REPUBLIC OF BOTSWANA

REPORT ON GEOLOGICAL SURVEY OF NORTHEASTERN BOTSWANA

CONSOLIDATED REPORT

FEBRUARY [illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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PREFACE

The Government of Japan, in response to the request of the Government of the Republic of Botswana, decided to conduct collaborative mineral exploration in an area stretching over the Northeast and Central District in the northeastern Botswana and entrusted its execution to Japan International Cooperation Agency (JICA) and Metal Mining Agency of Japan (MMAJ).

The survey started in 1979 had been accomplished under close cooperation with the Government of the Republic of Botswana and its various authorities.

This report hereby summarizes the outcomes of the project obtained in four years.

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

February 1983

Keisuke Arita
President
Japan International Cooperation Agency

Masayuki Nishiie
President
Metal Mining Agency of Japan

Fig. 1 Location map of the survey area

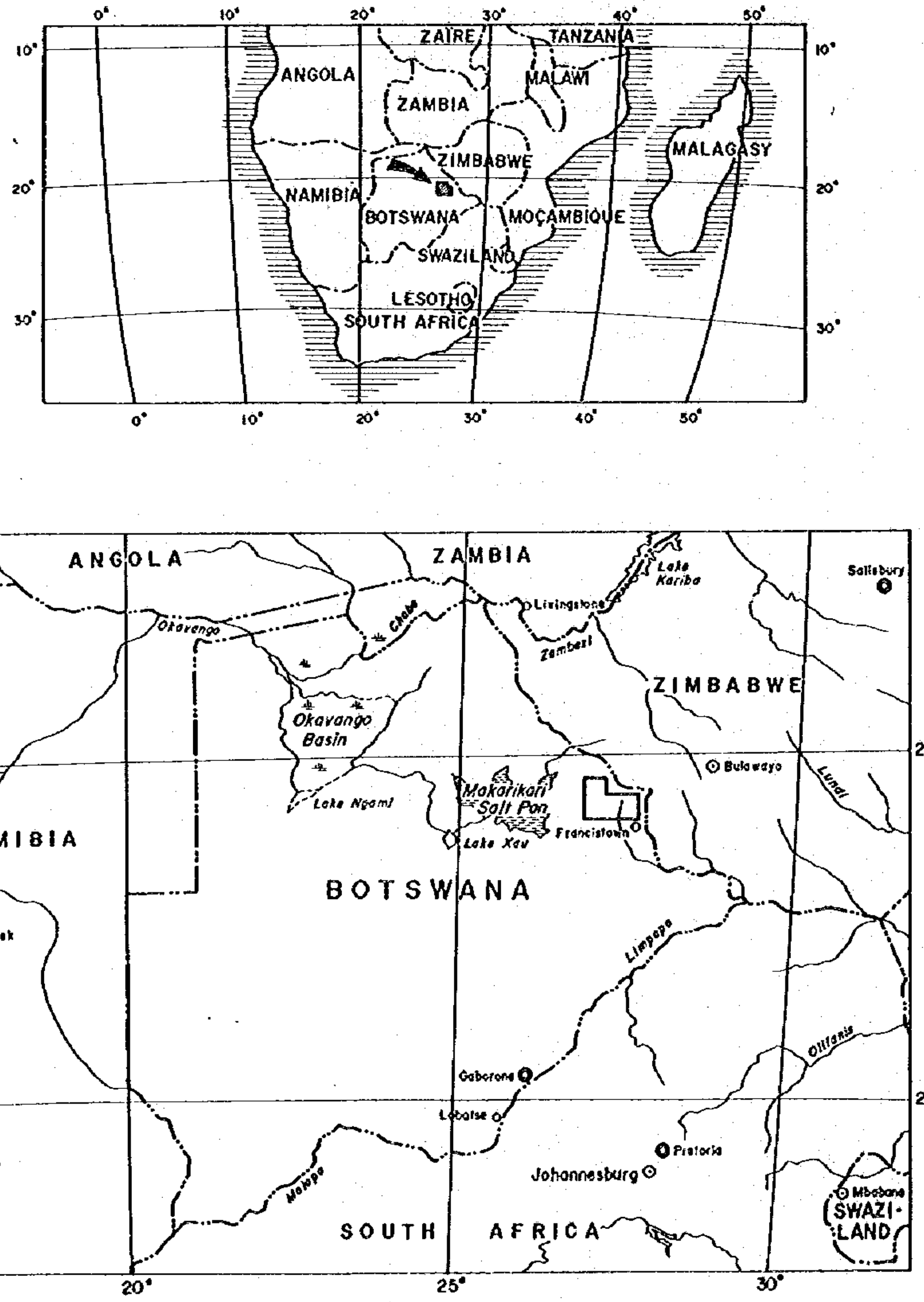
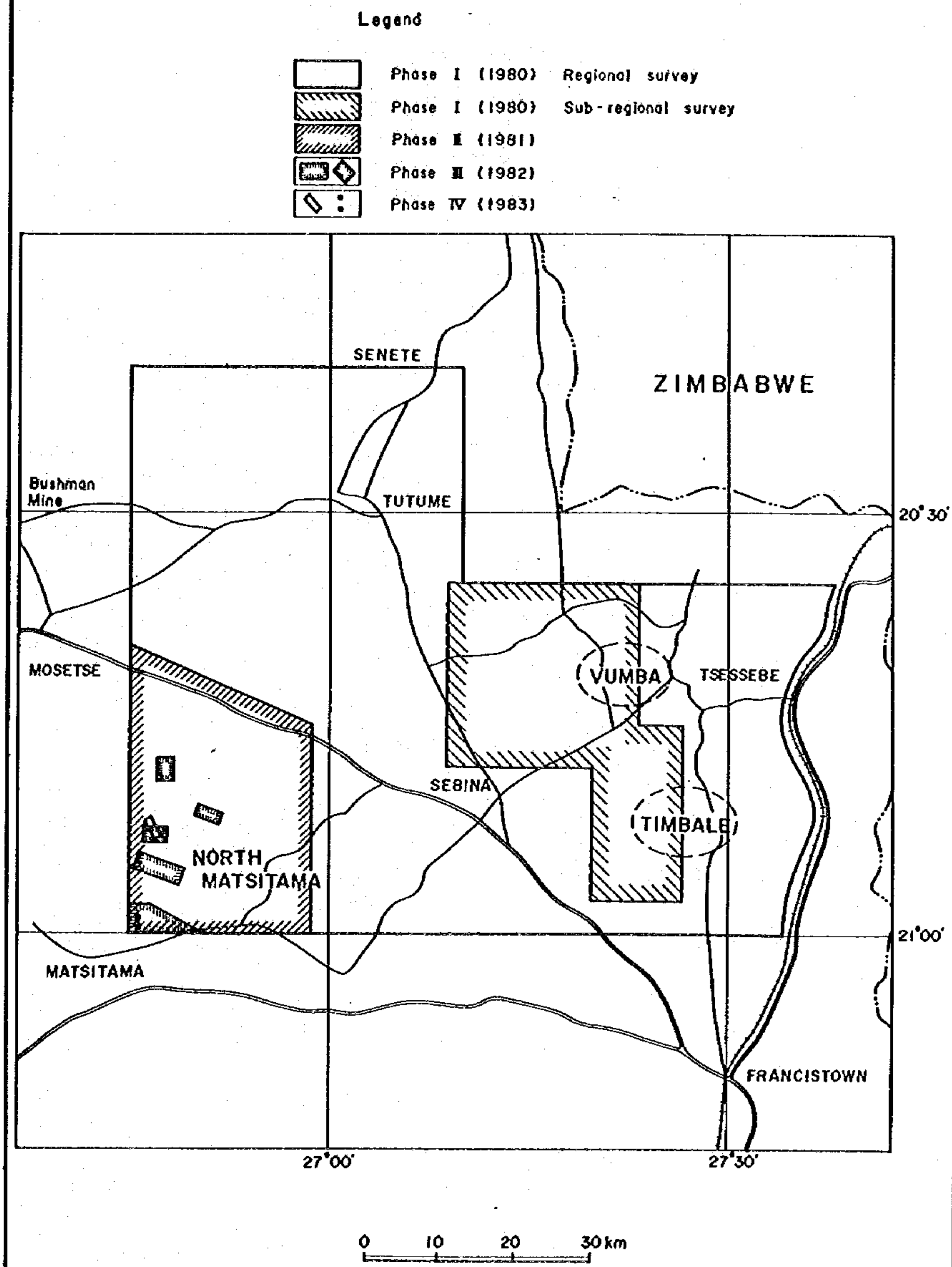


Fig. 2 Progress in survey



SUMMARY

These surveys have been conducted over the four years from July 1979 to February 1983 for the purpose of the development of mineral resources in the northeastern region of the Republic of Botswana.

The survey area, covering an 5,300 km^2 area, includes three areas: the Vumba area where occurrence of gold deposits and nickel and copper-containing sulphide deposits are hoped, the Timbale area offering the hope of copper and molybdenum deposits accompanied by rare element minerals in relation with pegmatite, and the northern Matsitama area giving the hope of occurrence of metasedimentary copper deposits.

Since the survey area is extensively covered with the Kalahari sediment of the Cenozoic showing very few outcrops, the survey work principally depended on soil geochemical survey with geological surveys, geophysical prospecting and other activities conducted in combination with it. The following is a general description of the survey of each of the three areas.

Vimba Area:

Gold mineralization has been found at places in the Vumba Volcanic Group in this area, and old mining sites remain there. The mineralization zones exist mostly as gold-containing sulphide-disseminated zones in or around quartz in amphibolite or in shear zones with a north-northwest trend. Possibilities for justifiable exploration were studied around Somerset mine which has the largest scale in the this area and has the record of operation and surrounding mineral indication area. However, particularly promising mineral indication was not discovered and no anomaly was recognized as the result of geochemical survey, so that the surveys were terminated with the end of the first year surveys.

Timbale Area:

Geochemical anomalies about copper and molybdenum, which are considered related with the intrusion of pegmatite, were found in the Timbale granite and aureole and in some parts existence of vanadium and yttrium was also reported (Litherland 1975).

In this area, a study of heavy minerals was made in addition to a geological survey and geochemical survey.

However, since no particularly mentionable mineral indication was found, further surveys were given up.

Northern Matsitama Area:

As the result of the geochemical survey in the first year, the originally 5,300 km^2 area was narrowed down to this area of 800 km^2 as an area with the possibility of bearing copper deposits.

In the second year program, airborne geophysical propecting (INPUT electro-magnetic, magnetic and radioactivity prospecting) was conducted over the entirety of this area, which was followed by ground geophysical prospecting (Pulse EM, IP and magnetic prospecting) on picked-up anomalies.

As the result, anomalies presumed to be attributable to a sulphide mineral or graphite were picked up. Also a semi-detailed geochemical survey was made on a part covering a 230 km^2 area and copper anomaly areas were extracted.

In the third year, drilling was made aiming at these geophysical anomalies mainly. As the result, most of these anomalies were judged to be ascribable to graphite, and sulphide minerals were scarcely found. Drilling for some part of geochemical anomalies resulted in confirming copper indications, though not in a great measure.

Also a geological survey, trenching and drilling made about small chromite outcrops discovered by the second year geological survey. This indication was confirmed to be small chromite ore bodies 5 to 10 m in length and 0.5 to 1 m in width, scattered in ultrabasic rock bodies.

The ore grade was found to be 32 to 36% of Cr_2O_3 and 17 to 19% of T. Fe.

In the fourth year, a detailed geochemical survey was made on an area centering on the above-mentioned copper indications, and drilling was made for anomalies picked up by the prospecting. The geochemical anomaly area was found to be oriented in the same direction as the strata, and the result of drilling showed copper indications over an extensive area, though slight; the anomaly area was judged to coincide with the deposit bearing horizon.

In addition, drilling was made also for a geochemical anomaly in the southwest of this area, and the survey team confirmed thin layers of limestone accompanied by a very samll quantity of chalcopyrite. This area is equipped with geological conditions similar to those of Matsitama deposits, and it was considered that there was still some possibility of justifiable prospecting activities.

As described in the above, this survey project has been advanced starting with the 5,300 km^2 area, and though any deposit was unable to be discovered, the survey team was able to narrow down a deposit-bearing horizon distribution area into an area of 1.3 km x 0.5 km. Since this district area tends to extend northward further, it is desired that continuous tracing and exploration of these mineral indications be made to confirm whether there is any deposit.

Also, geochemical anomalies in the southwest of the survey area include intensive ones and tend to extend further westward. Since this area has geological conditions similar to those of Matsitama deposits, and copper indications are found at places, it is desired that the exploratory scope be expanded to the west carrying out the method of confirming whether there is any deposit while narrowing down promising areas by geochemical survey.

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Chapter I. INTRODUCTION

1-1 Circumstances and Object of Surveys

The Republic of Botswana is an emergent nation with rich mineral resources which has made their development a national policy taking advantage of its position of adjoining the world-famous mineral resources dominant zone of southern Africa since its independence in 1966 and has succeeded in developing such mineral resources as copper, nickel, diamond and coal.

The republic positively carried out this policy with the cooperation of developed nations, and the Governments of the United Kingdom, Canada and West Germany had given their cooperation before Japan lent its cooperation.

In July 1977 Mineral Resources and Water Affairs Minister Dr. Chiepe visited Japan and advanced the request of the Government for cooperation in exploration of mineral resources. In response to it a survey team to select a project was sent from Japan in October the same year, and on this occasion the Geological Survey Department of Botswana came up with five proposed survey areas.

As a result of a development plan survey by the Japan International Cooperation Agency conducted in April through June 1978, the Vumba area was selected from among the five areas. The Government of Botswana, receiving the report of such selection, made an official request for cooperation in July the same year.

In May 1979 the Japanese Government, accepting the request, made negotiations with the Botswanan Government for an agreement for a prior survey including a site reconnaissance, which resulted in an exchange of verbal notes and the decision on execution of survey work.

A period of three years was scheduled for the survey work, which was started in July 1979. However, extension of the period by one year was requested by the Government of Botswana, and this project came to an end with the presentation of this report in February 1983.

The object of this survey work has been to reveal, with various means of exploration, the geology and geological structure of the survey area covering 5,300 square kilometers and the characteristics of mineral deposits, to pick out areas with high possibility of occurrence of mineral deposits, and finally to find new deposits.

1-2 Brief Description of Survey Work

The basic survey for cooperation in mineral resources development in the north-eastern region of the Republic of Botswana, which was carried out from 1979 to 1982, covered an area of 5,300 square kilometers comprising three areas, the Vumba mineralization area featured by gold mineralization, Timbale area expected rare elements and the northern Matsitama mineralization area where copper mineralization was expected.

In the survey project, the study of available existing data, the analysis of LANDSAT data, the interpretation of aerial photographs, geological survey, geochemical survey, airborne geophysical prospecting (EM, magnetic, and radiometric) geophysical prospecting on the surface (EM, IP, and magnetic), and drilling survey were conducted in order.

The progress of the survey project was made in the form that the results of the exploration methods implemented each year out of the above-mentioned methods were synthetically analyzed and thus the initial large survey areas were narrowed down in order into more promising areas possible of bearing mineral deposits.

The members who engaged in this project, coming from both Japan and Botswana, are listed in the following:

Members from Japan

	1979	1980	1981	1982
Planning exploratory method and negotiations (1st)	Kyuzo Tadokoro Setsuo Takemoto Toshio Sakasegawa Kenji Sawada Takashi Nakagawa	Toshio Koizumi	Nobuhisa Nakajima	
Planning and negotiations (2nd)	Yutaka Hatano Minoru Fujita Mitsuru Suemori	Toyo Miyauchi Toshio Koizumi Katsumi Yokogawa	Akira Takahashi Toyo Miyauchi Nobuhisa Nakajima	Hiroshi Iwasaki Tamotsu Nakajima
Geological survey and geochemical survey	Tamotsu Nakajima Iwao Uchimura Takehiro Sakimoto Akitsura Shibuya Keiji Nakano	Tamotsu Nakajima Iwao Uchimura Takehiro Sakimoto Atsumu Nonami Shigeyuki Saito	Tamotsu Nakajima Iwao Uchimura Takehiro Sakimoto	Iwao Uchimura
Geophysical prospecting		Masao Tatsugami (Toshio Koizumi) (Katsumi Yokogawa) (Tamotsu Nakajima)		
Drilling			Sakari Kon Hisao Ataku Akemichi Saito Mutsuo Saito Mitsuo Nagata Koichi Ito	Hisao Ataku Yoshikazu Sugawara Katsunori Murakami Mutsuo Saito Koichi Ito Takayuki Akashi

Members from Botsuwana

	1979	1980	1981	1982
Planning exploratory method and negotiations (1st)	C. R. Jones R. D. Walshow G. C. Clark D. Gould	G. C. Clark R. D. Walshow	G. C. Clark C. Black D. G. Hutchins	G. C. Clark C. Black D. G. Hutchins
Geological survey and geochemical survey	T. P. Machaiha D. Mothoki M. Sixpence	B. Aboneng M. Kgomaesele H. Kara	B. Aboneng M. Kgomoesele M. Ditlhogo	M. Sixpence
Geophysical prospecting		D. G. Hutchins		

The survey work carried out each year is described as follows:

Surveys in 1st year (1979)

For the 1st year survey project, over an area of 5,300 square kilometers which includes the three mineralization areas of Vumba, Timbale and northern Matsitama, the analysis of LANDSAT data, geological interpretation of aerial photographs, regional geological survey, and geochemical survey were carried out. Also a sub-regional geological survey and sub-regional geochemical survey were made over an area of 700 square kilometers of the Vumba – Timbale, which was considered to have the highest possibility of occurrence of deposits within the regional survey area from available literature and other information.

The resutls of the LANDSAT data analysis and the regional survey were put into a 1/100,000 scale geologic map (PL. 1) and others; the results of the sub-regional surveys were put into a 1/25,000 scale geologic map and others.

As the result of the synthesis of these results, an area of about 800 km² of the northern Matsitama area was selected as the survey area for the 2nd year.

Surveys in 2nd year (1980)

Airbone geophysical prospecting, which was entrusted to Geoterrex because of the patent license and a sub-regional geological survey were conducted over the above-mentioned area of about 800 km², which was picked out as a promising zone as the result of the 1st year surveys. These were followed by geophysical prospecting on the surface, a semi-detailed geological survey, and a semi-detailed geochemical survey carried out over an area of about 230 km² which is a part of the said area (PL. 2).

The results of these surveys were all put into 1/20,000 scale survey maps.

From among 47 anomaly areas found by synthesis of the above-mentioned results of the surveys, seven anomaly areas which were presumed to be attributable to same massive sulphides or graphite, and one chromite indicating area were confirmed.

Surveys in 3rd year (1981)

Survey were conducted, depending mainly on drilling, on five areas: four areas including indications presumably attributable to graphite or massive sulphides which were found by the geophysical prospecting over the 230 km² area in the northern Matsitama area in the 2nd year project, anomaly areas picked out by the geochemical survey, and the extension of a copper mineral indication discovered at a formerly made trench; and one chromite indicating area. In addition, a semi-detailed geological survey around these areas, and geochemical survey and a handy magnet survey over some parts were carried out.

The area covered by the survey of copper mineral indications totaled to 53 km² and the drilling was made to make 14 holes, the length of which amounted to 1,405.45 m in total.

As the result of these surveys, the promising copper mineral indication areas where geochemical anomalies overlapped with geophysical anomalies were further narrowed down to two areas. In the chromite indication area, four holes totaling 401.50 m were drilled in a 2 km by 2 km area, and the conditions of occurrence of chromite, though in a small scale, were revealed. In addition, an area with concentration of earthy graphite was found in an area of anomalies by only geophysical prospecting.

Surveys in 4th year (1982)

In order to ascertain the size and grade of two copper indications that had been confirmed by the survey of the 230 km² survey area in the northern Matsitama in its southwest part in the 3rd year survey work, a fourth year survey work was made by extending the period of the orginally planned three years by one year.

