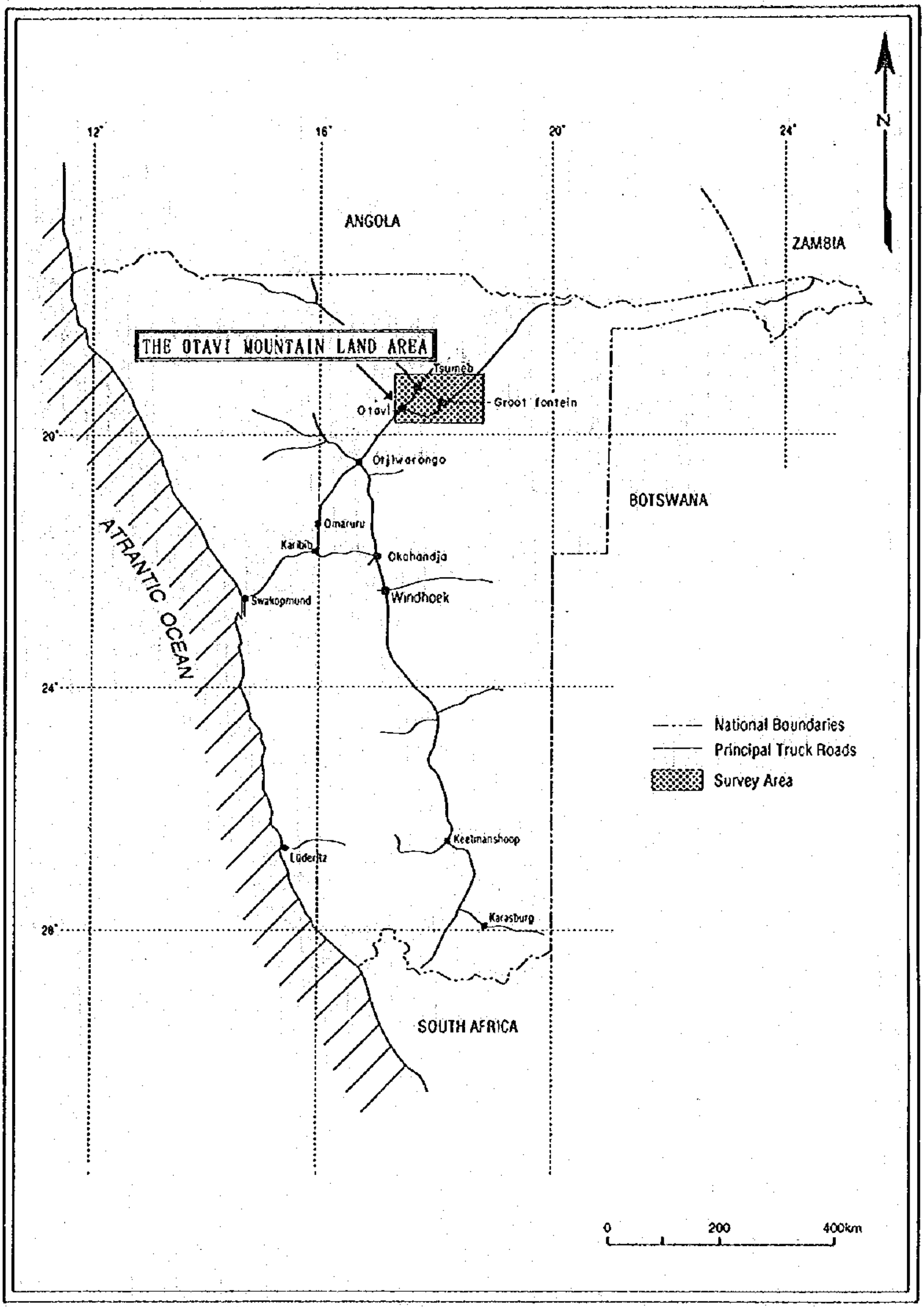

Fig. I − 1 − 1 Index Map of the Otavi Mountainland Area

Summary

The survey of Phase I was aimed at the analysis of geological structure as well as the encounter of a new deposit in the Otavi Mountain Land Area of the Republic of Namibia.

The exploration programme of the Phase I included compilation of existing data and information, geological survey and airborne geophysical survey. The relationship between geological structure and mineralisation interpreted from the previous information resulted in a model of ore genesis. The subsequent geological survey verified the type lithology, stratigraphic sequence and known mineral showings using the compiled geologic map.

The acquired aeromagnetic and radiometric anomalies were correlated to the geology of the exposed area of rocks. Based upon the correlation, the subsurface distribution of the formation and geological structure were analyzed and subsequently, lineaments favourable for mineral potential were extracted and evaluated in the context of the model of ore formation.

Most of the known ore deposits and mineralisation of the survey area are similar to those of so called Mississippi Valley Type ore deposits hosted in the Karst related sediments which filled caves formed in the carbonate rocks of Otavi Group of upper Proterozoic Damara sequence. The deep-seated faults and fracture system with NE-SW or ENE-WSW trend resulting from the basement structure are important for conduit of mineralized fluid from the depth.

Based upon the magnetic anomalies acquired by aeromagnetic survey, magnetic lineaments which might suggest extent of basement complex, deep-seated faults and folding structure, were extracted in the area covered with calcrete of varying thickness.
It was also revealed that the east and north of the area are underlain by deep-seated basement complex and thick carbonates of Damara sequence under the calcrete and the folding structure of the Mulden and Otavi Group were delineated by faint difference in magnetic intensity between the two Groups.

It seems that the known ore deposits are controlled by NE-SW trending lineament and fracture systems running west of Tsumeb and from Kombat through Harasib,Border,Khusib Spring to Abenab and as well as controlled by intersection of various trend of fracture system related to folding. Particularly, it is interesting that Tsumeb and Kombat are localized at the distorted primary synclinorium where NE-SW trending faults or fractures are duplicated.

The favourable areas of mineral potential were selected based upon the favourable criteria using aeromagnetic and aeroradiometric anomaly maps from the survey area covered by calcrete and a ground geophysical survey of the potential areas was proposed for Phase II programme.

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Part I General Remarks

Part I General Remarks

Chapter 1 Introduction

I-1-1. Background and Objective of the Survey

This survey is part of a three year-mineral exploration project which started in 1995. The survey is conducted in the Otavi Mountainland Area of Namibia, which is one of the most promising base metal provinces of the country. Three operating mines; Tsumeb, Kobat 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. This phase will be followed up by more detailed surveys and if warranted, drilling.

I-1-2. The Survey Area and Outline of the Phase I

Locality of survey area is shown in Fig.I-1-1. The outline on the work done in this year is as follows:

I-1-2-1. Research and Compilation of the Previous Information

A location map of the known mineral showings was prepared . The previous exploration work done was researched from the available open file grant reports which are archived in library of the Geological Survey of Namibia. During this stage the geology, geophysics, geochemistry, drilling and mineral showings were compiled.

The compilation and interpretation thereof resulted in the preliminary modeling of ore genesis and the definition of favorable ore controls.

I-1-2-2. Geological Survey

The compiled geological map was combined with TM satellite image. Based on this map, the type lithology and the geological structures as well as geological boundaries were field checked along the main roads. Because lineaments are not easily observed from the TM image, the field survey emphasised on locating fractures, shears and faults in the field.

To get a better understanding of the mineralisation and geological setting, mine visits to the Kombat and Tsumeb mines were arranged with TCL · For other field work the permission for admission was obtained from the land owners. Samples for laboratory tests were collected during these visits.

I-1-2-3. Airborne Geophysical Survey

The Airborne geophysical survey was performed under a contract with Geodass Co., Ltd. which both flew the aircraft as well as acquired the data. Preliminary anomaly maps were produced subsequent to each flight and these were used to select the areas for field investigation. Aeromagnetics and aeroradiometrics were used to the delineate subsurface geology and based on this the favorable loci for mineral potential were selected.

The Specifications of the Survey is shown in Table I-1-1.

Table I-1-1 Specifications of the Survey (1)

Items	Detailed Specifications and Amount
Research and Compilation of the previous Information	7 working days
Geological Survey	14 working days
Airborne Geophysical Survey (Aeromagnetic and Radiometric)	Coverage : 5,000 km^2 line : 26 km / line × 130 lines 54 km / line × 401 lines Total line Kilometre 25,034 line km Tie line Kilometre 2,484 line km

Table I − 1 − 1 Specifications of the Survey (2)

Items of Laboratory Test	Number
(1) Microscopic Identification of Thin Section	10 samples
(2) Microscopic Identification of Polished Section	20 samples
(3) Measurement of Geophysical Property (Magnetic Susceptibility, Resistivity, and Chargeability)	30 samples

I−1−3. Members of the Survey

The following members were organized for the survey team, planning of the project and negotiations between the two countries.

