REPORT
ON
THE MINERAL EXPLORATION
IN
THE MAKONDE AREA
THE REPUBLIC OF ZIMBABWE

SUMMARY

MARCH 1995

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

REPORT
ON
THE MINERAL EXPLORATION
IN
THE MAKONDE AREA,
THE REPUBLIC OF ZIMBABWE

SUMMARY

MARCH, 1995

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

Preface

In response to the request by the Government of Zimbabwe, the Japanese Government decided to conduct a Mineral Exploration Project in the Makonde 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 to Zimbabwe a survey team headed by Mr. Yoshioki Nishitani from 21 June, 1992 to 28 December, 1994.

The team exchanged views with the officials concerned of the Government of Zimbabwe and conducted a field survey in the Makonde area. After they returned to Japan, further studies were made and the present report has been prepared.

This report is summary of the results of survey that was carried out through three years.

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

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

February 1995

Kimio FUJITA
President
Japan International Cooperation Agency

Takashi ISHIKAWA
President
Metal Mining Agency of Japan

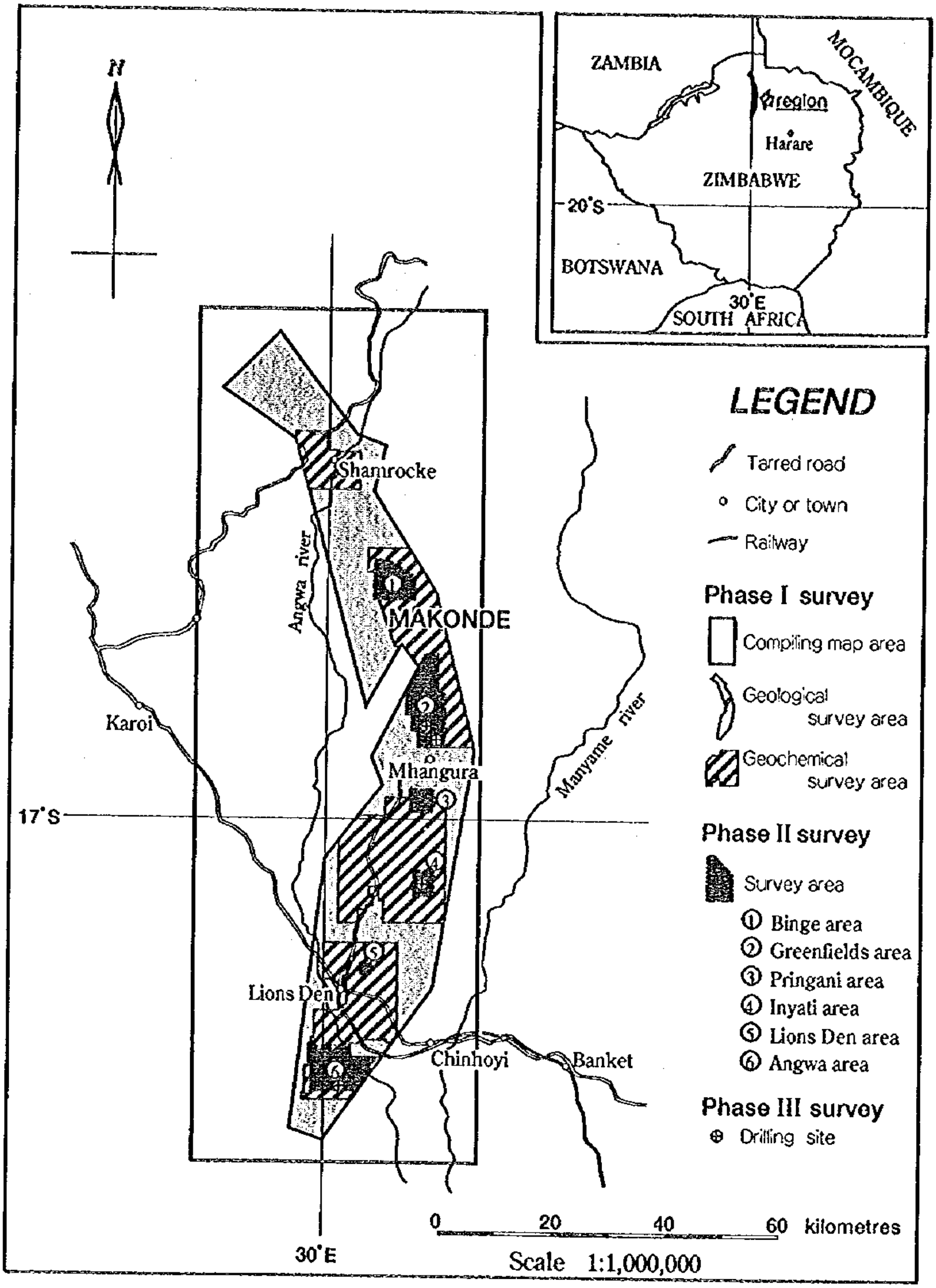


Fig. I-1-1 Locality of the survey area

Abstract

This report is summary of the Mineral Exploration Project in the Makonde Area.

1.Purpose of the survey

This survey was carried out in order to find out new ore deposits through the study of the geological setting and ore deposits of this area. At the same time, technological transfer from Japan to the related organization of Zimbabwe is one of the important purposes of this project.

2.Summary of works

Trough this survey, literature search, reconnaissance geological survey, soil geochemical exploration using GPS positioning system, analysis of previous geochemical data, geophysical IP exploration and drilling were carried out.

3.Results of the survey

Through the study of results of Phases I and II surveys and especially simulation analysis of geophysical IP anomalies, 4 exploration target sites for drilling were selected.
The following results of drilling exploration were obtained.

MJZM-5 obtained a mineralization of small vein and dissemination mainly consist of chalcopyrite and pyrite , which is concordant with the foliation of country rocks.

MJZM-7 and 10 obtained a weak mineralization of dissemination mainly consist of chalcopyrite, pyrite, bornite, chalcocite and sphalerite.

These mineralization are in same ore horizon of known ore deposits (United Kingdom Mine and Hans Mine) and show similar mineral composition, it seems to be obtained an extension or end portion of known mineralized zone.

On the other hand, by the results of chemical analysis of cores, maximum 4.7ppm of silver and maximum 0.45% of copper are observed. No expected ore with economical value are obtained.

By the results of drilling, weak mineralization was observed and around 0.5% of copper content may be obtained. However, high copper content ore that able to develop may be difficult to expect.

4. Recommendations foe the future

According to conclusions obtained through the survey results in Phases I to III and study of them, we would like to recommend the following for the future.

Though expected results with economical value were not obtained from the analysis results of mineralized zone, mineralization of sulphide minerals were recognized. Therefore, the following

survey method applied by the survey team can be recommended to be effective in the wide area with almost no outcrops like a the Makonde area.

1.Phase I : LANDSAT image interpretation, interpretation of previous works, geological reconnaissance survey and geochemical reconnaissance survey using GPS positioning system.

2.Phase II : Detailed analysis of existing geochemical data and geophysical survey (IP method).

3.Phase III: Drilling exploration on selected sites.

If the mineral exploration will be projected in similar area to Makonde area in the future, we will recommend to apply the above sequence of survey method.

If the geophysical IP survey will be projected, enough collection of ore and rock samples and physical property test of samples will be carried out before the IP survey. It will be necessary to able to separate the IP effect of ore and rocks.

CONTENTS

Figures

Tables

Part I General remarks

Part I General remarks

Chapter 1 Introduction

1-1 Area and purpose of the surveys

The Makonde area is located in the northern part of Zimbabwe. The distance and travel time by car from Harare are as follows.Locality of survey area is shown to Fig.I-1-1.

```
          1.5 hours                0.8 hours
HARARE ------------ CHINHOYI ------------ MHANGURA
       130 kilometres    ¦     70 kilometres
                         ¦       10 minutes
                         ------------------- ALASKA
                             12 kilometres
```

In the Makonde area, the target area of this survey, there are major Cu-Ag-Au deposits of Zimbabwe such as the Mhangura Mine and the Shackleton Mine. There are the high potentialities of the existence of the same type deposits which are undeveloped.

As the production of ore in these mines has been decreasing in recent years, the discovery of new deposits is urgently expected. Therefore, the Government of the Republic of Zimbabwe requested to conduct the Technical Cooperation for a Mineral Exploration to the Government of Japan.

The Government of Japan corresponded the request and conducted the survey within a period of three years commencing from 1992.

Through these surveys, the survey team was dispatched and carried out the survey in order to explore new deposits.

1-2 Method and Specification of the survey

Flow sheet of the Survey and flow chart of selection of the promising area are shown in Fig.I-1-2 and Fig.I-1-3.

Method and specification of the survey in each Phase are shown in TableI-1-1.

1-3 Terms and Members of the survey

Terms and Members of the survey in each Phase are shown in TableI-1-2.

[FLOWSHEET OF THE SURVEY]

Phase I

Survey Area (Makonde Area) 7,500 km²

↓

Analyses of the Satelite Image (Scale ; 1:250,000)
Literature Seach (Geological Compile Map, Scale ; 1:100,000)
Geological Survey (Geological Map, Scale ; 1:100,000)
Survey of the Mines and Mineralisation Areas ; 9 Areas
Soil Geochemical Survey ; 3,676 Samples
Physical Property Test of Rocks and Ore Samples ; 41Samples

↓

Analyses of Survey Resalts and Discussion

↓

Selection of the Promising Area

↓

Recommendation for the Phase II survey

↓

Phase II

↓

Previous Geochemical Data Analyses ; 5 Areas
(Total 110km², 33,681Samples)
IP Method Geophysical Survey ; 6 Areas
(Reconnaissance IP 51.0km, Semi-detail IP 23.2km)

↓

2.5 Demensional analyses of Geophysical Survey

↓

Analyses of Survey Resalts and Discussion

↓

Selection of the Promising Area

↓

Recommendation for the Phase III survey

↓

Phase III

↓

Drilling Survey 10 Holes Total 4,057.50m

↓

Analyses of Survey Resalts and Discussion

↓

Recommendation for Future

Fig. 1-1-2 Flow sheet of the survey

[FLOW CHART FOR SELECTION OF PROMISING AREA]

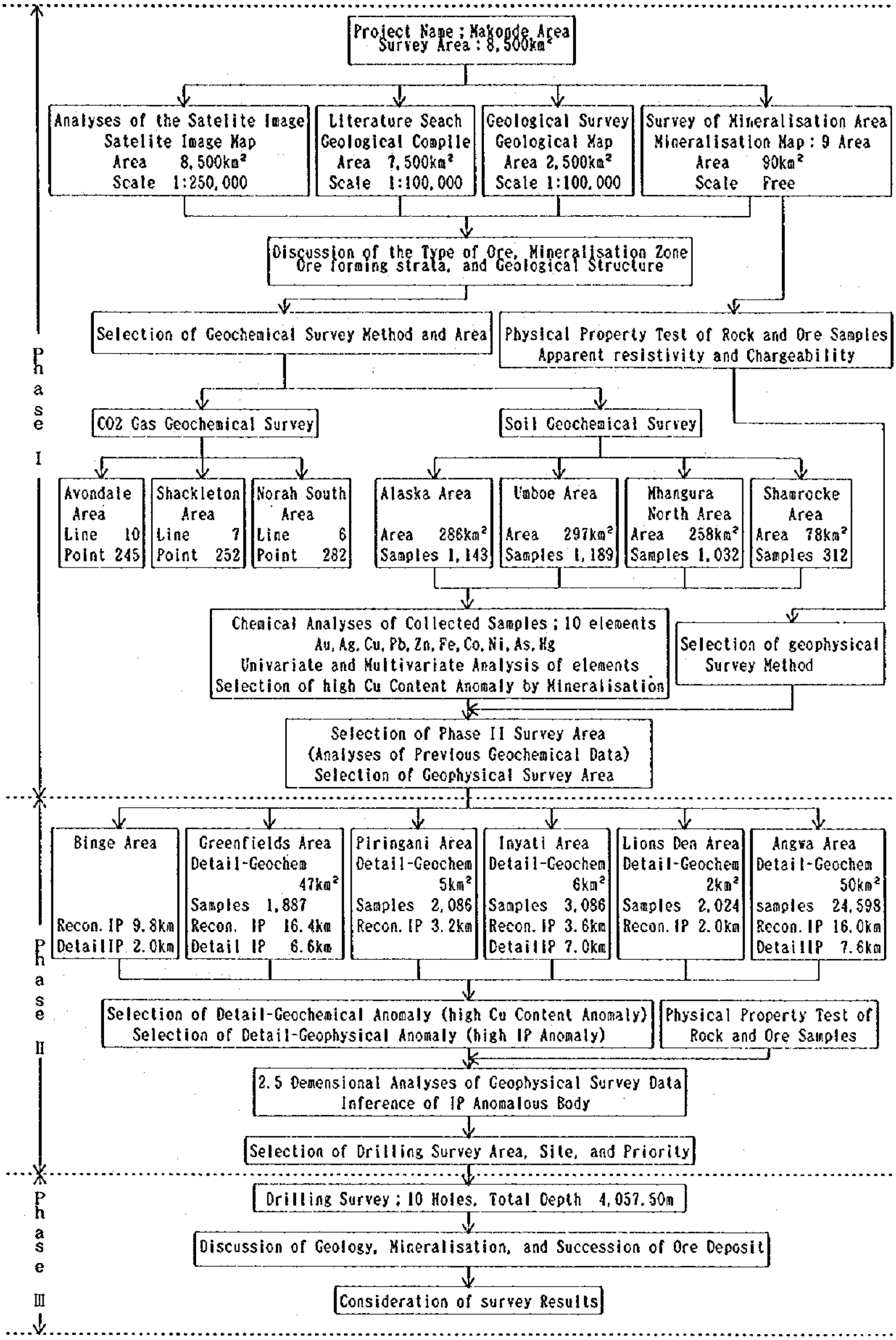


Fig. I-1-3 Flow chart of selection for the promising ares

Tablel-1-1 Contents of the survey

Phase	Phase I	Phase II	Phase III
Priod	1992.6.16～1993.1.25	1993.7.1～1994.2.15	1994.7.14～1995.2.20
Analyses of Satelite Image	Image Map 8,500km²		
Literature Seach	Geologic Map (1:100,000) 7 Sheets Reports of the Post Survey 1 Set Geological Documents 1 Set Airborne Magnetic Survey Data 14 Sheets	Previous Geochemical Data Analyses Green fields Area 47km² Piringani Area 5km² Inyati Area 6km² Lions Den Area 2km² Angwa Area 50km²	
Geological Survey	Survey Area Reconnaissance 2,250km² Mineralisation Zone (9 Area) 90km² Extension of Survey Line Reconnaissance 100km Mineralisation Zone (9 Area) 135km		
Geochemical Survey	Survey Area 916km² Soil Samples 3,676 Measurments(CO_2gas) 781		
Geophysical Survey		Survey Area: Green fields Area, Piringani Area, Inyati Area, Angwa Area Lions den Area, Rconnaissance Survey Total Line km 51km No.of Operation 656 Semi-Detail Survey Total Line km 23.2km No.of Operation 366	
Drilling Survey			No.of Drilling 10 Holes Total Depth 4,057.50m
Laboratory Test	Microscopic observation of rock thin section 50 Microscopic observation of ore polished samples 31 Chemical Analysis Ore 52 (Au, Ag, Cu, Pb, Zn, Co, Ni, Pt) Soil 3,636 (Au, Ag, Cu, Pb, Zn, Fe, Co, Ni, As, Hg) Measurement of Resistivity and Chargeability 41	Measurement of Resistivity and Chargeability 41	Microscopic observation of rock thin section 23 Microscopic observation of ore polished samples 11 Chemical Analysis Ore 183 (Au, Ag, Cu, Fe, Co, Ni, Pt) Soil 228 (Au, Ag, Cu, Pb, Zn, Fe, Co, Ni, As, Hg) Measurement of Resistivity and Chargeability 122

Tablel-1-2 Terms and members of the survey

Phase	Phase I	Phase II	Phase III
Priod	1992.6.16~1993.1.25	1993.7.1~1994.2.15	1994.7.14~1995.2.20
Planning and Negotiation	Ministry of Foreign Affairs Mr. Jiro KOMATU Ministry of International Trade and Industry Mr. Shinnji IKEDA Japan International Cooperation Agency Mr. Hitoshi SATO Metal Mining Agency of Japan Mr. Satoshi OKUMURA Mr. Takahisa YAMAMOTO Mr. Nobuyuki MASUDA Mr. Haruhisa MOROZUMI	Metal Mining Agency of Japan Mr. Haruhisa MOROZUMI	Japan International Cooperation Agency Mr. Ken-ichi TAKAHASHI Metal Mining Agency of Japan Mr. Haruhisa MOROZUMI Mr. Yoichi OKUIZUMI
	Geological Survey Department of Zimbabwe Dr. John Lisle ORPEN Mr. Surrender Mdunyiswa Nyahwa NCUBE	Geological Survey Department of Zimbabwe Mr. Surrender Mdunyiswa Nyahwa NCUBE Mr. Edson MUSHAYABASA Mr. Fdzanai Bornwell MUPAYA Mr. Jameson RUSHWAYA	Geological Survey Department of Zimbabwe Mr. Surrender Mdunyiswa Nyahwa NCUBE
Field Survey	DOWA Engineerig Co., Ltd. Mr. Yoshioki NISHITANI Mr. Naoya YUNOHARA Mr. Makoto SUGA Mr. Shin-ichi Iwaya Mr. Hirohide KONNO	DOWA Engineerig Co., Ltd. Mr. Yoshioki NISHITANI Mr. Hirohide KONNO Mr. Hiroshi JINGU Mr. Mitio TANAHASHI Mr. Kuraei IWAKI Mr. Tadashi NYUUI	DOWA Engineerig Co., Ltd. Mr. Yoshioki NISHITANI Mr. Katsunori SASAKI
	Geological Survey Department of Zimbabwe Mr. Fdzanai Bornwell MUPAYA	Geological Survey Department of Zimbabwe Mr. Fdzanai Bornwell MUPAYA Mr. Jameson RUSHWAYA Ms. Cheneso MUPFUMI Mr. Joseph MADEKENI	Geological Survey Department of Zimbabwe Mr. Fdzanai Bornwell MUPAYA

Chapter 2. Previous works

As regards the geology of this area and the surrounding area, geological maps of Zimbabwe on a scale of 1:1,000,000 and 1:100,000 are published by GSD.

