REPUBLIC OF BOTSWANA

REPORT ON GEOLOGICAL SURVEY
OF
THE NORTHEAST AREA, NORTHEASTERN BOTSWANA

PHASE V

GEOLOGICAL SURVEY

[illegible]

FEBRUARY [illegible]

METAL MINING AGENCY OF JAPAN
JAPAN INTERNATIONAL COOPERATION AGENCY
GOVERNMENT OF JAPAN

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REPORT ON GEOLOGICAL SURVEY OF THE NORTHEAST AREA, NORTHEASTERN BOTSWANA

PHASE I

GEOLOGICAL SURVEY
GEOCHEMICAL SURVEY

FEBRUARY 1980

METAL MINING AGENCY OF JAPAN
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PREFACE

The Government of Japan, in response to a request of the Government of the Republic of Botswana, has decided to conduct a geological survey for mineral exploration in an area straddling the North-East District and Central District of Botswana and has commissioned the work to the Japan International Cooperation Agency.

In consideration of the technical nature of the survey project, the Japan International Cooperation Agency, in its turn, has assigned the Metal Mining Agency of Japan to carry out the project, setting a target period of three years (1979 – 1981).

The survey plan was to be implemented in three stages: in the first stage a reconnaissance survey was to be conducted of the whole area (5,300 km²), in the second stage a semi-detailed survey was to be made of the more promising areas to be selected out of the whole survey area; and in the third stage a detailed survey of the most promising area was scheduled.

Between July 6, 1979 and September 9, 1979 the Metal Mining Agency of Japan dispatched a survey team consisting of five geologists in order to make a geological survey and a geochemical survey. During their stay, they would carry out the task in collaboration with the Geological Survey Department, Ministry of Mineral Resources and Water Affairs, Republic of Botswana and with the Embassy of Japan in Zambia.

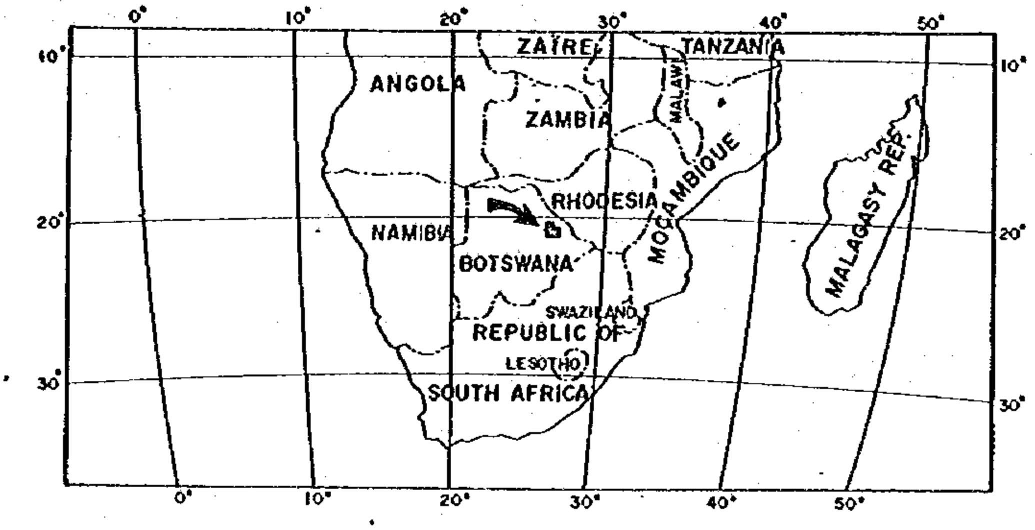
This report summarizes the results of the first stage survey (LANDSAT data analysis, geological survey, and geochemical survey). Simplified contents of this report will be included in the final report to be prepared in the third year upon completion of the third stage.