Planing and Negotiation

Japanese Representative	Namibian Representative
Mr. Kenji Nakamura (Metal Mining Agency of Japan) Mr. Koji Kuwayama (Ministry of International Trade and Industry, Japan) Mr. Haruhisa Morozumi (Metal Mining Agency of Japan)	Dr. H Shimutwikeni (Permanent Secretary Minstry of Mines and Energy) Dr. Brian G. Hoal (Director Geological Survey of Namibia) Dr. Gabriele I.C. Schneider (Dupty Director Geological Survey of Namibia) Mr. Herbert Roesener (Chief Geologist Geological Survey of Namibia)

Survey:

Japanese Member	Namibian Member
Mr. Tetsuo Hatasaki Chief of the mission Research and Compilation of the previous information Geological Mapping (Dowa Engineering Co., Ltd.) Mr. Yoshiaki Karino Research and Compilation of the previous information Airborne Geophysical Survey (Dowa Engineering Co., Ltd.)	Mr. Herbert Roesener (Chief Geologist Geological Survey of Namibia)

Field Supervisor:

Mr.Yoshiyuki Kita (Metal Mining Agency of Japan)

I-1-4. Terms of the Survey

The survey was conducted as the following programme.

Total Period Overseas: From 16 September to 16 November 1995

Research and Compilation of the Existing Information:

From 20 September to 26 October 1995

Geological and Airborne Geophysical Survey:

From 25 October to 12 October 1995

Preliminary Data Analysis and Ground checking:

From 28 October to 12 November 1995

Chapter 2 Physical Features

I-2-1. 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 Tsúmeb. Air Namibia's is also flying from the Eros airport in Windhoek to Tsumeb and Grootfontein.

I-2-2. 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.

I-2-3. Climate and Vegetation

The climate of the Namibia is between semi-arid and subtropical. The highest mean temperature for Windhoek are 23 deg centigrade in November and the lowest mean temrature is 17 deg centigrade in July. The annual average rainfall is 600 milimetres in the northern forest zone, 20 milimetres in the desert zone, and 350 milimetres 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 deg centigrade higher than in Windhoek while the annual average rainfall for Tsumeb is 572 milimetres.

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.

Chapter 3 Previous Work

I-3-1. Outline of 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.Kruger, 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.

I-3-2. General Geology

Regional stratigraphy is presented by Geological Survey of Namibia(1982) and the Geological Society of South Africa(1983). 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

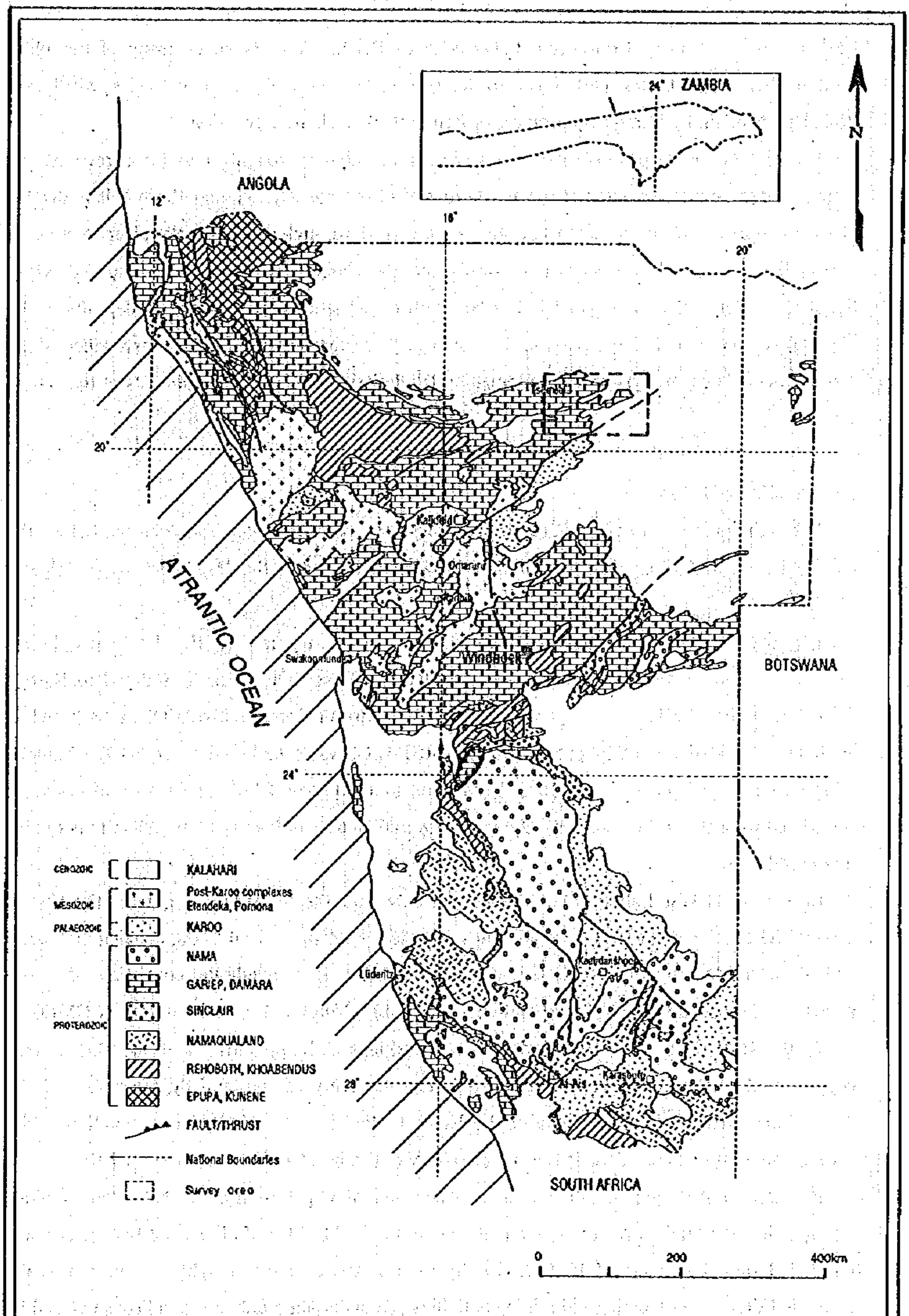

Fig. I — 3 — 1 Regional Geologic Map of Namibia

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.

I-3-3. Mining History

Although some small scale mining by the indigenous people of Namibian occurred before the coloniallisation of Africa, "modern" mining in Namibia started at the Matchless copper mine in 1855.

The copper deposits of the Otavi Montainland, were worked by the local people for generations prior to the arrival of European explorers. These mines were introduced to Europe for the first time by Mathew Rogers of South West African Company(SWACO) in 1892 and in 1900 The Otavi Minen und Eisenbahngesellschaft(OMEG) was established to exploit the Tsumeb mine which started production in 1905. From then to 1990 some 24.60 million tons of ore were mined and from this 1.7 million tons of copper, 2.8 million tons of lead and 0.9 million tons of zinc were produced.

During World War I all activities ceased and only after the SWACO was granted the title to the OMEG concession in 1921 were activities resumed. Exploration lead to the opening of Abenab and Berg Aukas vanadium deposits. After World War II a Syndicate consisting of seven companies formed the Tsumeb Corporation Ltd. (TCL) which purchased the assets of OMEG in 1947. By 1949 TCL made the underground workings fully operative and in 1962 a new copper-lead smelter complex was completed. The discovery of substantially ore bodies at the Asis mining area led to the opening of the Kombat Mine in 1962. Extensive exploration in the area to the west of Kombat has led to the discovery of the Kombat West ore body in 1970.

In order to stimulate investment in the Namibian Mining industry, the Namibian Minerals (Prospecting and Mining) Act of 1992 was drawn up by the Ministry of Mines and Energy and was enacted during the course of 1994. According to this Act, all mineral rights are vested in the state, and thus all prospecting and mining activities are undertaken only under a license issued by the Minister of Mines and Energy on recommendation by the Mining Commissioner.

The favourable location of this area has led to extensive exploration by private mining concerns. A large number of ore deposits varying in size have been mined till recently. However, Tsumeb and Kombat are the only two mines still operating. The mining of the Tsumeb deposit over hundred years resulted in the depletion of ore reserves and ore grade and this will lead to the closure of the mine at the end of 1996.

A couple of low grade and small size ore deposits are on line for development and treated at Tsumeb smelter. The successful exploration at the Kombat mine is highly expected.

I-3-4. Geological Setting and Mineralisation

The complex geotectonic history of the Damara orogen can be broadly summarised into an earlier extensional-rifting-spreading phase and a later compressional-convergence-collisional phase. During the initial phase, two northeast-trending intracontinental rifts were formed. These were filled with terrigenous sediments(Nosib Formation) which included meta-evaporites and peralkaline pyroclastic rocks. Associated with this phase are volcanogenic copper sulphides that occur in leucitic lavas south of Kombat (Askevold deposit).

Concomitant with continental margin deposition, carbonates accumulated on the extensive Northern Platform(Otavi Group) of the northeast-trending branch of the Damara Orogen. At a early stage, shelf and platform carbonate deposition was interrupted by widespread glaciation (Chuos Formation). Spreading culminated in the formation of a mid-oceanic ridge in the Southern Zone ocean(Matchless Amphibolite Member) with which several Besshi-type volcanogenic massive cuprous pyrite deposits are associated(Otjihase and Matchless).

Subsequent to spreading, the southern Kalahari Craton subducted beneath the northern Congo Craton at 650 Ma and the southern part of the northern rift became an active continental margin.