As regards the exploration data of this survey area, 30 explorations was carried out between 1948 and 1978 by Messia Transvaal Development Co.Ltd.(hereinafter called MTD Co.Ltd.), Rhodesia Copper Ventures Limited (hereinafter called RCV Ltd.), Rhodesia Section Trust Exploration Limited (hereinafter called RSTE Ltd.) and other organizations with Exclusive Prospecting Order (hereinafter called E.P.O.).

As regards the nation wide surveys, the airborne magnetic survey was carried out by the financial and technical cooperation of CIDA (Canadian International Development Agency) and GSC (Geological Survey of Canada) in 1983 and 1990. By this survey, the structure of Magondi Supergroup and low magnetic anomalies at the shallow deposit zones of the Mhangura Mine, the Angwa Mine and the Hans Mine are revealed.

As the theses, there are many papers about geology such as Mundon,1987; Shoko,1985; Vinyu,1985 and Jacobsen,1962, and about ore deposits such as Kyle,1972; Muchenje,1974 and Tsomondo,1980, As regards the other authors, Thole,1974 and Master,1991, studied about this area.

Zimbabwe Mining Development Cooperation (hereinafter called ZMDC) re-examined the Previous E.P.O.s and the various records kept in the Mangula Mine since 1987, and recommended the following guiding principles of survey (Simpson:1990).

1) As regards geology and geological structure of ore deposit.

a) Cyclic sedimentation associated with the building of alluvial fans, stream delta, etc.

b) Early anticlinal fold axis which are formed before lithofication of the sediments.

c) Airborne magnetic and soil geochemical trends which transgress the N-S basin in a NE-SW direction.

d) Early strike slip faults parallel to the basin edge which could act as feeder for mineralized fluids.

2) Guidance of the future survey and the survey area based on the examination above mentioned.

a) Geological mapping of known structural trends crossing the basin;

i) Wari-Shackleton-Avonshack-Nijri

ii) Kenilworth-Hans-Angwa

iii) Muni West-Muni-Munwa

iv) Veldesia

v) North and South of Greenfields

b) Reconnaissance mapping from airphotos of areas not covered above.

c) Test surveys with several geophysical methods to see it known ore bodies can be found.

d) Drilling of Wari, Muni West and Kenilworth zones down plunge from present intersection.
e) Drilling of the Muni under Muni West will require good surface mapping before hole placement. f) Drilling of Valdesia and Nijiri based on the surface mapping of the known mineralized areas.
g) Study of known ore bodies by geochemical and mineralogical methods to see if there is a marker alteration to the ore zone. This could be done by the University of Zimbabwe as several undergraduate projects or a graduate degree. Possibly a company geologist could do a master Degree on it part time.

Chapter 3. General geology

3-1 General geology

Geology of this area consists of gneiss, green rocks and granites of Archaean era which forms the basement, and sedimentary rocks and volcanic rocks of Proterozoic era called Magondi Supergroup. Geological map is shown in Fig.II-3-1. Schematic geologic column is shown in FigI-3-2.

The basement rock consists of gneiss, green rocks and granites. Gneiss is distributed in the northern part. Green rocks are distributed in the southern part and are composed of mafic rock and felsic sandstone. Granite is distributed in the eastern side of the Mhangura Mine and the southern part of the survey area.

Magondi Supergroup is divided into Deweras Group, Lomagundi Group and Piriwiri Group from the lower to the upper horizon.

Deweras Group mainly consists of alluvial fan sediments such as conglomerate, arkose with cross-bedding and grading, and pelitic schist partly associated with chemical sedimentary rocks. It shows the structure of repeated sedimentation of the unit of Playa. This Group is distributed in the central part of the area successively from the north to the south, and includes strata-bound copper deposits.

Lomagundi Group can be divided into the lower formation which mainly consists of dolomite and poke-marked quartzite and the upper formation which mainly consists of stripped slate.

Piriwiri Group mainly consists of phyllite, graywacke, graphitic slate and quartzite, and is partly accompanied with volcanic rocks and pyroclastic rocks. It is widely distributed in the western part of this area covering Lomagundi Group with conformity.

3-2 Geological structure

The Sedimentary rocks in Magondi Supergroup was formed by sedimentation within the rift valley which was extended by the left lateral fault parallel the Great Dyke direction. According to the extension of the rift valley, alluvial fan sediments and playa sediments (Deweras Group) which was originated from basement rocks were formed at first, and covered lagoon sediments(lower Lomagundi Group) which consists of dolomite, quartzite and slate, later. Finally, pelitic rocks, fissilitic phyllite which was originated from pelitic rocks and alteration of fallen volcanic rocks, and deep sea sediments (Piriwiri Group) deposited.

Initially, parallel faults and anticline axis cross obliquely to rift valley were formed by strike-slip fault according to extension of the rift valley. These faults and anticline axis were formed before compaction of Magondi Supergroup, and formed the environment of ore solution path and strata bounded disseminated copper deposits.

Second structural movement is so-called the Magondi Mobile Belt, which forms fold with N-S and NNE-SSW and thrust structure due to change of this area to compaction. The age of this mobile belt is considered to be 1,800Ma to 2,000Ma by Pb-Pb and Rb-Sr age determination method (Master, 1991).

Final Structural movement is called the Pan-Africa Zambezi Mobile Belt, which affected marked metamorphism to the northern part of this survey area and controlled the fold structure in the Shamrocke area.

3-3. Known ore deposits

The copper ore deposits are the only mineral resources which have economic feasibility. Silver and gold associated with copper ore deposits are also recovered. Besides the metal resources, crushed dolomite for construction and slate for building materials are worked in several places.

9 mines and ore deposits have operated before, but now only the Angwa Mine, the Shakleton Mine including the Avondale ore deposit, and the Mhangura (Miriam) Mine are still mining at present. These ore deposits are shown in Fig.II-3-1.

These ore deposits are roughly classified into the two deposits occurring in the Deweras Group and in the Lomagundi Group.

The former are strata bound ore deposits occurring within arkose of the Deweras Group. The Hans Mine, the Angwa Mine, the Shackleton Mine including the Avondale ore deposit, the Norah Mine and the Mhangura (Miriam) Mine are developed. The formation of the ore deposition is considered to be strongly controlled by the sedimentary environment and geological structure of country rock (Simpson, 1990). As the result of the survey of the ore deposits and the mineralization area, the anticline structure from the direction of the NW-SE is considered to be important.

The Old Alaska Mine in the south-western part of the area and the Shamrocke Mine in the northern part belong to the latter.

Moreover, There is the United Kingdom Mine as a vein type ore deposit.

Chapter 4 Environment of the survey

4-1 Traffics

There are paved national roads and local roads from the Capital to the survey area. Even during the rainy season of November to March, it is possible to access to the survey area.

However, roads between Karoi and Shamrocke are not paved, and only the 4WD cars can drive in the Safari area. So it is difficult to survey in the rainy season.

4-2 Physical features

4-2-1 Topography and river system

The topography of the survey area shows peneplain like a moderate swell of the elevation of 1,000 metres to 1,250 metres.

The mountain system is controlled by the geology in the area. The mountains stretch the direction of the NNE to the SSW in the southern part and NNW to SSE in the northern part.

Rivers flow to the direction of the west or the north, and flow into Angwa river which runs in the western part of the area. Angwa river runs to the north to flow into Zambezi river which make the northern border of Zimbabwe with Zambia.

All the rivers flow only in the rainy season. There is no water in the river except some pools in the dry season.

4-2-2 Climate and vegetation

The climate of the survey area is divided into the dry season (from April to October) and the rainy season (from November to May). Maximum temperature is constant of 25 to 28 degree centigrade through the year. Minimum temperature shows 17 degree centigrade in rainy season and from 5 to 10 degree centigrade in dry season. Rainfall of each month shows about 180 mm par month in the rainy season and from 1 to 5 mm par month in dry season. No rainfall is recognized in dry season.

As regards vegetation, except short broad-leaved tree as oaks which distributes in the mountainous district, the vegetation is generally thin in the survey area. Tall legume as acasias is usually distributed in the mountain skirts and in the plain, Many coconut palms and cycads characteristically grow along the river. No coniferous trees are generally seen except few in the pasture and afforested area.

The plain extended from the southern part of the survey area to the north of the Mangula Mine is owned by large-scale farmers to grow wheat, corn and grass, and pastures.

Chapter 5 Conclusion and recommendation

5-1. Conclusion

Trough this survey, literature search, reconnaissance geological survey, soil geochemical exploration using GPS positioning system, analysis of previous geochemical data, geophysical IP exploration and drilling were carried out.

Conclusions obtained these surveys are as follows :

(1) An active geochemical survey had been carried out to search the copper mineralization in the area from north of Mhangura to south of Alaska, many E.P.O.s reports, geological map, doctoral theses and others were published.

(2) All the deposits of large scale mines in this area are strata bound disseminated copper sulphide deposit type occurring in arkose of Deweras group.

(3) As the results of geochemical survey, following areas were considered to be important for future exploration.

1) Distribution area of results of the Deweras Group
2) High copper content area of soil geochemistry
3) Distribution of high score of 4th principal component for 6 elements (Cu, Pb, Zn, Fe, Co, Ni)

8 promising sites were selected based on this result.

(4) Based on the physical property test of ore and rock samples, it become clear that the IP method geophysical survey for deeper place is effective in this area. Therefore, reconnaissance and semi-detail IP survey was carried out at the geochemical anomalous sites, and 4 sites of IP anomalous source body was extracted.

(5) Through the study of results of Phases I and II surveys exploration target sites for drilling were selected. The following results of drilling exploration were obtained.

MJZM-5 obtained a mineralization of small vein and dissemination mainly consist of chalcopyrite and pyrite , which is concordant with the foliation of country rocks.

MJZM-7 and 10 obtained a weak mineralization of dissemination mainly consist of chalcopyrite, pyrite, bornite, chalcocite and sphalerite.

These mineralization are in same ore horizon of known ore deposits (United Kingdom Mine and Hans Mine) and show similar mineral composition, it seems to be obtained an extension or end portion of known mineralized zone.

On the other hand, by the results of chemical analysis of cores, maximum 4.7ppm of silver and maximum 0.45% of copper are observed. No expected ore with economical value are obtained.

By the results of drilling, weak mineralization was observed and around 0.5% of copper content may be obtained. However, high copper content ore that able to develop may be difficult to expect.

5-2. Recommendations foe the future

According to conclusions obtained through the survey results in Phases I to III and study of them, we would like to recommend the following for the future.

Though expected results with economical value were not obtained from the analysis results of mineralized zone, mineralization of sulphide minerals were recognized. Therefore, the following survey method applied by the survey team can be recommended to be effective in the wide area with almost no outcrops like a the Makonde area.

1.Phase I : LANDSAT image interpretation, interpretation of previous works, geological reconnaissance survey and geochemical reconnaissance survey using GPS positioning system.

2.Phase II : Detailed analysis of existing geochemical data and geophysical survey (IP method).

3.Phase III: Drilling exploration on selected sites.

If the mineral exploration will be projected in similar area to Makonde area in the future, we will recommend to apply the above sequence of survey method.

If the geophysical IP survey will be projected, enough collection of ore and rock samples and physical property test of samples will be carried out before the IP survey. It will be necessary to able to separate the IP effect of ore and rocks.

Part Ⅱ Details of the surveys

Part II Details of the surveys

Chapter 1 Analyses of satellite images

1-1. Outline of the area

The Makonde area where is the target area of analyses is located in the northern part of Zimbabwe. The center of the area is located in 30°E and 17°S. The survey area is in 29°50'E to 30°15'E and 16°15'S to 17°30'S. The area lies 50 kilometres from the north to the south and 170 kilometres from the east to the west and total area is 8,500 square kilometres.

The geology of the area belongs to the African shield and the strata of Archeozoic to Proterozoic period is widely distributed.

1-2. Remote sensing data

LANDSAT TM data which were interpreted are as follows.

TableII-1-1 List of LANDSAT data

The frame of orbit		Observation data	ID number	Sun Angle Amount of Elevation		
path	row			Clouds	Angle	Azimuth
170	71	22 June, 1984	5170071008417410	0%	36°	44°
170	72	22 June, 1984	5170072008417410	0%	35°	43°
171	71	29 June, 1984	5170071008418110	0%	36°	44°

1-3. Results of analyses

The satellite image interpretation map on a scale of 1:250,000 was made as the reference of the Mineral Exploration in the Makonde Area. The map was made by the aerophotograph interpretation method of LANDSAT TM images. On the interpretation, the geologic maps on scales of 1:100,000 and 1:1,000,000 and the Attached Explanation published by the Geological Survey Department of Zimbabwe were used as the references.The interpretation results are summarized below:

(1) The Zambezi fault bordered the Karoo System from the Pre-Cambrian System is clearly recognized. The mineral resources occur in the Pre-Cambrian System.

(2) The classification and the topographic characteristics of the basal composite rock body which was formed in Archeozoic era are interpreted. Therefore, the distribution of the basement became obvious.

Gold ore deposits accompanied with faults within the Archaean are known, and the deposits continue to the north-east from the target area. The noteworthy mineralization in the Zambezi mobile belt and the granite is unknown.

(3) The outline of geological structure and distribution of the Piriwiri, Deweras and Lomagundi Groups which were formed in proterozoic period were interpreted. Particularly, the outline of the structure and distribution of the Deweras and Lomagundi Groups in which banded type ore deposits occur became distinct.

(4) It is recognized by the interpretation that the faults from the north to the south and the north-eastern to the south-western directions from the central to the southern part and the faults from the north-eastern to the south-western directions are prominent as the characteristics of this area.

(5) There are difficult parts to interpret due to development of cultivation on the moderate topography.

Chapter 2 Literature search

List of the literature is shown in TableII-2-1. 4 copper mines are still worked at the present of 1992. Many surveys of ore deposit under E.P.O.s were carried out in the survey area.

TableII-2-1 List of literature

the leterature[1]	acounts
Geological maps a scale of 1:1,000,000 a scale of 1:100,000	 1 sheet 7 sheets
The prvious E.P.O.s.	30 (Nos. 4, 5, 6, 20, 21, 35, 42, 43, 61, 62, 71, 74, 75, 80, 82, 83, 101, 106, 122, 137, 152, 249, 297, 351, 377, 396, 414, 422, 507, 514)
Geophysical Survey aeromagnetic maps, a scale of 1: 50,000	14 sheets
Others	9 papers

1) See the refference.

2-1 Geology and economic geology

As regards geology of this area, there are "the Geological Map of Zimbabwe" on a scale of 1:1,000,000 (Stagman, 1978) and "the Geological Map" on a scale of 1:100,000 and "The Attached Explanation" (Fey and Broderic, 1990 ; Hahn and Steiner, 1990 ; Kirkpatrick, 1976; Stegman, 1959, 1961 ; Tennick, 1976 ; Wiles, 1961) published by the GSD of Zimbabwe.

1. Outline of geology

A comparison of stratigraphy of each map is shown in Table II-2-2. There are some contradictions among these comparison of stratigraphy. Therefore, the stratigraphy of the compiled geological map was made to add or to delete based on Simpson's stratigraphic classification (Simpson, 1990) after the comparisons of each stratigraphic classification of the geological map.

Geology in the area consists of the archaean era as the Basement Rocks, the Bulawayan Group, the Shanvaian Group and the Pre Magondi Intrusive Rocks, early proterozoic era as the Magondi Supergroup, the Guruve Metamorphic Complex, the Post Magondi Intrusive Rocks and the Sijarira Group, the Upper Karoo Formation of triassic, and Quaternary sediments from lower to upper.

The Basement Rocks is distributed in the northern part of the compiled area, and consists of tonalite or orthogneiss of the composition of granodiorite, the Zambezi Escarpment Paragneiss, Urungwe Paragneiss and Chitumbi Paragneiss which have originated from graywacke and arkose.

The Bulawayan Group is distributed in the south-eastern part. The Group consists of banded the iron formation which often develops in the basement, meta-dolerite, pillow lava and basaltic green rocks.

TableII-2-2 Correlation of stratigraphies

Ages	North West Fey & Broderick(1990)	North East Bahn & Steiner(1990)	Central West Wiles(1961)	Central East Stagman(1956)	Southern West Kirkpatrick(1976)	Southern East Stagman(1961)	Southen margin Tenick(1976)	Khangura to Alaska Simpson(1990)
Quarternary	Recent	Recent	Recent	Recent	Recent	Recent	Recent	Recent
Cretaceous/ Jurassic		Kadzi Beds						
Triassic		Upper Karoo						
Lower Proterozoic	Piriviri Group Lomagundi Group Argillaceous Formation Arenaceous Formation Deweras Group	Guruve metamorphic Complex Lomagundi Group Nyagari Formation Mcheka Formation Deweras Group	Intrusive Igneous Rocks (Divided by Metamorphic grades)	Intrusive Igneous Rocks Lomagundi System Argillaceous Series Arenaceous Series Deweras Series ? System Piriviri Series	Sijarira Group Igneous Rocks Lomagundi Group Zhonthi Formation Sinoia Caves Formation Deweras Group Piriviri Group Chitena Formation Kanyaga Formation Allochthonous Rocks of the Urungwe Klippe	Intrusive Igneous Rocks ? System Sijarira Series Intrusive Igneous Rocks Lomagundi System Upper Series Deweras Series ? System Piriviri Series	Various Ages Piriviri Group Umfuli Formation Lomagundi Group Nyagari Formation Mcheka Formation Deweras Group Arenaceous Formation Volcanic Formation	Post Magondi Intrusives MAGONDI SUPPER GROUP Piriviri Group Umfuli Formation Lomagundi Group Nyagari Formation Mcheka Formation Deweras Group Multi-colour schist F. Miriam Grit Formation Goobera Hill Volcanic F.
Archaean	Chitumbi Paragneiss Urungwe Paragneiss Escarpment Paragneiss Basement Complex	Younger Granitoids Older Granitoids Mafic/Ultramafic Intrusive Rocks Escarpment Complex Shamvaian Group Coeval Units Bulawayan Group		Intrusive Igneous Rocks Younger Granite Older Granite Shamvaian System Bulawayan System	Urungwe Group Gneissose Granite	Intrusive Igneous Rocks Shamvaian System Sedimentary Series Bulawayan System Volcanic Series	Intrusive Igneous Rocks Bulawayan Group Felsic Formation	Pre Magondi Intrusives Lamprophyre & Granodiorite Mangula (Young) Granite Archean (Old) Granite Diabase dyke Shamvaian Greenstone Belt

The Shanvaian Group consists of meta-arkose, graywacke, conglomerate and fine-grained siliceous rock.