Of the two mineral indications, a detailed geological survey, detailed geochemical survey and a drilling survey within a 0.65 km² area (500 m in width and 1,300 m in length) were made in the mineral indication lying north; in the one lying south, only a drilling survey was carried out. The quantity of the drilling work was 2 drill holes, 200.10 m in total length, in the south indication, and 8 drill holes, 1,003.30 m in total length, in the north indication, which totaled to 10 drill holes extending 1,203.40 m in all.

As a result of these surveys, the distribution of a copper mineral bearing horizon was confirmed in the northern part of the area. Some promise for further prospecting remains in the extension of this horizon.

The following table is a summary of the surveys and the quantities of work in each year.

Table 1 Survey Contents

Items	Quantities of survey work			
	1979	1980	1981	1982
Regional geological survey	5,300 km^2			
Regional geochemical survey	5,300 km^2			
Sub-regional geological survey	700 km^2			
Sub-regional geochemical survey	700 km^2			
Sub-regional geological survey		800 km^2		
Sub-regional geochemical survey		230 km^2		
Airborne geophysical prospecting		2,800 km		
Surface geophysical prospecting		EM, MAG 76.5 km IP 26.5 km		
Semi-detailed geological survey			53 km^2	
Semi-detailed geochemical survey			12 km^2	
Detailed geological survey			4 km^2	0.65 km^2
Detailed geochemical survey				0.65 km^2
Drilling			1,806.95 m	1,203.40 m
Analysis of LANDSAT data	5,300 km^2			
Interpretation aerial photos	5,300 km^2			
Analysis of soil	2,785 components	4,089 components	549 components	594 components
Analysis of ore	54 components	57 components	957 components	160 components
Analysis of whole rock	7 pcs	5 pcs		
Microscopic observation of thin section	107 pcs	108 pcs	74 pcs	20 pcs
Microscopic observation of polished section	5 pcs	7 pcs	24 pcs	20 pcs
K-Ar age determination	5 pcs	5 pcs		
X-ray diffractive analysis	5 pcs	4 pcs		
X-ray fluorescent analysis	4 pcs	7 pcs		

Chapter II. ENVIRONMENT OF SURVEY AREA

II-1 Situation and Access

The survey area, covering an 5,300 square kilometer area, is situated about 440 kilometers north-northeast of Gaborone, the capital of the Republic of Botswana, and is not very far from the border of the Republic of Zimbabwe. In administrative demarcation, the area stretches over the North-East District and Central District, and Francistown, the center of the North-East District, is the only town near it.

The access from Gaborone to Fracistown depends on the aircraft, automobile and railway. On the 400 km air route, a turboprop regularly flies everyday except Tuesday and Sunday taking an hour and a half.

When a car as used from Gaborone, one takes a trunk road that goes to Zimbabwe and Zambia after driving via Mahalapye and Francistown. The road from Gaborone to Francistown, a distance of 443 km covered by about six hours, is completely paved.

In almost parallel with this trunk road, there lies a railway coming from South Africa and leading to Zimbabwe, which is the former Rhodesian Railway. About 12 hours is taken to travel between Gaborone and Francistown.

Within the survey area there are such large villages as Sebina, Tutume, Sechele, Matapong and a large number of small villages are scattered; there are roads connecting these villages to Francistown.

The main road leading from Francistown to the survey area is a paved one going to Maun, which passes from the southeast of the survey area to the west, about two hours is taken to go from Francistown to the western end of the survey area. There are unpaved ways branching out of this road to come to various places within the survey area. They are usually narrow paths, and are cut off at stream crossings. So that there are many places making passing difficult even with a car with four-wheel drive. In the rainy season these paths turn muddy and obstruct passage even on foot.

II-2 Topography and Climate

The survey area is spread over the watershed of the two big drainage systems of Kalahari and Limpopo. The Kalahari water system, occupying the northwestern half of the survey area, drains itself to the large Makgadikgadi basin lying on the west of the survey area. The topography is flat and presents little undulations; it takes the form of a peneplain with an average altitude of about 1,100 m. Rivers there have scarce flowing water. The main ones are the rivers of Tutume, Semonwane, Mosetse, Lepashe and Mosope.

The Limpopo drainage system, occupying the southeastern half of the survey area, spreads on a plain which inclines southward gently from the watershed lying in the north.

On the plain, almost everywhere are seen hills rising about 100 m, among which the rivers of Shashe, Vukwi, Tati, Ntshe and others flow from west to east. Here the average altitude is between 1,200 m and 1,300 m.

The survey area is situated between 20°31' and 21°00' S Lat. and comes under a semi-arid area of the tropics. Annual rainfall at Francistown is about 440 mm on the average, most of which derives from thunderstorms during summer which extends from October to April. In winter, which continues from May to August, it is cool and dry, fair weather lasting steadily except for occasional dust storms.

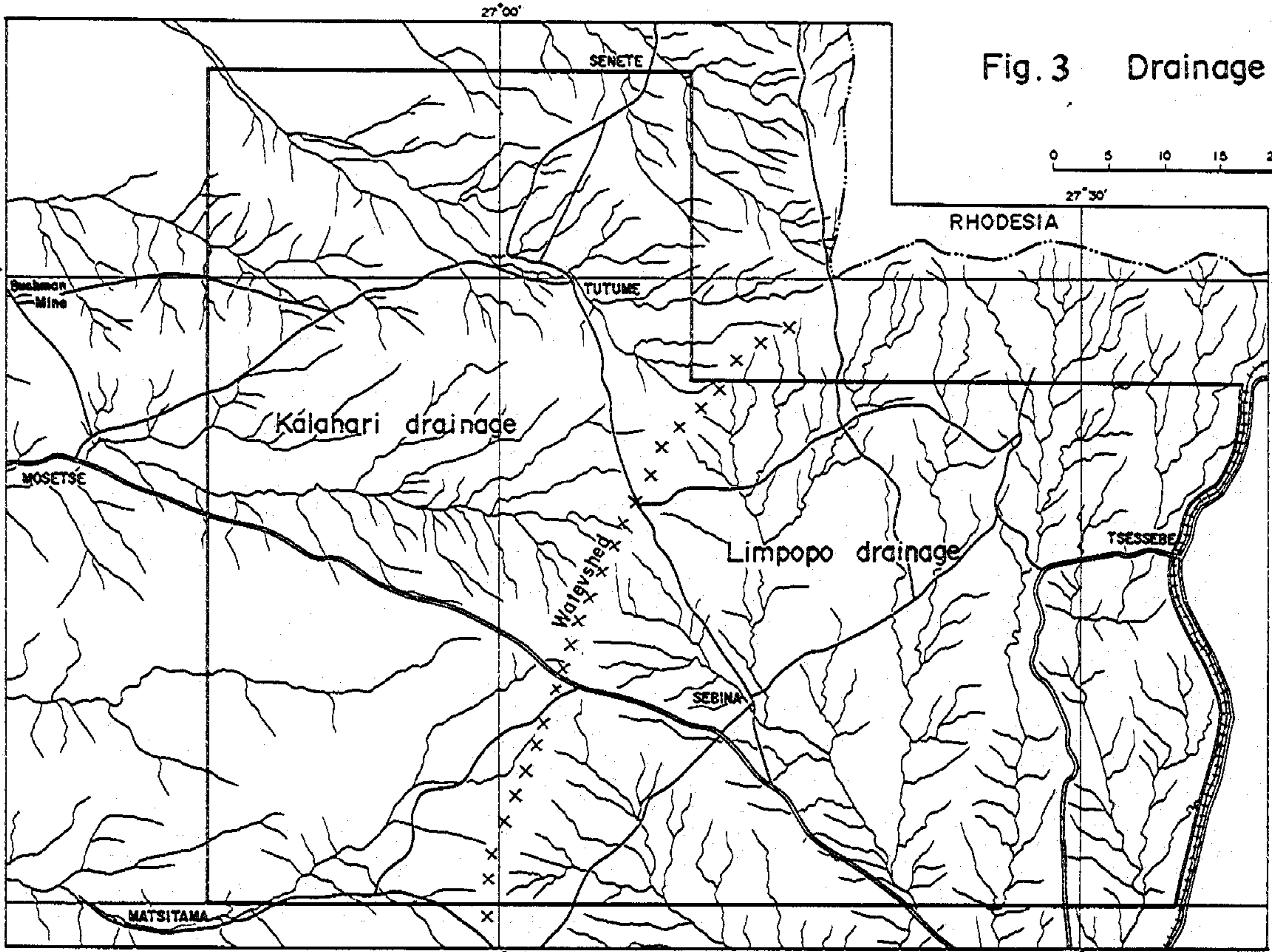
The air temperature in a year ranges between the mean maximum 28.4°C and the mean minimum 13.5°C, but the temperature variance is great, rising more than 40°C in summer and dropping less than -10°C in winter. The difference of temperature between daytime and night is also remarkable. Winter is the suitable period for field works.

The greater part of the survey area falls under the mixed tree savanna and usually thickets of thorny shrubs spread over it, but big trees luxuriate along streams and an open tree savanna can be seen on the highland that forms the watershed. Natural vegetation has been lost in places because of cultivation and pasturage.

2-3 Villages and Industry

As compared with the level of population in the country areas of Botswana, the density of population in the survey area is rather high with villages of 500 to 2,000 inhabitants being scattered in the area. The inhabitants make living by farming which is akin to the slash-

Fig. 3 Drainage system.



and-burn agriculture. Some parts have been turned into private farms operated by Europeans or Boers, which are enclosed with pasture fences and hindered geological survey work.

As for other industries, they remain at the levels of handicraft and brick making and there is no manufacturing industry. Exploratory works for mining in the survey area are suspended at present.

Securing water is the greatest problem in the area. As the volume of water is extremely scanty in all the rivers, on their surface water runs for only one or two weeks in all the year. However, in big rivers water as subsoil one flows even in the dry season, and the inhabitants use it through pits in sand and wells.

Chapter III. OUTLINE OF GEOLOGY IN SURVEY AREA

3-1 Outline of Geology

The geology of the whole Botswana is set forth in Table 2. Part of the geology is distributed in the survey area and it is broadly classified as follows:

(Age)		(Geological unit)
Cenozoic		Kalahari bed
～～～～～	Unconformity	～～～～～
Archean		Basement complex

This unconformity indicates an age difference of about 2,500 million years; the Archean formed of the basement complex in the survey area corresponds to the western end of the Rhodesian craton – an Archean unit stable since 2,600 million years.

The basement complex in the survey area is roughly classified into metasedimentary rocks, metavolcanic rocks, and granitic rocks, among which the granitic rocks are mostly widely distributed.

The metasedimentary rocks and metavolcanic rocks are distributed being divided in two by the granitic rocks at the middle of the survey area. Accordingly, the survey area is divided into the Sebina – Tshesebe area extending from the middle to the east and the Matsitama – Mosetse area lying in the west. Of the former there is a study by Litherland (1975), and of the latter a study by Bennett (1970). The following outline description is based on their views generally.

3-1-1 Sebina – Tshesebe Area

The Archezoic basement complex in this area consists of schist, granitic rocks, and small-scale dikes. Among them the schist zone lying in the middle part is a representative green rock zone called the Vumba schist relic, it is divided into the Tutume Meta-arkose Group and the Vumba Volcanic Group.

Table 2 Geological Sequence of Botswana

<table>
<tr><th rowspan="2">Age</th><th colspan="3">Stratigraphic Unit</th></tr>
<tr><th colspan="2">Group - System</th><th>Formation - Series</th></tr>
<tr><td>Cenozoic</td><td colspan="2"></td><td>Kalahari Beds</td></tr>
<tr><td rowspan="2">Jurassic
≀
Carboniferous</td><td colspan="2" rowspan="2">Karroo System</td><td>Stormberg Series</td></tr>
<tr><td>Ecca and Dwyka Series (Beaufort Series)</td></tr>
<tr><td rowspan="2">Late
Precambrian</td><td colspan="2">Damara System</td><td></td></tr>
<tr><td colspan="2">Ghanzi Group</td><td>Kgwebe Porphyry Formation
Ghanzi Beds Formation</td></tr>
<tr><td rowspan="4">Middle
Precambrian</td><td colspan="2">Waterberg System</td><td></td></tr>
<tr><td colspan="2">Transvaal System</td><td>Pretoria & Griquatown Series
Dolomite & Black Reef Series
Shoshong Series</td></tr>
<tr><td colspan="2">Vendersdorp System</td><td>Mogobane & Dipotsana Series</td></tr>
<tr><td colspan="2">Kanye Volcanic Group</td><td></td></tr>
<tr><td rowspan="2">Early
Precambrian</td><td rowspan="2">Basement
Complex</td><td>Vumba Volcanic Group</td><td>Upper Vumba Mafic Formation
Upper Vumba Felsic Formation
Lower Vumba Mafic Formation
Lower Vumba Felsic Formation
Vumba Mixed Volcanic Formation
Sebina Ultramafic Formation</td></tr>
<tr><td>Tutume Meta-arkose Group</td><td>Vukwi Meta-arkose Formation</td></tr>
</table>

(1) Tutume Meta-arkose Group

This group is distributed in the form of several belts as if to envelop the Vumba Volcanic Group lying in the middle, being distributed widely particularly to the west of the volcanic group, it is formed of layered meta arkose, amphibolite and granitic gneiss.

The meta-arkose is massive well jointed quartz-feldspar rock of medium grain with little mica. It is a white rock but the weathered surface is brown. Analysis of the heavy mineral fraction shows that zircon crystals in this rock are not euhedral but are often crushed or rounded. The rock is concordant with the upper volcanic sediments and underlies the Vumba schist belt. It is, therefore, thought that the meta-arkose is of sedimentary origin.

The amphibolite develops most near Tutume and is concordant with meta-arkose and granitic gneiss (G_2g mentioned later). So that it is considered to derive from lava-sill. It is mostly fine to medium-grained plagioclase amphibolite, but talc-chlorite schist is partly recognized.

(2) Vumba Volcanic Group

This group consists of ultramafic, mafic, and felsic metavolcanics. Depending on the facies, it may be classified into the following six formations:

The lower most Sebina ultramafic formation consists of ultramafic rocks and amphibolite with meta-arkose bands.

The Vumba mixed volcanic formation consists primarily of amphibolite with some ultramafics and felsic metavolcanics.

The lower Vumba felsic formation is made up of felsic metavolcanics, aluminous quartzite, and aluminous schist.

The lower Vumba mafic formation is composed of amphibolite with felsic metavolcanics and calclite.

The upper Vumba felsic formation is of aluminous schists and felsic metavolcanics.

The upper Vumba mafic formation consists of amphibolite.

The rocks comprising the above formations are described in detail below.

(i) Ultramafic Rocks

The most prominent of the ultramafic rocks is Main Serpentinite, which forms a characteristic small mountain range in the Vumba schist belt. The small mountain range is bent and extends from Sekakangwe in the north to Sechele in the south. Main Serpentinite occurs as a sill and shows the first stage of ultramafic activity. Lithologically, serpentinisation of olivine and tremolitisation of pyroxine are observed in the Main Serpentinite, which thus consist of assemblages of such minerals as antigorite, crysotile, tremolite, chlorite, magnetite, and calcite. To the east of Main Serpentinite and concordant with it, there are two parallel ranges of smaller mountains of meta pyroxinite. The rocks are massive, of medium grain size, and dark greenish grey in color. They are strongly jointed and no banding or tectonic fabric are observed. They occur as intrusive sills, which have undergone metamorphism. After intrusion, they are metamophosed from pyroxinite to meta-pyroxinite. They are concordant with Main Serpentinite.

Ultramafic rocks at Toteng are similar to the rock bodies described above; only they occur as serpentinite dykes in parallel with metapyroxinite, massive medium grain meta-diorite, and coarse meta-diorite, with clear boundaries between them. Like Vumba Main Serpentinite, the ultramafic rocks here are thought to be of dunite and pyroxinite origin. Its direction of intrusion is discordant to the schistosity plane of the country rock. Accordingly this ultrabasic rock is considered attributable to ultrabasic intrusion activity after the activity of the Main Serpentinite.

The ultramafic rock forming a hill near Tshesebe is considered to be a big dike which intruded into paragneiss and Ntshe quartz diorite in a NE–SW direction; this activity presumably occurred in the same age as the intrusion of Toteng ultramafic rock.

In addition, there are a small-scale serpentinite body of an unknown age which intruded into quartz diorite on the north side of an area distributed with metaarkose formation near Vukwi, a hill composed of dark green, coarse-grained serpentinite found in amphibolite in Tutume meta-arkose formation, and a small rock body of metagabbro distributed near the Moshambale granite.

(ii) Basic Rocks

In the Vumba schist belt, various types of amphibolites dominate. Generally, the basic rocks do not form kopjes and are often exposed along river streams.

Schistose amphibolite: It occurs in the entire Vumba area and is often exposed on the south and north sides of the Myshawe pulton. It is dark green to dark grey in color, is of medium grain size with strong schistosity, and has inconspicuous feldspar phenocryst. Occurrence is not restricted to specific horizons.

Speckled amphibolite: The surface is weathered and brown in color. It is of medium to fine grain and has well developed cleavages. Distribution is restricted to the volcanic beds in the lower Vumba felsic formation. It is exposed in the north of the Shashe river and in the south of the Myshawe pulton.

Gabbroic amphibolite: It is a massive, homogeneous, medium to coarse grain rock. Feldspar phenocryst is conspicuous. Occurrence is restricted to limited horizons underlying the Main Serpentinite.

Mesh amphibolite: It is a massive coarse, homogeneous rock with a mesh of black, platy amphibolite. Occurrence is restricted to horizons underlain by Vumba felsic formation.

Basaltic amphibolite: It is a massive fine grain homogeneous rock with conchoidal fractures and similar in appearance to fine-grained basalt. It is closely associated with mesh amphibolite.

Porphyroblastic amphibolite: This rock is schistose amphibolite with porphyroblasts of amphibole. Occurrence is restricted to marginal region of the Vumba schist belt in the migmatised areas.

(iii) Pyroclastic Rocks

Pyroclastic rocks consisting of fine-grained tuff and agglomerate occur along the Vukwi river. They are leucocratic and have laminas. Boundaries with host rocks are clear.

The breccia are angular to subrounded in shape and felsic. Matrix is fine-grained and leucocratic, and of pyroclastic origin.

Tuff is felsic rock with fine laminas.

Pyroclastic rocks forming kopjes are similar to amphibolite but they have basic groundmass with elongated leucocratic fragments and are compact and very tough. Therefore, they are thought to originate in intermediate to basic welded tuff.

(iv) Flesic Rocks

These are leucocratic with lineated amphibole phenocrysis which come as lenses in the Vumba mixed volcanic formation, lower felsic formation, and upper felsic formation. Feldspar is altered to epidote and sericite.

(v) Metasedimentary Rocks

Vumba iron stone: The Vumba area has no typical stratiformed iron formations, but only discontinuous small-scale horizon of iron lenses in crystalline limestone layers.

Micaceous schist: These are distributed in felsic rocks in the lower Vumba felsic formation and upper Vumba felsic formation, often exposed in the small tributary to the west of the Shashe river. They are composed mainly of quartz, feldspar, and muscovite, sometimes associated with sillimanite.

Quartzite: White quartzite exists in two horizons in the Vumba schist belt, associated with sillimanite, kyanite, and muscovite.

Limestone: Crystalline limestone associated with calc-silicates is found in the Vumba schist belt. The calc-silicates include diopside, clino-zoisite, tremolite, and actinolite.

(3) Granitoid Rocks

Granitoid rocks were predominant in the surveyed area. On the basis of field evidences, and chemical composition, they are classified into G_1, G_2, G_3 and G_4.

(i) Pulton (G_1)

They are distributed in an elliptical form in the center of the surveyed area. They are the oldest granitoid rocks. Pulton is divided into monzonite (G_1m) and tonalite (G_1t).