During the consequent D1 deformation (630-600 Ma), which resulted in uplift and exposure of the northern platform, karst structures developed in the thick carbonate succession of the Otavi Group. This was accompanied by the unconformable deposition of the northern molasse of the Mulden Group. During the D2 deformation(570-500 Ma) lead-zinc mineralisation of Mississippi Valley Type(Berg Aukas, Abenab, Abenab West etc.)and polymetallic mineralisation of Tsumeb Type(Tsumeb, Kombat) was emplaced into karst structures of the Otavi Group carbonates.

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 Interpretation and Discussion

I-4-1. Characteristics and Structural Control of Mineralisation

In the Northern Platform Zone of the Damara orogeny including the survey area, folding initiated prior to the Mulden period, has resulted in intraformational slip fold and faults parallel to the axial plane finally to form karst.

The fractures at a shallow depth thus formed could have played a role of ore loci. Meanwhile, another deeper fracture system for ascending fluid from the deep should be inevitably deep-seated faults controlled by internal structure of the basement complex overlain by thick dolomite. The internal structure may indicate northeasterly trending strikes of metasediments of the basement complex and the crosscutting dykes with north-northeast trending strikes, northwest of Grootfontein. Some of these deep seated faults may reach the paleosurface due to reworking during Damara Orogeny. This NE-SW trend coincides with rifting system since the initial deposition of Damara sequence. NNE-SSW trending lineaments are also recognized in preDamara basement area.

The shallow-seated fracture system also seems to be related to deformation of later stage. The crest of secondary synclinorium is believed favourable loci for intense fracturing with eastern, west-northwestern and northwestern trends.

It is concluded that the loci of ore deposit may be controlled to the intersection of NE-SW or NNE-SSW trending deep-seated fracture system and E-W,WNW-ESE,ENE-WSW or NW-SE trending faults or fracture system shallowly seated and is thus highly evaluated.

I-4-2. Relationship between Airborne Geophysical Anomalies, Geological Structure and Mineralisation

The aeromagnetic survey revealed that the surveyed area was divided into two zones by distinct east-northeast to east trending lineament; the southern half of the area is underlain by the basement complex at a shallow depth whereas the northern half is overlain by thick carbonate pile of Damara sequence. The lineament gives two zones a significant magnetic contrast suggesting possible deep-seated fault. Another magnetic feature of the survey area is quite faint magnetic contrast of the upper most Tsumeb Subgroup with the Mulden Group. This feature is supported by correlation using geologic map. The Group boundary is important for ore potential because ore deposit may be hosted in karst below the unconformity. The feature could be followed as continuous arcuate lineament giving an exploration tool.

The aeroradiometric survey revealed radioactive difference by lithofacies mainly in the area of rock exposure. The Abenab and Khusib Springs are obviously situated close to the northeasterly trending radiometric lineament showing lithological boundary.

I-4-3. Possible Ore Potential

Based upon the ore forming model, aeromagnetic and aeroradiometric lineaments ore potential of the surveyed area was evaluated aiming at a massive sulphide ore pipe-type deposit. The following four criteria were used for evaluation.

(1) Proximity of unconformity(or disconformity, termed TM contact thereafter) of Mulden Group and synclinal crest or crest of secondary folding.

(2) Intersection of aeromagnetic and or aeroradiometric lineaments with northeastern trend and east-northeastern trend and TM contact.

(3) Important shift of the basement linear structure associated with TM contact nearby

(4) Small aeromagnetic anomalies around TM contact

Criterion(1) duplicated with (2) and (3) was highly evaluated whereas criterion(4) was not used for single. Thus seven subareas were chosen for high to moderate ore potential. Out of seven subareas, Aregoas 282 and Cleveland 706 northeast and north of Abenab, are considered most prominent for further exploration.

Chapter 5 Conclusion and Recommendation

I-5-1. Conclusion

The survey of Phase I included research and compilation of the existing data, geological survey and airborne geophysical survey. The conclusion of the survey is summarized below.

1. Some features of the known ore deposits and mineralisation of the survey area are similar to those of so called Mississippi Valley Type ore deposits.

2. The ore deposits are hosted in the Karst related sediments which filled caves formed in the carbonate rocks of Otavi Group of upper Proterozoic Damara sequence.

3. The karst related sediments are principally permeable areneous sediment unconformably lying on the carbonate rock resulting in the conduit at a shallow depth for mineralized fluid from the depth.

4. The Damara sequence of the survey 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.

5. 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. The deep-seated faults and fracture system resulting from the basement structure are important for conduit of mineralized fluid from the depth.

6. Based upon the magnetic anomalies acquired by aeromagnetic survey, magnetic lineaments which might suggest extended basement complex, deep seated faults and folding structure, were extracted east of Grootfontein covered with calcrete of varying thickness.

7. It is revealed that the east and north of the area are underlain by deep-seated basement complex and thick carbonates of Damara sequence under the calcrete and the folding structure of the Mulden and Otavi Group were delineated by faint difference in magnetic intensity between the tow Groups.

8. Radiometric lineaments coincident with magnetic ones were also extracted based upon the contemporaneous aeroradiometric survey, indicating that those lineaments were originated from the depth.

9. It seems that the known ore deposits are controlled by NE-SW trending lineament and fracture systems running west of Tsumeb and from Kombat through Harasib,Border,Khusib Spring to Abenab and as well as controlled by intersection of various trend of fracture system related to folding. Particularly, it is interesting that Tsumeb and Kombat are localized at the distorted primary synclinorium where NE-SW trending faults or fractures are duplicated.

10. The favourable areas of mineral potential were selected based upon the appraisal of

aeromagnetic and aeroradiometric anomaly maps from the survey area covered by calcrete.

I-5-2. Recommendation for the Phase II

Based upon the result from the survey followed by total interpretation and discussion, the following exploration programme for Phase II is recommended.

I-5-2-1. Survey area(Fig. II -6-1)

The location of the area is represented by the alphabetical letter combined with the number which are given to each section five by five minutes in the flown area.

(1) G3 central area : Aregoas 282 Farm

(2) E3/E4 border area : Cleveland 706 Farm

(3) B3 northeast area : Aarhus 659 and Accra 660

(4) H3 north area : Guinab 277

(5) D4 north area : Cadix 678 and Christiana 705

(6) G2 south area : Vogelsang 284

(7) D3 central area : Demerara 699

I-5-2-2. Method

A massive copper-lead-zinc sulphide ore deposit is targetted. It may be of steeply emplaced pipe like-geometry underlying 50 metres to 100 metres deep from the surface. resistivity method using resistivity contrast between ore and host rock is most effective for search of such ore deposit. Taking the surface condition into consideration, Time Domain Electro Magnetic Method is the most favourable.

Coil disposition is of in loop capable of both vertical and horizontal surveys with loop size of 100 metres to 200 meters square for grid sampling.

Subsequent drilling exploration is also recommended when the result of the ground geophysical survey reveals favourable.

Part II Details of the Survey

Part II Details of the Survey

Chapter 1 Procedure of Survey and Interpretation

The procedure of the survey and interpretation work is illustrated in Fig.II−1−1. The objective of the Phase I survey is to delineate follow−up targets for the Phase II detailed survey.

In the research and compilation of existing information, the emphasis was placed on understanding the characteristics of the typical ore deposits in the area as well as effective exploration methods to be used. Discussions were held with mine geologists from TCL and geologists of the Geological Survey of Namibia. During the geological survey, special attention was paid to the distribution of magnetic lithounits. Samples were collected from various locality including the operating mines. Measurements of the relevant physical properties especially magnetic susceptibility was done as the aeromagnetic survey form the basis of the project Aeromagnetic anomalies were located and compared to the above mentioned data in order to establish the geological parameters for mineralisation control. Aeroradiometric anomalies combined with magnetic anomalies were used to help with the structural analysis.

Compilation and interpretation of Existing data

ITEM — ANALYSIS & INTERPRETATION

Tectonic evolution
  Stratigraphy
Geological structure <—— Satellite image
Type & Distribution of mineral deposits — Damara tectonic zone : massive sulfide (Cu)
  & Mississippi Valley Type (Pb, Zn, Cu)
 Loc. of ore formation
  Stratigraphic control —— dolomitic formation ; paleo karst
  Structural control —— WNW-ESE Fault ?
Exploration History
  Geochemical survey —— indicators ;
  Geophysical survey —— gravity ; airborne (magnetic, radiometric, electromagnetic)
   ground electronic, electromagnetic (resistivity, IP)
   logging (resistivity, magnetic susceptibility, radiometric)
 Geophysical property —— magnetic susceptibility, resistivity, chargeability
   porosity, density, radioactivity

Gelogical survey

Appreciation of geologic sequences —— preparation of route map
 (Collecting samples for thin section, polished section
 and measurement of geophysical properties
Geological structure —— paleo karst, faults

Inspection of ore deposit —— Outcrop of mineral showing and important operating mines.
 Host rocks, structure, folding, fault, boundary of sedimentary
 facies defining ore deposition.
 Appreciation of paleo karst.
 γ -ray activity in the fault zone and its BG value.
Field check of calcrete area —— Assumption of basement geology
 beneath the younger sediment.