The Pre-Magondi Intrusive Rocks are distributed in the south-eastern part, the east and the north-eastern part of this area. They also consist of serpentinized ultra-basic rock, meta-gabbro and porphyritic or even-grained granite called Younger Granite.

Magondi Supergroup is widely distributed from the central part to the western part of the area. It is roughly classified into the Deweras Group, the Lomagundi Group and the Piriwiri Group. The Deweras Group is divided into the Sandy Formation with mainly arkose with conglomerate and the Volcanic Formation of basaltic lava and pyroclastics. The grain size of arkose varies from granule to clayish. It is arranged such that the sediments consist of alluvial fan sediments, stream sediments and playa sediments in the so-called Magondi sedimentary basin which was formed by extension of rift valley. This Group is main country rock of copper ore deposits in this area. The Lomagundi Group consists of the Mcheka Formation and the Nyagari Formation, and is distributed surrounding the Deweras Group. Mcheka Formation consists of dolomite, quartzite and siliceous rock partly with basal conglomerate. The Nyagari Formation is composed of mountain sandstone, quartzite, felsic quartzite and slate. Only The Unfuli Formation is distributed in the compiled area as the Piriwiri Group. Graphitic slate is distributed in the boundary part of the Lomagundi Group in the lower part, and phyllite with graywacke is widely distributed. Quartzite and sandstone is partly recognized.

The Guruve Metamorphic Complex consists of mainly quartzite, biotite schist and hornblende schist and is distributed along the Zambezi fault scarp in the north-eastern part of the survey area.

The Post-Magondi Intrusives Rocks consist of biotite granite, mete-dolerite or doleritic rock, amphibolite, pegmatite and quartz (-carbonate) vein. Biotite granite which has intruded into the Piriwiri Group which is distributed in the north-western part of the area. Dolerite, amphibolite and quartz vein are also widely intruded in this area. Pegmatite is recognized in Younger Granite in the eastern part and is distributed within the Piriwiri Group showing a dyke form in the area of the western to the north-western part.

The Sijarira Group is exposed in the Younger granite area in the south-western part of the compiled area on a small scale.

The Upper Karoo Formation of the Triassic period is distributed along the Angwa river on a small scale in the northern part of the compiled area. It consists of aerolian or fluvial eroded sandstone with poor sorting.

There are two kinds of Quaternary sediments. One is composed of talus alluvial fan sediments which is distributed along the northern big river of Zambezi fault scarp in the northern part of the area. The other is composed of pebble, sand, soil and alluvial sediments which is markedly distributed along the rivers in the area of the southern to the central part.

2. Geological structure

The survey area is located in the Magondi mobile belt. The Magondi Supergroup which consists of Proterozoic sediments and volcanics is widely distributed from the direction of the south to the north. The Magondi Supergroup is roughly divided into the Deweras Group, the Lomagundi Group and the Piriwiri Group in ascending order horizon. Deweras Group is considered to be sediments within the sedimentary basin of the rift valley (Cooper, 1978) or the craton (Maiden et al, 1984). The eastern margin of the Group is controlled by fault from the direction of NNE–SSW. The thickness of the Piriwiri Group of the upper horizon becomes thicker to the western side, which indicates expansion of the sedimentary basin.

Structural analyses of the southern part of the Magondi Mobile Melt are carried out for the Copper Queen district which is located 60 kilometres west of Chinhoyi (Leyshon, 1969), Shackleton district (Treloar, 1988) and Chinhoyi district (Stowe, 1978). Three periods of deformation are distinguished in these district. The fold structure with the direction of the NE or NNE is considered to be the main facies (F1) which originated from the initial cleavage. The F2 fold in the Copper Qeen district has the same direction of fold axis of F1, however, the axial-plane inclined to the west. F3 with the direction of the NW forms an oblique fold against F1 and F2 folds (Leyshon and Tennick, 1988). The fold axis of the NW is considered to be F2 in Chinhoyi district and the axis of the direction of the NE is F3 (Stowe, 1978). F1, F2 and F3 have the directions of 10°E, 55°E, and 30°E, respectively. The NW trend is not recognized in the Shackleton district (Treloar, 1988).

On the other hand, there are three of the deformation structures which shows the NNE–SSW to the N–S and fold structure of the direction of the NE–SW, and lateral fault of the direction of the NE–SW in the northern part. However, the structure with the direction of the NW–SE is not recognized (Thole, 1974).

TableII–2–3 Geochronology of the Magondi mobile belt

Stratigraphy			Age (Ma)	Data	Events
			650~400	(K-Ar mica age(Clifford et al. 1967))	Pan-African Zambesi thermal event
			1659 ± 50	(K-Ar Piriwiri phyllite(Vail et al. 1968)	Magondi metamorphic age
			1753 ± 65	〃	
			1905 ± 70	(K-Ar Lomagundi striped slate(Vail et al. 1968)	
			1974 ± 70	〃	
			1780 ± 280	(Rb-Sr Piriwiri granulite(Treloar & Kramers, 1989)	
			1890 ± 260	(Rb-Sr Piriwiri enderbite(Treloar & Kramers, 1989)	
			2000~1800	(Treloar & Kramers, 1989)	
			2000~1700	(Hahn & Steiner, 1990)	
	Post Magondi Intrusive rocks		1960 ± 80	(Rb-Sr WR granitoid(Loeny, 1969))	Syn- to post-tectonic granites
			2153 ± 125	(Rb-Sr WR Urungwe granite(Clifford et al. 1967))	
			2150 ± 100	Rb-Sr Pegmatite and late Granite	Post tectonic granites
Lower Proterozoic	Magondi Super-Group	Piriwiri Series	2100 ± 200	Pb-Pb Copper Queen massive sulphide(Leyshon, 1969)	Sedimentation ages
		Lomagundi Series	–	――――	
		Deweras Series	2170 ± 100	Pb-Sr lava(Boehndorf, unpub. data, 1985)	
			2050	(Boehndorf et al. 1990)	
	Pre Magondi Intrusive Rocks	Younger Granite	2600 ± 70	(Hahn & Steiner, 1990)	
		Older Granite	2700	(Wilson et al. 1978)	
		Great Dyke	2460 ± 16	(Cahen & Snellig, 1984)	
			2514 ± 16	(Hamilton, 1977)	
		other Dykes	2490 ± 120	(Hahn & Steiner, 1990)	
Archaean	Shamvaian Series		–	――――	
	Bulawayan Series		–	――――	
	Chimbi paragneisses		2360 ± 90	Rb-Sr Chipisa paragneiss	Early Proterozoic crust forming event
	Urungwe paragneisses		2465 ± 53	Rb-Sr Kariba paragneiss	
	Escarpment paragneisses		–	――――	
	Basement Complex		–	――――	

3. The known ore deposits

The copper ore deposits are the only mineral resources which have economic feasibility. Silver and gold associated with copper ore deposits are also recovered. Besides the metal resources, crushed dolomite for construction and slate for building materials are worked in several places.

9 mines and ore deposits have operated before, but now only the Angwa Mine, the Shakleton Mine including the Avondale ore deposit, the Norah Mine and the Mangula (Miriam) Mine are still mining at present.

These ore deposits are roughly classified into the two deposits occurring in the Deweras Group and in the Lomagundi Group.

The former are strata bound ore deposits occurring within arkose of the Deweras Group. The Hans Mine, the Angwa Mine, the Shackleton Mine including the Avondale ore deposit, the Norah Mine and the Mangula (Miriam) Mine are developed. The formation of the ore deposition is considered to be strongly controlled by the sedimentary environment and geological structure of country rock (Simpson, 1990). As the result of the survey of the ore deposits and the mineralization area, the anticline structure from the direction of the NW–SE is considered to be important.

The Old Alaska Mine in the south-western part of the area and the Shamrocke Mine in the northern part belong to the latter.

2-2 E.P.O.'s reports

Mining activities in the survey area have a long history. The Old Alaska Mine had been in existence before the visit of the European peoples. The surveys of copper were carried out successively from the 1940's to the middle of 1970. The surveys of ore deposits are carried out under the Exclusive Prospecting Order (hereinafter called E.P.O.). All of the E.P.O. which were established in the survey area include Nos. 4, 5, 6, 20, 21, 35, 42, 43, 61, 62, 71, 74, 75, 80, 82, 83, 101, 106, 122, 137, 152, 249, 297, 351, 377, 396, 414, 422, 507 and 514. Almost all final reports of surveys are filed in GSD, and are available to examine. Summaries of the surveys of the E.P.O. No.1 to No.500 were published in the GSD (Morrison, 1972, 1974, 1978). A part of the original data is kept in the offices of the Mangula Mine and the Shackleton Mine.

List of previous survey is shown in Table II-2-4. The survey of the E.P.O. is ordinarily established within 3 years plan, however, the termination or extension is conducted depending on the situation in the middle of the plan. In case of continuation of the survey in the same area or in selected area, E.P.O. is re-established.

2-3 Others

1. Nationwide survey

Airborne magnetic survey was carried out through the financial assistance of CIDA (Canadian International Development Agency) and technical cooperation of GSC (Geological Survey of Canada)

Tablell-2-4 List of previous survey

EPO.No.	Holder	Duration	Previous EPOs	Metal sought	Remarks
263	Rio Tint Ltd	21.2.69- 21.2.72		Cu, Ni, platinoids	A continuation of the anomaly in EPO 217 was found.
217	Rio Tint Ltd	15.3.68- 15.3.71	70	Cu, Ni	Low Cu content in the anomalies.
297	S.A.Manganese Ltd	11.10.69- 10.10.71		Cu, Ni	Anomalous vanadium mineralisation noted.
377	MDC Ltd	27.2.71- 10.7.75	6, 21, 35, 43, 74, 75, 76, 101, 137, 152, 278	Cu	The EPOs covered the area around Alaska, Shackleton and Avondale copper mines.
383	Blanket Mine (Pvt) Ltd	27.3.71- 26.3.73	70, 217	Ni, Au, Cu	Disappoiting results.
396	Prospect of Rhodesia(Pvt) Ltd	10.7.71- 9.7.72		Ni, Cu and precious metals	
411	Blanket Mine (Pvt) Ltd	7.1.72- 7.1.74	8, 35, 39, 76, 84, 85, 152, 161, 278, 322, 324	Cu, Zn, Pb, Ni and Co	Cu mineralisation too low a grade
414	MDC Ltd	19.2.72- 9.9.77	3, 4, 5, 6, 16, 20, 21, 35, 42, 43, 71, 74, 75, 76, 82, 83, 101, 106, 137, 152, 351	Cu	Sub economic copper prospect.
514	LSM	18.10.75- 9.9.77		Cu	
518	Blanket Mine (Pvt) Ltd	29.11.75- 28.11.76		Au	
507	Nyaschere Copper	5.7.75- 18.2.77		Cu, Au	
528	Tarrus(Propriety) Ltd	16.1.76- 5.2.81		Cu, Ni, Co, Arsenic, precious metals	

for the federal government on a scale covering the whole country. The survey results are published as a Magnetic chart on a scale of 1:50,000 by the Geological Survey Department. The magnetic chart was based on the survey during May to June, 1983, and during October, 1990 to February, 1991 in the compiled area. The survey was carried out by the Kenting Earth Science Inc. and Intra Kenting. The surveyed data was converted to the mesh of 125 square metres and contouring was carried out.

The aeromagnetic map is shown in Fig.II-1-4. Although the original contour chart is every 5 gammas, this map is simplified by the contour of every 50 gammas. Generally, the chart reflects the geological structure of the Magondi Supergroup. It is noteworthy that there are low anomaly areas near the Mangula Mine, the Angwa Mine and the Hans Mine which occur with a comparatively shallow horizon.

2. Study for the doctoral theses

Underground and surface surveys have been carried out for doctoral theses (including master's course's theses and graduation theses) in this area. Many of the graduation theses and master's course's theses on the Magondi Supergroup at the University of Zimbabwe are to make geological maps (Mundondo, 1987 ; Shoko, 1985 ; Vinyu, 1985 and Jacobsen, 1962). As regards the geological survey and study of ore deposits, there are the following papers on the survey of the Shamrocke Mine (kyle, 1972) and the Mangula Mine (Muchenje, 1987 ; Tsomondo, 1980). As regards the doctral theses, there are the following detailed studies about the Shamrocke mine (Thole, 1974) and the Mangula to Alaska Mines (Master, 1991).

Almost all the papers are available in the library of the Geological Survey Department.

3. The report of ZMDC

The Mangula Mine (Miriam and Norah ore deposits), the Norah Mine, the Shackleton Mine (Avondale ore deposit) and the Angwa Mine are in operation at present in the survey area. All these Mines are managed by ZMDC. Depletion of the resources gives cause to anxiety in recent years. ZMDC commenced the survey planning to summarize the pervious works' results, and made recommendations around the Shamrocke Mine (Simpson, 1988) and also made the future guiding principle of survey for the area from the northern part of the Mangula Mine to the southern part of the Alaska Mine (Simpson, 1990). The survey program according to the guiding principle is commencing.

Many anomalous places have been extracted in the Shamrocke area. These Cu anomalies cause deformation and removal by metamorphism. There are no profitable ore deposits except the Old Mine Office area in these anomalous places. Exploration cost is considered to be expensive, because of the steep topography of this area. Therefore, as a result, the survey of this area must be carried out after the survey fails in all the other expected areas (Simpson, 1988).

A part of E.P.O. data which was carried out in the area of the northern part of the Mangula

Mine to the south of the Alaska Mine by the old Messina Group is kept in the Mangula Mine. The study of the data commenced at the end of 1989, and "Report on the Work done and Recommend in the Area from North of Mangula to South of Alaska" was reported (Simpson, 1990).

The above report contains all the files, mine data and knowledge of mining engineers. It is one of the best summaries about this area. The discussions and recommendations in the report highly deserves to be examined in order to better carry out survey of this area.

Occurrences of ore deposits are classified into the following two. One is sedimentary environment of country rock, and the other is controlled by geological structure.

Miriam style deposits–

1) Basement – sediment contact.
2) Alluvial fan with fine sediment transgression.
3) Possibly an anticline warp.

Norah – Shackleton – Angwa style deposit–

1) Cyclic graded bedding of a river of delta complex.
2) Anticlinal warp to act as trap (similar to modern oil traps).

As regards geological environment for re-evaluation of potentiality on a wide scale, following points were noticed :

1) Cyclic sedimentation associated with the building of alluvial fan, streams, deltas,etc.
2) Earlier anticlinal fold axis which are formed before the lithofication of sediments
3) Airborne magnetic and soil geochemical trend which transgress the N–S basin in the NE–SW direction.
4) Early strike slip faults parallel to the basin edge which could act as feeders in a NE–SW direction.

Based on the above expression, the areas necessary to explore are as follows:

1) Geological mapping of the known structural trends crossing the basin;
   a) Wari–Shackleton–Avonshack–Nijiri
   b) Kenilworth–Hans–Angwa
   c) Muni West–Muni–Munwa
   d) Valdesia
   e) North and South Greenfields
2) Reconnaissance mapping from airphotos of areas not covered above.
3) Test surveys by several geophysical methods to see it known ore bodies can be found.
4) Drilling of the Wari, Muni West and Kenilworth zones down plunge from present intersection.
5) Drilling of Muni under Muni West will require good surface mapping before hole placement.

6) Drilling of Valdesia and Nijri based on surface mapping of the known mineralized areas

7) Study of known ore bodies by geochemical and mineralogical methods to see if there is a marker alteration to the ore zones. This could be done by the University of Zimbabwe as several undergraduate projects or a graduate degree. Possibly a company geologist could do a Master Degree on it part time.

2-4 Summary

The surveys which were carried out during the late 1940's to 1970's were emphasized in geochemical surveys because of to poorly outcrops. As regards chemical analyses, Cu analysis of most of the samples were carried out, however, chemical analyses of Ni, Co, Pb and Zn were also partly carried out. There are geochemical anomalies in this area due to mineralization of Cu, mafic dykes and volacanics. Therefore, it is difficult to distinguish by Cu anomalies. As regards geochemical anomalies, verifications of origin of anomalies were carried out by trenching, pitting, wagon drilling and diamond drilling. Judging from the past intensive survey in E.P.O.s, it is not too much to say that extraction of the Cu anomalous places of surface by geochemical survey have almost completed the purpose to identify potential copper resources, in the area of the northern part of the Mhangura Mine to the southern part of the Alaska Mine and the Shamrocke Mine.

There are 54 claim areas which indicate Cu anomalies in sedimentary rocks in the area of the northern part of Mhangura to the southern part of Alaska by results of the previous works. Many mineralization areas exist in the survey area found by previous works. Within these areas, the existence of ore deposits can be expected as profitable mining instead of known ore deposits.

Chapter 3 Geological survey

3-1 Outline of geology

Geological map, geological cross section, schematic geological column are shown in Fig.II-3-1. to II-3-3, respectively.

The archaean Basement Rocks, Paragneiss, the Bulawayan Group, the Shanvaian Group and the Pre-Magondi Intrusive Rocks, the Magondi Supergroup, the Guruve Metamorphic Complex, the Post-Magondi Intrusive Rocks and the Sijarira Group of proterozoic era, the triassic Upper Karoo Formation and quatemary sediments are the member of this area in ascending order. The Magondi Supergroup is divided into the Deweras Group, the Lomagundi Group and the Piriwiri Group in ascending order. This Supergroup is the sediments in the Magondi sedimentary basin which was formed by extension of the rift valley.

This area was affected at least three stages of metamorphism through the period of the Magondi orogenic movement to Pan-Africa Zambezi orogenic movement. The last metamorphism (Pan-Africa Zambezi orogenic movement) develops only in the northern part of this area.

3-2 Geology

3-2-1 Basement rocks

The basement rocks are widely distributed in Doma Safari area in the north western part of the survey area.

The basement rocks mainly consists of orthogneiss of granodiorite component and is accompanied with paragneiss of sedimentary origin. The origin of paragneiss is considered to be sandstone and shale. It sometimes shows banded structure with few cm to ten and more cm thick alternation of white felsic part and biotite concentration part in the outcrop.

Microscopic observation is as follows :

Orthogneiss is petrologically identified as epidote (clinozoisite)-biotite gneiss which shows granoblastic texture. Quartz, plagioclase, orthoclase and biotite are the major component minerals and there are small amounts of iron oxides, sphene, rutile, apatite and zircon. There are two types of paragneiss. One is epidote-biotite gneiss which shows granoblastic texture and the other is hornblende-epidote-muscovite gneiss which shows blastopsamitic texture. The former consists of quartz,plagioclase, orthoclase, muscovite and epidote with small to rare amounts of hornblende, iron oxides, sphene, apatite and zircon. The latter is composed of quartz, plagioclase, orthoclase, biotite and epidote with small or rare amounts of muscovite, iron oxides, sphene, apatite and zircon.