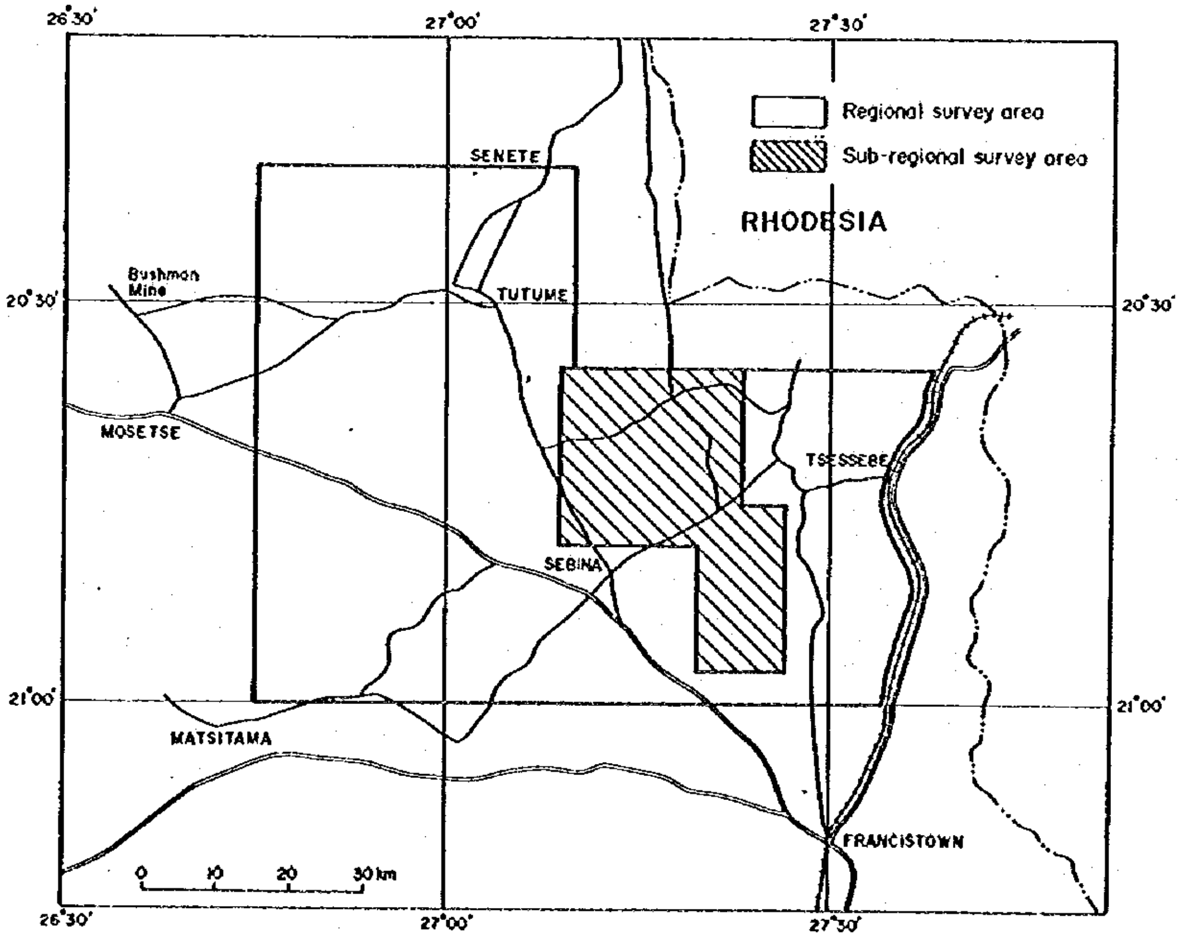
We wish to express our heartfelt gratitude to the competent authorities of the Government of the Republic of Botswana, including the Geological Survey Department, for the kind cooperation and support they extended to the Japanese survey team.