Airborne geophysical survey

Magnetic survey
 Long wave length anomaly —— Estimation of basement rock types and its depth.
  Extraction of the large trend of the geological structure.
 Small or Linear anomaly —— Extraction of fault, lineament for favorable places
  where ore deposit is located,
  especially beneath the younger sediment .

Radiometric survey —— Interpretation of basement rock types.
 Extraction of deep fault and lineament.

Fig. II－1－1 Flow Chart of the Survey

Chapter 2 Study of Previous Information and Literature

A list of studied literature and list of mineral showing and previous exploration are shown in TableII-2-1 and TableII-2-2 respectively. A location map of previous exploration activity and location map of known mineral showings are illustrated in Fig.II-2-3 and Fig.II-2-4 respectively.

II-2-1. Geology

II-2-1-1. Regional Geology of Namibia

Regional Geologic Map of Namibia is shown in Fig.I-3-1. The Geology of Namibia largely consists of cratonic shields and geosynclinal mobile belts. A part of Congo Craton which had been stabilized since 1600 Ma occupies the north of Namibia, while a part of Kalahari Craton which had been stabilized since 1100 Ma occupies the south. The Damara belt formed between the two cratons.

The geology of Namibia is divided into the following five main periods of lithogenic activity according to regional geologic map published by Geological Survey of Namibia(1988) and the Geological Society of South Africa(1985).

Tertiary to Recent (<65 Ma)
Carboniferous to lower Cretaceous (345 to 120 Ma)
Namibian (1000 to 570 Ma)
upper Mokolian (1800 to 1000 Ma)
Vaalian to lower Mokolian (>2100 to 1800 Ma)

The northern shield is composed of metamorphic rocks of Vaalian and Mokolian periods. the southern shield consist of metamorphic rocks of Mokolian age. The Namibian sequence is underlain in the Damara geosynclinal mobile belt.

In the northern Namibia the Damara belt is further divided into seven Tectonostartigraphic Zones based upon a series of tectonic events such as intracratonic rifting, continental drift and accretion, subduction and collision (The Mineral Resources of Namibia 1995). Tectonic evolution in the Northern Platform where the Otavi Mountainland is located is summarized below.

(1) Rift stage

Sedimentation began between 900 and 1000 Ma and involved infilling of four 50-70 kilometres wide troughs. The Nosib Group, consisting of up to 6 kilometre thick terrigenous sediments with minor rhyolitic and alkaline volcanics was deposited during this stage. Sediments are mainly arkosic arenites with local conglomerate. At the top of the Nosib Group marine transgression seems to have occurred.

(2) Thermal subsidence stage

At approximately 830 Ma the area of deposition in the Damara basin widened with sedimentation overstepping basement highs and extending onto the Northern Platform Zone. A thick succession of stromatolitic dolomites and limestones of the Otavi Group accumulated on a stable, shallow-marine shelf of the Platform. To the south of it, terrigenous clastic and especially carbonate sediments are present to form the basal part of the Swakop Group.

(3) Crustal loading stage

In the central part of the country, sedimentation of eugeosynclinal flish-type proceeded. The Khomas Subgroup, which embeds the 500 kilometre long Matchless Amphibolite was deposited during this stage.

In the north, the Mulden Group (570-660 Ma) consisting of shallow-water mollase facies of the crustal loading stage was deposited onto the carbonate platform. The Mulden Group is correlated to the Nama Group in the south of Namibia.

Table II-2-1 Studied Literature in Phase I (1)

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)	2 scenes
Aeromagnetic Anomay 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)	5 Grants
Grant No. 19 Company ETOSHA PETROLEUM CO.	
150 ETOSHA PETROLEUM CO.	
192 ETOSHA PETROLEUM CO.	
193 ETOSHA PETROLEUM CO.	
162 ETOSHA PETROLEUM CO.	

Table II－2－1　Studied Literature in Phase I　(2)

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 Opono & 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 S.W.Africa by P.J.M.Ypma	geology	
				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./Phi contact	69-110m subsurface	Pb-Cu-V		Ore 157,000t Pb:5.85% Cu:1.54%, Ag:15g/t	Tsumeb Corporation1989
		Auros595 Sommerau757	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 96t 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	
	Okarundu pipe	2.5km west of Abenab	brecciated limestone	Calcite coating	V・Ds		Sulphide ore 51592t	Verwoerd 1957
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.58600t V205:18.5% 1947 Production cease	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, Woltramite ・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	Thirian 1973 Paverd 1975
6	Tsumeb West	2.5kmSW of Tsumeb	breccia zone and faults crossing Tsumeb Syncline quartzitic sandstone pipe (QSP)	matrix mineralised	Cu・Co, 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 T8 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, Co, 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) Co, 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:36%	TCL1978
14	Deutsche Erde Area Deutsche Erde Hagestolz 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	Gecchem. 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, Cc, 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	HarasibⅠ	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 Gauss45	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:Willemite Ds:Descloizite Cc:Chalcocite Mal:Malachite Py:Pyrite Cup:Cuprite Az:Azurite Co:Covelline Cr:Chrysocolla Sm:Smithonite Tet:Tetrahedrite Zc:Zincite