Monzonite (G_1m) occurs in the Kalakamate area, where it is known as Kalakamate monzonite. The rock is a massive homogeneous rock of medium grain size, and has linear fabric defined by the alignment of feldspar and amphibole.

In our survey, K-Ar dating of quartz monzonite from this rock body gave 2,270 m.y. (Table 3)

Tonalite (G_1t) occurs as the Mushawe pluton, Shashe pulton, Kalakamate pulton, Sekakange pulton, and a few other small rock bodies. Except that the Myshawe pulton forms a small hill in the north, no other hills are observed. The rock is fissile. No banded texture, xenolith, or intruded veins are observed.

Our geological survey and microscopic observation revealed fine to coarse grained granite in addition to G_1m and G_1t. Fine-grained biotite granite found to the east of Kalakamate had a small quantity of molybdenite dissemination. Analytical results are shown in Table 4.

(ii) Paragneiss (G_2)

Paragneisses account for most of granitoid rocks in the surveyed area. They still show the original banded texture or layering. They are subdivided into granitic and tonalite gneisses.

Granitic gneiss (G_2g): It is the main component of the Tutume Meta-arkose Group. It is a migmatic gneiss which is granitic - quartz monzonitic in composition typical of which is grey, medium grain size biotite granitic rocks, which form kopjes. In addition, there are amphibole-rich gneisses. In some parts, the gneisses have porphyroblasts and are known as Marapong porphyroblast gneisses. In our recent investigation, samples were taken from granitic gneisses and porphyroblastic granitic gneisses and subjected to K-Ar dating, which gave 1,800 m.y. and 1,860 m.y. respectively. (Table 3)

Tonalitic gneiss (G_2t): This occurs from the central to eastern parts. It does not form hills in areas other than Timbale. The rock is plageoclase-rich and medium to coarse in grain size. To the east of the Vumba schist belt, amphibole-rich facies are found.

Our K-Ar dating of tonalite gneiss (S-46) samples collected from the Makaleng area gave 1,810 m.y. (Table 3)

(iii) Anatectite (G_3)

Occurring along the Ntshe river in the eastern part of the surveyed area, it is known as Ntshe tonalite (G_3t). It is surrounded by tonalite gneiss (Gwt) and intruded by Timbale granite (G_4).

The rock is pale blue and medium to coarse grained, consisting mainly of quartz, plageoclase, and mica.

(iv) Granitic Rocks (G_4)

These are the latest stage granitic intrusive rocks in the surveyed area. They have clear boundaries with surrounding rocks and have received no metamorphism.

They occur as intrusive mass at Timbale, Moshambale, Dombashaba, and as stocks at Sechele and Central Vumba.

The Timbale granite differs from the others in many respects, but nevertheless it is of the latest stage granite in that it cuts the S_2 structure and intrudes into G_3 tonalite.

The intrusive mechanism of G_4 granite differs from that of G_3 anatectite and obviously is not controlled by stratigraphy.

The Moshambale granite rocks are outcropped on the Tutume-Sebina roadside and the typical rock type is coarse, leucocratic, and porphyritic.

The Dombashaba granite rocks intrude into G_1 pulton, forming hills. The typical rock type is of coarse and pink potash feldspar. Marginal facies consist of banded

Table 3 Data on K-Ar Isotope Dating

Sample No.	Place	Location		Rock	Age (m.y.)	Scc Ar^{40R} 9 m x 10^{-5}	% Ar^{40} Rad	% K
		Long. (E)	Lat. (S)					
S–54	Kalakamate	27°18′34″	20°36′28″	Quartz Monzonite (G_1)	2,270 ± 114	66.3 65.7	98.0 99.0	3.71 3.74
S–66	Vumba Hills	27°20′29″	20°41′57″	Biotite Granite (G_4)	2,020 ± 101	86.7 85.0	98.7 98.5	5.91 5.93
S–30	Nshakashokwe	27°08′08″	20°46′47″	Granite Gneiss (G_2g)	1,800 ± 90	64.7 60.9	97.0 98.5	5.23 5.24
S–46	Makaleng	27°17′14″	20°50′07″	Tonalite Gneiss (G_2t)	1,810 ± 91	88.6 84.0	98.8 98.2	7.14 7.14
S–29	Sebinanyane	27°07′24″	20°56′54″	Granite Gneiss (PG_2g)	1,860 ± 93	86.7 85.5	98.6 98.3	6.80 6.85
S–8	Chirungkwe river	26°51′06″	20°43′30″	Amphibole Schist	1,764 ± 88	3.06 3.10	73.0 79.3	0.26 0.27
S–40	Lepashe river	26°49′20″	20°49′30″	Granite Gneiss	1,841 ± 92	69.9 70.4	98.7 98.9	5.61 5.67
S–48	Lepashe river	26°53′58″	20°49′33″	Granite Gneiss	1,839 ± 92	82.5 83.3	99.5 99.4	6.66 6.68
S–104	Mosope river	26°51′35″	20°57′37″	Granite Gneiss	1,837 ± 92	74.5 74.9	98.4 99.0	6.00 6.05
S–112	Mosope river	26°59′06″	20°56′18″	Amphibole Schist	1,755 ± 88	3.48 3.56	74.1 81.6	0.30 0.31

Notes: 1. The analysis was performed on a hornblende separate for S–8, S–112, and on a biotite separate for the other samples.
2. Constants $\lambda\beta = 4.962 \times 10^{-10} yr^{-1}$ $\lambda c = 0.581 \times 10^{-10} yr^{-1}$ $K^{40} = 1.167 \times 10^{-4}$ atom per atom of natural K.

Table 4 Chemical Analysis of Rock Samples

Sample No.	S-54	S-66	S-30	S-46	S-29	S-1	S-55	S-8	S-40	S-48	S-104	S-112
Rock	Q-Monzonite G_1	Biot Granite G_4	Granite Gneiss G_3g	Tonalite Gneiss G_3t	Granite Gneiss PG_1t	Amphibolite Schist G_1m	Granite	Amphibole Schist	Granite Gneiss	Granite Gneiss	Granite Gneiss	Amphibole Schist
Location	Kalakamate	Vumba Hills	Nishakashokwe	Makaleng	Sebinanyane	Mosope	Kalakamate	Chirungkwe river	Lepaske river	Leposhe river	Mosope river	Mosope river
SiO_2	63.39	66.51	67.20	67.73	71.13	47.26	76.05	52.8	72.9	69.6	71.1	50.1
TiO_2	0.77	0.50	0.50	0.43	0.29	1.94	0.03	0.79	0.26	0.42	0.24	1.25
Al_2O_3	14.26	14.84	14.96	14.85	14.35	13.00	13.25	12.7	14.5	16.1	15.8	13.8
Fe_2O_3	1.86	2.59	1.82	1.31	1.10	7.37	0.48	2.61	0.58	0.87	0.40	1.67
FeO	2.74	1.09	1.86	2.19	1.17	7.47	0.36	8.28	1.57	2.08	1.03	10.66
MnO	0.07	0.08	0.06	0.06	0.03	0.20	0.04	0.18	0.04	0.04	0.02	0.14
MgO	2.33	1.42	1.30	1.52	0.72	7.12	0.07	9.50	0.77	0.99	0.47	6.68
CaO	3.65	2.90	4.31	4.12	2.06	8.24	0.47	10.48	2.47	3.38	2.48	11.64
Na_2O	3.45	4.29	4.39	4.05	3.95	3.19	4.87	1.16	4.39	4.97	5.25	1.77
K_2O	5.00	2.98	1.17	1.40	4.06	0.70	4.30	0.25	2.27	1.37	2.61	0.30
P_2O_5	0.19	0.20	0.13	0.14	0.10	0.22	0.02	0.07	0.11	0.12	0.07	0.12
H_2O^+	0.82	1.06	0.47	0.48	0.29	0.82	0.11	0.71	0.50	0.43	0.52	0.92
H_2O^-	0.16	0.18	0.10	0.12	0.13	0.44	0.14	0.14	0.14	0.10	0.13	0.10
Total	98.69	98.64	98.27	98.40	99.38	97.97	100.19	99.67	100.50	100.47	100.12	99.15

pegmatite, coarse granite, biotite-rich zones.

Sechele stock intrudes into the Vumba schist, consisting of quartz monzonite of medium to coarse grains.

Central Vumba stock consists of coarse grain quartz-monzonite and is altered slightly. Previously, it was thought that this rock has a relationship with adjacent gold sulfide mineralization.

Our K-Ar dating gave 2,020 m.y. The sample used in the dating, viz., S-66 had been strongly chloritised and epidotised. (Table 3)

Timbale granite is of the largest scale among all G_4 intrusions, occurring over an area of about 100 km^2. The typical rock type is of medium to coarse grain quartz-monzonite with little biotite. In the marginal part, this rock has abundant quartz, pegmatite, and aplite veins, which are believed to be related to the rare element mineralization in the Timbale region.

(4) Dikes

There are a large number of dikes in this area; basic dikes are divided into four groups and acidic ones into seven groups, mainly by the ages of intrusion.

(i) Basic Dikes

Dike B_1: This is fine-grained metabasalt intruding into the Vumba Volcanic Group and is the earliest intrusive rock in this area.

Dike B_2: This is a small-scale dike which has intruded into the region of gneiss obliquely crossing its schistose facies it is folded.

Dike B_3: Found in the north of this area, it is a group of metadolerite dikes lying in the direction of N70°E, dipping vertically. Their width ranges from several meters to hundreds of meters.

Dike B_4: This is a group of dolerite dikes of the late Karroo to post-Karroo ages. There are two trends of N70°W and N50°E. In addition, sheet-like rock bodies with composition close to dolerite are widely distributed.

(ii) Acidic Dikes

Dike A_1: This is related with the activity of granite G_2 and is a quartz and feldspar dike.

Dike A_2: This is a quartz and feldspar dike formed after the activity of granite G_2.

Dike A_3: This is a dike related with the mineralization of gold and sulphides.

Dike A_4: This is a dike mainly composed of pale red to pink-toned granite to pegmatite, with various lithofacies. They have prominent trends. One is in the N80°W direction, another E–W direction.

Dike A_5: This is related with the activity of granite G_4; it occurs at fracture zones.

Dike A_6: This is associated with the Timbale granite.

Dike A_7: This is a quartz or silicified vein related with tectonic movement of the late Karroo to post-Karroo ages.

In addition to the above, in the southern part of this area, small-scale dikes of diorite, granite and granodiorite are found.

3-1-2 Matsitama -- Mosetse Area

The Archean basement complex of this area also is formed of schist, granitic rocks and small-scale dikes. It is divided into the Mosetse River Gneiss Group and Matsitama Schist and Metasedimentary Group.

(1) Mosetse River Gneiss Group

This group is distributed occupying the greater part of this area. It is principally formed of granitized gneiss and has been subjected to the regional metamorphism of amphibole facies. The extent of metamorphism differs from part to part and the conditions of distribution are not clearly known as a systematic survey has not been finished.

In the upper reaches of the Mosetse and Matsitama rivers, a small amount of amphibolite are interlaid, with lenticular limestone in the gneisses.

(2) Matsitama Schist and Metasedimentary Group

Apparently located above the Mosetse River Gneiss Group, this group consists of nongranitic schists and metasedimentary rocks. It has undergone low-grade regional metamorphism.

Only part of this group is distributed in the southwestern corner of the surveyed area.

Although stratigraphy of the group is not clear, combination of facies suggests that the group may be divided into four formations: Tsarutsaru Transitional formation, Lepasha-Mmalongong Greenschist and Metasedimentary formation, Palamela Metasedimentary formation, and Sebilogae-Sebotha Greenschist and Metasedimentary formation. Only the second and third named ones are distributed in the surveyed area.

The Palamela Metasedimentary formation, distributed to the east of Lepasha as though to frame the Mosetse River Gneiss Group, is composed of limestone, felsic quartzite, mica schists, and small amphibolite.

The Lepasha-Mmalogong Greenschist and Metasedimentary formation is distributed in the southwestern corner of the surveyed area. It comprises amphibolite, green schists, mica schists, limestone, quartzite, and serpentinite, which are accompanied by felsic quartzite and meta-arkose above them. Analysis of the amphibolite (S–1) are shown in Table 4.

3-2 Geological Structure

The survey area falls under the southern extremity of the Rhodesian Craton as it is called, one of the oldest cratons, with the Limpopo mobile belt distributed on its south side.

As above-mentioned, the survey area has been set to stretch over the two structural blocks of the Sebina – Tshesebe area and the Matsitama – Mosetse area, which are separated at the middle of the survey area by granitic rocks.

The geological structure of the Sebina – Tshesebe area, macroscopically consists a semicircular form of structure opening to the east. There have been compressive folding accompanied by granitification, followed by tensional folding, and also, cutting these folds, development of major strike fault groups in a NNW direction (Tutume faults) and in a NS direction (Ramokgwebana), which have been followed by a derivative strike fault group in a NWW direction. The mechanism of formation of these faults, joints and dikes is elucidated in Fig. 5.

The Matsitama – Mosetse area has a folding structure on an axis in a NW–SW direction, in a miogeosyncline zone within the Rhodesian Craton; part of the east wing of the structure is distributed in the survey area.

The volcanic groups at Vumba, Maitengwe, Matsitama, and Tati are separated from one another by the Tutume group or the group correlated to it. Stratigraphy of each volcanic group is established but correlation between the stratigraphies is not established as yet although attempts have been made to do so.

Correlation between the Tati and Vumba groups has been made on the basis of combination of strata and lithofacies, and that between the Maitengwe and Matsitama, on the basis of similarity of lithofacies (Litherland, 1975).

Correlation based on lithofacies, however, gives different results depending on whether formation or group is used as the unit.

In the case of Maitengwe area and Vumba area, for instance, if formation is used as the unit, the Maitengwe ultramafic formation consisting of ultramafic rocks and basic rocks would be correlated with the Vumba mixed volcanic formation. Also, the Maitengwe banded iron formation would be correlated with the lower Vumba felsic formation. Thus, the relationship of the two formations would be reversed between the two volcanic groups.

In the case of the Matsitama area and Vumba area, Matsitama's Sebilogae-Sebothe Green schist and Metasedimentary formation which consists of ultramafic and basic rocks with limestone bands would be correlated with the upper Vumba Mixed formation and lower Vumba Felsic formation.

The Mosetse River Gneiss Group which consists of granitic gneiss is similar in lithofacies to the G_2 t-dominant Tutume Meta-arkose Group, so that the two groups is correlated.

However, since the Mosetse River Gneiss Group has intercalated limestone, there is a possibility that the group is correlated with the Vumba Volcanic Group.

3-3 Geological History

The tectonic movement of the Rhodesian craton which includes the survey area first began with compressive folding, which was followed by progress of granitification. As a result, regional metamorphism advanced to reach a metamorphic grade upto the hornblende hornfels facies at maximum. Following it, there was tensional folding. In the Karroo age and subsequently there were two times of faulting activity. The detail of the geological history is outlined as shown in Fig. 4 by Litherland (1975), and the mechanism of the formation of fault systems in the Karroo age and thereafter is summarized as set forth in Fig. 5.

Dating was once made on Timbale granite (G_4) in this area, and the age was found to be 2,540 million years. (Key 1976)

In the first year of the survey project dating and complete analysis were made of one sample of G_1, three of G_2 and one of G_4. The result was that, as shown in Tables 3, 4, the age was found to be 2,270 million years for G_1; 1,800 million, 1,810 million and 1,860 million years for G_2; 2,020 million years for G_4. These ages are by far younger than the ones presumed in the past; in particular the age of G_2 is the youngest, even younger than G_4. This could be attributed to change in quality or weathering of the samples, or rejuvenation due to some change or degeneration.

In the second year, four samples were taken from the Mosetse River gneiss group and one from the Matsitama schist and metasedimentary group to make dating. As the result their ages were found to be 1,841 million, 1,839 million, 1,837 million, 1,755 million and 1,764 million years respectively. These figures almost agree with the ones for G_2 obtained in the first year.

As above-mentioned, the Tutume metaarkose group where G_2 is dominant is presumed to be on the same horizon as the Mosetse River Gneiss Group from their lithofacies and distribution, and the same judgement can be made from the age also.

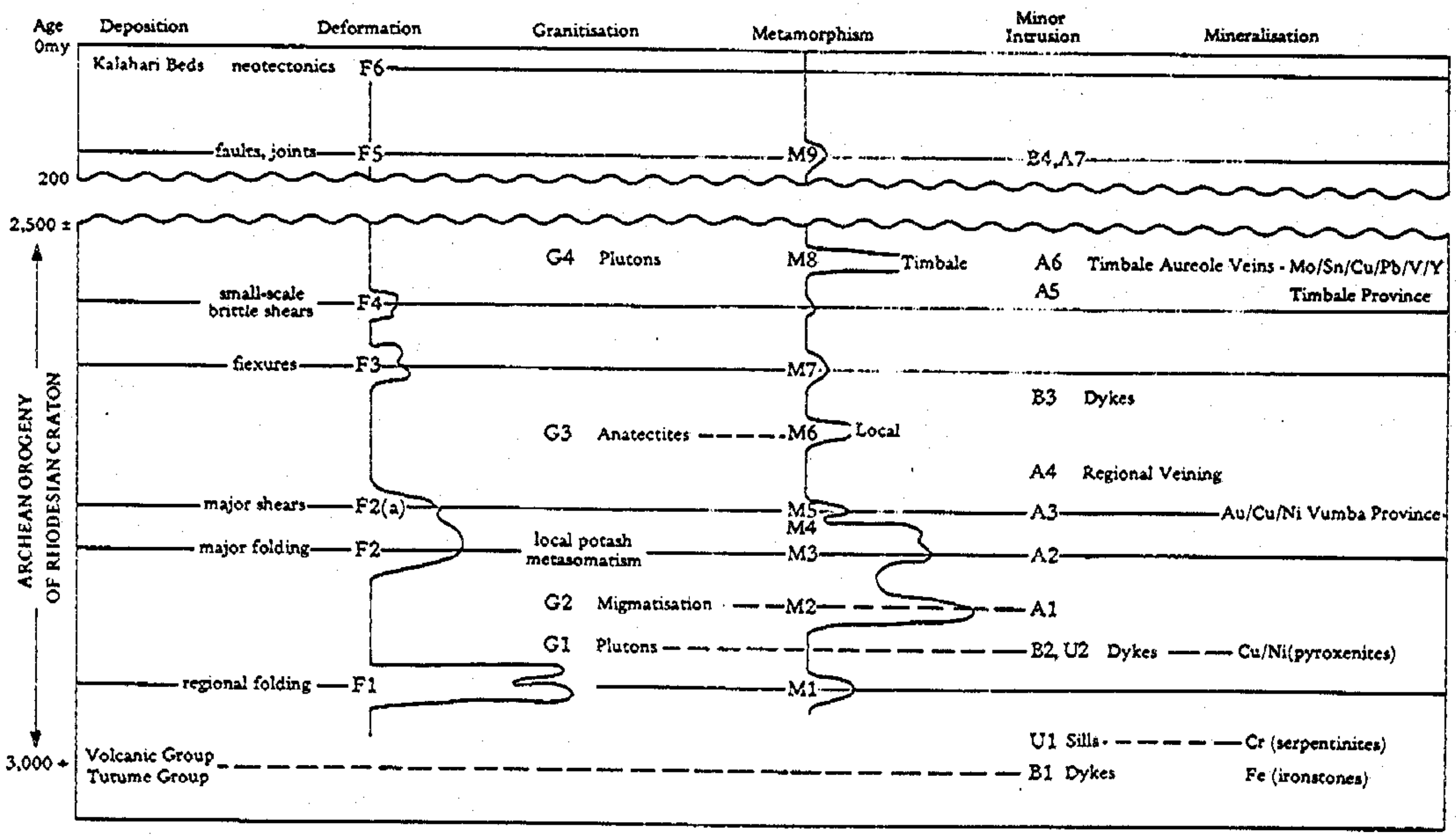


Fig. 4 Geological history (Litherland 1975)

In Fig. 9, and throughout this report, following symbols are used to denote geological events.