Keisuke Arita
President
Japan International Cooperation Agency

Masayuki Nishiie
President
Metal Mining Agency of Japan

Fig. 1 Location map of the survey area.





ABSTRACT

The surveys for the first year, conducted over an total area of 5,300 square kilometers in the northeastern part of the Republic of Botswana in cooperation with the Geological Survey Department, Republic of Botswana, consist of a geological survey and a geochemical survey.

The purpose of the first year survey was to clarify the geological structure of the survey area and was identify promising area within the survey area as targets for detailed surveys in the following years.

For this purpose, LANDSAT data analysis, photogeological interpretation, regional geological and geochemical surveys in the whole area and sub-regional geological and geochemical surveys in the selected area were carried out respectively.

The results of these surveys and studies are summarized as follows:

1. Analysis of LANDSAT data

Various analytic techniques were applied, centering about digital analysis of LANDSAT CCT. As the results, the geological units of intrusive granite, ultramafic rock, basic rock, etc. within the survey area were distinguished by the differences in color tones.

From the trends of instrusive rock and the lineation shown in the drainage system patterns, the three major structural systems of NW-SE, NNW-SSE, and NE-SW were picked up. Also, as a regional structure including such surrounding areas as Maitengwe, Matsitama, Francistown, etc., a semicircular structure opening to the east in a manner of surrounding Vumba Schist Relic was identified.

2. Geological Survey

The geological survey was carried out, in parallel with the geochemical sampling work, along the geochemical survey lines, but only the general features of the geology were obtained because detailed tracing of strata and so forth were not made. Accordingly, concerning geology and geological structure, we followed the views of Litherland (1975) and Benett (1970)

basically. However, after conducting age determination of granitic rock by K-Ar method and rock tests, and making comprehensive studies taking in the results of the analysis of LANDSAT data, interpretation of the air photographs, etc., we have had different opinions with the views expressed in the past, about stratigraphic correlation and the age of intrusion of the intrusive rock, which have remained as problems. Further consideration is necessary.

3. Mineral Deposits

As the results of the geological survey, the three mineralised zones of Vumba, Timbale, and North of Matsitama were found in the survey area. In the North of Matsitama, the possibility has been found that Matsitama schist and Metasedimentary Group bearing syngenetic copper deposits may extend into the survey area. As the results of the geochemical survey also have revealed similar indications, it has been judged that further exploratory works are suggested.

4. Geochemical Survey

The geochemical survey conducted over the whole survey area was on soil for the five elements of copper, nickel, lead, zinc, and molybdenum.

A total of 512 samples were collected from grid patterns with the survey line intervals of 6 km and the sampling point spacing of 2.5 km in the regional survey area and with the survey line intervals of 2 km and the sampling point intervals of 2.5 km in the sub-regional area; in addition, 27 samples were collected from Matsitama copper deposit as samples for comparison with unknown mineralied area. The analysis was started with the study of the relations between the environment of the sampling points and the indicative elements in addition to the characters of the samples. As the result, it was found that the color tones of the soil, which are considered to be most reflecting the chemical composition of the country rocks, corresponded generally to the geological units and vegetation. Also discovered were the fact that the content of elements varied according to the differences in geological units and the color tones of soil. However, the differences were not so large as to allow discrimination of geology according to the differences in the color tones of soil and in element contents. In addition, in geochemical anomalies extracted from the distribution of the elements, those brought about by rock overlapped with those bringing from mineralisation, and the distinction between the two was considered difficult. Among the indicative elements, molybdenum content was almost entirely found not more than 3 ppm as the result of chemical analysis and was decided as inappropriate as an indicative one. Extraction of mineralisation anomalies by analysis for each element was found difficult, so that analysis by the method of principal component analysis which seeks comprehensive characteristics of some elements was made.

First, the characteristics of the principal components of Matsitama deposit, i.e., a known copper mineralized area, were obtained, and then samples with similar characters were sought in the survey area. As the result, 10 anomalous areas were extracted. Among them the anomalous area in the southwest corner of the survey area was found most high in the degree of anomaly and extensive, and a more detailed survey has been justified.