3-2-2 Paragneiss

1. The Zambezi Escarpment Paragneiss

It is distributed along the Zambezi escarpment in the northern part of the survey area.

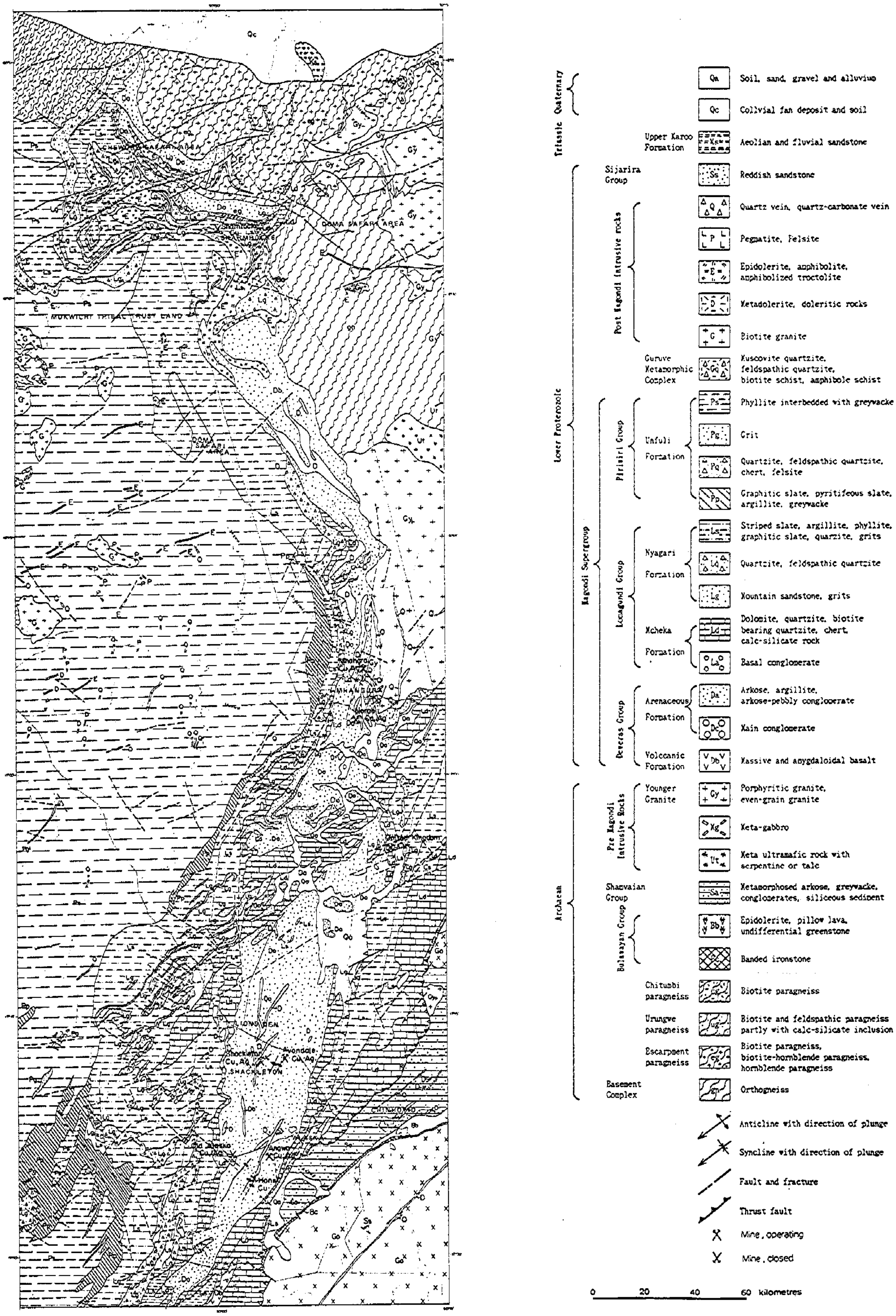


Fig.II-3-1 Geological map

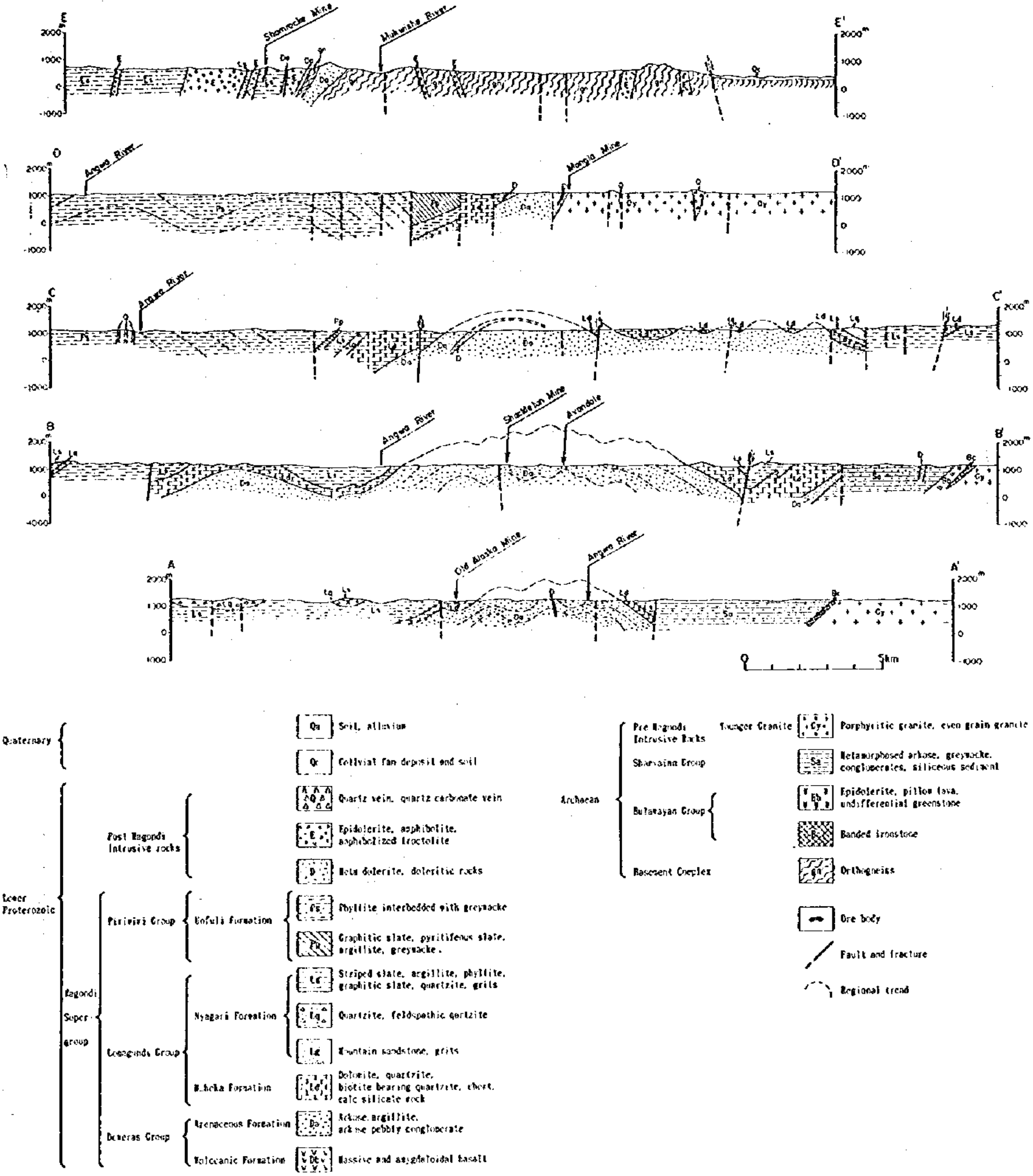
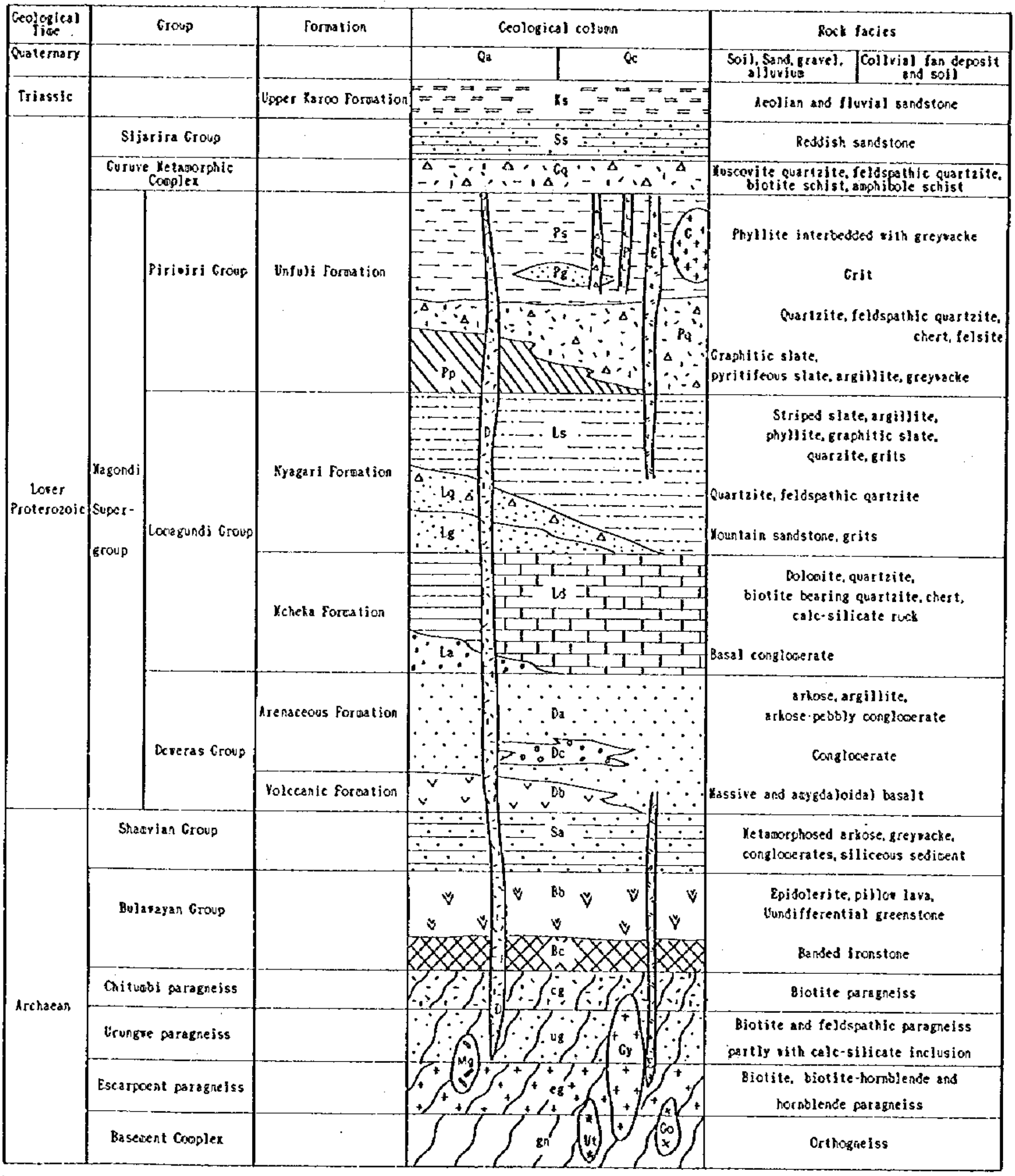


Fig.II-3-2 Geological section



Post Magondi Intrusive rocks

Q :Quartz vein, quartz-carbonate vein

P :Pegmatite, Felsite

E :Epidolerite, amphibolite, amphibolized troctolite

D :Metadolerite, doleritic rocks

G :Biotite granite

Pre Magondi Intrusive Rocks

Gy:Porphyritic granite, even-grain granite (Younger Granite)

Go:Fine granite, granodiorite, tonalite (Older Granite)

Mg:Meta-gabbro

Ut:Meta ultramafic rock with serpentine or talc

Fig.II-3-3 Schematic geological column

The main rock facies is biotite-hornblende gneiss which is considered to be originated from sedimentary rocks such as arkose, quartzite and graywacke (Fey and Broderick, 1990).

2. The Chitumbi Paragneiss

It is distributed along Zambezi escarpment in the north-western marginal part out of the survey area.

The main rock facies is biotite gneiss (Fey and Broderick, 1990).

3-2-3 The Bulawayan group

It is distributed along the marginal part of Younger Granite which describes later in the southern part out of the survey area.

The description about this Group in the survey area was made by Stagman (1961). The Group consists of banded iron layer which overlies the basement and green rocks. Banded iron formation generally shows blackish colour with fine alternation and grading of quartz and magnetite. Green rock layer consists of altered basaltic volcanics.

3-2-4 The Shanvaian group

It is distributed surrounding to Bulawayan Group. The centre of the area is Chinhoyi City which is located in the southern part out of the survey area.

The description of this Group in the survey area was made by Stagman(1961). It consists of many layers of conglomerate and sandstone. Most of gravels are granite origin. However, there are some green coloured or banded iron gravels. It is affected by regional metamorphism. Biotite, chlorite and hornblende was formed by component change of iron-magnesium ratio.

3-2-5 The Pre-Magondi intrusive rocks

1. Ultramafic rocks

They are distributed along the boundary part of the Basement Rocks and the Younger Granite in the eastern central part, outside the survey area.

They are the western extending part of Chipingabadza complex rock body (Hahn and Steiner, 1990). According to the adjoining map, they are dark greenish coloured, medium-grained massive rock body which are hornblendized pyroxenite. Pyroxenes are replaced by hornblende, serpentine and chlorite (Hahn and Steiner, 1990).

2. Meta-gabbro

It is distributed within the basement rocks as small rock bodies with approximate 1 kilometres of diameter in the north-eastern marginal part out of the survey area.

The detailed description about the rock body was made by Chenjerai (1988). According to this description, the grain size changes from medium to coarse grained from the marginal part to the centre. Feldspar phenocryst grows over 1 centimetre. By microscopic observation, main rock forming minerals are homblende and feldspar. Feldspar altered into diopside and hornblende with garnet.

3. The Younger granite

The distribution is divided into two part. One is in the south-eastern part out of the survey area and the other is in the eastern part of the centre of the survey area.

In the survey area the rock is pink coloured, medium-grained biotite-muscovite (or muscovite-biotite) adamellite.

Microscopic characteristics are as follows:

The specimens which were sampled at the north-east of Mangula Mine shows hipidomorphic texture. The main rock forming minerals are quartz, plagioclase, orthoclase with biotite, muscovite, iron oxides, sphene, rutile, apatite and zircon. They are sometimes accompanied with epidote, chlorite and calcite.

3-2-6 The Magondi supergroup

1. The Deweras group

(1) Volcanic formation

It is distributed between the Shackleton Mine and the Old Alaska Mine. A part of dolerite on the geological map is possible to be classified into this member. Basalt lava in the Freda Farm shows dark greenish to greenish gray colour, and is observed amygdaloidal texture. As the outcrop of this rock facies is narrow, detailed occurrence is indistinct.

Microscopic characteristics are as follows:

The specimen (KR3) collected at the Freda Farm shows blastoporphyritic texture. It is mainly composed of plagioclase and hornblende. In addition to them, quartz, biotite, epidote, tourmaline and iron oxides, and rare amounts of sphene, apatite and zircon. On the other hand, the specimen (YR104) collected at the southern edge of the area has no hornblende and biotite, and comparatively larger amounts of chlorite and calcite grow.

(2) Sandy formation

It is distributed stretching from the north to the south in the central part of the survey area.

It is the main country rock of copper ore deposits in this area. In the southern to the central part of the area it is sometimes affected to weak metamorphism with poor cleavage observed by the naked eye. The grade of metamorphism becomes higher from the central part toward to the northern part in the survey area. The southern to central part of the area lies in the Magondi Mobile Belt. On the other hand, the northern part lies in the Zambezi Mobile Belt.

It mainly consists of arkose which includes conglomerate with mainly consists of granite gravels. The characteristic is the development of graded bedding and cross-bedding. This formation covered the Younger Granite of the Pre-Magondi Intrusive Rocks unconformally along the Brenville

Farm of the northern part of Mhangura. The sedimentary cycle from coarse-grained arkose to shale, evaporites composed of anhydrite and thin layer of dolomite are observed in the underground tunnel of the Avondale Mine. This formation consider to be alluvial fan sediments, river sediments and playa sediments (Master, 1991).

Characteristics by microscopic observation are as follows :

Arkose shows blastopsamitic texture, and mainly includes quartz, plagioclase and orthoclase with biotite and muscovite, and includes small to rare amounts of iron oxides, sphene, apatite and zircon. Comparatively large amounts of hornblende and epidote are formed in the specimens at the northern part of the survey area. In the same specimen, tourmaline and diopside are partly observed.

2. The Lomagundi group

(1) The Mcheka formation

It is distributed in both the side of the Deweras Group in the southern part of the survey area, and is distributed along western wing of the same Group in the central to northern part of the area.

It is composed of dolomite, quartzite and biotite bearing quartzite. The distribution of basal conglomerate is not recognized in this survey area.

Dolomite shows white to grayish colour and is composed of fine to coarse grained carbonate minerals and quartz grains. Grading is sometimes observed partly. The typical quartzite of this formation is called "pock-marked" quartzite by its spotted texture of brownish to reddish brown colour. Chemical component of dolomitic rocks of this member varies from dolomite to dolomitic quartzite (Tennik, 1976, Stagman, 1961).

Microscopic observation is as follows :

Dolomite specimens show saccharoidal or decussate texture, and includes dolomite and quartz with rare amounts of iron oxides, sphene, apatite or zircon. It sometimes includes small amounts of plagioclase and orthoclase. Phlogopite sometimes grows with tremolite in the recrystallized specimens around Shamrocke Mine. Quartzite specimens show granoblastic texture, and includes quartz with plagioclase, orthoclase and muscovite and quartz with carbonate minerals. Both the samples include rare amounts of iron oxides and sphene.