Table II − 2 − 2 Mineral Showings and Previous Exploration

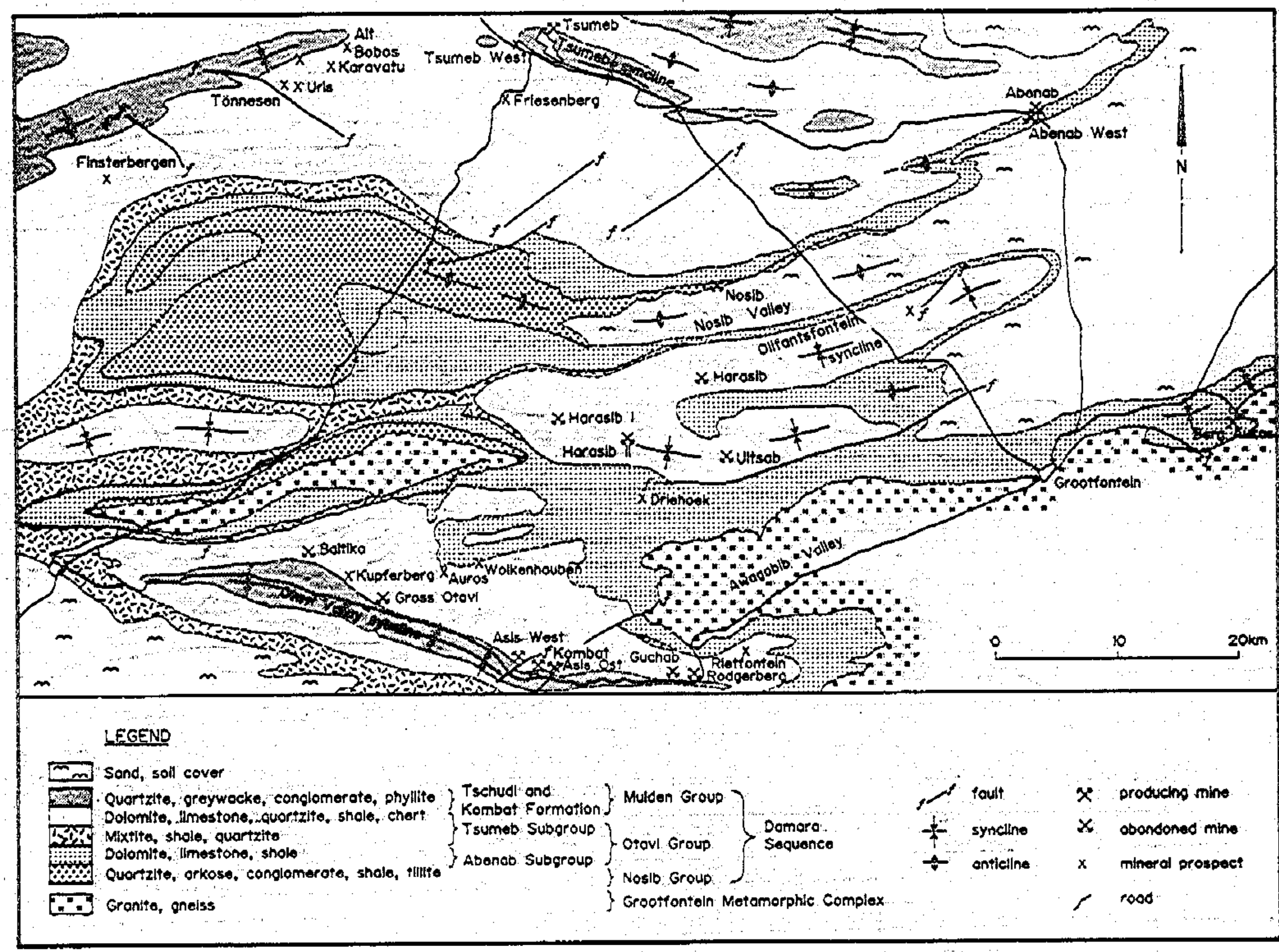

Fig. II − 2 − 1 Local Geologic Map of the Otavi Mountainland Area

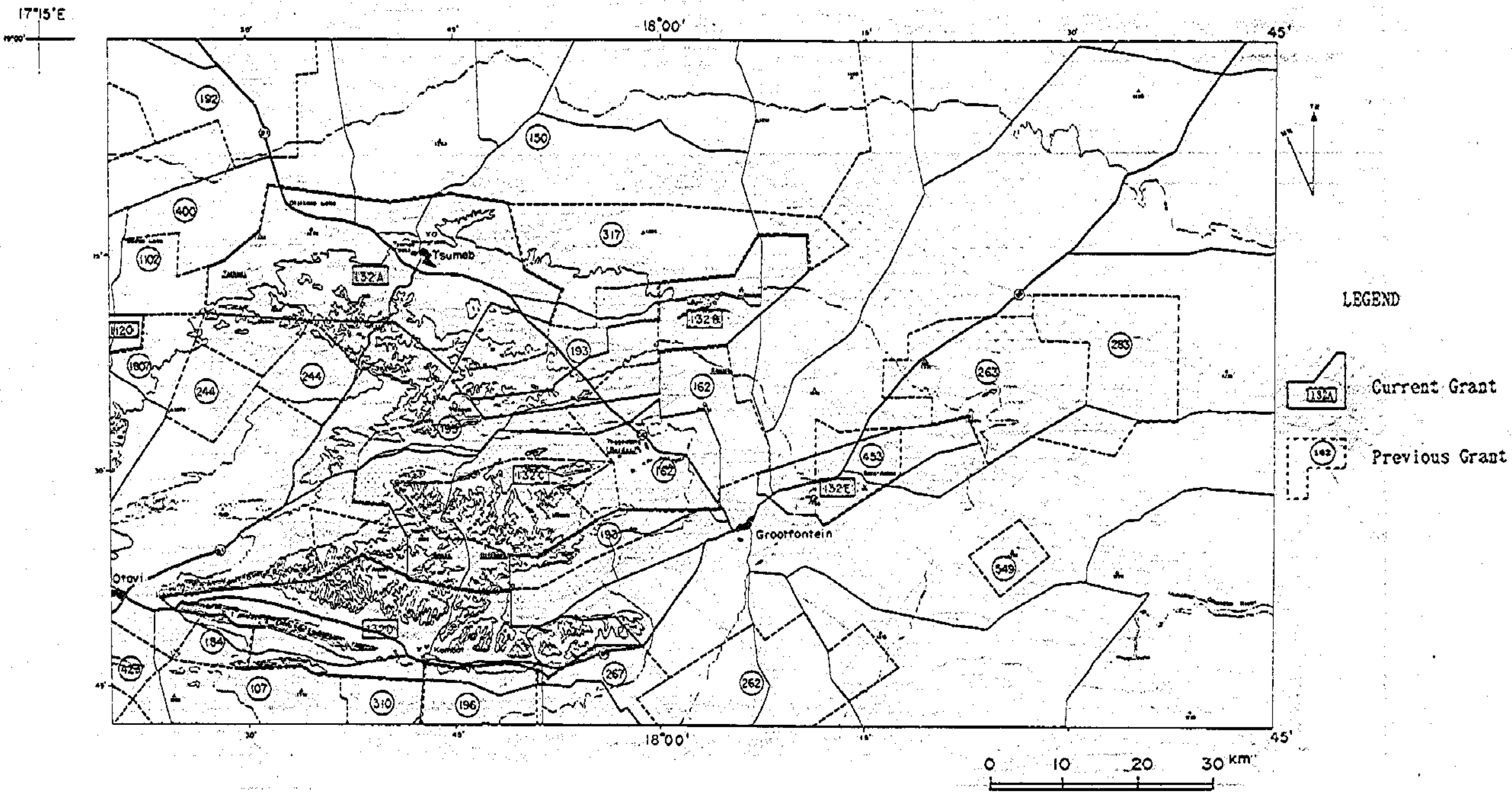

Fig. II — 2 — 2 Location Map of Previous Exploration Activity

II -2-1-2. Local Geology of the Area

Local geologic map and geologic sequence of the Otavi Mountain Land are illustrated in Fig. II -2-1 and Table II -2-3 respectively. 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.

(1) Grootfontein Basement Complex

Coarse-grained gneissose prophyritic hornblende-biotite granite is the main rock type outcroppingexposed. 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 exsistence of a large poorly exposed basic intrusive body in the Grootfontein area.

Table II − 2 − 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	
			Maiebeig	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	

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.

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.

(4) Mulden Group

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 karsts 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.

(5) 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.

(6) 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.

Geological Structure

Fold structures prevailing the area are commonly symmetric open fold with an overturned sincline 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.

II-2-2. Ore Deposit

II-2-2-1. Tsumeb

(1)History

The first report on Tsumeb was in 1893 when M.Rogers reported a malachite-stained mound some 180 metre long, 40 metre wide and 12 metre high. In 1901 Otavi Minen und Eisenbahngesellschaft(OMEG) was established and started ore production in 1905. Thereafter the ownership of the mine was transferred to Tsumeb Corporation Limited of Gold Fields Group and Tsumeb Mine became one of the largest producer of lead in Africa.

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 it is envisaged that the mine will close in 1996. At present selective mining on the periphery of high grade ore previously mined is taking place. The actual monthly production of ore in 1995 varied between 25,000 to 38,000 tons and ore grade varied from 1.3 to 1.6 percent Cu, from 0.6 to 0.8 percent Pb and from 53 to 93 g/t Ag.

(2)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.

The pipe locus consist of two main breccia types which both formed by solution collapse. The origin of one type is associated with the circulation of meteoric water which caused solution above and below the North Break which is a prominent conformable aquifer in the dolomite sequence. The subterranean solution channel eventually breached the floor of a basin in which deposition of the Tschudi Formation was in progress. This caused the influx of mainly arenaceous sediments into cavities and breccias.

Ascending hydrothermal fluids caused solution and alteration and the formation of the subsequent second solution collapse breccias. Calcitisation within the pipe extended upward to 570 metre below the present surface and reached maximum intensity at about 1120 metre depth. Silicification is the prominent alteration at lower levels.

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.

(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.

(4)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.

II-2-2-2. Kombat

(1)History

The mineralisation in the Kombat area was firstly reported by Sir Francis Galton in 1851. Subsequent prospecting was undertaken intermittently until 1911 when the Otavi Minen und Eisenbahn Gesellschaft started mining operations. In 1954 the Tsumeb Corporation Limited began exploratory drilling to find additional ore reserves. During a production hiatus from mid-1976 to late 1978, underground development led to the discovery of Asis West.

In June, 1995 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.

(2)Geological Setting and Ore Deposit

The ore deposits are hosted in dolomite of Hüttenberg 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 deposit is composed of a series of small ore bodies; Asis Ost, E900 ore body, Kombat East, Kombat Central, Kombat West and Asis West lining up en echelon over 3.6 kilometres from east to west. Two faults, with dextral displacement, run northeasterly between Asis East, the Kombat ore bodies and Asis West.

The sulphide ores of Kombat deposit are of epigenetic hydrothermal and fracture-filling and metasomatic replacement type.

The iron–manganese oxide/silicate association occurs in the feldspathic sandstone apparently on the hanging wall side of the sulphide mineralisation showing compositional and textural layering. The assemblage shows no replacement texture and overprints the sulphide mineralisation preserving primary sedimentary texture. 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 mineralization.

(3)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.

(4)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.

II–2–2–3. Abenab Mines

This mine was closed in 1958 and used to be one of the largest vanadium mine in the world. It was apparently discovered by Bushmen in 1920. 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 argile, 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.

II-2-2-4. Berg Aukas

The deposit was reportedly discovered in 1913. The ore bodies are embedded in dolomite of the Berg Aukas and Gauss Formation on the northern limb of the Berg Aukas syncline, which is a large drag fold along the southern limb of the major Grootfontein 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.

II-2-2-5. Tschudi

Tschudi Mine is situated 25 kilometres west of Tsumeb and is on the way of exploration by TCL at contact between Tschudi Formation and underlying Huttenberg Formation. A large number of trenches 15 metre long, 0.8 metre wide and 3.0 metre deep were excavated in the direction of N35 to 40° W.

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.

A 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.

II-2-2-6. Khusib Springs

The prospect is located on the farm Khusib 8, some 40 kilometres southeast of Tsumeb. Ore deposit was intersected in drill holes undertaken by Gold Fields Namibia in 1993. TCL announced that mine development at a cost of N$ 9 million is underway and production is expected to start in March 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 unconfomities (Kombat, Abenab, Rietfontein)

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

The sandstone bodies filling dolomite karst of Otavi Group are originated from the areneous sediment of the Mulden Group and the MVT ore deposits were emplaced possibly during the deposition of the Mulden Group.

Vanadium mineralisation associated with copper, lead and zinc of MVT ore deposits is considered to postdate the MVT type mineralisation and the vanadium bearing minerals seems to have formed contemporary with the supergene enrichment stage of the MTV ores.

For example, the mineralisation containing principally lead and vanadium scattered in the north of Kombat is accompanied by the remarkable quartz network veins and possibly postdates the copper-lead-zinc mineralisation and Tschudi, west of Tsumeb seems to be of secondary origin of dipersion from primary ore.