S_0	– Bedding	M_1, M_2 etc.	– Metamorphic phases
F_1, F_2 etc.	– First and second phases of deformation etc.	A_1, A_2 etc.	– Phases of minor acid intrusions
S_1, S_2 etc.	– Schistosity surfaces produced by F_1, F_2 etc.	B_1, B_2 etc.	– Phases of minor basic intrusions
L_1, L_2 etc.	– Linear fabric produced by F_1, F_2 Etc.	U_1, U_2	– Phases of ultramafic intrusion.
G_1, G_2 etc.	– Phases of the granite series		

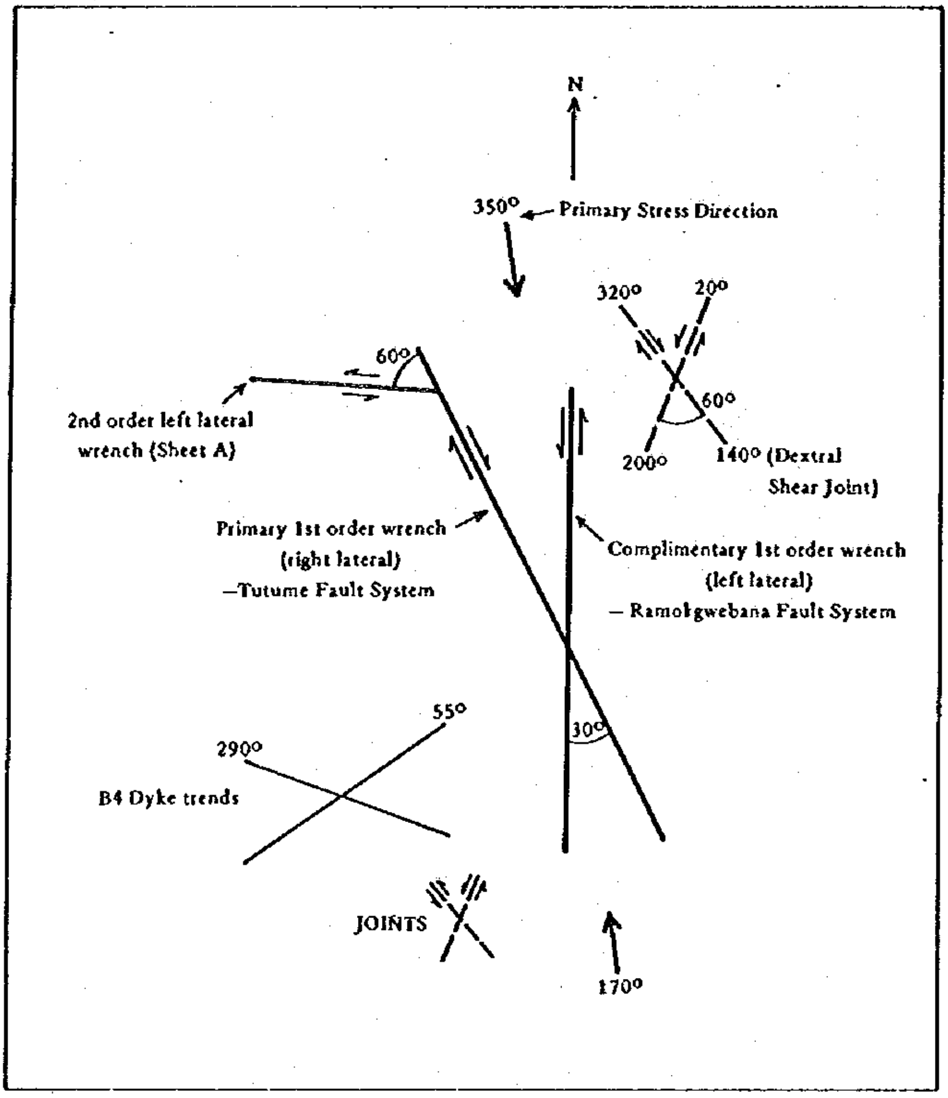


Fig. 5 Fault-Joint-Dyke stress system (Litherland 1975)

3-4 Ore Deposits

3-4-1 Foreword

The surveyed area contains three mineralized zones: They are the Vumba zone, where gold deposits and nickel-bearing copper sulfide deposits are expected to be found: the Timbale zone, where rare element-bearing copper molybdenum ore deposits related to pegmatite intrusion are expected: and the North Matsitama zone, where copper deposits of syngenetic origin are likely to exist. Some parts of the three zones were explored during the years from late 1960's to early 1970's by the Anglo American Group. The extent of exploration is shown in Table 5 and Fig. 6.

3-4-2 Ore Deposits and Mineralization in Vumba Zone

In the Vumba Volcanic Group in this zone, there are many points where gold mineralization is recognised. In fact there are abandoned gold prospects previously explored and mined by the ancients, European prospectors and modern mining organisations. Table 6 and Figs. 7, 8 summarise the previous gold mining activities.

Mineralization is found in a sheared zone which has a north-northwest trend in amphibolite. In the sheared zone, gold is found in the gold-bearing sulfides disseminated in or around quartz bands in amphibolite or elsewhere in the amphibolite. The sulfides occur in masses in the quartz and in fine grains disseminated in amphibolite. They include pyrite, pyrrhotite, arsenopyrite, loellingite, and chalcopyrite, but it is not known yet in what form gold occurs.

Near mineralization zones, there are often quartz diorite in the shape of small stocks, and it is presumed that the mineralization took place in metamorphic differentiation diposits that here related with the intrusion of this quartz diorite.

Of the mineral showings listed in Table 6, Somerset is the largest and the only that has been mined. Judging from the previous mining records and the mine site condition there, gold-bearing quartz vein exists in a sheared zone which has a NNE–SSW trend, the vein having an extension of 200 meters and a width of 1 meter and the grade of gold is estimated at 5 g/t. At the mine site, there are about 2,500 tons of stocked ore and some heaps of waste dump (Fig. 9).

In this zone, the Anglo American Group conducted explorations for nickel-bearing copper sulfide in the period of from the late 1960's to the early 1970's. As part of the explorations, the group drilled two holes (TSM–1, TSM–2) underneath the Somerset outcrop for exploration of gold. Neither of the holes intersected mineable ore deposits in depth. It was, therefore, thought that mineable ore existed only in the secondary enrichment zone near the surface. Thus, exploration was given up.

In our recent survey, we were unable to carry out detailed investigation of all the showings listed in Table 6, but took samples from the three showings of Somerset, Sheba and El Dorado to check the potentiality of the zone. Assay results are shown in Table 7.

None of the showing are typical hydrothermal gold-bearing quartz veins associated with intruded granitic stock. Rather, they are so-called saddle reef type ore deposits in which quartz is concentrated at the top or bottom of minor foldings or in the sheared zone by metamorphic differentiation which took place when the Vumba Volcanic Group underwent regional metamorphism. Generally, the ore deposits seem to be irregular and small, with gentle dipping. The results of sample analysis are shown in Table 8. Gold is associated with sulfides. Primarily it is of low grade, but is enriched in the weathered residual zone near the surface. Particularly in the area between the Somerset showing and Sheba showing to its north, unrecorded sulfide-rich outcrops and pits are found scattered and there seemed to be much concentration of sulfide minerals.

However, in this zone a detailed survey by geochemical survey had been made, as mentioned later, for copper-containing nickel deposits, and as the result no anomaly was found. Accordingly, it was judged that there was no need for further exploration including the indication of a copper-containing nickel sulfide mentioned later, and no survey was continued after the first year.

The Anglo American survey consisted of a series of investigation starting with airborne geophysical surveys, followed by a geological survey, geochemical survey and heavy mineral sampling. Anomalies found in the airborne geophysical surveys (magnetic and electromagnetic) were subjected to systematic follow-up on the ground. With regard to two anomalies (TA03, TA06) which were determined to be due to bed rock, three holes were drilled but they failed to intersect any mineralized zone. Only slight sulfide dissemination was found. Surveys in the zone were discontinued as a large copper-bearing nickel ore deposit was discovered in the Selebi-Phikwe area and exploration efforts were diverted there for the most part. A summary of the Anglo American surveys is shown in Table 6 and Fig. 7. According to open file records

Fig. 6 Areal map showing the relationship of GS-17 project and previous surveies.

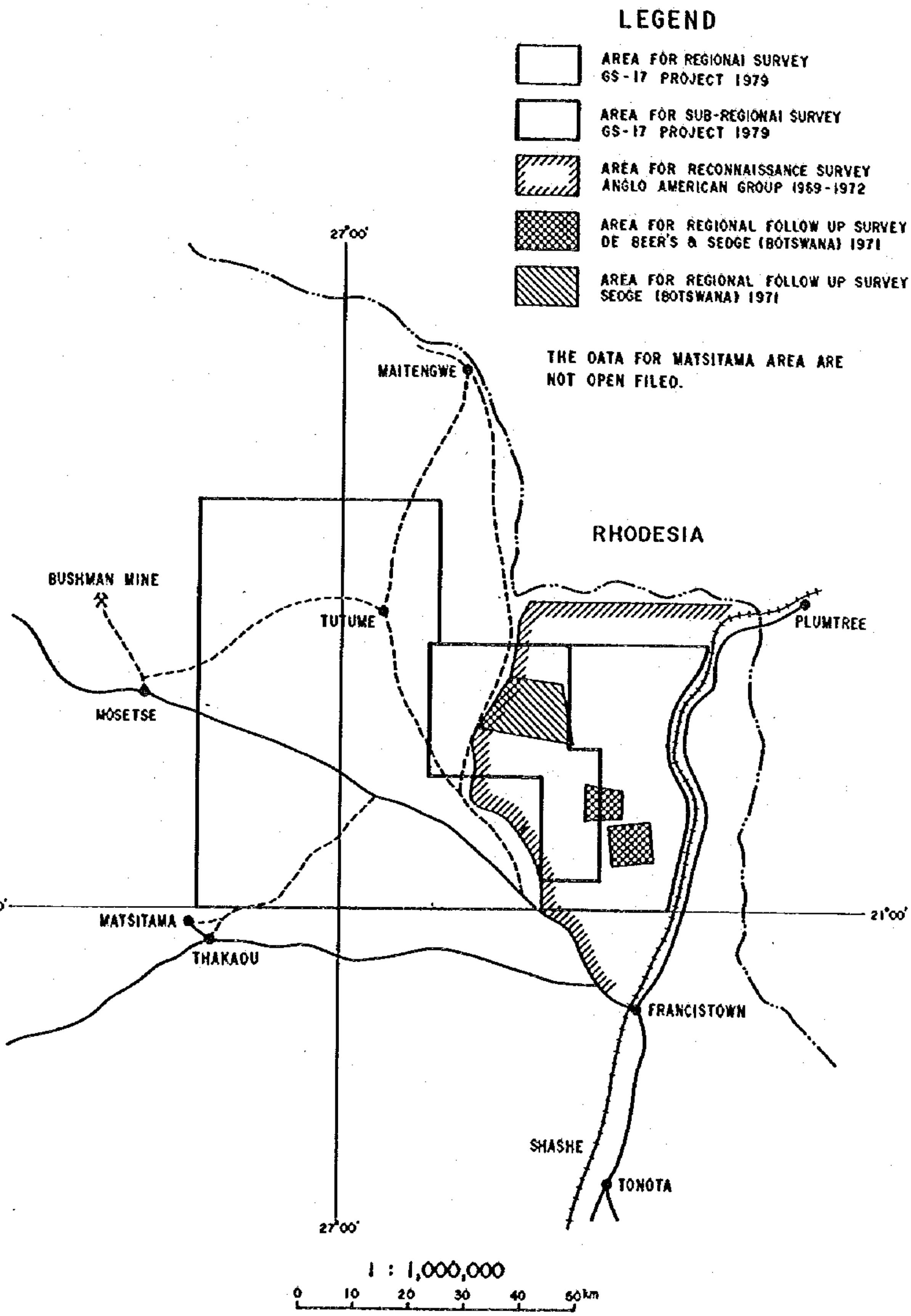


Fig. 7 Previous exploration localities, Vumba mineralized zone (Anglo-American group open file report 1971, 1972)

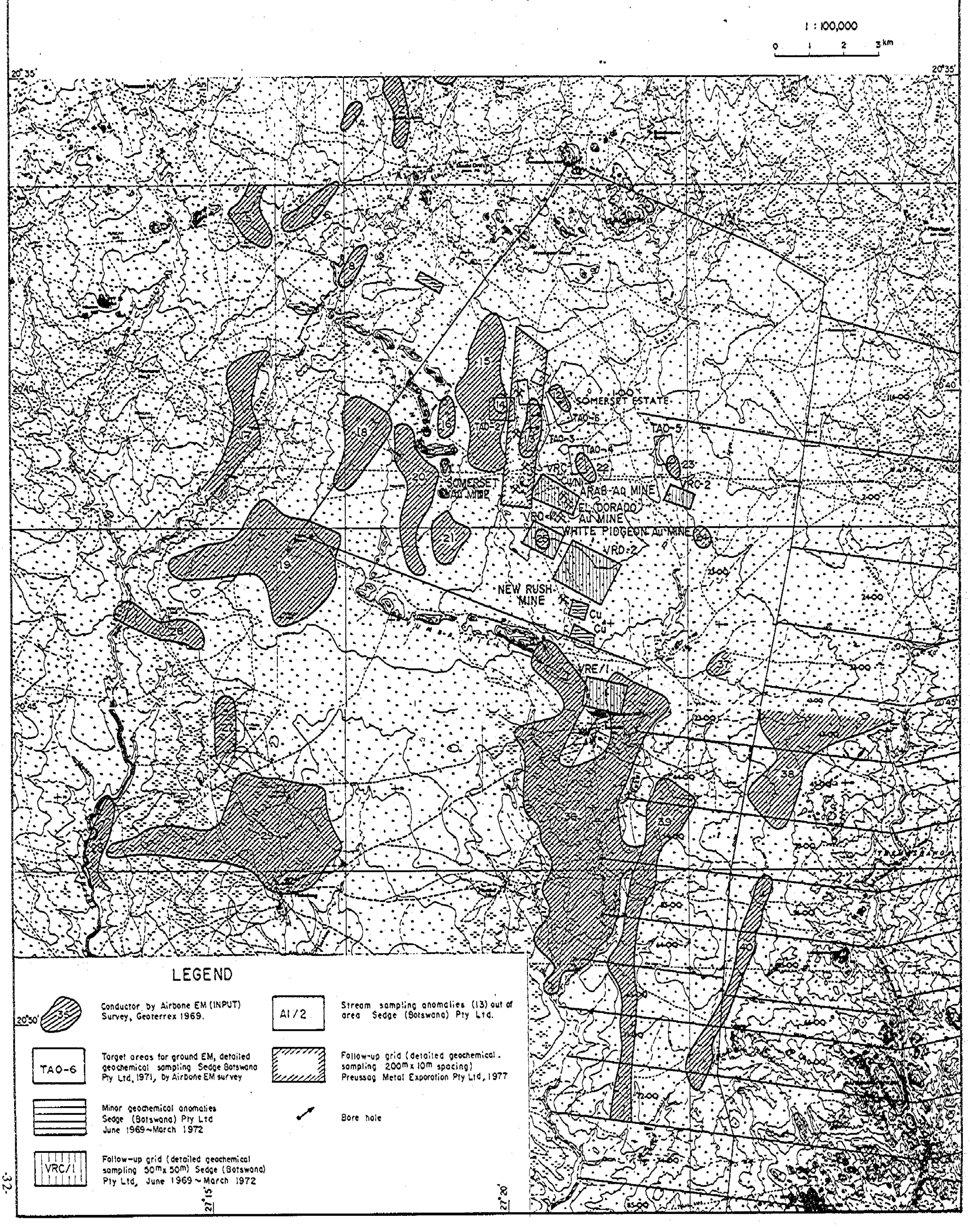


Table 5 Previous Exploration Records (Airborne geophysical survey and follow-up exploration) from open-file report, geological survey Botswana

Anomalies by airbone EM (INPUT) 1969	Recommendations by Geoterrex 1971	Priority	Follow up by Sedge (Botswana) Pty Ltd. from June 1969 to March 1972
Zone 2 conductor	Surficial conductor (Brakish water)		
3	Surficial conductor (Brakish water)		
4			
5			
7	Bedrock conductor (Halo around Zone 6. Would be examined for disseminated mineralization after Zone 6 shown good results.)		
8	Surficial conductor (Brakish water)		
12	Bedrock conductor (Ground magnetic, EM surveies were recommended.)	3	TAO-6, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Magnetometry), Diamond drilling (1 Hole, TAO6-1)
13	Bedrock conductor (may be combination of bedrock & surficial sources)	4	TAO-3, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Megnetometry), Diamond drilling (2 Hole, TAO-3-1, TAO3-2)
14	Bedrock conductor (Follow up on this one may be considered contingent on the result obtained (Zones 12 & 13)	4	TAO-2, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Magnetometry)
15	Surficial conductor (Weathering product)		
17	Surficial conductor (Brakish water)		
18			
19	Surficial conductor (Weathering product)		
20	Surficial conductor (Weathering product)		
21	Surficial conductor (Brakish water)		
22	Bedrock conductor (Very weak conductor)	4	TAO-4, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop GM, Magnetometry)
23	Bedrock conductor (Good possibility for a thin bedrock source)	3	TAO-5, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop GM, Magnetometry)
24	Surficial conductor (Brakish water)		
25	Surficial conductor (Weathering product)		VRD-1, 50m x 50m spacing, geochemical sampling
26	Surficial conductor (Weathering product)		
27	Surficial conductor (Weathering product)		
28	Surficial conductor (Brakish water)		
29	Surficial conductor (Agricultural higher soil moisture)		
37	Surficial conductor (Weathering product) (Brakish water)		VRE-1, 50m x 50m spacing, geochemical sampling
38	Surficial conductor (Weathering product) (Brakish water)		
39	Surficial conductor (Weathering product) (Brakish water)		
40	Surficial conductor (Weathering product) (Brakish water)		
			TAD-3 Detailed 200m x 10m spacing, geochemical sampling does by Preusage Metal Exploration 1977 VRD-2 50m x 50m spacing, geochemical sampling VRC-2 50m x 50m spacing, geochemical sampling

Fig. 8

Old gold workings in the Vumba mimeral province
(SEDGE Botswana Pty. Ltd. 1972. open-file report)