(2) The Nyagari Formation

It is widely distributed surrounding the Deweras Group and the Mcheka formation. It consists of sandstone, quartzite, slates and banded iron oxides. The sandstone is called "mountain sandstone" and shows dark grayish colour and massive structure with no bedding. Quartzite is distributed within slates in the southern part to the central part out of the survey area and forms folded hilly country. Slates are called "striped slate". They show black colour and developed cleavages crossing to bedding plane. Scattered euhedral pyrites are observed. Boulders of banded iron ore are observed in Rivington Farm area. But, no outcrop is observed.

Characteristics of microscopic observation are as follows :

Main rock forming minerals of the sandstone specimen are quartz, plagioclase, orthoclase with biotite and muscovite. Slate specimen includes fine grain quartz, biotite and graphite with small amount of plagioclase and orthoclase. In the specimen at the northern part of survey area, staurolite and garnet are formed. Banded iron ore specimen (YR60) shows banded texture of sandy rock part mainly with quartz and euhedral magnetite by microscopic observation. Magnetite changes to hematite along the crystal surface.

3. The Piriwiri group

It is widely distributed in the western part of the area.

This Group consists of graphitic schist, quartzite, sandstone, graywacke and phyllite. Graphitic schist shows black colour and developed lamination. Quartzite is cherty quartzite within slate. Sandstone and graywacke alternates in phyllite. Phyllite shows various tones of colours and textures (Tennick, 1976).

Characteristics of microscopic observation are as follows :

Graphitic slate specimen (NR63) is composed of graphite, quartz, plagioclase as main minerals, and includes orthoclase, muscovite, iron ore and sphene. Phyllite specimen (YR70) shows decussate texture and mainly includes muscovite and chlorite. In addition to them, quartz, plagioclase, hornblende, iron ore, sphene and apatite are observed.

3-2-7 The Guruve metamorphic complex

It is distributed along the Zambezi Escarpment in the north-eastern margin out of the survey area.

Rock facies varies such as marble, felsic to arkosic sandstone, meta-arkose, meta-graywacke, and meta-sediments including amphibolite (Hahn and Steiner, 1990)

3-2-8 The Post-Magondi intrusive rocks

1. Granite

It is distributed as several stocks on a scale of several km in the north-western part out of the survey area.

It consists of biotite granite and gneissose granite. Both the types of granite have similar petrographic characteristics (Wiles, 1961).

2. Dolerites

They are distributed in the southern to the central part of the survey area, and intruded into the formations of the Bulawayan Groups to the Piriwiri Group in ascending order. The distribution within the Deweras Group was compiled on the maps based on the distribution of the outcrops, airborne magnetic survey and E.P.O. surveys. A part of this rock which was shown on geological map is possible to be the volcanic formation of the Deweras Group.

It shows dark greenish to dark grayish colour and has massive structure.

Characteristics by microscopic observation are as follows :

The specimen collected at the southern part of Mangula Mine shows blastoporphyritic texture. It is composed of hornblende, plagioclase, quartz as main rock forming minerals and iron ore, sphene and apatite as accessory minerals. Growth of epidote, chlorite, tourmaline and calcite crystals are sometimes observed.

3. Amphibolites

They are distributed as many dykes and sheets in the central part to the northern part of the survey area.

The amphibolites are considered to be mafic volcanics origin, because of the same component of dolerites which are distributed in the southern part of the area. The difference of rock facies is considered to occur due to difference of metamorphic grade.

Characteristics by microscopic observation of this rock are generally the same in those of dolerites. However, amphibole shows oriented arrangement, the amount of quartz is slightly much more than in dolerites, and biotite is growing as one of the characteristics.

4. Pegmatite

It is distributed within gneiss in the north-eastern part of the survey area and within the Piriwiri Group in the western part out of the area on a small scale.

It composed of quartz, orthoclase, muscovite, tourmaline and beryl. Muscovite occurs with block like shape within pegmatite the western part out of the area. Pale bluish coloured and transparent beryl is mined as aquamarine by small workers on a small scale (Wiles, 1961).

5. Quartz vein

It is distributed as veins within the Younger Granite which is the intrusive rock of the Pre-Magondi Group in the central part of the survey area and the western part from the area.

It consists of milky white to white transparent massive quartz, and partly changes to granophyre like texture. Iron oxides mainly composed of hematite with dark grayish metal luster are developed as network in the southwest of Nyamanyoko farm.

Characteristics by microscopic observation are as follows :

The specimen of quartz vein within the Younger Granite in Glen View Farm shows lepidoblastic texture, and includes mainly quartz and muscovite with small amounts of iron ore and apatite. The specimen at Alpha A Farm in the west of the Mangula Mine is granophyre with micrographic texture. It includes mainly quartz, plagioclase and orthoclase with hornblende, iron ore, sphene and apatite.

3-2-9 The Sijarira group

The distribution is observed in the Younger Granite area on a small scale in the south-eastern part out of the survey area.

It is composed of reddish sandstone (Stagman, 1961).

3-2-10 The Upper Karoo formation

It is distributed under the Zambezi fault scarp on a small scale in the northern part out of the survey area.

It is composed of alternation of sandstone with cross-bedding, siltstone, and conglomerate with lenticular shape pebbles. It is calcarious (Chenjerai,1988).

3-2-11 Quaternary sediments

Alluvial fan sediments with pelitic and sandy pebble, and talus deposits under Zambezi escarpment are widely distributed.

3-3 Geological structure

Many studies about the history of geological structure of the survey area and their detailed examination were carried out (Stagman, 1961; Jacobson, 1962; Blaiss, 1970; Stowe, 1978; Sutton, 1979; Treloar, 1988; Simpson, 1990; Master,1984,1991 etc). These studies were carried out mainly about the Magondi Mobile Belt of the southern part of Mhangura and the Zambezi Mobile Belt of the northern part of the survey area.

The initial event of geological structure with relationship to the Magondi mobile belt was the extension of rift valley which formed the Magondi basin. The rift valley is considered to be formed along the left lateral fracture zone by the activity of Great Dyke in the eastern part out of the survey area. The eastern margin of sedimentary basin in the eastern part of the area is limited by the direction of the NNE-SSW with generally parallel to the Great Dyke. The margin is bent to the direction of the NNW-SSW in northern part of Mhangura of the centre of this area.

The Deweras Group is consisted of alluvial fan sediments, stream sediments and playa sediments. During the period of sedimentation, several mafic igneous activities occurred. The Lomagundi Group is considered to be formed in sedimentary environment of coast. Piriwiri Group is Black Sea type underwater sediments, It is presumed to be formed in the environment of continental slope or seabed fan (Master, 1991).

Most of the survey area is located within the Magondi mobile belt, and was affected by metamorphism of several times. The main geological structure shows different characteristics in the southern and the northern part of the survey area.

The main geological structure of the southern part of the survey area is characterized by isoclined fold with the direction of the NNE to the NE and thrust along the eastern margin of Magondi sedimentary basin. These structures are cut by right lateral fault of the direction of the NE-SW. Fault of the direction of the NW-SE also develops within Lomagundi Group and Piriwiri

Group in the western part out of the survey area.

As regards the relationship between the Archaean younger granite and the Deweras Group near Mhangura in the central part of the area, the contact of the granite and the Deweras Group by thrust is observed in underground of mine and unconformity is observed at the surface.

The direction of the NNE-SSW to the N-S direction, fold structure of the direction of the NE-SW and lateral fault of the NE-SW direction are recognized in the northern part, however no structure of the NW-SE direction is recognized (Thole, 1974).

3-4 Mineralization

3-4-1 Survey of the mines and mineralization areas

Survey results of mineralization zones is shown in TableII-3-1.

1. The Alaska area

(1) The Old Alaska mine

location : The foot of Chezui Hill, 20 kilometres west of Chinhoyi City.

Present situation : Closed. The Vertical shaft at the southern foot of Chezui Hill and old opencut (approximate 400 metres from the east to the west, 200 metres from the north to the south) are still existing.

History : This mine was considered to be developed in prehistoric age. Modern development and mining were commenced by MTD Co.Ltd. during 1956 to 1961, and the mining finished in 1977.

Scale: Estimated production amount of crude ore is 5,000,000 tons approximately. (Simpson, 1990).

Geology : The geology around and in the opencut is composed of conglomerate and arkose of Deweras Group, dolomite, dolomitic slate to phyllite and dolomitic sandstone of Lomagundi Group. The geological structure is controlled by main oblique axis with moderate plunge with small anticline and syncline. The structure is cut by fault with the direction of NW-SE.

Ore deposit : Main ore mineral is malachite which occurs as dissemination and thin vein along platy joints and cleavages within dolomite, sandstone and shale of Lomagundi Group. In addition to malachite, chalcopyrite is characteristically recognized with psudomorph of pyrite. Chalcopyrite, natural copper, chrysocolla, cornetite, plancheite, dioptase, cuprite and tenorite were reported as ore minerals(Master, 1991).

By microscopic observation of the polished samples of ore minerals at opencut, network and vein type malachite, bornite and chalcocite with irregular shape, foliated and platy covelline crystal aggregates and small amount of chalcopyrite are recognized. Chalcocite occurs in the thick part of malachite vein. Bornite is replaced by chalcocite, and chalcocite is replaced by covelline. Chalcopyrite appears within bornite with vein or irregular shapes.

(2) The Angwa mine

Location : The Goldenvale farm, 4 kilometres of the eastern part of Old Alaska opencut.

Present situation : In operation

TableII-3-1 Summary of the survey for mines and mineralization area

Name of Mine and Mineralized Area	Locality Coordinates	Situation	Type of deposits	Mineralized Metal	Ore reserve	Metal grade	Main ore minerals	Accessory minerals	Gangue minerals	Host rock	Present Production
(1)Hans	17°25.47'S 30°01.95'E	closed	Stratabound and disseminated ore	Cu, Ag	0.3million tons Cu1.0%	AgMax93.5g/t CuMax3.71%	Mal. Bo, Cc	Cp	—	Arkose Conglomerate	
(2)Angwa	17°23.96'S 30°03.37'E	Operating	Stratabound and disseminated ore	Cu, Ag	4.5million tons Cu0.95%	AgMax62.6g/t CuMax1.59%	Bo. Cc. Cp	Py, Mt, Hem	—	Arkose Conglomerate	16.000t/m Cu0.6%
(3)Old Alaska	17°23.87'S 30°00.87'E	closed	Stratabound and disseminated ore	Cu, Ag	5million tons? Cu1.5%	AgMax62.6g/t CuMax1.59%	Mal. Bo. Cc	Cp. Py. Cv, Mt. Hem	—	Lomagundi. G Dolomite	
(4)Shackleton	17°18.08'S 30°02.67'E	closed	Stratabound and disseminated ore	Cu. Ag	6million tons Cu1.2%		Bo, Cc	—	—	Arkose Conglomerate	
(5)Avondale	17°17.86'S 30°04.11'E	Operating	Stratabound and disseminated ore	Cu. Ag	4.4million tons Cu0.9%	Ag 11.6g/t Cu 0.45%	Cc	Bo. Cp	—	Arkose Conglomerate	16.000t/m Cu0.8%
(6)United Kingdom	17°04.67'S 30°11.24'E	closed	qz-cal Vein	Cu, Ag		AgMax45.9g/t CuMax2.69%	Mal. Cc	Cv	Qz. Cal. Hem	Arkose	
(7)William	16°53.31'S 30°09.59'E	Operating	Stratabound and disseminated ore	Cu. Ag. Au Pt. Pd. Se	60million tons Cu1.0%	AgMax33.2g/t CuMax13.0%	Bo. Cc. Cp	Py. Mt. Hem	—	Arkose Conglomerate	4.000t/d Cu0.7%
(8)Norah	16°56.21'S 30°09.16'E	Operating	Stratabound and disseminated ore	Cu. Ag. Ag	8million tons Cu1.2%	AgMax170g/t CuMax13.0%	Cp. Bo. Cc	Py. Cv. Sph. Mt. Hem	—	Arkose Conglomerate	
(9)Shamrocke	16°25.78'S 30°09.52'E	closed	Stratabound and disseminated ore	Cu. Ag. Au	5million tons Cu1.0%	AgMax 8.1g/t CuMax3.47%	Po. Cp	Cub. Sph. Py. Mc. Mt	—	MetaArkose	
(10)Nyamamyoko Hill	16°50.63'S 30°10.57'E		qz-mt Vein	Au. Ag?	Extension2km	Au0.03g/t Ag4.5g/t	—	Hem. Mt	—	Granite	
(11)Rivington	17°00.40'S 30°04.82'E		Banded iron	Fe			Mt. Hem	—	—	slate	
(12)Zawi	17°13.88'S 30°01.58'E		Dolomite	Dolomite			Dolomite	—	—	Lomagundi. G Dolomite	
(13)Hilltop	17°19.01'S 30°07.74'E		Slate	slate			slate	—	—	Lomagundi. G slate	

Abbreviations

Py:pyrite Mc:marcasite Po:pyrrhotite Cub:cubanite Cp:chalcopyrite Bo:bornite Cc:chalcocite Cv:covelline Sph:sphalerite
Mt:magnetite Il:ilmenite Hem:hematite Mal:malachite Qz:quartz Cal:calcite Ot:other gangue minerals

History : Surface drilling was commenced in this mine in 1958. The development including sinking of vertical shaft was commenced in 1965. The regular production was commenced in 1973.

Scale: Ore reserves: 4,500,000 tons (Simpson, 1990). Present production of crude ore is 16,000 tons/month (Cu, 0.6 %, Ag, 18 g/ton).

Geology : Geology shows the sedimentation of the unit of conglomerate of Deweras Group, arkosic pelitic rock. It is partly accompanied with pyroclastic rocks. Doleritic dykes exists interruptively from Hans Mine in the western side of this area. Geological structure shows the strike of NE and the dip of 40° to 60° NW with moderate fold.

Ore deposit : The ore deposit is divided into the upper and the lower zone. The upper ore deposit occurs in arkose which is located just under pelitic rock, and controlled by development and succession of the pelitic rock of hanging wall. As the upper ore deposit is more stable in grade and succession compared to the lower ore deposit, the upper ore deposit is the main ore deposit of this mine. On the other hand, the lower ore deposit occurs on conglomerate of foot wall. The scale and thickness are more predominant compared to the upper ore deposit, however, the shape, distribution and grade are irregular. The main ore minerals are chalcocite and bornite, in addition to them, few covelline, chalcopyrite and pyrite are recognized. Occurrence of silver is reported as micro-composition. Chalcocite and bornite frequently show psudomorph of pyrite. These ore minerals occur as dissemination or fine veins filled up among particles within conglomerate and arkose packing within gaps of particles.

By microscopic observation of polished sample of ore minerals at 360 W mining block of the underground, chalcopyrite, bornite, chalcocite with irregular shape, columnar and irregular shaped hematite, and euhedral and granular magnetite are recognized. Chalcopyrite and chalcocite coexists. There is paragenesis of bornite and chalcocite with graphic texture. Some bornites partly change to chalcocite. Magnetite is replaced by hematite, and sometimes it is entirely replaced by hematite.

(3) The Hans mine

Location : The border of Dicheat farm and Pamane Estate, 3 kilometres south-east of Old Alaska opencut.

Present situation : Closed. Surface dimple by collapsing due to mining of old pit, the entrance of inclined shaft, old facilities and mound of waste are still existing.

History : The production was commenced in 1974, and finished in 1976.

Scale : Production amount of crude ore is 30,000 tons (Cu ; 1.0%). Reserves of mineral ore is 100,000 tons.

Geology : Geology around the mine is composed of arkose and pelitic rocks of Deweras Group. The mine is located near anticline axis with NE-SW direction.

Ore deposit : The ore deposit is reported to occurs within boundary of pyroclastic rocks of hanging wall and conglomerate, however, ore minerals near the entrance of inclined shaft and at collapsed dimple occur in the country rock of white to pink arkose or green pelitic rock.

Main ore minerals are malachite, bornite, chalcocite and chalcopyrite.Malachite occurs as dissemination and narrows vein along platy joints and cleavages. Weak disseminated bornite, chalcocite and chalcopyrite are recognized.

2.The Shackleton mine including the Avondale ore deposit

(1) The Shackleton mine

Location : 9 kilometres north-north-west of Alaska smelter.

Present situation : Although the operation of this mine was finished, the facilities are still operating to treat ore minerals from Avondale Mine, and Angwa Mine.

History: The exploration was commenced by soil geochemical survey in 1958. Based on this exploration, drilling was commenced. Production and regular production were commenced in 1968 and 1972, respectively. Mining was finally finished in August, 1984.

Scale : The amount of production including test mining of crude ore was 6,000,000 tons (Cu, 1.2 %, the document of the Mine).

(2) The Avondale ore deposit

Location: Avondale farm and Maningwa farm, 9 kilometres north of the Alaska Smelter.

Present situation : In operation. The crude ore is rifted through Shackleton vertical shaft.

History : The development of transportation level from Shackleton vertical shaft was commenced in 1975, and production was commenced in 1982.

Scale : Ore reserves at initial development is 4,400,000 tons (Cu, 0.90 %). Present is 16,000 tons/month (Cu, 0.8 %, Ag, 16 g/ton),(the document of the Mine).

Geology : The surface of Shackleton and Avondale deposit is widely occupied by cultivated field with a part of wood. No outcrops can be seen in this area.

The Geology based on the existing data including the data of the Mine around the ore deposit is composed of arkose and pelitic rock of Deweras Group. These rocks are composed of conglomeratic sandstone to sandstone of the basement horizon, fine-grained arkose and sandstone of the upper horizon and pelitic to calcarious pelitic rock of the uppermost horizon. They forms a sedimentary cycle, and the sedimentation was made repeatedly. The boundary of each sedimentary cycle shows marked unconformity.

Geological structure shows moderate anticline with the general trend of NE-SW repeating small folds with NNE-SSW direction. There is prominent fault zone with NNW-SSE direction in the western side of Shackleton ore deposit. Dolerite dyke (Shackleton dyke) is recognized along the fault zone.

Ore deposit : The ore deposit is strata-bounded copper deposit which occurs just under the peritic rock of hanging wall or occurs between the upper and the lower pelitic rock.

Ore minerals are mainly dissemination of chalcocite, bornite and chalcopyrite. A part of them occurs as small vein within the bedding plane or fracture zone.

By microscopic observation of polished samples in Avondale Mine, irregular shaped chalcocite, bornite, chalcopyrite and columnar hematite are recognized. Chalcocite, bornite and chalcopyrite coexist. Bornite sometimes spottedly exists within chalcocite.