Concerning to structural control of ore deposit, at both mines of Tsumeb and Kombat, ore deposits seem to be controled by fractures and karst related to fold structure and ellipsoidal pipe. A northeast-striking, sub-outcropping dyke of olivine dolerite just west of the Tsumeb mine, and dykes and sills of kersantite in the mining area, provide evidence of post-ore magmatic activity however, earlier magmatism may have possibly occurred along this prominent linear structure. In addition, aeromagneitc surveys in the Otavi Mountainland have indicated that the northeast-striking lineament is reflected in the configuration of the basement rocks. Isopach studies undertaken by TCL have revealed that the lineament was active during deposition of the Otavi Group. The lineaments or deep faults parallel to this lineament possibly may have conducted heat from granitic intrusives farther southwest and this activated convection systems could have driven metalliferous fluids into permeable structural loci.

Faults thus controlling the configuration of the basement rocks and believed to have been active intermittently even after ore emplacement, are called "growth faults" in the United States where such a fault is believed to be a geological criterion defining loci of ore deposition in the MVT mineral belt, west of Appalachian where aeromagnetic anomaly maps and gravity maps were used for localization of growth faults.

Althoug such deep seated faults as the growth faults must have played an important role for karsting during Mulden period, still remain controversial.

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 within sandstone pipe.

II-2-3. 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.

II-2-4. Geochemical Prospecting

Soil geochemical prospecting is most commonly in the survey area. The some examples and results are shown below.

II-2-4-1. Grant 192(Etosha Petroleum Co.)

The calcrete covered area northwest of Tsumeb was selected for soil geochemical prospecting after airphoto interpretation of an area originally six hundred square kilometres in size. Samples were taken from a spacing of 400 by 100 metres and were analysed for Pb, Zn and V.

II-2-4-2. Grant 193(Etosha Petroleum Co.)

In 1970 Stream sediment and soil sampling at Driehoek and Gauss Farm resulted in defining the following geochemically anomalous zones. The anomaly maps indicated that the place one thousand and four hundred metres northwest of the triple point of Poolmans Kluft Farm boundary was of the most intense anomalies of Pb and Zn. In 1971 Eland Exploration Co. conducted geochemical prospecting of soil and stream sediment in Driehoek. The geochemical anomaly map thus prepared at a scale of 1:36,000 showed the anomaly thresholds of Zn as <300 ppm, 300-600, 600-1,200, 1200-2,000 and >2,000 ppm, those of Cu as <35, 35-75, 75-150, 150-300, 300-600, >600 and those of Pb such the same as for Zn. On the farms Kielberg, Sumas, Gauss, Ghaub, Gute Hoffnung, Auros, Nosib Block and Awagobib sampling located showings associated with a fracture zone within Gauss Farm.

II-2-4-3. Grant 162(Etosha Minerals Co.)

A progress report on the geochemical prospecting of Border property in 1970 reported that samples assayed for Pb were taken on a density of 100 metres by 50 metres and those samples assayed for Zn on a density of 100 by 100 metres. The assay resulted in the defenition of the threshold values as indicated below. This programme led to a subsequent detailed geochemical survey during which at a total of 17,444 samples at 100 metres spaced grid and a additional 22,345 samples at 50 metres spaced grid were collected.

Pb: 0-99, 100-199, 200-299, 300+ ppm

Zn: -299, 300-499, 500-650, 650+ ppm

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

II-2-5. Geophysical Survey

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.

II-2-5-1. 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.

II-2-5-2. 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.

II-2-5-3. IP method electric survey

On farm Driehoek within Grant 193, northwest of Grootfontein, Eland Exploration Pty Ltd. conducted IP surveys to define the target for drilling. The specifications of the survey were as follows.

Total : 5 grids with approximately 500 metres by 1,000 metres for each grid

Each grid included about 5 lines of which the line interval was some 100 metres

Method: Time domain IP method, pole-dipole disposition

The fine dipole interval was 50, 100 feet and the coarse dipole interval 200,400 feet.

(1)Objective:

<1> Vertical surveys at some points were done to determine such parameters as geometry of the polarized rock, the thicknes of the weathered zone, the extent of surfcial conductivity and the maximum response.

<2> Mapping of subsurface extension of the dissemination sulphides observed on outcrop and comparison of the data to geochemical prospecting.

(2)Results of <1>

1) The weathered zone is about 5 metres thick.

2) Specific resistivity of host rock is around 15,000 Ω m (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.

(3)Results of <2>

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

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

3) Comparatively high IP anomalies of surface layer may be derived of polarized argile.

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

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

(4)Conclusion:

From the results mentioned above, the IP method is considered not to be favorable for evaluation of mineral potential.

II-2-5-4. Gravity survey

During 1971, a gravity survey was done on Grant 193. This survey was undertaken on a line spacing of 100 metre and a gravity as
well as residue gravity map were prepared on a sale of 1:5,000 with 0.05 mg contours. The interpretation identified north-northeast-trending faults as well as north-south, north-west and north-east trending gravity low anomalies.

In 1974 a gravity survey conducted on Grant 150, consisted of 300 points and on Grant 193, 1960 points delineated gravity anomalies over farm Driehoek.

II-2-5-5. Other geophysical surveys

In the survey area seismic, specific resistivity and artificial thermoluminescence were previously used.

II-2-6. 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 lenght 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 avarage 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.

II–2–7. 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 %

II–2–8. Status map of Grants

The Grant map as of 1995 is illustrated in Fig. II –2–3. 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 –2–3, 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 grantsas exploration in calcrete covered areas is difficult.

Chapter 3 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 is nearing an end and this has resulted in difficulties in obtain high grade as well as adiversity of samples.

The compiled geologic map is illustrated in Fig. II −3−2 and the result of microscopic identification of thin sections is shown in Table II −3−1.

II −3−1. 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.

II −3−2. 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 Chous Formations, the Damara Sequence largely consist of thick carbonate