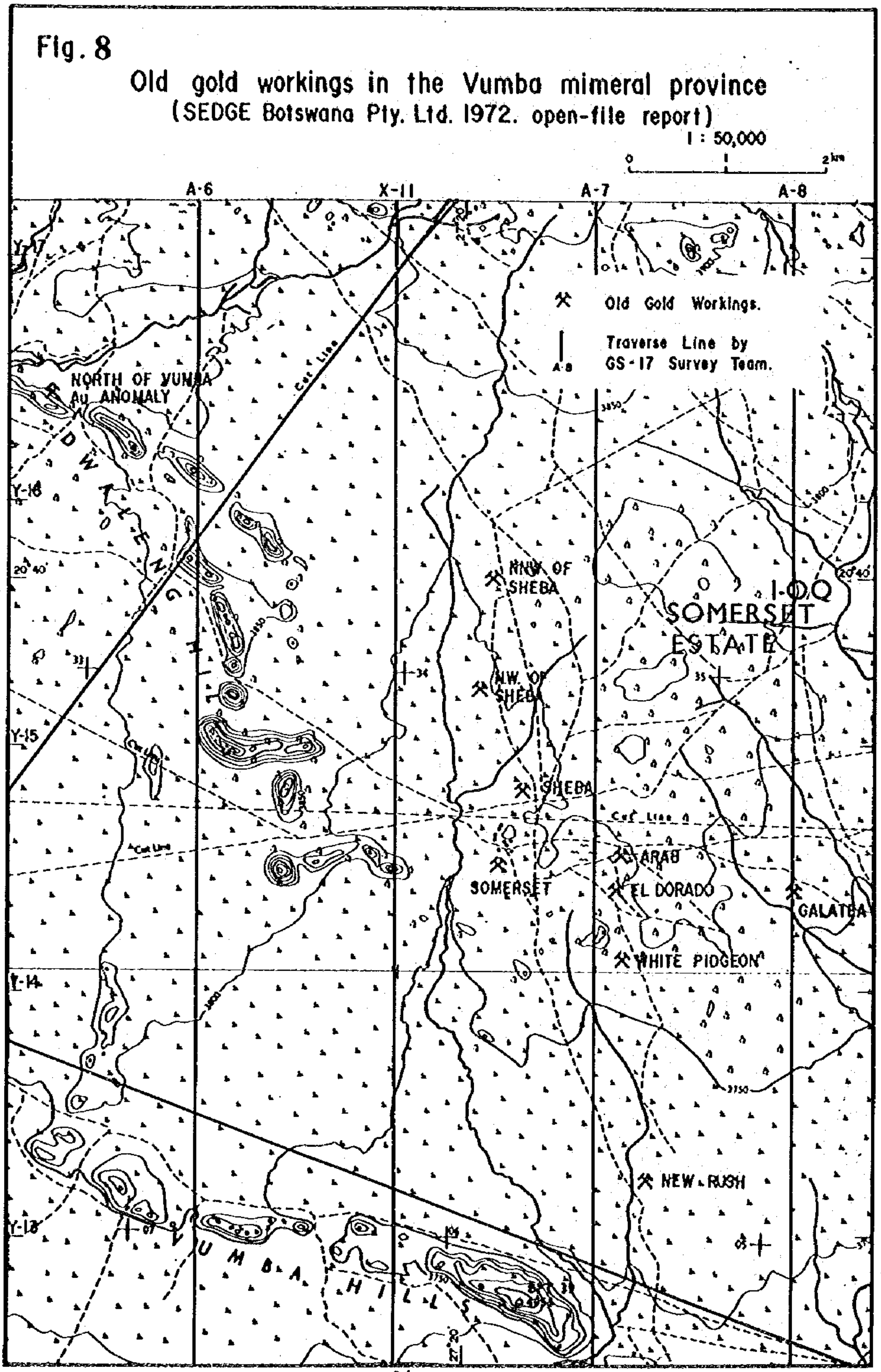


Table 6 Description of Old Gold Workings in The Vumba Mineral Province
(Open Filed Sedge (Botswana) Pty. Ltd. 1972, Report from Geological Survey Department)

Name	Location	Geological Setting	Scale		Grade g/t (T.P.M.)	Operation Records
			Strike (m)	Width (m)		
New Rush	Southern most in the area	Steeply inclined quartz vein in highly metamorphosed amphibolite. NNE direction	400	±1	Max. 2.23	Prospecting by 3 shafts sinking, trench
Arab	Near Dead Mule ranch to Tsessebe road	The vein consists of quartz containing some pyrrhotite in NW shear plane. N45°W direction	220	±1	Max. 2.91	Working area not extensive, random shafts sunk, prospecting stage.
Sheba	NW extention of Arab workings	The identifiable quartz veins in NW zone have a NE trend and do not look promising.	Zone strike 300	-1	Max. 9.00	Do not seem to have yielded much ore. Prospecting stage.
El Dorado	About 1 km SE of the Arab mine shear	Quartz vein in shear plane which is on the same trend as Arab shear	+30	±0.5	Max. 1.05	Propsecting stage. It consists of a shaft and pits
Galatea	Near the eastern margin of Vumba schist belt	Situated on the contact of a small granodiorite plug and green schist. Quartz vein with some pyrrhotite. Assay results were poor except one sample	30	±0.5	Max. 10.2	Prospecting and mining by a shaft & a glory hole
White Pidgeon	Near El Dorado mine	East of the main granodiorite. Quartz veins in NW trend shear zone in green schist	110	±0.5	9.95	Workings extend below a depth of 30 m which is water level in the shafts. There is a honeycomb of interconnected small underground workings from which some 5,000 - 10,000 tons of ore was probably obtained.
Workings north of Sheba mine	2 km north of Somerset mine and are in vicinity of input 12, 13 Anomalies	Quartz veins in shear zone in green schist			5.50	Development does not seem to have passed the prospecting stage.
Workings mine of Sheba mine	1.2 km north of Somerset mine	Two sets of quartz veins in coarse grained green schist. Some 200 m SE of the main workings, there is an opaline gossan which to be of no economic value.		±0.3		A few hundred tonnes of ore was probably extracted. There small shafts have opened up.
North Vumba gold anomaly	North western side of serpentinite	Obtained when panning. The rocks consist of basic rock and serpentinite intruded by acidic rock.			None	Trench sampling results proved to be negative.
Somerset mine	In the vicinity of Dead Mule ranch	Set of quartz veins extend over 200 m on a NNE trending. The sidewalls of the veins are virtually unmineralized. Veins were payable only in the zone of supergene enrichment.	+200	±1	5.0	The largest old working in the north Tati schist belt, working extend over 150 - 200 m. Total 2,500 tonnes ore expect. Neither of two bore holes intersected any mineralization beneath the old workings.

Fig. 9 Workings of Somerset mine.

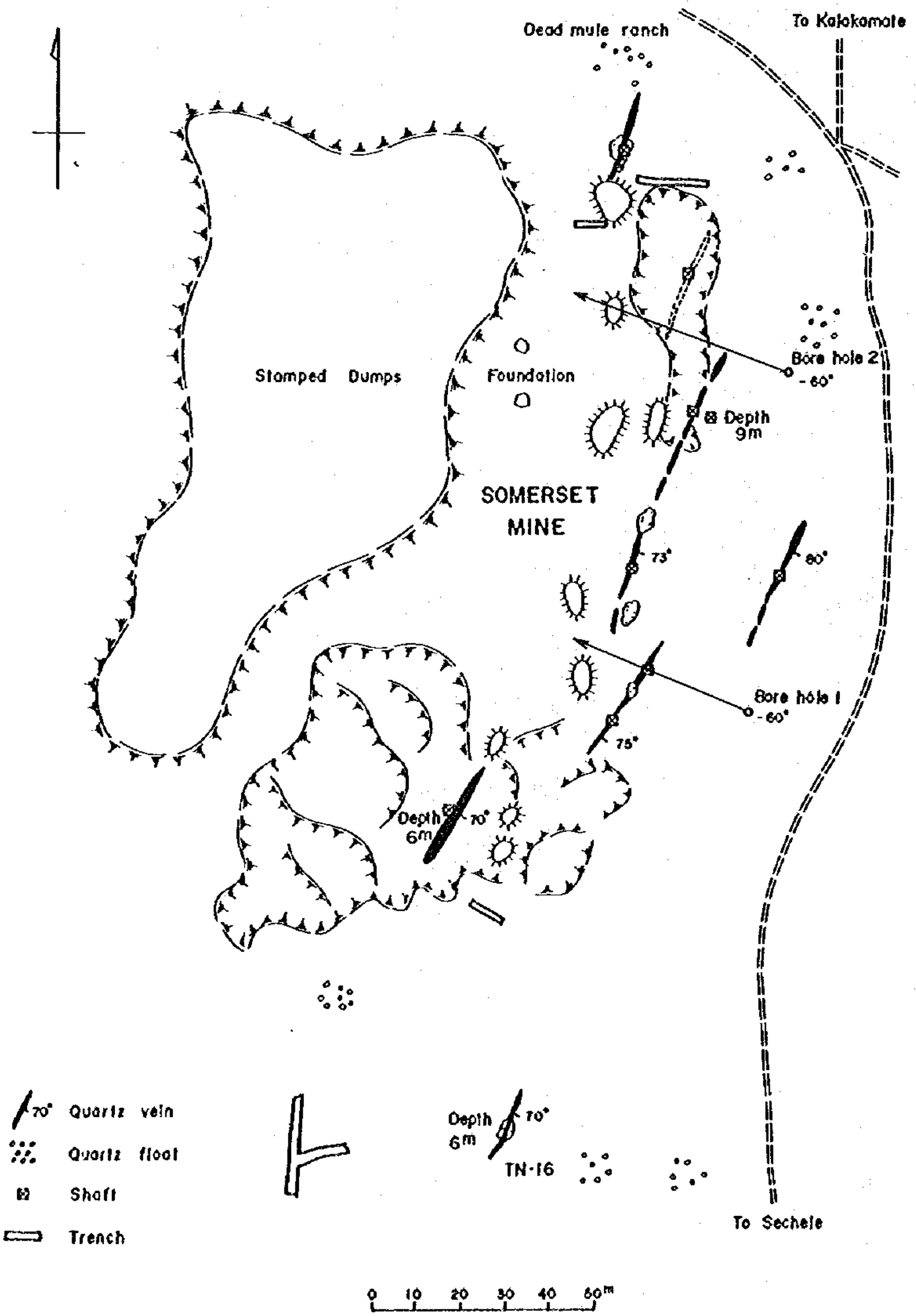


Table 7 Analytical Data on Ore

(1) Chemical Analysis

	Location	Analysis (%) Au (g/t)						
		Au	Cu	Pb	Zn	Ni	Co	Mo
S - 1	Matsitama	-	0.02	0.00	0.01	0.01	0.00	0.000
S - 55	Kalakamate	-	0.00	0.00	0.00	0.00	0.00	0.160
S - 554	Somerset Mine	0.4	0.04	0.00	0.01	0.01	0.01	0.000
S - 556	El Dorado Mine	0.0	0.00	0.00	0.01	0.00	0.00	0.000
S - 557	El Dorado Mine	0.0	0.01	0.00	0.01	0.02	0.00	0.000
S - 558	Sheba Mine	2.3	0.03	0.00	0.02	0.01	0.00	0.000
S - 559	Sheba Mine	7.8	0.06	0.00	0.01	0.01	0.00	0.000
S - 560	Matsitama Mine	0.3	3.61	1.00	5.97	0.00	0.01	0.000

(2) Natures of Ore

	Sample	Ore Microscopy
S - 1	Fine amphibolite schist	
S - 55	Micro mus. - bio. granite with M_oS_2 dissemination	M_oS_2: 30 x 60 μ ~ 0.2 x 1.0 m/m
S - 554	Quartz patch in banded amphibolite	
S - 556	Banded amphibolite with thin layer of quartz	
S - 557	Porous quartz vein	
S - 558	Quartz patch in banded amphibolite	Cp (4 ~ 20 μ). Py (10 ~ 60 μ)
S - 559	Limonitized amphibolite	Py (20 μ ~ 0.8 mm), Cp (16 ~ 80 μ), Po (20 μ ~ 0.1 mm) Lo (50 μ ~ 1 mm)
S - 560	Banded copper ore in carbonaceous layer of amphibolite	Cp (5 μ ~ 1.2 mm), Sp (0.1 ~ 0.8 mm), Gn in Cp, Sp
S - 98	Dombashaba G_4 biot. granite	Cp (4 ~ 20 μ)

Cp: Chalcopyrite, Gn: Galena, M_oS_2: Molybdenite, Po: Pyrrhotite, Py: Pyrite, Sp: Sphalerite
Lo: Loellingite

of the Geological Survey Department, the explorations described below were conducted for the two anomalies.

Anomaly TA03, located in the central part of the Vumba zone, was given fourth grade priority in the airborne EM survey of the Vumba – Tati area. It is located in amphibolite, green schist, and quartz-amphibole schist in the Vumba Volcanic Group. Concerning this anomaly, ground follow-up was conducted and revealed that limonite occurs on a boundary of the rocks and shows a nickel content of 300 – 350 ppm. Also, EM anomaly overlapping the limonite position was detected. Two holes 100 meters apart were drilled under the limonite outcrop. Dissemination of pyrite and pyrrhotite in amphibolite was confirmed at 61.3 – 63.9 m and 69.4 – 78 m depths in one of the holes, and at 92.4 – 94.6 m depth in the other hole.

Anomaly TA06, located 800 meters northeast of Anomaly TA03, is found in amphibolite. Analytical value of geochemical survey was 145 ppm nickel and 80 ppm copper. Nevertheless, drilling was conducted because EM anomaly and magnetic anomaly overlapped the geochemical anomaly. However, the drilling hole did not intersect any mineralized zone.

3-4-3 Ore Deposits and Mineralization in Timbale Zone

In 1969, geochemical exploration for heavy mineral concentration was done by De Beer's in the Timbale igneous complex and copper and molybdenum anomalies accompanied by vanadium and yttrium anomalies were found in the complex and its aureole, related to pegmatite intrusion (Litherland, 1975). Although not investigated in detail, the environment showed certain similarities with the copper-porphyry type of mineralization.

The geochemical survey was followed by regional geochemical survey by soil sampling. For the anomalies found, an IP method geophysical prospecting was conducted and two most promising points were selected. Two holes were drilled in one of the two points and gave maximum values of 1,500 ppm copper and 50 ppm molybdenum, so that exploration was suspended. The extent and results of the De Beer's survey are shown in Fig. 10.

Some of other anomalies, including vanadium, yttrium, nickel, copper, niobium, molybdenum, tin, tungsten, gold, and lead, were thought to be related to rare metal mineralization, but since no outcrop was found, there was no field evidence. It is likely that these anomalies were not caused by a single type of mineralization, but involved many factors, for example: some copper, molybdenum, and yttrium anomalies are associated with pegmatite veins which intruded in the later stage of Timbale granitic activity: some anomalies are related with dolerite intrusion; vanadium anomalies are associated with pegmatite veins which intruded in the later stage of Timbale complex.

In our survey, heavy mineral sampling by panning was performed in the Timbale zone and, for comparison, in northern Sebina at two points each. Each sample was subjected to X-ray diffraction analysis and X-ray fluorescence analysis (Table 8).

Geology at these places is: in the Timbale area, granitic rocks (G_4) and dolerite, while in northern Sebina, Vumba schist relic, granitic rocks (G_1 and G_2) and dolerite. Sandy sample concentrated to 1/n x 1,000 by panning were used in the X-ray diffraction. In these samples, heavy minerals excluding magnetite and ilmenite were recognized only in small quantities, except for S–549 in which such minerals were found to be contained in somewhat large quantities when seen with the naked eye as well as observed with mineralight.

Ilmenite, magnetite and monazite were confirmed by X-ray diffraction analysis as heavy minerals in samples from the Timbale zone (S–542, S–549). The X-ray fluorescence analysis revealed a very large amount of Ti, Fe, Mn, a rather large amount of Y, Zr, Nb, Th and traces of Cr, Ni, Cu, Zn, Pb, Rb, Sr, Ta, La, Ce, Pr, Nd, V.

In the Sebina zone, monazite was absent but other heavy minerals were found in a similar combination to that in the Timbale zone, as similar minerals occur in the two zones. In S–546, no La or Ce was detected. This presumably because the sampling point was near ultramafic rocks. (S–545)

Although our investigation did not cover the entire area in detail, the results of geological and geochemical surveys indicate little possibility of porphyry type copper-molybdenum ore deposits in the Timbale zone.

Concerning rare elements, there is no large rare element ore deposit, at least in the very limited area that 2 panning samples cover.

Since no mineralized outcrop was discovered by the first year surveys, though possibility for exploration still remained widely, exploration in the Timbale area was terminated, the stress of exploratory work being shifted to the northern Matsitama area for the second year and on.

In the course of regional geological survey dissemination of a very small quantity of

Fig. 10 Geochemical distribution of molybdenum, timbale block.

(De beer's-sedge Botswana open-file report 1972)

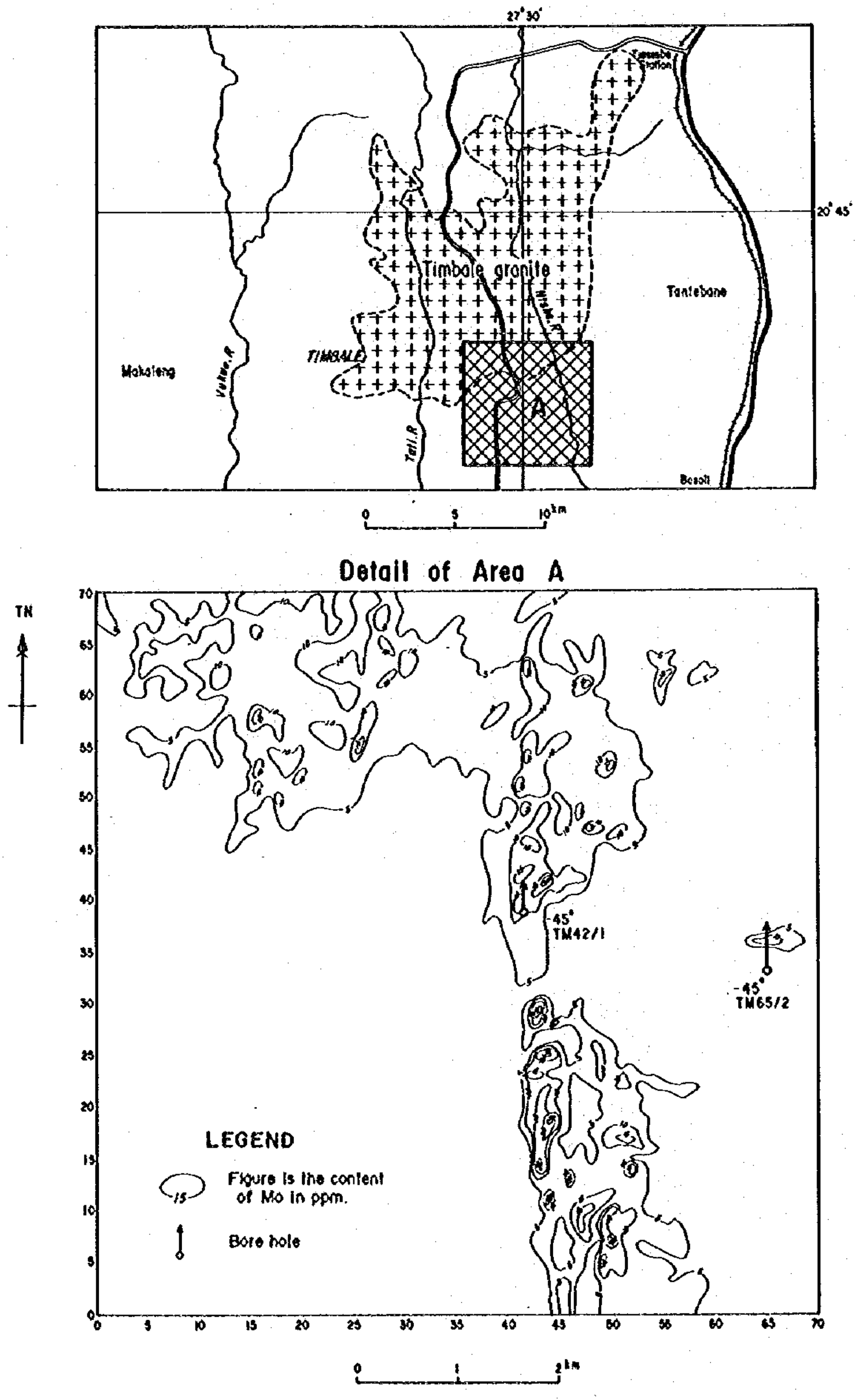


Table 8 Data on X-ray Diffraction and Fluorescence Analysis

(1) X-Ray Diffraction Analysis

Sample No.	Location	Geology of Surroundings	Quartz	Feldspar	Ilmenite	Magnetite	Amphibole	Monazite
S - 542	Timbale Hill	G_4 Granite, Dolerite ~ Gabbro	+++	+++	++	+	+	
S - 549	Timbale Hill	G_4 Granite, Dolerite ~ Gabbro	+++	+++	+			–
S - 545	7 km N W of Sebina	Ultramafic, Amphibolite, Tonalite - Granite	+++	+++	+++	+	+	
S - 546	9 km N W of Sebina	Gneiss (G_{2g}, G_{2ht}, G_1), Meta-arkose,	+++	++	+++		++	

(2) X-Ray Fluorescence Analysis

Sample No.	Ti	Cr	Mn	Fe	Ni	Cu	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ta	La	Ce	Pr	Nd	Th	V
S - 542	+++	–	++	+++	–	–	+	–	–	+	+	++	+		–	–	–	–	+	
S - 549	+++	+	++	+++	–	+	+	+	+	+	+++	+++	+++	–	+	+	+	+	+++	–
S - 545	+++	+	++	+++	–	–	+	–	–	–	+	++	+		–	+	~	–	+	
S - 546	+++	+	++	+++	–	+	+			+	+	+++	+						–	

+++: Abundant, ++: Common, +: A little, –: Rare molybdenite in fine-grained biotite granite belonging to G_1 Pluton to the east of Shashe Drift was found; 0.16% of molybdenum was detected as the result of analysis and exploration was continued with the same hope as that with the Timbale granite, but it was judged that its occurrence was extremely slight and of small scale and there was no need for further study.