3. Umboe area

(1) The United Kingdom mine

Location : the Inyati farm, 40 kilometres north of Chinhoyi, 20 kilometres SSW of Mangula Mine.

Present situation : Closed. Opencut, basement concrete of building and trace of trench are still existing.

History : The process of discovery of this mine is unknown. Small mines were operated during 1939 to 1940. After the mining, three trenching and drilling were carried out around 1972, however, re-development was not carried out.

Scale : Production amount of copper is 2.74 tons, Au 59 kg (1939 - 1940, Bartholomews, 1990).

Geology: Arkose of Deweras Group and quartzite, dolomite and shale of the Lomagundi Group is distributed around the ore deposit. In the western part of the Opencut, doleritic dyke intruded with the N-S direction. In the eastern part of the Opencut, quartz-calcite vein intruded parallel to the dyke.

Ore deposit : The ore deposit is ore vein type which occurs in the boundary part of quartz-calcite vein and doleritic dyke. Malachite is the main ore mineral. Weak dissemination of malachite, limonite and hematite is recognized in the boundary part of dyke and quartz-calcite vein, within joints and cleavages along thin quartz-calcite vein, and on the side of dykes.

By microscopic observation of polished samples, irregular shaped chalcocite, platy and foliated covelline which partly replaced chalcocite, and fibrous crystals of malachite aggregates are recognized.

4. The Mhangura area

(1) Miriam ore deposit

Location : 70 kilometres north of Chinhoyi City.

Present situation : In operation. Opencut mining (North Molley, South Miriam, South Molley) was finished. Mining in pit used to Miriam vertical shaft and East vertical shaft is operating.

History : The exploration of this mine was commenced by Anglo American in 1930's. RCV Ltd. explored this mine in 1940. MTD Co.Ltd. obtained the mining right from RCV Ltd. in 1950 and commenced to develop. Production began in 1956.

Scale : Ore reserves is 60,000,000 tons (Cu, 1.0 %). Present production of crude ore is 4,000 tons/day (Cu, 0.7 %, Ag, 8.2 g/ton, Au, 0.068 g/ton). Capacity of mineral processing plant is 4,500 ton/day.

Geology : The basement rock of Archaean granite is distributed in the eastern part of this ore deposit. Arkose, pelitic schist and chlorite schist of Deweras Group distributes in the western side separated by the thrust with N-S direction. Geological Structure shows N-S strike and the dip of E50° - 60°and continues the south to the north.

Ore deposit : The ore deposit occurs within conglomerate, arkose and pelitic rock with the characteristics of alluvial fan sediments. It shows as dissemination or quartz-microcline narrow vein type ore which mineralized along the fracture zone and cleavages. The main ore minerals are chalcocite, bornite and chalcopyrite, and pyrite comes to next. Very small amount of molybdenite, native silver, argentite, wittichentite, uranite and native gold occurrence are reported (Master 1991).

The ore deposit is strong oxidized zone on the surface of South Molley opencut, and shows dissemination of malachite and narrow ore vein.

The surrounding of ore deposit is characterized by hematite. Typical example is recognized in arkosic reddish beds among the bodies of ore deposits. although, strong alteration is not recognized.

By microscopic observation of polished samples, irregular shaped bornite, chalcocite, chalcopyrite, columnar hematite and euhedral granular magnetite are recognized. Bornite, chalcocite and chalcopyrite coexist. Bornite, chalcocite coexist with graphic texture. Some bornites replaced chalcocite. Some chalcopyrites filled among particles of arkose and some include sphalerite are recognized.

(2) The Norah mine

Location : The Plateau farm, 5 kilometres south of Miriam deposit.

Present situation : The operation of this mine was finished in October 1992.

History : The exploration of this mine was commenced by Anglo American in 1930's. RCV Ltd. commenced to develop in 1940's. MTD Co.,Ltd. obtained the mining right from RCV Ltd. in the middle of 1950's. Production of crude ore was commenced in 1972.

Scale : Ore reserves is 8,000,000 tons, Cu, 1.2 %.

Geology : This deposit is located in the southern extending part of Miriam ore deposit. Geology around the mine is the same of Miriam ore deposit area.

Ore deposit : The ore deposit is located in the upper horizon correspond to Miriam ore deposit, and occurs within fine to coarse-grained arkose which shows cross-bedding, and also occurs within dolomitic rock.The hanging wall rock of the ore deposit consists of chlorite-quartz sandstone and chlorite-calcarious schist characterized by containing evaporite thin layer such as anhydrite, barite, celesitite, chlorite, tourmaline and sulphide.

The main ore minerals are chalcocite and chalcopyrite with bornite and pyrite. The ore deposit has clear boundaty at the side of hanging wall rock, however, in the side of foot wall rock, has no clear boundary because of poor grading in coarse-grained arkose.

By microscopic observation of polished samples, chalcopyrite, bornite, chalcocite, sphalerite, covelline, hematite and magnetite are recognized. Chalcopyrite, bornite, chalcocite and sphalerite show irregular shapes. Covelline shows platy or foliated. Hematite is long to radial columnar. Magnetite is euhedral. Chalcocite, bornite and chalcopyrite coexist. Chalcocite and bornite with graphic texture are recognized as paragenesis.There are chalcocites which replaced bornite is recognized. There are hematites which are partly replaced magnetite, and which grow radially with euhedral shape to chalcopyrite and bornite.

5. The Shamrocke area

(1) The Shamrocke mine

Location : 80 kilometres north-east of Karoi City.

Present situation : Closed.

History : This mine was discovered in the late 1950's. Rand Mines explored interior and exterior of the mine during 1958 to 1961. The development of the mine was carried out by Nyashere Copper (Private) Limited since the middle of 1960. This mine was operated since 1972 to 1978.

Scale : Ore reserves are approximate 5,000,000 tons. expected residual ore reserves at mining was suspended 1,000,00 tons.

Geology : Graphite schist, quartz-feldspar-hornblende schist, meta-arkose and biotite-actinolite schist are distributed in the ore deposit area.Incline fold structure with plunge of approximate 40°SE is the prominent structure.

Ore deposit : The ore deposit occurs as sulphide dissemination zone in fine-grained calcarious meta-arkose layer within graphite schist.

The ore minerals are mainly dissemination ore of pyrrhotite and chalcopyrite, and small amount of arsenopyrite, chalcopyrite, hematite, ilmenite, pentlandite and sphalerite.

By microscopic observation of polished samples, irregular shaped pyrrhotite and chalcopyrite coexist, and marcasite which replaced pyrrhotite are recognized. Platy or foliated cubanite and chalcopyrite by exsolution within chalcopyrite, magnetite with hematite rim, euhedral pyrite and ilmenite, irregular shaped sphalerite and chalcocite which appears sphalerite are recognized, respectively.

3-4-2 Characteristics of mineralization

Strata bound disseminated copper sulphide deposit, copper vein type ore deposit accompanied with quartz and calcite vein, banded iron deposit, and dolomite deposit are located in Makonde area. These ore deposits have close relationship to the special horizon, rock facies and geological structure.

Relationship among mineralization and geological horizon, rock facies and geological structure is described in this chapter.

1. Strata bound disseminated copper ore deposit

All the deposits of large scale mines including the mine which is suspended in this area are this strata bound disseminated copper sulphide deposit type. Old Alaska Mine, the Angwa Mine, the Hans

Mine, the Shackleton including the Avondale ore deposits in the southern part of this area, the Mangula Mine and the Norah Mine in the central part of this area, the Shamrocke Mine in the northern part belong to this type of deposit.

From the viewpoint of the geological horizon, the ore deposits mainly occur in arkose of Deweras Group, however, the Old Alaska Mine and the Shamrocke Mine occur in dolomite and metamorphic rocks of Lomagundi Group.

From the viewpoint of the rock facies of ore deposit, there is a sedimentary cycle which is composed of one unit of conglomerate, arkose with grading and cross-bedding and pelitic rocks includes various evaporites. The ore deposits generally occur both within just under pelitic rock.

From the viewpoint of mineral assemblage, irregular shaped chalcocite, bornite and chalcopyrite are main ore minerals and dissemination ore minerals packed among particles of country rock are ordinary seen, particularly in small vein along bedding, In cleavage and fracture zone is rarely recognized. Particularly, high grade crude ore includes the mineral dissemination and small vein written above. Besides the accessory minerals, covelline, magnetite and hematite are recognized. In Shamrocke Mine, essential minerals are pyrrhotite and chalcopyrite with small amounts of pyrite, cubanite, chalcocite, covelline, sphalerite, magnetite and ilmenite.

From the viewpoint of grade of crude ore, grade of Au is within the range of 0.01 to 0.5 g/ton and becomes more than 1 g/ton in narrow vein, grade of Ag is always within the range of 1 to 30 g/ton and becomes more than 60 g/ton in narrow vein, and grade of Cu is within the range of 0.01 to 3.5 %. grade of Ni, Co and Pb, is in several 10 ppm. Zn becomes partly more than 1,000 ppm at the Shamrocke Mine and the Norah Mine, but is within several 100 ppm. Pt content in most of the samples is under the detectable limit.

From the viewpoint of related igneous rocks, doleritic dykes always exist near the ore deposits. However, doleritic dykes are often seen even in the non- mineralized zone, therefore, it is difficult to determine that doleritic dykes have relationship to mineralization.

As result, the discussion is summarized as follows :

1) According to expansion of rift valley, vesicular rocks such as conglomerate to arose were widely formed.

2) According to marine transgression, fine-grained politic rocks including evaporates were partly sedimented.

3) Deweras Group was formed due to repeated activity of above 1) and 2).

4) Various scale of fold structure, fault zone and fracture zone were formed by mobile activity.

5) Ore solution rose along the fault zone and fracture zone selectively through vesicular rocks, and fine-grained pelitic rocks formed the cap rock at the time.

6) Through the process, copper sulphide educed, and formed dissemination and narrow vein type ore deposit.

7) Present form of ore deposit was formed by movement after deposition.

2. Metalliferous vein type ore deposit

Only two places of quartz-calcite copper vein (United Kingdom ore deposit) and quartz-magnetite vein (Nyamamyako Hill) were recognized as metalliferous vein type ore deposit.

The former is dolerite dykes with inclined to the east which intruded along anticline axis with the direction of N-S and NNE- SSW of quartz-calcite vein. It is possibly to be formed by the activity which came to next of intrusion of dykes.

On the other hand, the latter is quartz vein occurring within the Younger Granites which is generally extended from the north to south. Similar quartz vein can be recognized in Nangaza Hill and Guma Hill, and they are considered to be formed by tension release in the late stage of granite formation.

Judging from the scale of ore deposits and grade of crude ore, both the types can be recognized neither capability of development nor economical value.

3. Bedded iron ore deposit

This deposit occurs in dolomitic shale of Lomagundi Group, which is so-called banded iron ore deposit. The ore deposit is considered to be by chemical precipitation ore deposit which is formed in marine basin. However, only one boulders ore deposit is recognized in this field. Therefore, the detail is still unknown.

Chapter 4 Geochemical surveys

4-1 Reconnaissance soil geochemical survey

4-1-1 Purpose of the survey

Though the multiple elements have been analyzed in the geochemical surveys in this area, the univariate analysis is mainly applied. Regional multivariate analysis has never been applied regionally. Therefore, the studies to discuss the geochemical outline for the characteristics and anomalies in this target area were carried out by multivariate analysis.

4-1-2 Selection of areas for soil geochemical survey

The locations where geochemical surveys were conducted are shown in Fig.II-4-1. The areas of potentialities of copper ore deposit occurrences are considered to be the distribution area of the Deweras Group from the central to the southern part, and to be the contact parts of the basement rocks, the Deweras Group, and the Lomagundi Group from the central to the southern part.

The soil sampling areas were determined based on the results of the existing data and geological survey. The standards of the selection of the areas are as follows:

1) the distribution area of the Deweras Group and the adjacent area.
2) the high potentiality place of copper ore deposits judging from the literature survey.
3) not polluted area by mining, dressing and refining.
4) the place which can be positioned with the GPS.

The selected 4 areas based on the above criteria are listed from the south as follows :

Table.II-4-1 List of selected soil geochemical survey area

Name	Area	Number of samples
1) The Alaska area	286km^2	1,143
2) The Umboe area	297km^2	1,189
3) The Mhangula area	258km^2	1,032
4) The Shamrocke area	78km^2	312
Total	919km^2	3,676

4-1-3 Sampling

The locations of sampling sites were positioned with the GPS. The samples were collected in the interval of every 500 metres (4 samples per 1 square kilometre). After removing the soil in

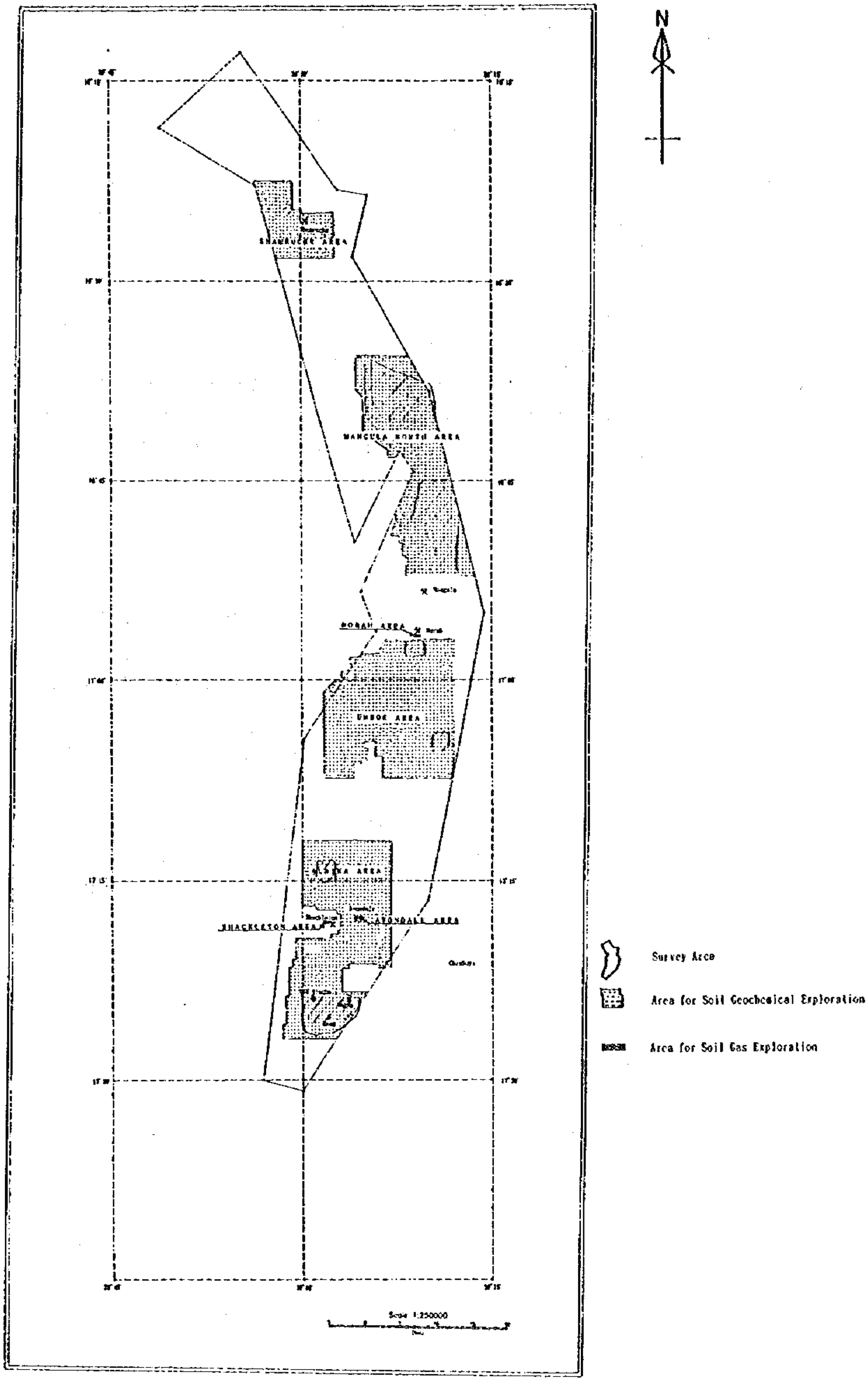


Fig.II-4-1 Locality of the geochemical survey area the A layer with pickaxes and shovels, the samples were taken from the B horizon.

4-1-4 Indication elements

The numbers of the analyzed components are 10. They are Au, Ag, Fe, Cu, Pb, Zn, Co, Ni, As and Hg.

4-1-5 Statistical processing of the analyzed values

The univariate analysis and multivariate analysis were applied to the results of the chemical analyses. The gap between the standard deviation multiplied by an integer and the geometrical mean value are adopted as a threshold in order to define the density distribution of the content of each component, that is, the concentration contour value I_{ij} for i times of the standard deviation is calculated as ;

$$I_{ij} = m_j \times 10^{\sigma_j \times i}$$

where mj and σ_j re the geometrical mean value and the standard deviation for the j-th component, respectively.

Analyzed values less than the detectable limit were treated as the half of the detectable limit.

Though 4 areas were studied, the statistical processing was carried out in one lump for all the areas.

The principal component analysis was carried out both with all the 10 elements and with 6 elements except Au, Ag, As and Hg of which more than a half of the samples were less than the detectable limits. Discussion is made on the characteristics of the axis of the principal component.

The correlation coefficient matrix was used as the initial matrix.

4-1-6 Evaluation of the soil geochemical anomalies

1. Characteristics of univariate analysis

The geometrical mean values, logarithmic standard deviation, and other basic statistical values are shown in TableII-4-2.

The characteristics of the statistical values and frequency distributions of the univariate analysis for all over the area are as follows :

TableII-4-2 List of statistical values of soil chemical analysis values

	Au	Ag	Cu	Pb	Zn	Fe	Co	Ni	As	Hg
	(ppb)	(ppm)	(ppm)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppb)
All sample Geometric average Standard deviation (logarithm)	1.4 0.47	0.08 0.32	26.0 0.45	15.3 0.39	48.9 0.55	2.17 0.27	8.0 0.34	51.1 0.26	2.2 0.54	5.6 0.14
Deweras group Geometric average Standard deviation (logarithm)	1.8 0.49	0.08 0.32	20.4 0.47	13.2 0.40	38.0 0.55	1.91 0.26	7.2 0.34	51.3 0.26	2.1 0.52	5.3 0.14
Maximum grade	450	8.5	819	129	6,297	8.58	85	658	151	130
Under detection limit(%)	53.9	79.3	1.4	6.1	2.9	0	3.8	0	71.4	97.8

Au: A remarkable bending point is recognized near 15 ppb, but the frequency of the population of that high concentration is less than 1 %. There is a population whose maximum frequency occurred at near 3 ppb. The cumulative frequency of the population larger than 3 ppb is 26 % of the total. At least the 48 % of the population less than the detectable limit did not belong to the population and can be estimated to form another population of the low concentration.