On the basis of the above-mentioned results integrated, the North of Matsitama area covering an area of about 800 km^2 has been selected as the survey area for the second year.

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GENERAL INFORMATION

1. Introduction

1-1 Purpose of Survey

The basic purpose of the first phase survey of this project was to identify promising areas within the project area as targets for detailed surveying in the following year.

For this purpose, LANDSAT data analysis, photogeological interpretation, regional geological and geochemical surveys in the whole area and sub-regional geological and geochemical surveys in the selected area were carried out respectively as the first phase survey in accordance with the survey schedule described in the SCOPE of WORK agreed upon between the Japanese mission for cooperative mineral exploration in Botswana and the Ministry of Mineral Resources and Water Affairs, the Republic of Botswana.

1-2 Location of the Project Area

The project area, covering about 5,300 square kilometers, straddles the North-East District and Central District of Botswana near the Rhodesian border and is bounded by the lines connecting the 6 coordinates written below.

Northwestern Limit	S. Lat 20°20′ and E. Long 26°45′
Northwestern Limit	S. Lat 20°20′ and E. Long 27°10′
Central Limit	S. Lat 20°20′ and E. Long 27°10′
Central Eastern Limit	S. Lat 20°35′ and E. Long 27°39′
Southeastern Limit	S. Lat 21°00′ and E. Long 27°36′
Southwestern Limit	S. Lat 21°00′ and E. Long 26°45′

The sub-regional survey area was set in an area of about 700 square kilometers centering on Vumba in the above project area.

Refer Fig. 1.

1-3 Topographic Maps

At the time of this survey, the following topographic maps were available.

(1) Topographic map (on the scale of 1:250,000) of the whole project area.

(2) Topographic maps (on the scale of 1:125,000) of the whole project area.

(3) Topographic contour maps (on the scale of 1:50,000) of the whole project area.

Topographic maps enlarged to scale of 1:25,000 and 1:10,000 from original 1:50,000 maps prepared by the project team were used for sub-regional surveys.

In addition, LANDSAT image data and aerial photographs to a scale of about 1:50,000 and 1:40,000 were used supplementally.

1-4 Published Geological Maps

Geological maps which cover the whole country - viz., a map of the Geology of Botswana, 1973 to a scale of 1:1,000,000 and a map of the tectono-metamorphic complex of eastern Botswana, 1971 to a scale of 1:500,000 – were published by the Botswana Government.

Detailed geological maps which cover the southeastern part of the project area are also available.

These area: "Sebina-Tshesebe" "Maitengwe" and "Mosetse-Matsitama" to a scale of 1:125,000 published by the Geological Survey Department of Botswana.

1-5 Periods of Surveys

Periods of the surveys are shown in Table 1.

Table 1. Periods of Surveys

Kind of Survey	Number of Geologists	Term
LANDSAT data Analysis	3 Japanese Geologists	June – December 1979
Photogeological Interpretation	1 Japanese Geologist	June – December 1979
Geological and Geochemical Survey	5 Japanese Geologists 1 Botswana Geologist 2 Botswana Field Assistants	July – September 1979

1-6 Survey Work and Laboratory Work

Types and amounts of the survey and laboratory investigations are summarised in Tables 2 and 3.

Table 2. Summary of Field Survey Work

Type of Survey	Area (km^2)	Map Scale
Regional Geological and Geochemical Survey	5,300	1 : 100,000
Sub-Regional Geological and Geochemical Survey	700	1 : 25,000

Table 3. Summary of Laboratory Work

Type of Laboratory Investigation	Number of Samples	Place
Chemical Analysis of Geochemical Samples	539	Japan
Chemical Analysis of Ore Samples	8	Japan
Chemical Analysis of Rock Samples	7	Japan
Microscopic Observation of Thin Sections	107	Japan
Microscopic Observation of Polished Sections	5	Japan
K-Ar Age Determination	5	U.S.A.
X-Ray Diffractive Analysis	5	Japan
X-Ray Fluoressence Analysis	4	Japan

1-7 Progress of Work

LANDSAT data analysis and photogeological interpretation were commenced in the middle of June 1979, in Japan.