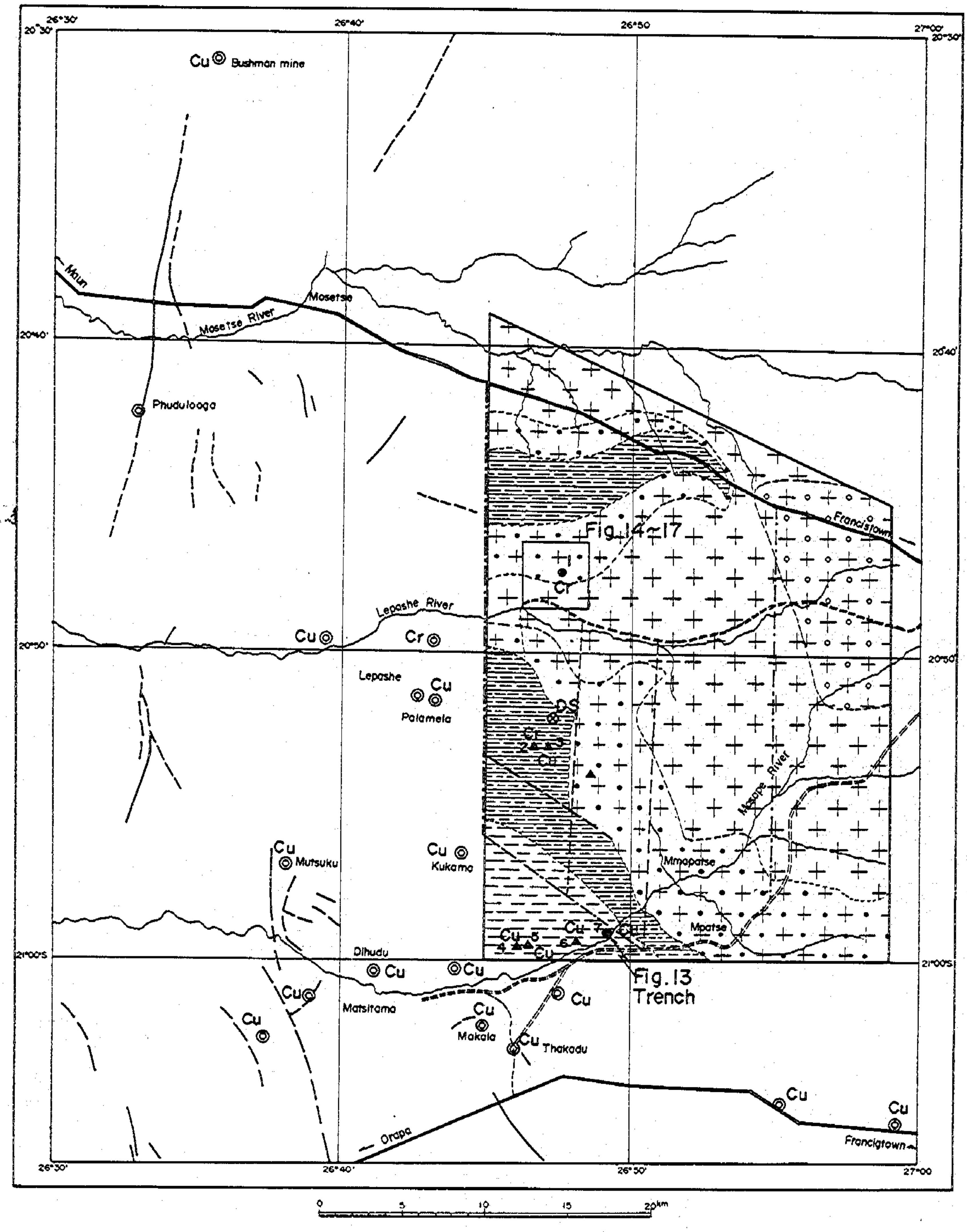
3-4-4 Ore Deposits and Mineralization in Northern Matsitama Zone

The southern end of the survey area falls under the Matsitama sedimentary basin which is considered to form part of the Rhodesian craton. Distributed irregularly here is the Matsitama Schist and Metasedimentary Group which has undergone amphibolite facies regional metamorphism and is formed of basic schist, amphibolite, quartzite, graphite schist, limestone, and banded iron ore. Sulfides, mainly copper sulfides occur in the limestone (varying within the extent from siliceous limestone to calcareous quartzite) and biotite schist in this group. In the ore considerable quantities of sphalerite and galena are recognized with the naked eye; the content of copper and that of nickel are not in proportion to each other. This is in contrast to the Vumba area mineral indications showing the trend of high contents of both copper and nickel. In view of the very small quantity of nickel and the accompanying of gold, silver, lead and zinc minerals and of the form, the sulfides are presumed to be of sedimentary origin. As the type of deposits, it is said that they differ from metasedimentary deposits of the copper-nickel type found in the Selebi – Phikwe and Tati schist zones in the east, and rather resemble sedimentary copper ore deposits in the Damaran Mobile Zone in the east of this country. There are a number of old prospecting and mining sites in this sedimentary basin, and as the result of such activities there is a mine known as Matsitama mine which was found by the Anglo American Group in 1962; around the mine considerable activities of prospecting have been done following its discovery.

Up to the present a total of 17 mineral indications have been made known: they are Thakadu, Makala, Logolo, Peolane – Noko, Nakalakwana Hill, Dihudi, Sebotha – Samsonga – Esoka, Mutsuku, Kamela, Lengau, Nare, Nakalakwana Prospect, Kukama, Lepashe, Agente, Palamela, Tholo. For the two deposits of Thakadu and Makala, which are the center of mineralization, reserves of 8 million tons of the grade of 2.2% Cu (including copper oxide ore) have been proven (J.W. Baldock, 1977). The main scene of exploration in this area moved in 1977 to the Selebi – Phikwe deposit area, as it was found in 1968.

The survey area is located at the northwestern edge of the Matsitama sedimentary basin. Among the above-listed copper indications, the northern marginal line connnecting those at Lengau, Nare, Nakalakwana Prospect and Nakalakwana Hill almost coincides with the southern

Fig. 11 Mineral deposits, occurrences and showings (Cu, Cr)



Legend	
Matsitama schist and metasedimentary group (Upper)	Mineral deposits (Cu, Cr)
Matsitama schist and metasedimentary group (Lower)	Mineral occurrences (Cu, Cr)
Mosetse river gneiss group (Upper)	Mineral showings (Cu, Cr)
Mosetse river gneiss group (Lower)	Drilling site (D.S)
Mosetse river gneiss group (Lower) Porphyroblastic gneiss	Highway (asphalted)
Faults	Road

Newly constructed cutline by GS-17J

Repaired cutline by GS-17J

Notes

1. The numbers of the mineral occurrences and showings here are same as those of Table 9
2. Location of faults and mineral deposits is after Bennett (1970) except that of the surveyed area (1981)

marginal line of the survey area. The Matsitama Schist and Metasedimentary Group has a strike of NW–SE and dips apparently to the south, and on its north side the Mosetse River Gneiss Group, in which granitic gneiss lying lower than the former group is dominant, is distributed. Therefore, the former's extent is limited. So that it was thought that the Matsitama Schist and Metasedimentary Group which was considered to be a deposit bearing group would not be distributed as far as the northeast side, the survey area; and the above-mentioned mineral indications were not valued highly. However, from the fact that Mosetse River Gneiss Group has interposing limestone, and from the results of geological survey on the surface and of geochemical survey, and in view of the lithofacies, the possibility came to be justified that part of the group may be included in the Matsitama Schist and Metasedimentary Group. So the hope of occurrence of deposits of the Matsitama type in the survey area came to grow (Fig. 11).

There is Bushman mine on the north-northwest extension of the Matsitama schist belt, outside of the survey area. Bushman deposits are distributed in a shear zone called the Bushman lineament. The deposits have the country rock of graphite-containing quartzite – quartz schist in siliceous limestone or dolomite that was taken into a shear zone. But their form of occurrence has characteristics greatly differing from the Matsitama deposit group in the respects that there is clear structural control by a NS trend shear zone, that graphite schist exists in the country rock, and that the mineralization is closely related with graphite concentrated in a shear zone. The ore minerals are almost the same as those of the Matsitama ore deposit group except for the facts that silver minerals are found in more quantities than in the deposits of the said group and that they contain fluorite. At present in this mine the Falconbridge Co. group is carrying out prospecting work aiming principally at the part under the Kalahari sediment in the northern part, as the result of which the ore reserves are being increased.

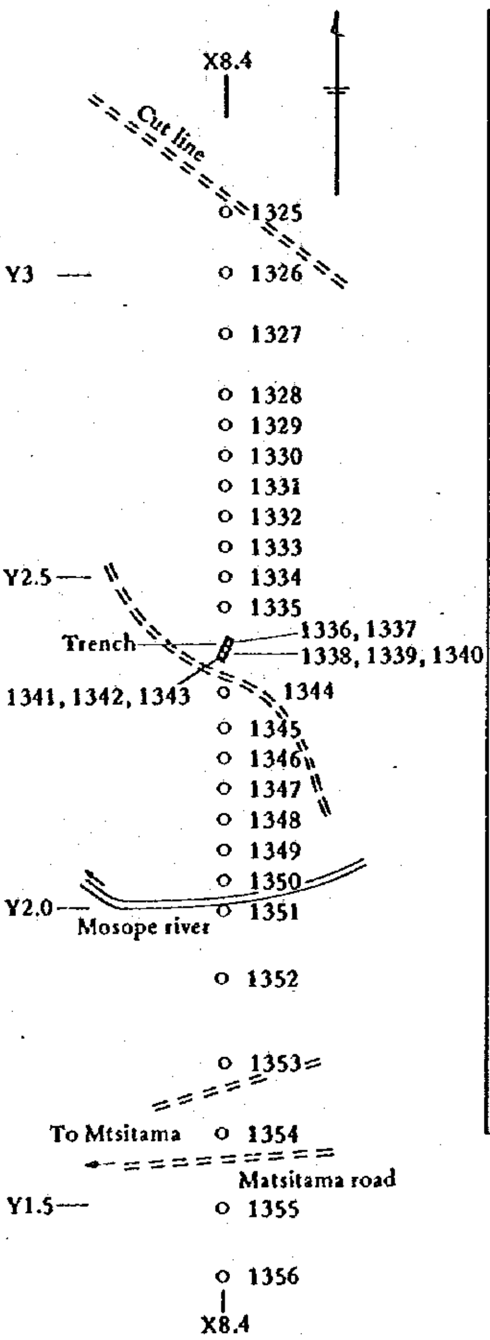
The survey area is situated between Matsitama mine and Bushman mine.

(1) Copper Indications

In the west of the survey area there is an old trench (Figs. 12, 13) where exploration was made before, which is located in a flatland about 300 m to the north of Mosope river. Outcrops are not seen in the neighborhood except for the inside of the trench and very limited parts of the river. The rock in the trench has been so much weathered as to make identification of the original rock impossible.

Geology of the vicinity is formed of quartzite, biotite quartz schist, muscovite quartz schist, calcareous quartz schist – quatzite, which belong to the upper of the Matsitama Schist and

Fig. 12 Geochemical sampling around the trench



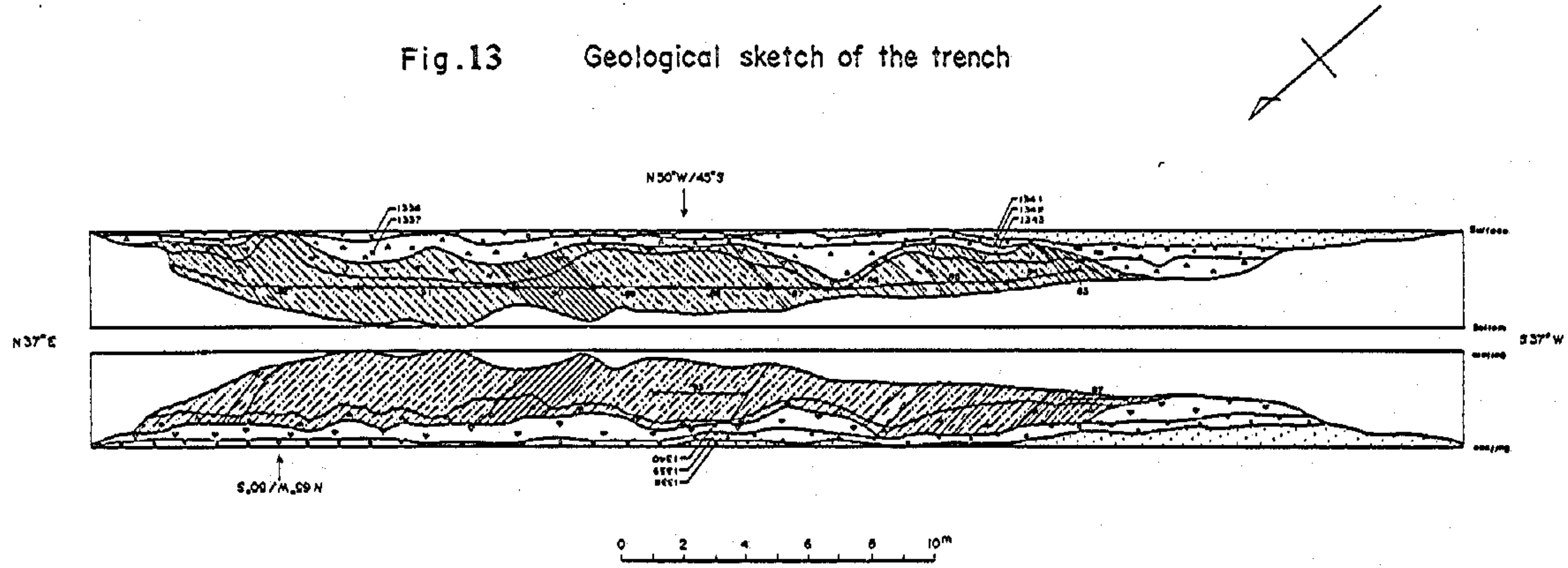
Sample No.	Analysis (ppm)			Remarks
	Cu	Pb	Zn	
1325	19	7	23	Gravel (cal. Q)
1326	11	3	15	Gravel (cal.)
1327	20	5	33	Gravel (cal.)
1328	13	3	11	Brown soil
1329	12	3	9	Brown grey soil
1330	19	3	14	Brown soil
1331	21	3	15	Gravel (sch. Q Qtz.)
1332	14	3	13	Brown soil
1333	13	3	13	Gravel (Q)
1334	17	3	14	Brown soil
1335	14	3	18	Gravel (cal. Q)
1336	37	3	19	Gravel (Q)
1337	28	30	11	Gravel (cal.)
1338	13	4	20	Brown grey soil
1339	316	6	23	Gravel (Q)
1340	872	9	18	Gravel (cal.)
1341	225	7	28	Brown grey soil
1342	275	7	27	Gravel (Q)
1343	395	13	26	Calcretized, weathered rock
1344	42	8	30	Brown grey soil
1345	28	6	28	Brown grey soil
1346	17	3	18	Brown grey soil
1347	20	3	19	Brown grey soil
1348	16	3	14	Light grey soil
1349	14	3	13	Brown grey soil
1350	21	4	22	Light grey soil
1351	24	7	23	Gravel (cal.)
1352	27	5	19	Brown soil
1353	24	3	16	Brown soil
1354	28	5	18	Brown soil
1355	26	4	23	Brown soil
1356	17	4	21	Brown soil

Trench (1336–1343)

Sampling depth: 30 cm
Topograph: flatland
cal; calcrete, Q; quartz, Qtz.; quartzite
sch.; schist

0 500 m
s = 1/1,000

Fig.13 Geological sketch of the trench



Legend

	Sand and Soil
	Sand and gravel (gravel : mainly quartz)
	Calcrete
	semi-calcretized-weathered zone of the country rock
	Schist (mica, mica-chlorite schist)
	Quartzite
	Carbonate bearing schist
	Garnet bearing schist
	Copper mineral
	Copper cobble (φ=5-10cm)
	Sampling width and Sample No.
	geochemical sampling point and No.

Analysis

Samp.No	Width m	Cu %	Pb %	Zn %	Au g/t	Ag g/t	notes
82	2.0	0.10					
83	0.4	0.46	0.00	0.04	<0.2	< 5	
84	2.0	0.08					
85	3.0	0.03					
86	2.7	0.04					
87	2.0	0.06					
88	3.0	0.63	0.00	0.04	< 0.2	< 5	Apex.1,2,3
89	2.5	0.15	0.00	0.06	< 0.2	< 5	
90	2.5	0.14					
91	5.0	0.01					
92	6.0	0.00					
93	3.0	0.44	0.00	0.03	<0.2	< 5	

geochemical analysis

Sample No	Depth cm	Cu ppm	Pb ppm	Zn ppm	notes
1336	25	37	3	9	gravel (Q)
1337	75	28	30	11	gravel (Cal)
1338	15	13	4	20	brown grey soil
1339	40	316	6	23	gravel (Q)
1340	70	872	9	18	gravel (Cal)
1341	25	225	7	28	brown grey soil
1342	45	275	7	27	gravel (Q)
1343	70	395	13	26	Calcretized and weathered country rock

Q : quartz
Cal : calcrete

Table 9 Mineral Occurrences and Showings

No.	Location	Outcrop, Float	Type	Ore mineral	Geology	Note
1	X5.4 Y24	Outcrop Float	Cr	Chromite	Ultrabasic rocks Gneiss	Chromite floats are found in the area of 3 km x 3 km S-22 Cr_2O_3 50.8% S-32 Cr_2O_3 35.6% S-33 Cr_2O_3 34.6% S-34 Cr_2O_3 33.6% S-35 Cr_2O_3 33.7% S-39 Cr_2O_3 9.8%
2	X3.7 Y13.5	Float (1)	Cr	Chromite	Ultrabasic rocks Amphibole schist etc.	S-55 Cr_2O_3 33.7%
3	X4.6 Y13.5	Float (1)	Cu	Malachite	Amphibole schist	Malachite film in amphibole schist
4	X3 Y 1.8	Float (1)	Cu	Chalcopyrite	Amphibole schist, Quartzite, Biotite quartz schist, Limestone, Phyllite	Chalcopyrite grain in quartzite
5	X3.5 Y 1.7	Float (1)	Cu	Malachite	Amphibole schist, Quartzite, Biotite quartz schist, Limestone, Phyllite	Malachite film in limestone
6	X6.5 Y 2	Float (1)	Cu	Malachite	Amphibole schist, Quartzite, Biotite quartz schist, Limestone, Phyllite	S-68 Cu 5.20% Pb 0.06% Zn 0.15% An 0.2 g/t Ag 54 g/t
7	X8.4 Y 2.4	Outcrop (trench)	Cu	Malachite	Quartzite, Mica schist, Carbonate	S-82 Cu 0.10% (w = 2.0 m) S-83 Cu 0.46% (w = 0.4 m) S-88 Cu 0.63% (w = 3.0 m) S-89 Cu 0.15% (w = 2.5 m) S-93 Cu 0.44% (w = 3.0 m)

Note
(1): figure in parenthesis is the number of float found in this survey.
The floats of No. 2–No. 6 samples are of coble size.