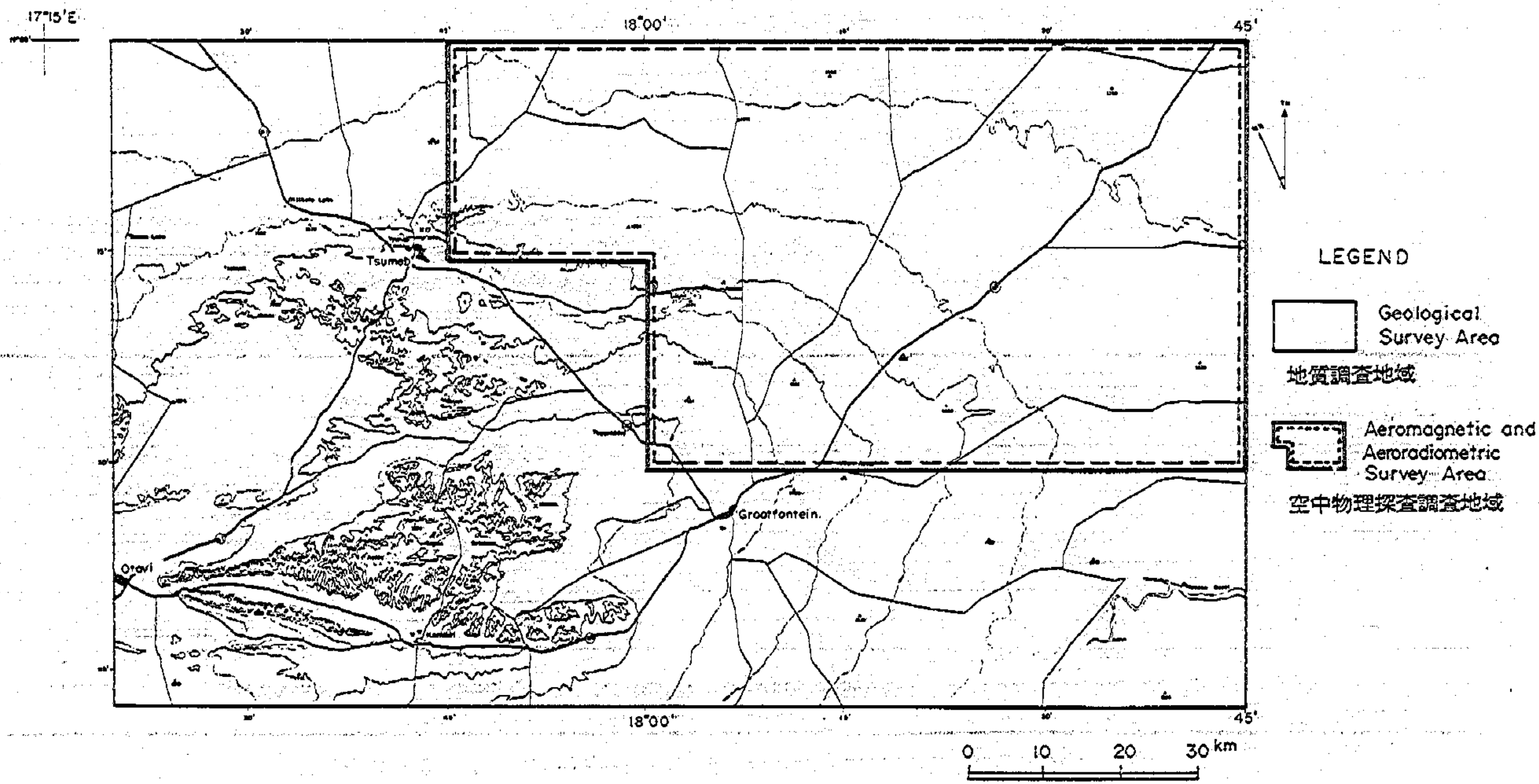

Fig. II — 3 — 1 Location of Geological Survey and Airborne geophysical Survey

Table II — 3 — 1 Microscopic Identification of Minerals in Thin Section

No.	Sample No.	Rock Name	Form. code	Constituent minerals										Accessory minerals									Sec. minerals			
				Qz	Pl	Kf	Hb	Mu	Bi	Cal	Dol	Ser	Chl	Sp	Mt	Zr	Ap	Tm	Lx	Ep	Hm	Op	Ser	Chl	Ep	Cal
1	100504	Biotite-hornblende granodiorite	Mgr	◎	◎	○	○		○					△	△	※	△				△		△	△		
2	100603	Quartz with opaque mineral	Mgr	◎								○					※	※				◎				
3	100605	Quartz hornblendite	Mgr	△	○		◎							△	△		※						○		△	
4	100607	Micro quartz diorite	Mgr	△	◎	△	○							※		※	※					△	○	△	△	
5	100608	Dolomite with calcite vein	Na	△							◎															◎
6	101308	Quartz-chlorite schist	Nc	◎	○							○	◎	△				※		△		○				
7	102103	Biotite-muscovite granite	Mgr	◎	○	◎		△	△					△			※						○	△		
8	102106	Altered porphyrite	Mgr	△	◎		◎												△		※		○	○	○	△
9	110601	Calcareous medium sandstone	Nm	◎	○	○				○		○				※		※				△				
10	110705	Dolomite	Nt	※							◎											△				

◎: 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 rocks with low magnetic susceptibility.

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

II-3-3. Faults and Lineaments

Structural features like faults and bedding within the basement show northeast and east-northeast-trends. The faults and the fractured system within the Damaran carbonate sequence show the following trends:

(1) Fracture zones at a quarry of Maria Bronn : N70° E/85° S

(2) A fracture in dolomite, Route B1 west of Tsumeb : N70° E/70° W

(3) Fault and fractured zones, near Railway southwest of Tsumeb : N30° E/75° E, N50° E/90°

(4) Fractured zones and the filling calcite veins in dolomite, south of Tsumeb :

N15° E/80° W, N80° /80° S, N60° W/90° ; N80° W/20-65° N or S

(5) Quartz network and silicified zone at Harasib old digging : N85° W

(6) Remnants of silicified dolomite, north of Kombat : N35-50° E, N85° E

(7) Fractured zones, west end of the Otavi Valley : N5-20° E/70° W, N5-10° W/80-W

(Calcitization vein): N80° W/80° S

From these field observations it may be concluded that north-northeast and east-northeast-trending faults and the lineaments essentially predominate over the survey area. However, a subordinate perpendicular trend of north-northwest and west-northwest is also developed.

II-3-4. Mineralisation

The results of microscopic identification of polished sections of ores is shown in Table II-3-2.

Vanadiferous mineral was identified in a high grade ore from the dump of closed Bobos mine. It is aggregate of coarse- grained dendric 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 thed isseminated feldspathic sandstone, cuprite with native copper and malchite 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 postore events such as diagenesis and thermal alteration.

Table II − 3 − 2 Microscopic Identification of Minerals in Polished Section

No.	Sample No.	Locality	Rock Name	Sulphide & primary oxide											Hydroxide	
				Cp	Gn	Sp	Py	Cc	Bo	Nc	Cup	Dg	Cv	V	Fe	M
1	100401	Tschudi mine	Malachite-galena ore		○			△1)				※	※			○
2	100405	Bobos mine	Mottramite ore											●2)		
3	100407	Tsumeb West mine	Chalcocite ore				※	○				※	※			◎
4	100408	Tsumeb West mine	Chalcocite ore					●								
5	101104	Rodgerberg mine	Chalcocite-covellin ore					●1)					○			
6	102004	Harasib mine 1	Descloizite ore											●		
7	102005	Harasib mine 1	Fe-hydroxides-Cu-Sp ore			◎−○				◎4)					●3)	
8	102006	Harasib mine 2	Galena sphalerite ore		◎6)	○							△5)			
9	102010	Harasib mine 3	Chalcocite ore					●		※						
10	102501	Abenab mine	Sphalerite galena ore		◎−○	◎	△									
11	102505	Abenab mine	Galena ore		○	△7)	△				△		△−※			
12	102506	Abenab mine	Sphalerite galena ore	※	◎	●−◎	△								○	
13	102507	Abenab mine	Sphalerite pyite ore		◎−○	◎	◎−○						※			
14	110601	Kombat-W E80 14L	Secondary copper ore					○		△	◎					◎
15	110602-1	Kombat-W L15/1 No.5	Chalcocite cuprite ore			※		△		※	△					
16	110602-2	Kombat-W L15/1 No.5	Fe-Mn ore					△							○?	
17	110603	Kombat-W E80 14L	Chalcocite bornite ore					◎	◎8)							
18	110604	Kombat-W 16L/1 No.2	Galena Chalcopyrite ore	●−◎	●−◎	○			○				△			
19	110605	Kombat-W 16L/1 No.1	Chalcopyrite galena ore	●	◎−○		△	◎−○								
20	110701	Tsumeb Mine,L10No.1	Chalcocite covellin vein				※	◎−○		※			△			

● : 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

1)Frequently coexists with covellin.
2)Enhedral to subhedral,showing zoning texture. Primary ore mineral.
3)Locally showing colloform texture,occurs as accicular 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.

Chapter 4 Aeromagnetic Survey

II-4-1. Objective and Method

The objective of the aeromagnetic and radiometric survey is to define lithologies by means of their magnetic and radioactive characteristics. The interpretation of the inferred subsurface geology will then be used to locate favorable areas for follow-up exploration. Calcrete covers more than three quarters of the survey area, mainly in the northeast.

During this high resolution aeromagnetic survey a Cecium magnetometer was used. For higher accuracy of data acquisition, low flight altitude and a small line spacing were maintained. Magnetic storms were measured and daily magnetic deviation was calibrated by a Proton magnetometer situated on the ground at the magnetic observatory station

II-4-2. Specifications of the survey

(1) The magnetic and radiometric data acquired within the flown area are shown in Fig. II-3-1.
(2)The direction of the flight line was planned basically north to south.
(3)The line spacing was determined as 200 metres.
(4)The tie line was planned at 2.5 kilometres intervals.
(5)A Cessna-type small aircraft was used.
(6)Constant altitude of the equipment was maintained at 80 metres, provided the aircraft and the equipment towed were safe.
(7)GPS-Video Tracking parallel method was used for navigation.
(8)The effects of artificial noise, climate and magnetic storm were minimized when flown.

Flight path is illustrated in Fig. II-4-1 and the coordinates of ends of lines are shown in Table II-4-2. Total line kilometre flown was 27,518 kilometres including the tie lines. The horizontal sampling interval was no less than 9 metres.

II-4-3. Equipment

The equipment used is shown in Table II-4-1. A supplementary brief about aeromagnetometer is given below.

(1)Disposition : The magnetometer was set at the tip of a thin rod which was attached to the tail of the aircraft.(see Appendix photo) The induced magnetic field caused by aircraft was cancelled by self-bucking.

(2)Principle and Capability: Cesium magnetometers works on the principal of photo pumping using Cesium 133 as a sensor. The magnetometer converts the Zeman orbital difference, changing due to the intensity of respective geomagnetic field, into AC electric signals. The frequency of the signals is called Lamor frequency, which correlates to the intensity of the geomagnetic field.