During the geological and geochemical survey from July to September 1979, one Japanese geologist checked the ground truth in the training areas.

LANDSAT data calculations by computer for analysis by IMAGE-100 were commenced in mid-August 1979 in Japan in collaboration with the staff of the Remote Sensing Centre, under the guidance of Prof. Y. Ishii at the University of Tokyo. Digital analysis included geometric correction, contrast stretch, rationing and second derivative processing. Results of the digital analysis were used for the compilation of the geological map together with the results of photogeological interpretation.

In accordance with the schedule, one geologist was dispatched to Botswana preliminarily to finalise the survey schedule and prepare for the field survey.

Vehicles, camping equipment and other materials for field work had been procured mainly in Gaborone, and transferred by vehicle to the campsite via Francistown. The regional geological and geochemical survey for the whole area was carried out from mid-July to mid-August, and the sub-regional geological and geochemical survey in the selected block was completed at the end of August.

During the field survey, all camp supplies were sent by vehicle from Francistown to the campsite about 65 km. Water also was carried about 30 km from the water tanks at Sebina as occasion demanded. In a normal year the district's dry season extends from April to October, but in 1979 there was rain and thunderstorm toward the end of August.

1-8 Members

Members engaged in the project are listed as following.

List of Members

Botswana Counterparts		Japanese Counterparts	
C.R. Jones	Director, Geological Survey Department, Botswana	Takashi Nakagawa	Ministry of International Trade and Industry
R.D. Walshaw	Deputy Director, Geological Survey Department	Setsuo Takemoto	Japan International Cooperation Agency
G.C. Clark	Assistant Director, Geological Survey Department	Kyuzo Tadokoro	Metal Mining Agency of Japan
D. Gould	Senior Geologist, Geological Survey Department	Toshio Sakasegawa	Metal Mining Agency of Japan
T.P. Machacha	Geologist, Geological Survey Department	Minoru Fujita	Metal Mining Agency of Japan

(List of Members cont'd)

Botswana Counterparts		Japanese Counterparts	
D. Motlhoki	Field Assistant, Geological Survey Department	Kenji Sawada	Metal Mining Agency of Japan
M. Sixpence	Field Assistant, Geological Survey Department	Yutaka Hatano	Metal Mining Agency of Japan
		Mituru Suemori	Japan International Cooperation Agency
		Tamotsu Nakajima	Metal Mining Agency of Japan
		Iwao Uchimura	Metal Mining Agency of Japan
		Takehiro Sakimoto	Metal Mining Agency of Japan
		Akitsura Shibuya	Metal Mining Agency of Japan
		Keiji Nakano	Metal Mining Agency of Japan

The writers are most grateful to Dr. J.C. Brower, Economic Consultant to the Ministry of Mineral and Water Affairs, Government of Botswana, for his kind support and valuable information.

Also we are indebted to Prof. Y. Ishii, at the University of Tokyo, for his guidance in the digital analysis of LANDSAT data.

Dr. Chong Kim, at Jubilee Hospital, Francistown, and his family are also thanked for their kind help in the field campsite.

2. General Information on the Project Area

2-1 Access

Francistown, North-East District, is the only convenient approach to the project area.

The following modes of transport exist between Gaborone and Francistown, the mining centre of Botswana:

(1) Air Route

Gaborone – Francistown (400 km in a straight line) about one and half hours by turbojet, daily flight except Friday.

Francistown-Camp site (65 km) about one hour by car.