Ag: The cumulative frequency distribution curve above the detectable limit is almost linear. This could be because the effective digit is 0.1 ppm or because the population has a large standard deviation. In any case, it is difficult to estimate the population of the analyzed value.

Cu: The relative frequency distribution of the Cu shows that there are 3 populations whose maximum frequencies occurred at 8 ppm, 13 ppm, and 40 ppm, respectively, and other populations whose frequencies are less than the detectable limit.

Pb: The shape of the cumulative frequency distribution curve of the population more than the detectable limit is a declining parabola. Though frequency distribution has 2 peaks near 15 ppm and 25 ppm, these populations cannot be evaluated as the meant values only from these data.

Zn: There is a clear point of inflection near 200 ppm in the cumulative frequency distribution curve. The population can be divided into the smaller population which has the maximum frequency near 600 ppm and the larger population which has the maximum frequency near 45 ppm.

Fe: The frequency distribution curve is convex with a gentle slope in the population of the lower concentration. The cumulative frequency distribution curve has bending points near 0.8 %, 1.6 %, and 5 %.

Co: The cumulative frequency distribution curve has a broad slope in the low densities. It is difficult to separate some populations.

Ni: The frequency distribution shows that there are a large population with the maximum frequency near 55 ppm and a small population with the peak frequency near 25 ppm. The cumulative frequency distribution curve has bending points near 25 ppm and 100 ppm.

As: In general, the concentration of As in granite is about 1 ppm ,so in case of this area, where arkose is dominant, the population less than or equal to the detectable limit are considered to be the majority. Above the detectable limit, there is a population with the peak near 40 ppm. The cumulative frequency less than 40 ppm in this population is about 6 %. This is equivalent to the 12 % of the population.

Hg: Though the cumulative frequencies curve above the detectable limit are linear, the characteristics of the whole populations are not clear.

In case of the area where the Deweras Group are distributed, the geometrical mean values of Cu, Pb, Zn and Fe are less than those for the whole areas by 5.6 ppm, 2.1 ppm, 10.9 ppm, and 0.26 %, respectively. Those of the other elements are similar.

2. Characteristics of the results of bivariate analysis

The combinations whose correlation coefficients are more than or equal to 0.3 are as follows. Fe, Cu, Pb, Zn and Co, the correlation coefficients are between 0.30 and 0.69, which are large. The correlation coefficients of Ni and Fe, Ni and Co, and As and Zn are 0.35, 0.49 and 0.40, respectively. For Au, Ag, As and Hg, the densities whose frequencies are less than or equal to the detectable limit are majority. Hence the population of the analyzed values does not show the real distribution of the population, the correlation coefficients are not reliable.

3. Characteristics of multivariate analysis

Among the 10 elements analyzed in this survey, the frequencies of Au, Ag, As and Hg less than or equal to the detectable limit are majority. This means that the variances of these elements are not equal to those of the population. Therefore, the 6 elements excluding 4 elements above mentioned will be discussed below.

The contribution of the 1st principal component is 53.0 %. This component explains more than the half of the feature of the geochemical behavior of 6 elements. As the cumulative contribution ratio of the 1st to 4th components is 88.8 %, these 4 principal components will be discussed below.

The factor loadings of the 1st principal component show that it has positive correlations with all the elements. The correlation coefficients are from 0.55 to 0.87, which are high. The contribution values show that this component mainly explains the feature of Cu, Zn, Fe and Co. Like as the 1st principal component for 10 elements, this principal component is estimated to suggest the feature of the rocks which are original materials of the soil.

The factor loadings of the 2nd principal component show that it has negative correlations with Cu, Pb, Zn and Fe and positive correlations with Co and Ni. Especially, the correlation with

Ni is 0.76, which is highly positive. The contribution values show that this component explains the feature of Ni.

The factor loadings of the 3rd principal component show that it has a positive correlation with Ni and negative correlations with Cu, Zn, Fe and Co. Especially, the correlation coefficient with Pb is 0.70, which is highly positive. The contribution values show that this component mainly explains the feature of Pb as well as Cu. When the elements of small contents in mafic rocks and siliceous rocks are compared, in general, the contents of Cu, Zn, Fe and Co are larger in mafic rocks than in siliceous rocks, while the content of Pb are larger in siliceous rock than in mafic rock. From the sign of the coefficients of the eigenvalues, the elements which have low correlations with this component reflected existence of mafic rocks.

The factor loadings of the 4th principal component show that it has positive correlations with Cu, Pb, and Ni and negative correlations with Zn, Fe and Co. Especially, the correlation with Cu is 0.53, which is highly positive. The contribution values show that this component mainly explains the feature of Cu as well as Fe.

From the contribution values of these principal component analyses, the principal components which well explain the feature of Cu are the 1st and 4th components. At the 4th principal component, the sign of the coefficient of the eigenvector of Cu is positive, while those of Zn, Fe, and Co are negative.This structure of the eigenvectors give a small value when the contents of Zn, Fe and Co are large and vice versa. This can be used as the index to distinguish the mineralization of Cu and mafic rock. Therefore, Cu mineralization zone can be extracted by the feature which shows high Cu concentration and high score of the 4th principal component for 6 elements.

4. Characteristics of each area

(1) The Alaska area

There are the Hans Mine, the Angwa Mine, the Old Alaska Mine, Shackleton Mines including the Avondale ore deposit in this area. Besides these mines, the Alaska smelter is located in the south-eastern part of this area. These mines except the Old Alaska Mine, which is worked from the prehistoric time, were discovered by past soil geochemical surveys for Cu and the succeeding precise surveys. The existence of several Cu-anomaly places in the sedimentary rock in addition to the existing mines and ore deposits is pointed out by the past E.P.O.s' surveys. This area has high potentiality of undeveloped copper ore deposits.

Cu concentration indicates relatively high values widely in the southern part of the Shackleton Mine. The concentrations more than 73 ppm is shown in adjacent area of the Old Alaska, Angwa and Hans Mines which are already known. Remarkable Cu anomalies around the outcrops of the Avondale ore deposit is not recognized, and the mineralization zones were not detected with the sampling density in this survey. In comparison to the geological map, the distribution areas of doleritic dykes in the northern part of the Old Alaska Mine and basaltic lava flow of the Deweras Group show the high concentration more than 73 ppm. On the other single element anomalies, Fe concentration reflects the boundary of the arkose of the Deweras Group and the dolomite of the Lomagundi Group in the eastern marginal part of this area. The distributions of the concentrations of Au, Pb, Zn, Co and Ni show the tendency of which harmonizes the distribution of mafic rocks, however, it is difficult to say the high concentration or the low concentration halos which are directly reflected the occurrences of ore deposits like Cu concentration. As regards Ag and Au, the spots whose contents are less than detectable limits are scattered. Therefore, the interpretation by the single element concentration on the ore deposits is difficult.

By the distribution of scores of the 4th principal component of principal component analysis for 6 elements, the high concentration place over m+2σ is widely distributed in the area where is centered by the Old Alaska Mine. The Cu high anomalous concentration place in the northern part of the Old Alaska Mine is excluded from this high score places of this principal component, it is considered that the place is useful as the filter to distinguish the Cu mineralization which is the distribution area of mafic rocks from mafic rocks which have no relationship to the Cu mineralization.

(2) The Umboe area

The United Kingdom Mine is located in the south-eastern part of this area. As regards the geology of this area, arkose of the Deweras Group is distributed and dolomite of the Lomagundi Group is distributed surrounding the arkose. Doleritic dykes are intruded into the arkose.

Judging from single component, Cu, Au, Ag and Fe highly concentrate around the existing mine comparing to the surrounding area. Cu concentration has the tendency of higher concentration in dolomite of the Lomagundi Group than in arkose of the Deweras Group. The high concentration is recognized in the distribution area of mafic rocks same as in the Alaska area. The similar tendency for Fe and Zn is recognized, and the distribution of the concentrations of these elements harmonizes the boundary of strata. As regards the distribution area of the arkose of the Deweras Group, there are several places where shows high concentration places more than 73 ppm including the existing mine area. The high concentration zones more than 73 ppm are widely distributed in the Livington, Riversdale and the Zagulen farm areas in the north-western part of this area. The anomalous zones are not shown on the geological map, but, it is considered to correspond to the distribution of mafic rocks by the past E.P.O.s' (No. 74 and 414) surveys. Therefore, the possibility of Cu mineralization in the sedimentary rock is low.

The distribution of scores of the 4th principal component using 6 chemical elements shows high scores of m+2 in the several places including the United Kingdom Mine. Within the high scored places, the scores in the northern part of the United Kingdom mine and the southern part of the Norah Mine correspond to the Cu high anomalous areas.

(3) The Mangula north area

The soil geochemical survey has not been carried out in the northern half of the area. The distribution width of arkose of the Deweras Group is narrower in the part than in the southern part. The width from the east to the west is nearly 4 kilometres. The Basement Rocks and the Younger Granite are widely distributed in the eastern part of this area.

Judging from the single element, Cu concentration is generally low in the distribution area of the Younger Granite, and high anomalies are not recognized. The high anomalous places more than 73 ppm are widely recognized in the distribution area of the Deweras Group, Some of them are distributed in the boundary area of the Basement Rocks and the Younger Granite where does not correspond to the distribution area of mafic intrusive rocks on the geological map. The high anomalous places more than 73 ppm in the distribution area of the Basement Rocks in the Binge and Dwing Farms in the northern part of the area. The verification of the geology of adjacent area is necessary. The same tendency is recognized as the high concentration of Au. The high concentration places of Zn, As and Hg are scattered all over the area regardless of the strata, therefore, interpretation by single element is difficult.

The scores by the 4th principal component for 6 elements are generally low, the places with high score more than 73 ppm are only two places. All the distribution areas of Cu high concentration (more than 73 ppm) which is corresponded to the distribution of the mafic rocks are less than $m + 2\sigma$ of this principal component. Within the area of the score less than $m + 2\sigma$ of this principal component which are recognized the overlapped places by 73 ppm are around the lowest horizon of the Deweras Group from Chilomboji through Greenfieldin to Wilden in the northern Mhangura.

Besides the above distribution, some of them are spotted in the distribution area of mafic rocks.

(4) The Shamrocke area

This area is differ from the other three areas and shows mountainous topography. The Shamrocke Mine is located in this area, and mined copper and silver. The ore deposit occurs within the Lomagundi Group.

Judging from the single element, Cu concentration shows higher in this area than in the other areas, high anomalous places more than 73 ppm are scattered. However, The remarkable anomalous places are recognized around the Mine. The width of chemical anomalous zones which were detected by past E.P.O.s' surveys stretch several ten metres from the east to the west. They cannot be detected by this survey due to the rough sampling interval.

4-2 Detail soil geochemical surveys (Analyses of previous geochemical data)

4-2-1 Purpose of the survey

Based on the results of the reconnaissance geochemical survey, this survey was carried out in order to extract the high potential areas for the existence of new ore deposits.

4-2-2 Selection of the survey areas

Areas were determined based on the results of the reconnaissance survey. Totally 33,681 chemical analysis data include around of target area ware for computer analysis.
Summary of the selected areas are as follows:

TableII-4-3 List of area of the existing data analysis

selected area	square of the area	number of analysis data in the area	number of analysis data for study
1) Greenfields area	$47km^2$	1,684	1,887
2) Pringani area	$5km^2$	591	2,086
3) Inyati area	$6km^2$	1,144	3,086
4) Lions Den area	$2km^2$	551	2,024
5) Angwa area	$50km^2$	19,085	24,598
Total	$110km^2$	23,055	33,681

4-2-3 Collected data

Chemical analysis data of previous soil geochemical survey and partly these compiled data which kept in GSD and ZMDC are used for computer analysis.

List of collected data is shown to TableII-4-4.

TableII-4-4 List of collected data

Collected data	specification
E.P.O.No.351,514 Progress map (scale 1:50,000) Chemical assay maps (scale 1:5,000)	 1 sheet 9 sheets (L1WEST,L1EAST,L12WEST,L12MID, L12EAST,L13WEST,L13MID,L13EAST, L16WEST)
E.P.O.No.414 Progress map (scale 1:50,000) Chemical assay map (scale 1:5,000)	 1 sheet 1 sheet (J2)
Mhangua Mine Geochemical Survey Chemical assay maps (scale 1:2,500)	 7 sheets
ZMDC Copper soil geochem plan maps compilied by Simpson.H.(1990)	2 sheets (Figure No.7,No.8)

4-2-4 Statistical processing of the analyzed values

The univariate analysis are applied to the results of the chemical analyses. Though 5 areas were studies, the statistical processing was carried out in one lump for all the areas.

4-2-5 Result of survey

(1) The characteristics of soil geochemical anomalies

The statistical parameter such as geometrical mean and standard deviation of logarithm and the zonal classification of the analysis are Table in TableII-4-5.

TableII-4-5 Statistical parameter and zonal classification of the analyzed values

statistical parameter		zonal classification	
element Number of samples	copper 33,681	I zone	$m \times 10^{-\sigma} \sim m \times 10^{\sigma}$ 11.0ppm ~ 27.8ppm
maximum value minimum value	66,000 ppm 5 ppm	II zone	$m \times 10^{\sigma} \sim m \times 10^{2\sigma}$ 27.8ppm ~ 70.1ppm
mean geometrical mean	52.484 ppm 27.765 ppm	III zone	$m \times 10^{2\sigma} \sim m \times 10^{2\sigma}$ 70.1ppm ~ 177.1ppm
standard deviation standard deviation(log)	428.478 ppm 2.526 ppm	IV zone	$m \times 10^{2\sigma}$ < 177.1ppm <

*m:geometrical mean, σ:standard deviation(log)

The characteristics of the statistical values and frequency distributions of the copper univariate analysis for all over the area are as follows;

The geometrical mean value and the maximum value are 27.8ppm and 66,000ppm. The 0.35% of the population are less than the detectable limit. The relative frequency distribution shows that maximum frequencies occurred at 25ppm.

On the other hand, there is a inflection point near 100ppm in the cumulative frequency distribution curve. The population can be divided into low copper concentration group with steep curve and high copper concentration group with flat curve.

Arkose of Deweras group distribute generally in the area high copper concentrate group suggest a enrichment of copper curved by mineralization.

(2) The characteristics of each areas

The geochemical survey is summarized in Fig.II-4-2.

The anomalous zones due to the Cu-Ag-Au mineralization of this area are judged to be the following three places by the reconnaissance geochemical survey.

1) The distribution area of arkose of the Deweras group

2) The high concentration zone of single component of Cu

3) The high scoring places of the 4th component by principal component analysis used the six components of Cu, Pb, Zn, Fe, Co, Ni

The characteristics of each survey area is as follows:

1. Greenfields area

Chemical analysis data and compiled data used for the study in this area, because of many original chemical analysis data were scattered.

Cu high concentration of this area are distributed in the south-central part of the Wolwehoek farm, the north-central part of the Chimusenga farm, the western part of the Greenfields farm, the Geduld farm and the eastern part of the Chironbozi farm.

1) The Wolwehoek farm

The high concentration part widely distributes in this area. It corresponds to the distribution of the dolomites of the Lomagundi group and the basic intrusives. This site was not decided to be mineralized anomaly because of the low scoring of the principal component analysis of reconnaissance study. It was known that the distribution area of the Lomagundi group and the basic intrusives show Cu high concentration anomaly without mineralization. This high Cu concentration zone is not by mineralization but the reflection of geological conditions.

2) The Chimusenga farm

The small scale high concentration areas are scattered in this area. They correspond to the distribution of the arkose of the Deweras group and the small scale basic intrusives. This site slightly satisfied the above three conditions, and judged to be a mineralization anomaly by reconnaissance study. This high concentration zone is considered to be formed by both the mineralization and intrusion of basic intrusives.

3) The western part of the Greenfields farm

The distribution is narrow. It corresponds to the distribution of the boundary part of the arkose of the Dewelous group and the basement granite. This boundary is the ore-bearing horizon of the Mhangura mine. The Cu high concentration zone shows rather wide distribution by reconnaissance study. And, it was judged to be a mineralization anomaly. Small scale high concentration zones which corresponds to the anomalous zone were detected by this study. These high concentration is considered to be formed by the mineralization.