Table II − 4 − 1 Specifications of Equipment

System	Maker	Type	Specification	Num.
Airborne magnetic survey system	Scintrex	H8 Cesslum vapour magnetometer	Dynamic range: 20,000nT (69,972Hz) ~ 100,000nT (349,860Hz) Gradient :up to 50,000nT/m Sensitivity:0.005nT(10/sec)	1
Airborne radiometric survey system	Exploranium	GPX 2048,256 γ -ray detector	NaI-crystal:2048in3-Down 256in3-Up Absolute sensitivity : 8%	each 1
	Exploranium	GR-820-3 γ -ray spectrometer	Channel:256;(K40,Bi214,Th208 were selected)	1
Ground fixed magnetic system	Geometrics	G856-X Proton Magnetometer	Sampling rate : 1 time/30sec	1
Altitude measuring system	Intellisensor	AIR-DB-2B DigitalBameter/altimeter	Op.Range : -700m ~ 4206m RMS-Sense: ± 0.01mbar(0.1m) at sea level	1
	Sperry	Sperry 200-A Radar altimeter	Relative Accu. Altitude ± 3'(± 1m) ; 0 ~ 30m ± 3% ;30 ~ 152m	1
Navigation system	National Panasonic	AC-7450 S-VHS Video system	Tracking : Flight path Magnetic data	1
	Garmin	Differential GPS SRVY II system	Sence : ± 100m (flighting) : 3-10m (post flight)	1
Aircraft	Cessna	Cessna Titan 404	Twin engine Fuel capacity : 2400 l (9hours) Maximum gross weight:8400las Production speed : 260 ~ 300Km/hr	1

Equipment	Maker	Type	Specification	Num.
IP Transmitter	IRIS Instrument	IP-L Time domain O.S.C.	Output: 1 μ A ~ 100 μ A max10V	1
IP Receiver	SCINTREX	IPR-12 Multichannel receiver	Input: 8 Channel,14 Windows Input Range : 50 μ V ~ 14V	1
Electrode		Platinum		1
Magnetic susceptibility Meter	Geofyzika Brno Czechoslovakia	KAPPAMETER model KT-5	Sense: 0.01 × 1E-3 SI Range: 0.00 ~ 999 × 1E-3 SI	1
	Bison	Model-3101A	Sense: 1 × 1E-6 cgs Range: 0 ~ 100,000 × 1E-6cgs	1

Table II – 4 – 2 Boundary Points of the Survey Area

	XTM	YTM	Latitude			Longitude		
			Deg.	Min.	Sec.	Deg.	Min.	Sec.
1	131410W	303956N	19	15	0.000S	17	45	0.000E
2	131608W	331632N	19	00	0.000S	17	45	0.000E
3	105284W	331800N	19	00	0.000S	18	00	0.000E
4	78962W	331931N	19	00	0.000S	18	15	0.000E
5	52640W	332025N	19	00	0.000S	18	30	0.000E
6	26320W	332081N	19	00	0.000S	18	45	0.000E
7	26280W	304410N	19	15	0.000S	18	45	0.000E
8	26240W	276738N	19	30	0.000S	18	45	0.000E
9	52481W	276681N	19	30	0.000S	18	30	0.000E
10	78723W	276585N	19	30	0.000S	18	15	0.000E
11	104965W	276451N	19	30	0.000S	18	00	0.000E
12	105126W	304126N	19	15	0.000S	18	00	0.000E

II–4–4. Data Processing and Interpretation Procedure

Flow chart of data processing and interpretation is illustrated in Fig. II –4–2. This is followed by an explanation of the fundamentals and some technical terminology of the flow chart which concerns aeromagnetic interpretation.

II–4–4–1. Rock Magnetism

Rock magnetism can be described in terms of magnetic susceptibility and remnant magnetism. The susceptibility signifies a grade to which a rock is subject to magnetization induced by geomagnetic field. The greater this value is, the more easily a rock acquires magnitization. When a rock with magnetism is subjected to thermal or chemical episode, it is remagnetized parallel to the contemporary geomagnetic field and this magnetization is called Remnant Magnetism. The total magnetism is indicated by the combined vector of the induced magnetization and the remnant magnetization asindicated in the formula below.

$M=R+kH$

where M:Total magnetization R:Remnant magnetization k:Magnetic susceptibility H:Intensity of magnetic field

The R/kH ratio is termed as Konigsberger ratio which is abbreviated to Q ratio. The Q ratio for thermal remnant magnetization in igneous rock ranges 2 to 20 and that for depositional

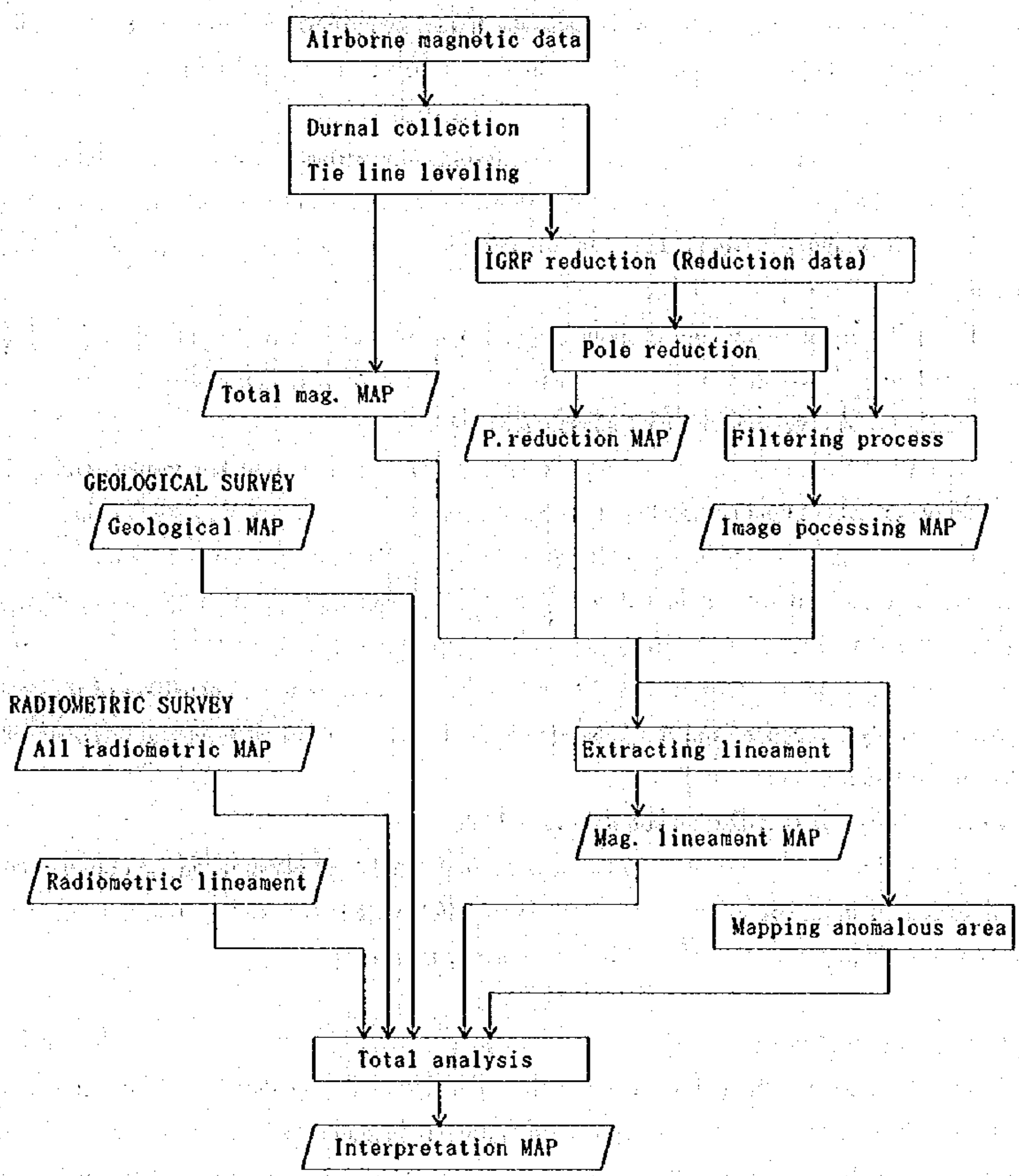

Fig. II − 4 − 2 Flow Chart of the Aeromagnetic Survey

remnant magnetization of sedimentary rock is less than 1. The thermal remnant magnitization is quite stable, it is therefore believed that the magnetization hardly gets modified over some tens to hundred million years. Some intrusive rocks, which had been emplaced prior to Tertiary age, thus show magnetic anomalies with a different direction to the current magnetic field.

II-4-4-2. Magnetic anomaly

A magnetic anomaly results from the local heterogeneity within a magnetic rock unit. The magnetization of a magnetic rock unit is proportional to the volume of magnetic minerals within the unit. The common magnetic minerals are magnetite, titanomagnetite and pyrrhotite. The characteristics of magnetic anomaly are as follows:

<1> The positive-negative pattern of magnetic anomaly varies with latitude giving only a positive peak or negative peak at the both poles.

<2> The pattern is reversed with the hemisphere.

<3> Short wave length component dominates when a magnetic rock unit lies shallow and long wave length component dominates when it is seated deep.

<4> The declination and inclination of magnetic field in Namibia are −10 and −60 degrees respectively. A positive pattern of induced magnetization will be formed to the north of the magnetic rock unit where as a negative pattern will form to the south.

The observed total magnetization in the aeromagnetic survey is the combination of regional magnetic anomaly component and the geomagnetic field which is deduced from the International Geomagnetic Reference Field (IGRF).

II-4-4-3. International Geomagnetic Reference Field

The IGRF is a global standard magnetic field, approximated from global magnetic observations and is calculated by means of an eight dimensional unfolding formula with a spherical function. The geomagnetic field varies yearly and is revised every five years.

II-4-4-4. Pole reduction

As anomalies have both positive and negative peaks the exact localization of magnetic rock poses difficulties. For qualitative interpretation, polar-reduction a mathematical calculation is used to remove all the outside magnetic influences so that only the magnetism of the underling rocks is reflected.

II-4-5. Result and Interpretation

II-4-5-1. Result of Measurement

Total field magnetic intensity contour map, Contour map of total field magnetic intensity data reduced to the pole and Magnetic Image Processing Products are shown in Fig. II-4-3, Fig. II-4-4 and Fig. II-4-5 respectively.