(2) Overland Route

Gaborone – Mahalapye – Serule – Francistown (443 km) about 6 hours, by road which is all-weather paved except from Mahalapye to Serule 152 km. The road between Mahalapye and Serule is now in bad condition because of road reconstruction.

(3) Railway Route

Gaborone – Francistown

Passenger train service on a part of the Rhodesian railway is also available from Gaborone to Francistown.

Owing to the high population density, there are many bush tracks in the dense thorn-scrubs besides the major roads. But there are few localities that can be reached by four-wheel drive vehicles because of the narrow tracks and water course hazards. During the rainy season, travel in the project area on these tracks is often interrupted.

2-2 Climate, Vegetation, Population, and Land Use

(1) Climate

The area falls within the tropics and has a semi-arid climate. Mean annual rainfall at Francistown, about 65 km southeast of the campsite, is about 440 mm. Almost all of this falls in the summer months, between October and April. Winters, between May and August, are cold and dry with occasional dust storms.

The maximum annual mean temperature is about 28.4°C and the minimum 13.5°C, but it varies from above 40°C in summer to -10°C in winter.

Winter is the season for field surveying.

(2) Vegetation

Most of the area is classified (Weare and Yalala 1971) as mixed tree savanna: a scrub forest dominated by *Colophospermum mopane* and *Acacia nigrescenes.*

Large tracts of the latter thorn-scrubs grow over areas underlain by Archean schist. Riverine-type vegetation consisting of large trees occurs beside the main watercourses. In the high ground of the watershed, vegetation merge into mopane open-tree savanna, the only occurrence of this vegetation type in Botswana.

Andansonia digitata (Baobao) may be found in this region, Grasses are indigenous but may be overgrazed. Many areas of natural vegetation are lost to cultivation.

(3) Population and Land Use

By local standards the project area is densely populated. It is peopled mainly by the Bakalaka. The complex migratory and political history of the various tribal elements who settled in the northeastern-Botswana is reported. The land system is termed as "land suitable for both cultivation and managed grazing but liable to erosion." Large villages of 500 – 2,000 inhabitants are scattered throughout the area. The local population rear cattle and grow subsistence crops. Cuttle overgrazing is a serious problem. Near the Botswana/Rhodesian border there is a photogeological light/dark demarcation owing to overgrazing on the Botswana side.

Certain areas of the North-East District have been divided into ranches which are owned by people of European or Cape origin. Fences impede geological surveying in these areas.

The area of the Timbale hills is termed "unsuitable for agriculture" with a suggestion that it would be used as a forest reserve.

There is no industry, as opposed to local crafts and brickmaking.

No prospecting activities for mining are in progress in the project area.

Fortified kopjes (rockhill, or knoll) are scattered throughout the area. Generally, these have rough, drystone walls. However, there is at least one example of fashioned stone Zimbabwe-type structure which consists of fortified kopje with an adjacent walled living area in the north central part of the project area near Kalakamate.

This fort, known as the Dombashaba ruins, represents the southeasterly extent of the Zimbabwe-type stone structures.

2-3 Physiography and Drainage System

The project area straddles the watershed between the Limpopo and Kalahari drainage systems. (Fig. 2)