Metasedimentary Group. Besides, in this trench found are several seams of darkgreen hard rock, each about 15 cm in width, in which plenty of garnet is contained in schist. According to X-ray diffraction and microscopic analysis, this hard rock is composed of garnet principally, quartz, feldspar, actinolite talc, calcite, hematite, and malachite. In some cases this hard rock contains high-grade copper oxide minerals, while in the other cases they are scarcely contained.

There are two layers of copper mineralization zones in the trench composed mainly of green copper ore, the apparent width of which is.6 m and 0.4 m respectively, but the primary width of this mineralization is unknown. The result of analysis is shown in Fig. 13, the richest part of which is Cu 0.63% for 3 m width (S–88). The profile of this trench, changing from the surface downward, is: superficial soil and sand, a gravel bed formed mainly of quartz gravel, a calcrete layer (gravelly calcrete mostly), country rock which has turned into calcrete, and clumbly country rock which has been extremely weathered. Calcrete immediately above the ore bed contains 872 ppm of copper, but the superficial layer has only 13 ppm. Soil around the trench was taken at 50 to 100 m intervals for analysis as shown in Fig. 12, and it was found after all that the top layer has only a small amount of copper. This means that the area near the trench is covered with recent sediment deriving from the Mosope river.

As the result of geochemical survey followed by a drilling survey on the copper indications near the trench, it was found that there had been intrusion of basalt for several times into the Matsitama Schist and Metasedimentary Group in this area, which had been accompanied by strong alteration of the country rock.

The copper mineralization is distributed irregularly and on a small scale, as small-scale secondary copper minerals, in weathered zones near the intrusive dikes, and the copper content is presumed to derive from copper that was contained in the basalt. In addition, for an area including four places of mineral indications, prospecting was made mainly depending on drilling over a zone that has similar geological conditions as a part on the extension of the Matsitama deposit group and that has also geophysical and geochemical anomalies. The geophysical anomalies are presumably almost attributable to the existence of graphite schist, excluding a weak pyrite dissemination area. The graphite schist was found to be distributed particularly clearly in Area III in the third year surveys; there was some of it in a drill hole, though partially, showing the contents of 66.8% of carbon, 7.3% of volatile matter, 24.8% of ash, and 1.1% of moisture.

According to the result of surveys carried out in anomaly areas found by geochemical survey, mineral indication, though weak, were found in all of the areas. In particular in an area which was set as Area II in the third year and where in the fourth year too detailed geochemical survey and drilling were proceeded with along the extension of the strike, copper mineralization in a disseminated form was widely, though weakly, found along the horizon of amphibole schist in the Matsitama Schist and Metasedimentary Group. Its extension is probable, and an enriched part can be expected by doing detailed surveys.

In the Matsitama Schist and Metasedimentary Group, in addition to the above-mentioned copper indications, floats containing copper minerals have been discovered at four places (Table 9).

Among them, float No. 5 is limestone with some malachite and others, but no carbonate mienral is recognized in floats No. 4 and No. 6. The float No. 6, which is of fist size, contains malachite with copper content of 5.2% (S–68). The malachite occurs in thin porous layers of quartzite – quartz schist. It is possible that sample S–68 primarily contained some calcareous mineral. Sample No. 4 is quartzite containing chalcopyrite. Sample No. 3 is a float of amphibole schist containing film-like malachite, belonging in the lower of the said group.

In addition, in the soil of the lower of the same group were found copper anomalies of 560 ppm in the geochemical survey sample No. 1228 and 520 ppm in No. 1240.

To give a brief summary of the above-stated, copper indications and anomalies in the survey area are often found in the Matsitama Schist and Metasedimentary Group which presents a monoclinical structure, especially in the upper strata.

In this survey area, such a shear zone with copper mineralization accompanied by graphite as the Bushman lineament has not been found by a geological survey on ground.

(2) Chromite Indications

Chromite indications were first discovered, in the form of lumpy chromite ore of fist size, near the point (X7, Y23.7) when a general geological survey was being made along a north – south survey line during the first year survey.

On the occasion of geochemical sampling in the second year, reconnaissance was made along survey lines of 500 m intervals as a rule; for some of indications a survey was made on a crisscross pattern over a 200 m distance on each line. The finding from such prospecting is as follows:

The chromite indications are located to the north of the Lepashe River and also to the south of an A.A.C. drilling site, as shown in Fig. 11.

The chromite is accompanied by serpentinite and intensively magnetic ultrabasic rock with magnetite. These ultrabasic rocks are presumed to be distributed in the form of small rock bodies in the strata of gneiss and other rocks, judging from the distribution of their floats. The ultrabasic rock with magnetite is intensively magnetic, dark-green rock containing a dark mineral in banded, disseminated and meshy forms. An example of its analysis result (S–39) is 12.9% of T. Fe and 9.8% of Cr_2O_3.

In an area to the north of the Lepashe River, as indicated in Fig. 14, small outcrops and floats of ultrabasic rock are scattered in an extent of 3 km by 3 km, and at several places outcrops and boulders of chromite are found. Except for the points of ($X_{5.4}$, Y_{24}) (X_5, $Y_{25.3}$) and (X_4, Y_{24}) among them, only black lumpy ore and ultrabasic rock are found in all of the scatterings. Around the points of (X_5, $Y_{25.3}$) and (X_4, Y_{24}), two or three pieces of black lumpy ore, each 30 to 50 cm in size, are found as boulders together with ultrabasic rocks.

The mineral indication groups near point ($X_{5.4}$, Y_{24}), which are divided into indications A, B, C and D, are on a completely flat land, as shown in Figs. 15, 16.

They were formed accompanying ultrabasic rock borne by gneiss.

Indication A is formed of small outcrops of lumpy chromite scattered over an 1.5 m square area. An outcrop of magnetite-containing ultrabasic rock is found nearby.

Indications B, C and D are groups of mineral indications found intermittently in a N35°E direction.

Indication B is formed of boulders of black lumpy chromite ore and a small quantity of ultrabasic rock which are scattered in an extent of 10 m by 30 m area. At the southern extremity of this indication area there is a small outcrop of chromite and ultrabasic rock in a 1 x 1 m area approximately. The prospecting of the southwestern extension of Indication B has not been made adequately.

Indication C is of the same size and about the same character as Indication B, but a positive outcrop is not seen there and it has a smaller quantity of boulders of ultrabasic rock.

There scarcely are boulders between Indications B and C. Boulders of granitic gneiss are found in these indications.

Indication D is located 30 m to the northeast of Indication C. Between C and D there is an outcrop of ultrabasic rock with N–S trend cracks. No chromite is recognized over an about 80 m distance of the northeast extension of Indication D. Indication D is formed of a group of black lumpy chromite boulders scattered in an extent of about 10 m diameter.

All of the above-mentioned chromite is hard, black lumpy chromite with scarcely any mixture as far as observed by the naked eye. As the result of microscopic observation, it was all found to be mainly composed of chromite grains about 0.2 to 0.4 mm in size, and the space between them is filled up with serpentine to chlorite and talc. The chromite grains are almost impervious to light. According to X-ray fluorescence analysis of the chromite (S–34), Cr, Fe, Mn and traces of Ti, Vi, Ni, Co, Cu and Zn have been detected.

The grade of ore from Indications B, C and D is, as shown in Fig. 15: 34 to 36 % of Cr_2O_3, 18 to 19 % of T.Fe, 9 to 11 % of SiO_2, 12 to 13 % of Al_2O_3, 14% of MgO, the ratio of Cr to Fe is 1.2 to 1.4.

In addition to these outcrops, as the result of the third year surveys, relatively sizable quantities of chromite outcrops were confirmed in a southwest port ($X_{4.66}$, $Y_{23.31}$) of the survey area. These are of a lenticular, small ore body of chromite interposing between ultrabasic rock, distributed broadly in a 100 m by 30 m area. They have been divided into two, Indications E and F, according to their distribution (Fig. 17).

Indication E is in a train but divided into two ore bodies: one being 0.5 m wide and 3 m long and the other 0.5 m wide and 6 m long. They have a strike of N60°E and a dip of 85°N.

Indication F, located about 3 m north of Indication E, is distributed on a scale of 1 m in width and 10 m in length, showing a strike of N60°E and a dip of 50°N.

Both of these indications have a part with intensive magnetism on the hanging wall side.

About 50 m west of Indication F too, a small outcrop of intensively magnetic chromite is seen on a scale of 0.3 m in width and 3 m in length.

Beside the above-mentioned, chromite indications are found, as small floats, sparsely at a few places in the survey area, but there is none of mentionable size.

It is said that chromite occurs also in bedded serpentinite in the Lepasche area, outside of the survey area, which is 10 km southwest of these chromite indications (Bennett, 1970).

Although it is difficult to find the size of chromite ore bodies and their relations with geological structure only from the distribution of chromite on the surface, the conditions of occurrence of these ore bodies have been presumed as follows by additionally taking into consideration the results of the trenching and drilling which are mentioned later.

As a result of trenching, it was found that the extent of 1 to 1.5 m depth from the surface is the top layer formed of sand, gravel and soil. Since chromite is distributed in a scattered form as boulders from the top of an ore body, what looks like a chromite outcrop often turns out to be gravel in the top layer. Accordingly, the real scale of ore bodies is by far small as compared with the distribution on the surface.

The size of the ore bodies is estimated to be 0.5 to 1 m in thickness and 5 to 10 m in length. Ore bodies as seen in the trenches of T–3 and T–4 in Indication B present a comparatively clear strike and dip, and GSJ–2 aiming at their lower extension reached four layer of ore bodies. They are, however, considered to be individual ore bodies in view of their depth.

These chromite ore bodies have no definite orientation. They have been controlled by the local structure of the country rock, ultrabasic rocks, to be oriented in various directions, and also their shapes are inferred to be lenticular or pod-like. This means that the survey allowed the team to grasp only part of the total ore bodies, and it is presumed that other similar bodies may occur.

On the other hand, as for the country rock, ultrabasic rocks, its small bodies are interposed between gneiss or schist, but there are only few outcrops of them, and their shape, structure, and other features are unclear. Out of such outcrops, it is in the deposit areas of A to D and also E and F that sizable outcrops can be seen, and only little of small outcrops and floats are found in the other parts. As for their extent of their distribution area, they are scattered in a NE–SW direction on the whole, and the individual outcrops are also distributed often in a manner of extending in the same direction.

As found by GSJ–1 and 2, gneiss is seen in their lower parts. Judging from the distribution of gneiss on the surface, its floats with ultrabasic rock dip east. Accordingly, from a broad point of view, it is presumed that ultrabasic rocks are interposed between gneiss in a NE–SW trend and that chromite ore bodies also are concordant with this trend.

Fig. 14 Distribution map of chromite showings

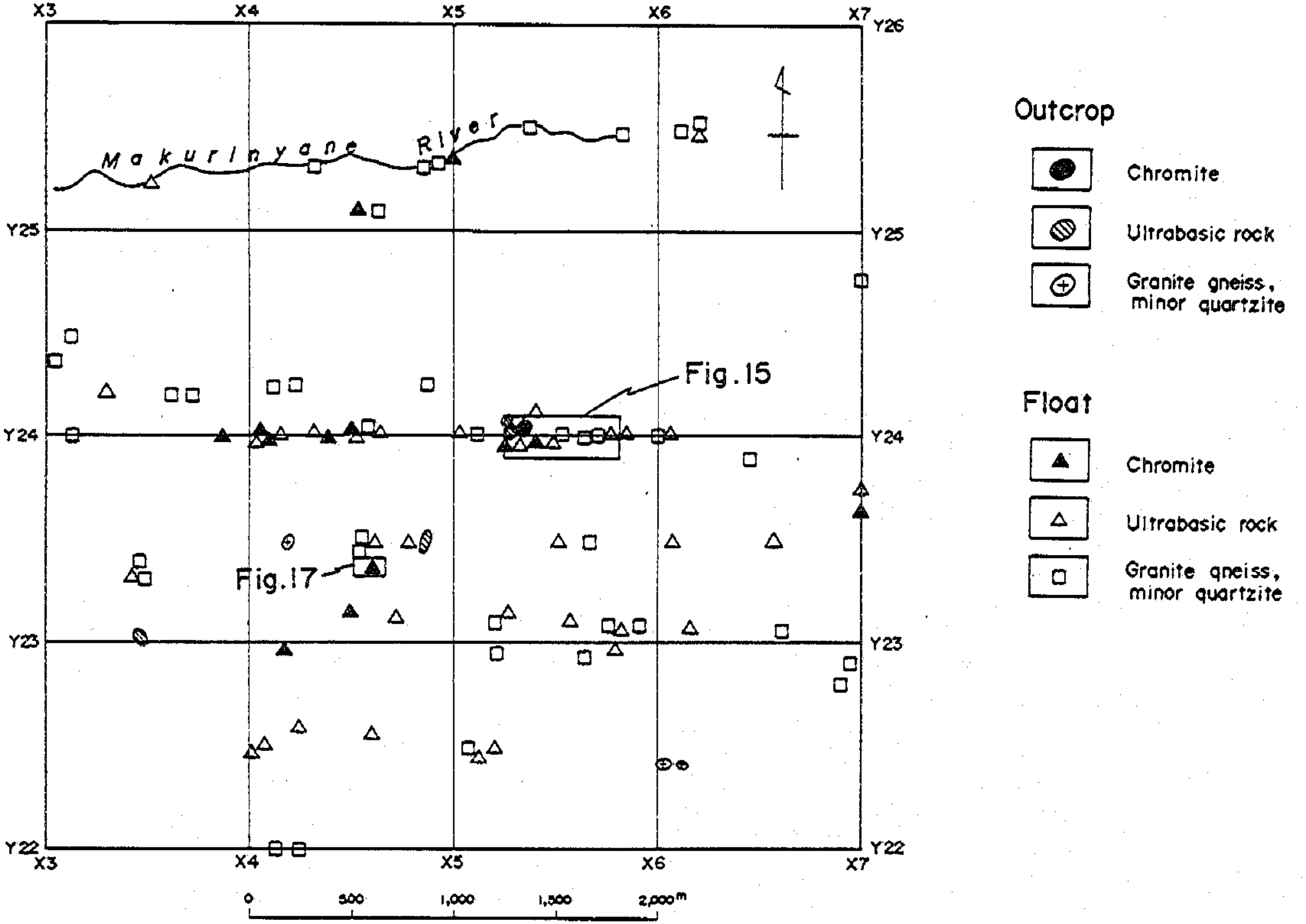
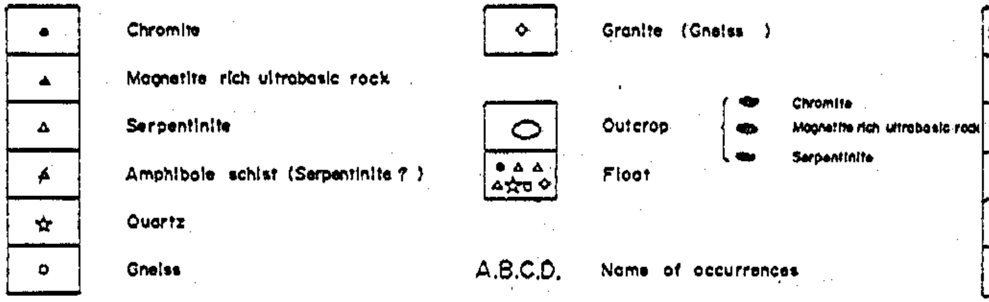


Fig. 15 Main chromite occurrences



Sample No	Width[m]	Cr_2O_3 %	T.Fe %	SiO_2	Al_2O_3	MgO	Cr/Fe	note
S-32	1.0	35.6	17.9	9.4	13.4	13.9	1.4	D
S-33	1.0	34.6	18.4				1.3	C
S-34	1.0	33.6	18.4	10.8	11.6	13.8	1.3	B
S-35	1.5	33.7	19.2				1.2	A Outcrop
average		34.4	18.5	10.1	12.5	13.9	1.3	

Geochemical analysis (No.96)

ppm			note
Cu	Pb	Zn	
60	7	52	brown grey soil

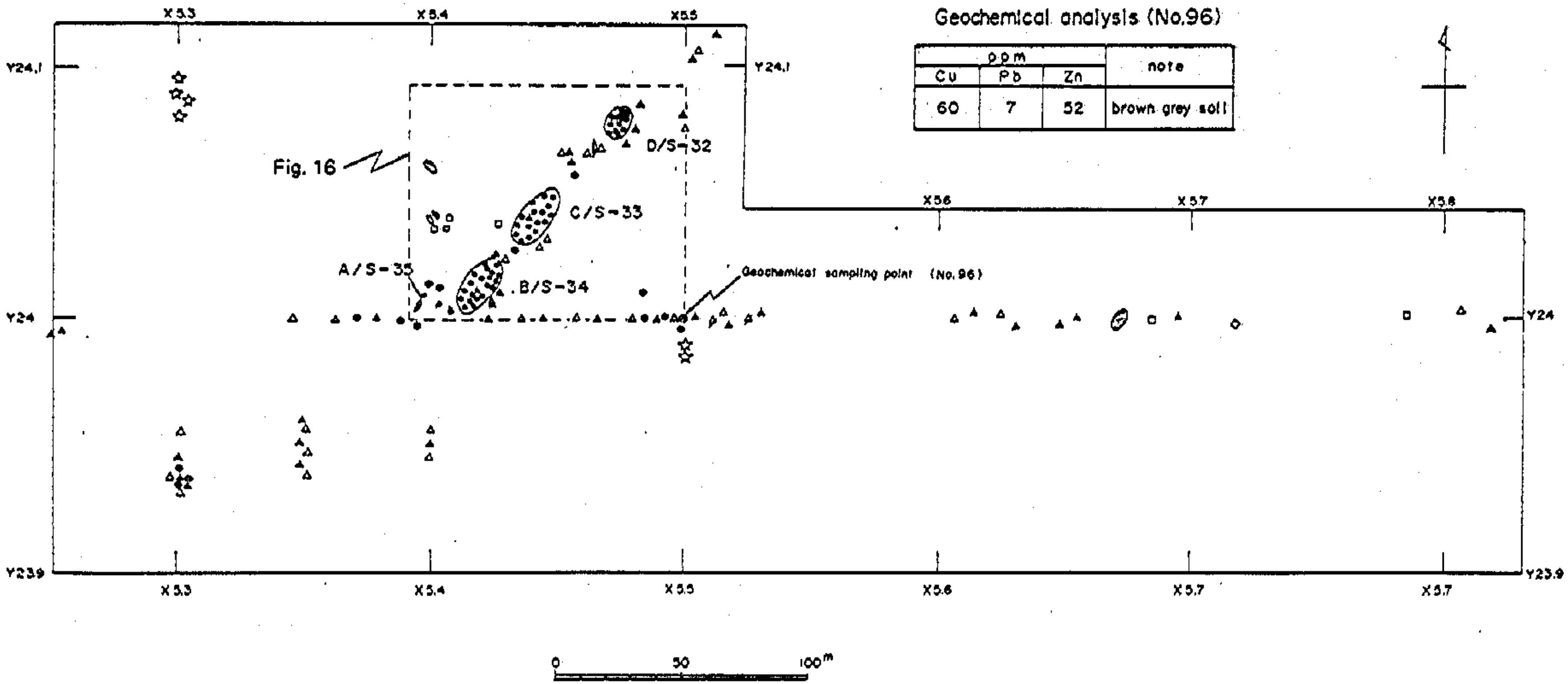


Fig. 16 Occurrence of chromite deposits (A,B,C,D)