4) The Geduld farm

The high concentration parts are widely distributed in this site. They correspond to the

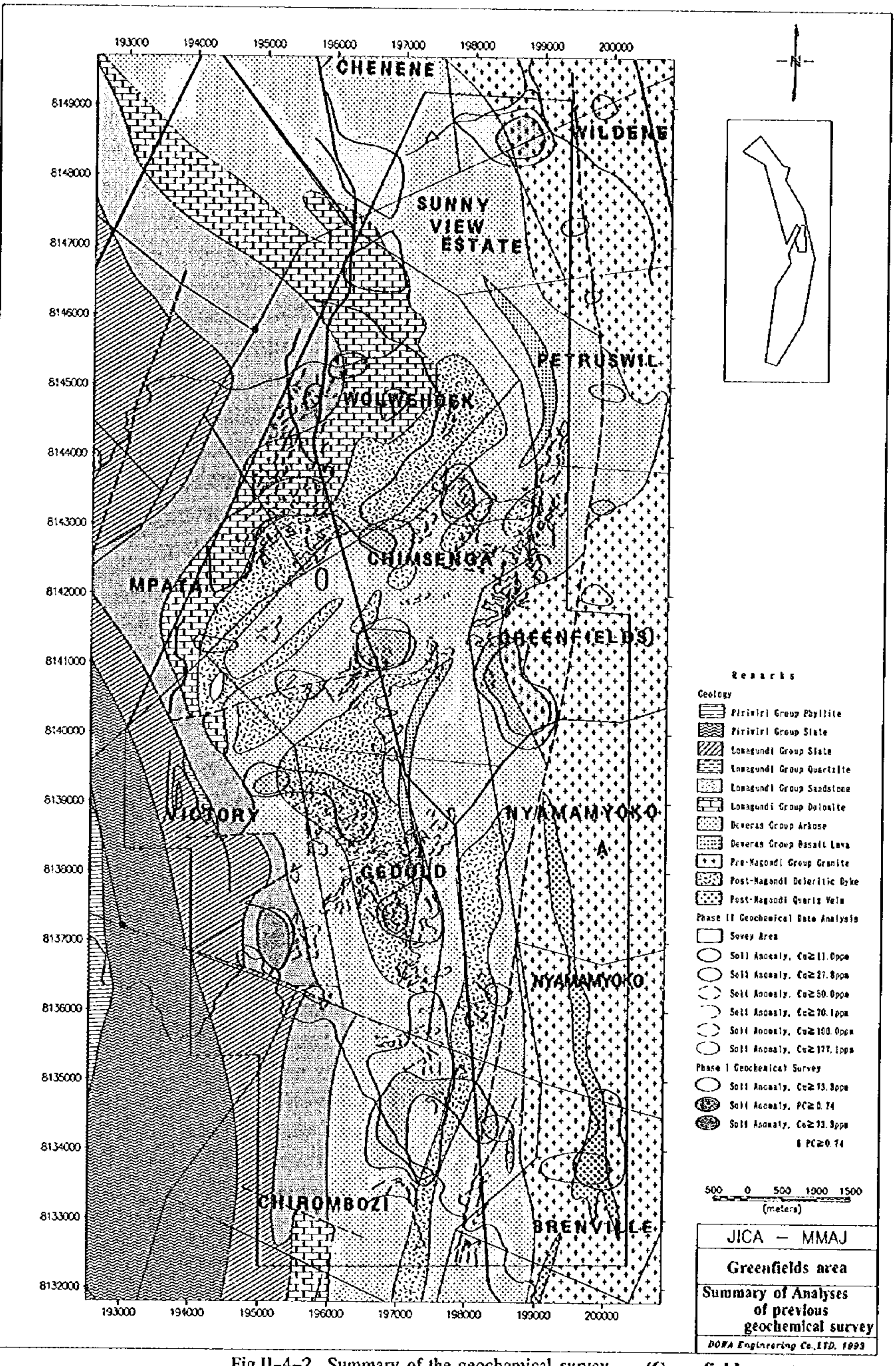


Fig.II-4-2 Summary of the geochemical survey (Greenfields area)

distribution of the basic intrusives within the Deweras group. This site shows low scoring of the principal component analysis, and was not judged to be a mineralization anomaly. The wider high concentration zone was detected by this study. This zone is considered to be formed by basic intrusives.

5) The eastern part of the Chironbozi farm.

The small scale high concentration areas are scattere about this site. The high concentration part of the western side of the main road corresponds to the basic intrusives. The high concentration area of the eastern side of the main road corresponds to the boundary of the arkose and basement granite, and it intends to continue from the north to the south. The high Cu concentration detected by this study is considered to be formed by the mineralization and basic intrusives. The high concentration zone of the eastern side which is located in the boundary area of the arkose and the granites has a high probability and being formed by mineralization.

2. The Piringani area

Chemical analysis data and these compiled data also used for the study in this site.

The zone of more than 50ppm of Cu concentration is widely distributed in this area. On the other hand, The distribution of the zone more than 100ppm of concentration is limited to a narrow area. The high concentration zone is located in the southern part of the Nohra mine. It is considered to be formed by mineralization.

3. The Inyati area

The Cu high concentration zones are widely distributed in the northern, the eastern and the western marginal part of the area. The small scale high concentration zones lie scattered in the central part of this area. The high concentration zones of the marginal parts correspond to the distribution of dolomite of the Dewelous group. The high concentration zone of the central part corresponds to the distribution of basic and quartz vein. The old United Kingdom mine is situated in the marginal part of the basic vein and quartz vein. The high concentration zone of the central part is considered to be originated by the basic intrusives and mineralization, however, the scale is very small.

4. The Lions Den area

The Cu high concentration zone(Cu>70.1ppm) of this area has the characteristics which narrowly continues from NNW to SSE in the central part of this site. The Cu concentration zone of more than 27.8ppm is distributed in the NS direction with a tree like shape. This high concentration zone corresponds to the extension part of basic vein. This high concentration zone which is narrowly elongated shows characteristic distribution due to the basic dykes of this area.

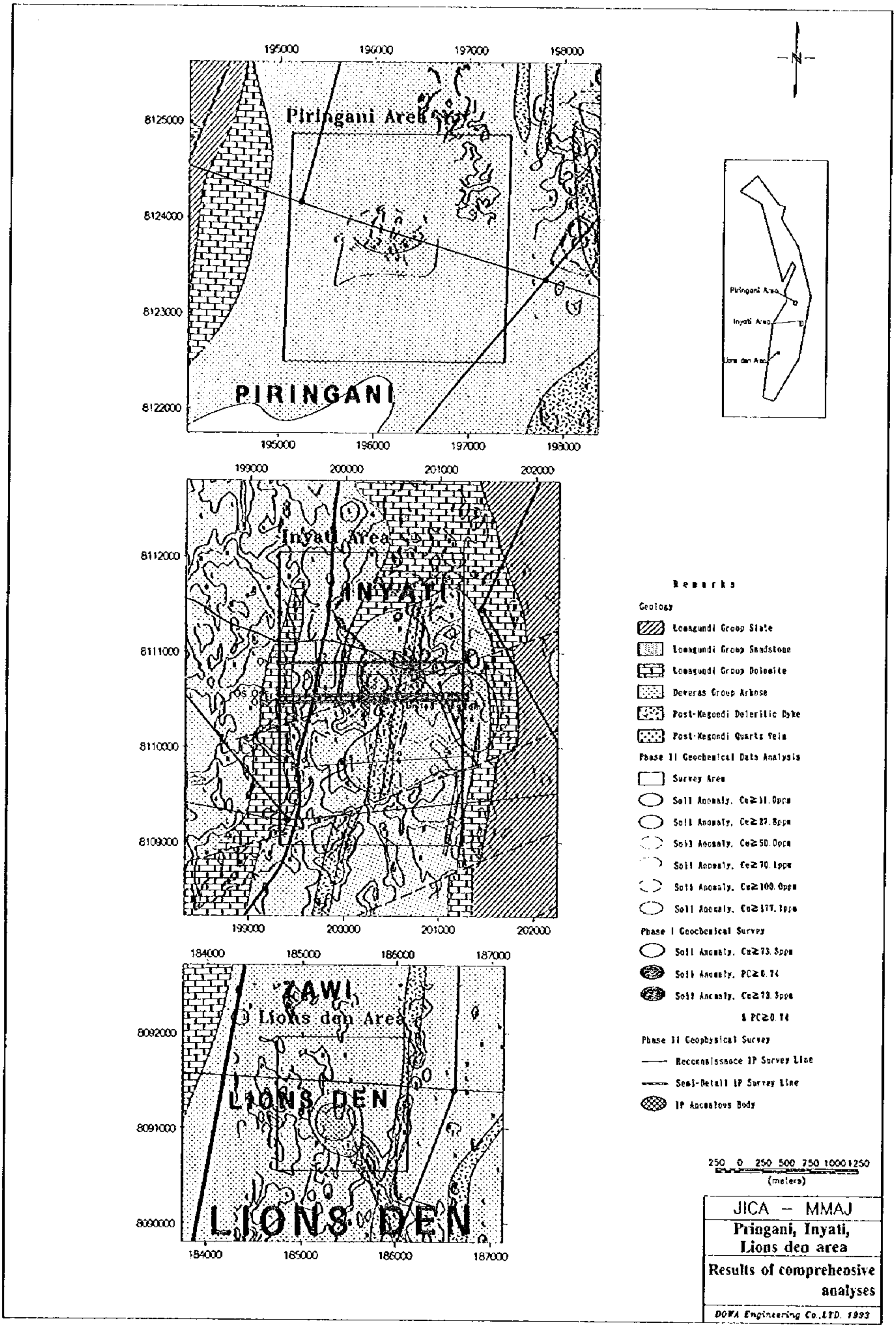


Fig.II-4-2 Summary of the geochemical survey (Pringani, Inyati, Lions den area)

5. The Angwa area

The distribution of high concentration zone(Cu>70.1ppm) of this area is classified into the following four sites.

1) The wide high concentration zone around the Old Alaska mine

The high concentration zones are distributed from the central part of The Old Alaska mine to the central part of the Stonebyres farm, the northern part of the Glenshields farm and the western part of the Alaska farm. These high concentration zones correspond to the basic dyke in the southern part of the mine, and the dolomite of Lomagundi Group in the western part of the mine. In addition to these characteristics, mounds of waste are scattered around the mine and waste ores also are spottedly left in the farm. The high concentration zone of Cu is considered to be formed by the complicated activities of dolomite of the Lomagundi group, basic intrusives, waste ores and mineralization.

2) The successive high concentration zones from Greenshields farm, The Goldenvale farm, the Belltrees farm and the Freda farm

These narrowly continuous high concentration zones correspond to the basic dykes in the northern part of the site. There is no corresponding basic dykes in the southern part, however, it suggests the existence of extensions of the dykes. It cannot be considered to be a high concentration zone formed by mineralization.

3) The high concentration zone from the Alaska smelter to the Sinoia Drift Estates farm

The high concentration zone is widely distributed from the Alaska smelter to the Sinoia Drift Estates farm. This high concentration zone neither shows the characteristics of geology nor geological structure. Waste of the smelter was left in the southern part of the smelter, and there is no facilities for flue gas treatment. It can be considered to be formed by dressing, and difficult to be formed by mineralization.

4) The high concentration zone from Angwa Mine to the Hans Mine

The medium to small scale high concentration zones successively continue from the Angwa mine to the Hans mine. Both the mines are included in the high concentration zone. These high concentration zones have two directions of NE-SW and NNW-SSE. These two directions are harmonized to the direction of the strike, fold axis and fault zone of this site.
The high concentration zones and the high scoring places of the principal component analysis were also detected in the southern part of the Angwa mine and the northern part of the Hans mine by reconnaissance study. This high concentration zone is considered to be possibly formed by mineralization.

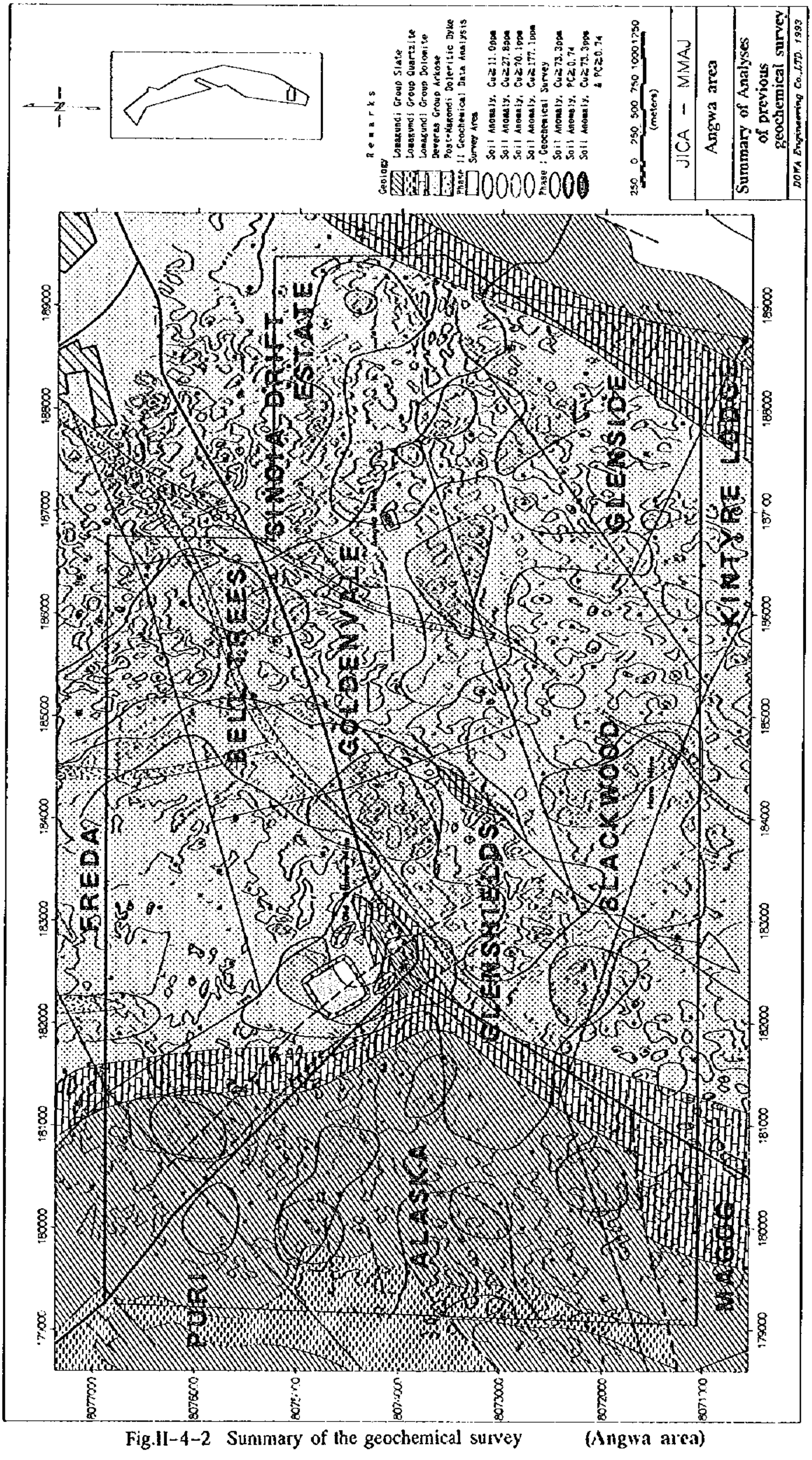


Fig.II-4-2 Summary of the geochemical survey (Angwa area)

6. The other geochemical anomalies

The geochemical anomalies were detected in the northern part of the Greenfields site(the Wilden farm) and Binge site(the Chipiri farm, the Tchetchenini farm, the Binge farm and the Redwing farm) by reconnaissance. No geochemical prospecting has been carried out in this site, all these detections are completely new facts.

4-3 Gas chromatography survey

4-3-1 Selection of the areas of gas chromatography survey

The gas chromatography survey was carried out in the three selected area around the known ore deposits. The areas are as follows :

1) The sub-outcrops of the Avondale ore deposit ------ Avondale area
2) Just above the Shackleton dyke -------------------- Shakleton are
3) The south of the Norah ore deposit ---------------- Norah area

Two intervals of the survey line, 20 metres and 40 metres, were determined, and surveys were carried out based on the scales of the target ore deposits.

4-3-2 Method of measurement

The measurement was carried out in the holes. The holes which made to drive iron pipes with 2 inches diametre into the soil nearly 50 centimetres and with drew the pipes later. The holes were left during several days and the measurements were conducted twice. The data were the average value of the twice measurements.

The measurements were also conducted by glass test tubes. This method is as follows: The reagent which changes the colour by the reaction of CO_2 gas was enclosed in the test tube. When some amount of air was inhaled, the reagent changes colour. The measurement is carried out to read the amount of reagent which turned the colour with working curve. The inhaled amount of air was 100 ml per one measurement. It took about 4 minutes to inhale the air.

4-3-3 Evaluation of gas chromatography anomalies.

The high CO_2 gas concentrates within the soil in the exposing place of ore deposit than in the ordinary place is known (Rose et al.,1979, Lovell et al., 1983, Kravtsof and Reiman,1965). CO2 gas in soil generates by the growth of plants, decomposition of organic materials within the soil and activities of insects. Besides these organic effects, CO_2 gas is considered to generate by the reduction reaction of carbonate minerals and sulphide. Several CO_2 gas chromatography surveys just above ore deposits using the latter characteristics have been carried out for the ore deposit in the desert of Namibia and Alizona, the United State (anilova,1968, Dyck,1974). In this project, the same surveys were carried out in the three areas where occur different type of the ore deposits each other.

The basic statistics about the CO_2 gas measurement, and the distributions of the relative frequency and the cumulative frequency distributions are shown in Table II-4-6.

TableII-4-6 Statiotical parameta of CO_2 gas chromatographic measurement

Area	number of lines	number of sites	maximun (%)	minimun (%)	geometric average (%)	standard deviation (logarithm)
Avondale	10	245	0.67	0.07	0.153	0.155
Shackleton	7	252	0.25	0.03	0.063	0.138
Norah	6	284	0.82	0.03	0.083	0.214
whole area	23	781	0.82	0.03	0.092	0.234

The description about the measurement is reported in the following:

1. The Avondale area

The Avondale area is located on the area where is considered to be the outcrops of the Avondale ore deposit by past survey. The western margin of the area is the Avondale vertical shaft. 20 survey lines were arranged from the direction of N20E which crosses at right angles to the strike of the ore deposit. 245 stations on the survey lines were installed. The survey was carried out in the field covered by deciduous trees and grasses with little artificial changes. There are many anthills. The anthills which are about 30 cm high are scattered with the interval of several metres. Several anthills with nearly 1 m high are observed in the area.

CO_2 gas concentration of geometrical mean in soil in this area is 0.153 % which is generally higher comparing to the concentration in air. Several high concentration places with the maximum 0.67 % as halo were observed. As the high concentration places are not located in the high Cu concentration zone of the existing soil geochemical survey, it is difficult to consider that the high concentration is originated in high concentration anomaly accompanied with the mineralization. It is properly considered the CO_2 high concentration due to the underground activity of ants.

2. The Shackleton area

The Shackleton area is located nearly 1km north west north from the Shackleton Mine. The survey lines were arranged from the direction of N8E which nearly crosses at the right angles to the Shackleton intrusives which have relationship to the mineralization of the ore deposit. Numbers of the survey lines and stations were 7 and 252, respectively. The area is flat corn field. The survey was carried out in bare field after harvest.

CO_2 gas concentration in soil of geometrical mean in this area is 0.063 % which is generally low. Some high concentration places as anomalies were spottedly observed on the Shackleton dyke (doleritic dyke). As the high concentration places are difficult to say to be significant comparing to the other high concentration places.

3. The Norah area.

The distribution of CO_2 gas concentration in soil is shown in Fig.II-3-17.

The Norah area is located nearly 0.5 kilometres south from the Norah Mine. The direction of survey lines were arranged from the direction of N8E. Numbers of the survey lines and stations were 6 and 282, respectively. The area is flat corn field. Thick reeds with about 100 metres in width are spotted.

CO_2 gas concentration in soil of geometrical mean in this area is 0.083 % which is generally low. The high concentration zone with the maximum 0.82 % were distributed in the above place with thick reeds. The high concentration zones are considered not for the mineralization, but due to decomposition of organic matter deposited at the place.