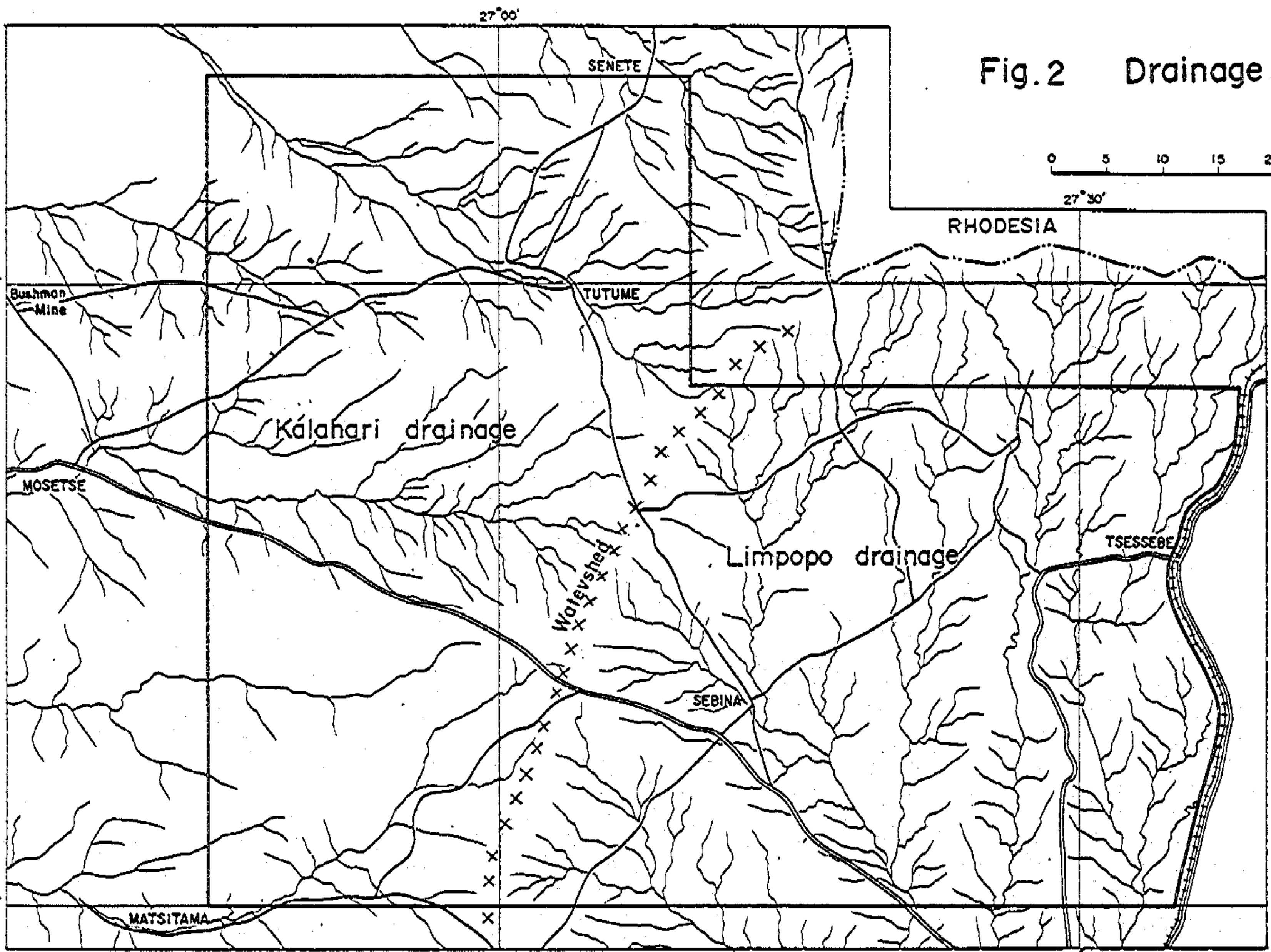
The Kalahari drainage system, developed on the northwestern half of the project area, is directed to the vast Makgadikgadi Pan and there are little slope and poor flows in its ephemeral rivers and streams. Pans are geenrally restricted to this side of the watershed. Poor flows are concentrated in the Tutume, Semonwane, Mosetse, Lepasha and Mosope rivers.

The Limpopo drainage is of steeper gradient and is concentrated in Shashe, Vukwi, Tati and Ntshe rivers which occur from west to east. There is a gentle gradient from south of the area to the watershed in the north with occasional kopjes (rocky hills) which rise about 100 m above the gently undulating plain.