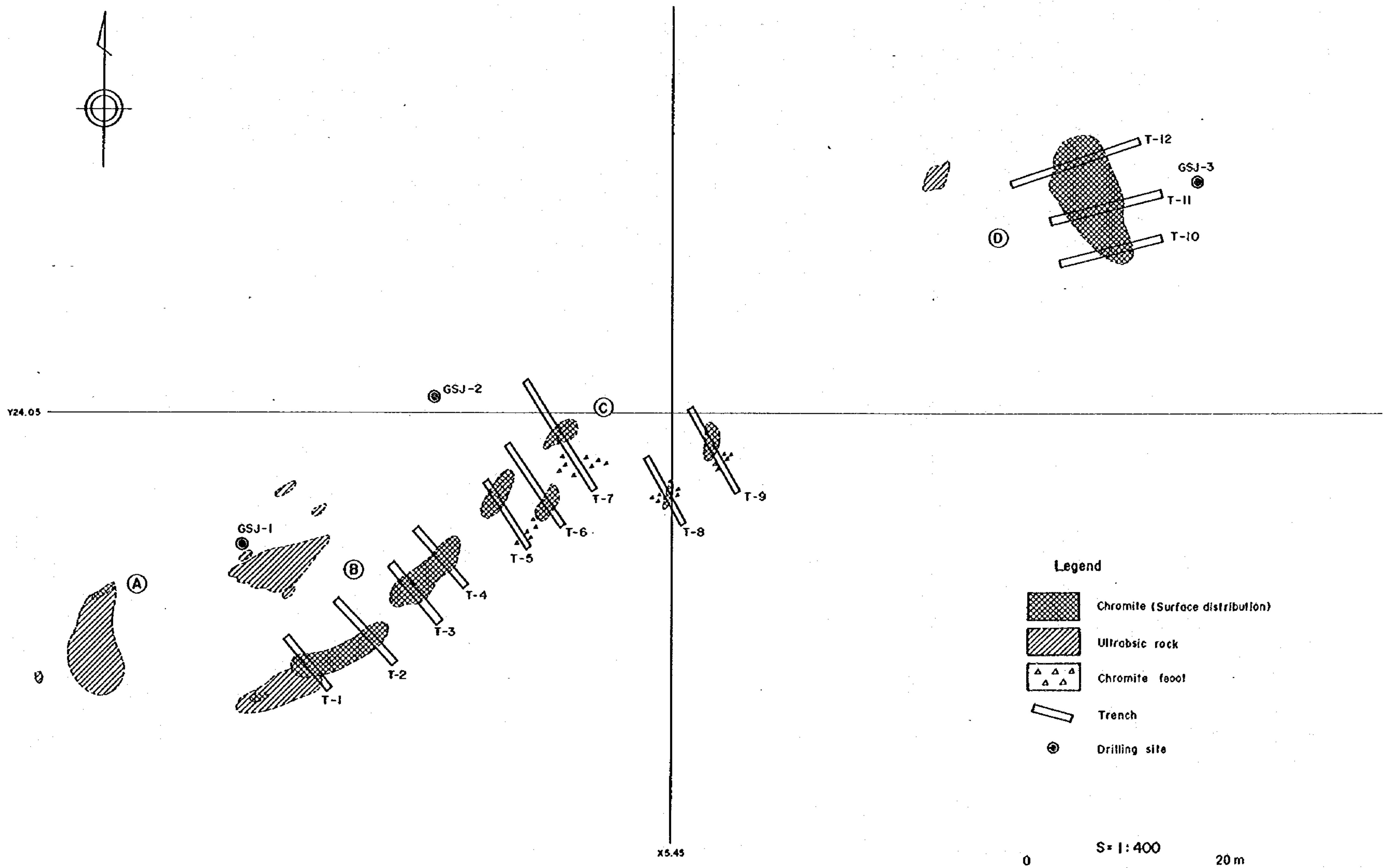
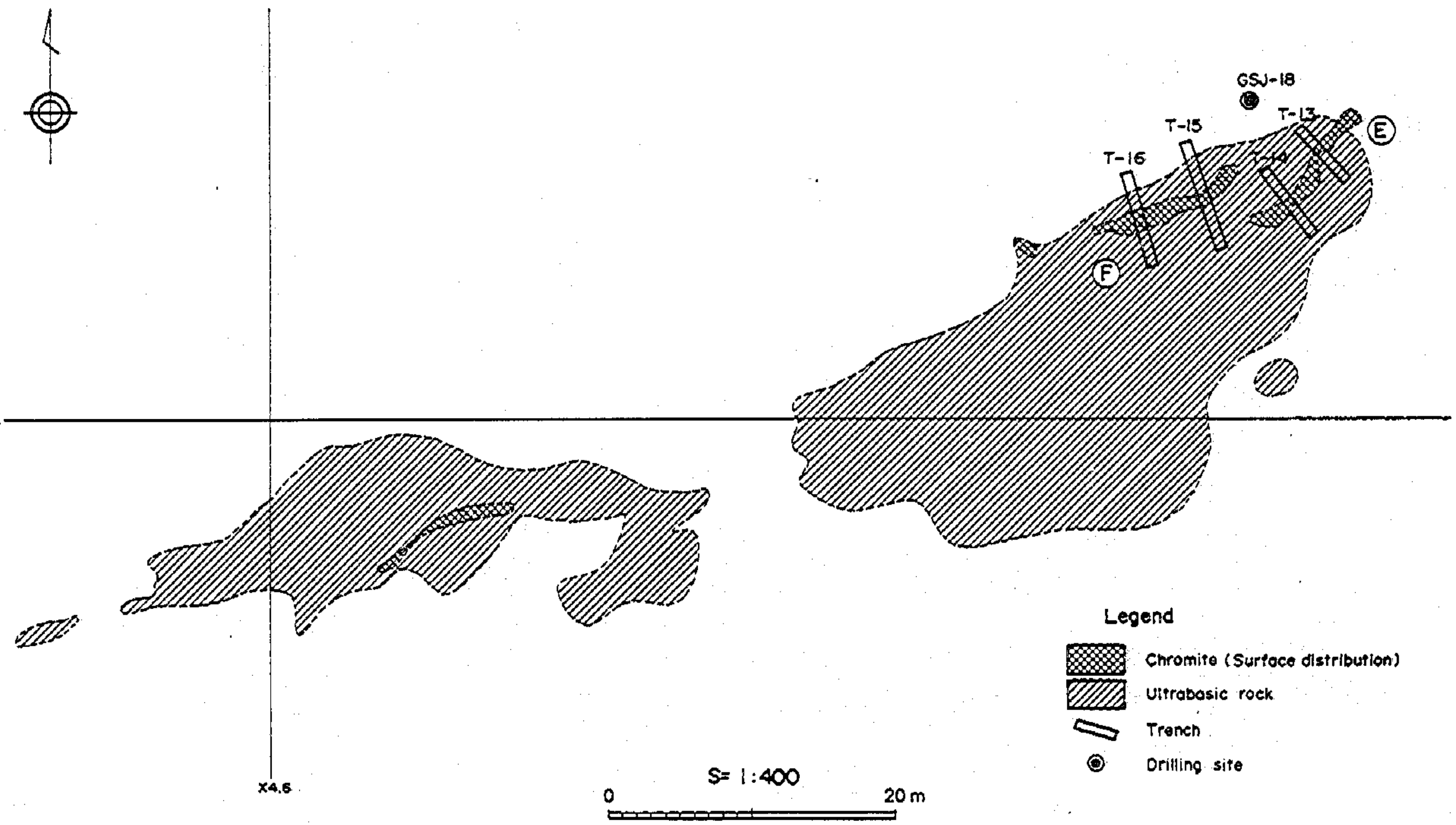


Fig. 17 Occurrence of chromite deposits (E,F)



Chapter IV. SURVEYS IN THE FIRST YEAR

4-1 Methods of Surveys

4-1-1 Analysis of LANDSAT Data

Various analytical methods were applied centering on digital processing of LANDSAT CCTs.

(1) Data Used

The analyzed area was included in two scenes. The CCTs used were as follows:

I.D. No. E2209-07275	shot on August 19, 1975
I.D. No. E2209-07281	ditto

The scope covered by these CCTs and the survey area are shown in Fig. 18.

(2) Method

As shown in Fig. 18, the LANDSAT CCTs containing the Analised area extend over two scenes. The two CCTs were therefore connected to produce a one-scene CCT that centers on the survey area. The produced one-scene CCT was used for analysis.

Images by digital processing of CCTs are much clearer than those by photographic processing. Besides, digital processing makes various analysis possible. We, therefore, used this processing method.

The analytical procedure was based on the metal Mining Agency's report on investigation for development of technology for mineral resource exploration (Development of analytical techniques for remote sensing information). Images obtained through digital processing were displayed on IMAGE 100 and while watching the displayed images we decided the processing method. Image processing was carried out for the following procedures:

Fig. 18 Index map of LANDSAT images

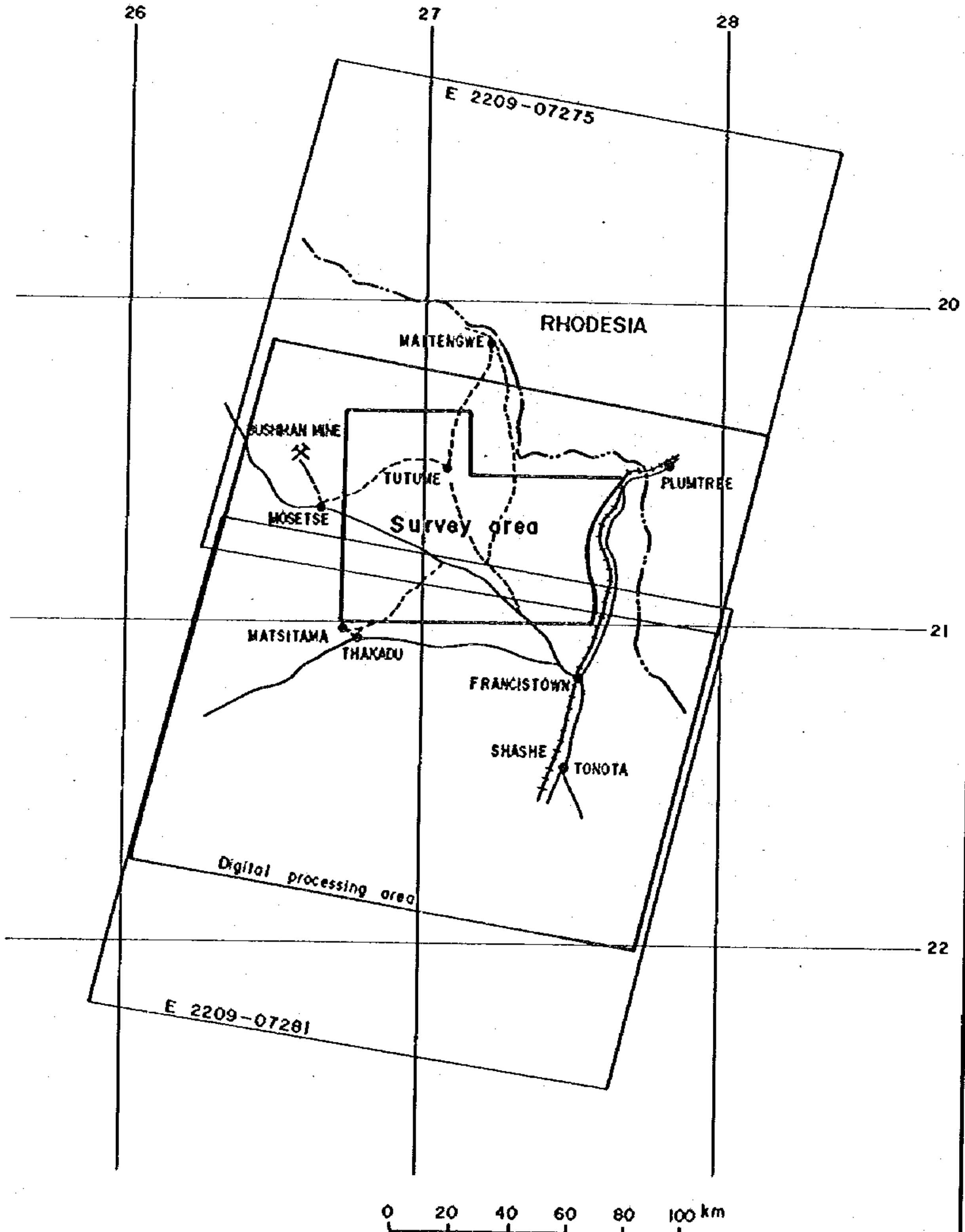
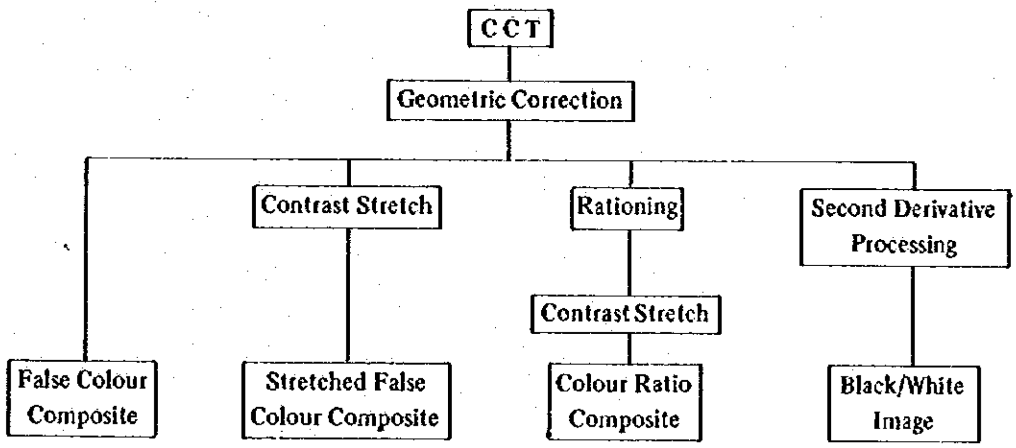


Fig. 19 Flow chart of digital processing



With regard to digital data recorded on LANDSAT CCT, the processing described below was applied.

(1) Geometric Correction

LANDSAT digital data shown on an ordinary image display will be heavily distorted. This is because LANDSAT image data have geometric distortion due to the movement of the satellite and the mechanism of the scanner.

Geometric correction eliminates this distortion so that the produced image will be geometrically similar to a given topographic map. The correction will make it possible to overlay the image upon such other data as topographic or geological maps.

Geometric correction is made as follows: Determine which points on the image correspond to which points on an ordinary topographic map, then obtain the coordinates of pixels. Make sure that the points on the image are distributed evenly, so that the condition of distortion will be known. On the basis of that condition, rearrange all the pixels. The image will then agree with the topographic map.

(2) Contrast Stretch

When digital data are to be converted to images by means of an image display or film recorder, contrast must be adjusted. Data to be input to these devices usually have brightness values ranging from 0 to 255. But brightness values of actual digital data are distributed over part of this range. When such data are input, the image output on the display will have a poor contrast. By stretching the brightness values over the effective range of form 0 to 255, images with sharp contrast can be obtained. This operation to enhance contrast is known as contrast stretch. In our present analysis, we used the linear stretch method in which a linear equation is employed to stretch the brightness values over the entire enhancement range.

(3) Rationing

Ratioing is used as a means of compensating for any change in apparent brightness or color that may be caused by changes in sun illumination angle due to undulations on the ground surface.

LANDSAT image data are represented by the quantities of light entering the multispectral scanner. The main component of the incident light is reflected light from ground objects illuminated by the sun. The intensity of reflected light is equal to the product of reflexibility of the surface of an object and intensity of light illuminating a unit area of the surface. The intensity of light reflected from the same object is largest when the sun shines perpendicularly on the surface of the object, diminishes as the illumination angle decreases, and becomes zero as the object enters the shade. The intensity ratio of reflected light of different spectral bands is proportional to the ratio of band-to-band average reflexibility of the object irrespective of the angle of sun illumination. This means that objects of the same kind share the same characteristics and that different objects can be distinguished more easily.

(4) Second Derivative Processing

In LANDSAT data, various lineaments stand out, providing direct and indirect clues to earth crust conditions. Some lineaments are clearly visible, but others need enhancement.

Different methods are available for enhancement. We used second derivative processing by Laplace operation (without smoothing), a method developed by Prof. Yoshinori Ishii at Tokyo University. The Laplace operators used are as follows:

	X		X	
X	□	Δ	□	X
	Δ	O	Δ	
X	□	Δ	□	X
	X		X	

O	:	1.4332
Δ	:	0.7972
□	:	0.1602
X	:	-0.6578

4-1-2 Geological Survey

Judging from the nature of the survey that a flat and semi-desert-like survey area of 5,300 km^2 with very little outcrop should be narrowed down to a promising area of about 700 km^2 for occurrence of mineral deposits as the object of surveys for the second and subsequent years, the limited length of time and number of team members for the surveys, the method of the survey work depending mainly on geochemical survey on a grid pattern over the whole area and relying secondarily on geological survey was adopted. Consequently, for geological survey, a geological reconnaissance over the whole area along survey lines for geochemical survey (1 : 100,000) and a general survey of the Vumba area, which is a part of the survey area, were made. So the way of survey was that the result of these works were synthesized with the compiling of existing data, the analysis of LANDSAT data, and the interpretation of photogeology. Thus the regular way of geological survey in which all the rivers and streams within the whole area are explored was not taken.

4-1-3 Survey of Mineral Deposits

In the survey area, three promising areas for mineralization had been known: the Vumba area where gold deposits and nickel-bearing copper sulphide deposits were hoped, the Timbale area offering the hope of occurrence of copper/molybdenum deposits accompanied by rare element minerals in relation with pegmatite, and the northern Matsitama area where meta-sedimentary copper deposits were hoped.

In this survey, it was decided that potentials were to be studied from material of the survey area that had been collected in advance from among data made open by the Geological Survey Department of the Republic of Botswana and that the emphasis of exploration was to be placed on the Vumba – Timbale area for the first year, and the following surveys were carried out.

- o Survey of deposits along survey lines for regional geochemical survey over the whole area.
- o Survey of outcrops over the Vumba mineralization zone
- o For the Timbale mineralization zone, survey of outcrops and survey of heavy minerals through panning of drift sand
- o For the northern Matsitama area, survey of outcrops, and survey of outcrops of Thakadu ore body in Matsitama mine, which is outside of the south of the survey area, to know the conditions of a typical ore body for the sake of comparison.

4-1-4 Geochemical Survey

Geochemical survey was conducted over the whole survey area on soil for the five elements of copper, nickel, lead, zinc and molybdenum (also for cobalt in some part).

A total of 512 samples were collected from points of two kinds of rectangular grid patterns: with survey line intervals of 6 km and sampling point spacing of 2.5 km in the regional survey area, and with survey line intervals of 2 km and sampling point spacing of 2.5 km in the sub-regional survey area, the sampling depth being 30 cm. In addition, 27 samples were taken from Matsitama deposit as standard ones of a mineralization zone. All the samples were taken from under a 80 mesh sieve on the site, and after air-drying they were analyzed in Japan. The analysis was made by the atomic absorption spectroscopy method.

In the analytical research, we studied various items of related information recorded when the samples were taken, such as tones of color and grain size of the soil samples, whether organic matters existed or not, extent of dryness, vegetation, topography, kind of gravel, whether exposed rock existed or not, and mutual relation between the kind of the rock and the indicative elements.

As it was found that the contents of Cu, Pb, Zn and Ni were high in basic to ultra-basic rocks and also high values of them were indicated in red-reddish soil and in part of black soil, it was judged difficult to find mineralization anomalies by the method of analysis with a