While the elevations of the watershed and Timbale mountain in the Limpopo drainage area range from 1,300 m to 1,200 m, the alluvial peneplane of the Karahari drainage area is about 1,100 m above the sea level.

Rivers are ephemeral and may flow for only one or two weeks a year. There is

Fig. 2 Drainage system.



subsurface flow in the larger watercourses throughout the dry season and this provides the major water supply for the local inhabitants via sand-pits and wells. Over a hundred water boreholes have been drilled in the area (Geological Survey Department's records).

Of these, about a third have produced little or no yeild. Recent work by Houston (1972) at Francistown indicates that Archean basement rocks may be weathered to depths of 37 metres, and it is in this highly decomposed zone that ground water occurs. The variability of this thickness controls yield differences. The more jointed, fissured and weathered the rock, the deeper and richer will be the resulting aquifer.

Jordan (1968) has noted that soils overlying archean schists have a higher permeability and as weathering is often deep, this rock type is probably the most favourable of all Archean formations for groundwater exploitation. It is noticeable that no unsuccessful boreholes have been sunk into the schists of the present area, and as a rule, they are not found in the easily weathered tonalitic rocks.

2-4 Outline of Geology, Ore Deposits and Previous Explorations

The rocks of the area can be initially divided as follows.

(Age)	(Geological Units)
Cenozoic	Kalahari bed
– unconformity –	
Archean	Basement complex

The unconformity represents a time gap of about 2,500 m .y.

The area of Archean basement complex is underlain by metasedimentary rocks, metavolcanic rocks, granitoid rocks with large schist relic and ultramafic associations. These rocks lie in the western part of the Rhodsian Craton – an Archean unit stable since c. 2,600 m. y.

Metasedimentary rocks and metavolcanic rocks are distributed mainly in the central and southwestern parts of the project area. Metasedimentary rocks in the central part can be divided into two groups, the lower and the upper.

The lower group is the Tutume meta-Arkose group which is subdivided into two formations. This is a layered granitoid unit in which belts of amphibolite, granitic gneiss and metaarkose are interstratified. These layers are concordant to those of the Vumba volcanic group.

The upper group is the Vumba volcanic group which is subdivided into six formations. Most of these formations are composed of mafic and felsic volcanic rocks with a small amount of intercalated thin bedded limestone and ultramafic rock. Rock layers in these groups are generally steeply dipping and are discordant to contact with surrounding granitoid rocks. (Litherland, 1975)

Metasedimentary rocks in the southwestern part are referred to as the Matsitama schist belt and can be divided into two groups, the lower and upper.

The lower group is the Mosetse river gneiss which is composed of granitised quartz-feldspar-biotite gneiss with some amount of ultramafic rock and migmatite. This group has undergone regional metamorphism under amphibolite facies conditions. Because of the lack of a key bed, subdivision of the lower formation is difficult. Moreover, some granitic gneisses leave room for doubt as to their being a member of the granitoid rocks.

The upper group is the Matsitama schist and metasedimentary group, which is subdivided into a four formations whose stratigraphic relations remain uncertain. Most of these formations are composed of nongranitic schists and metasedimenary rocks with a small amount of intercalated thinly bedded limestone and have, for the most part, undergone only low-grade regional metamorphism under green schist or low amphibolite facies conditions. Copper is associated with the calcareous host rock in this group.

The stratigraphical relationship between the Matsitama schist belt and the Vumba schist belt is still unclear (J.D. Benett, 1970).

Further consideration is necessary.

The granitoid rocks form the bulk of the Basement complex. Many are gneissic. These can be divided into tonalitic orthogneisses with monzonitic intrusions, granitic paragneisses, tonalitic paragneisses, granites and tonalites.

Episodes of deformation have been recognised, two of which (F-1 and F-2) are regional events producing a penetrative schistosity (S-1 and S-2) and major folds. Interspersed between the phases of deformation are granitic events, two of which (G1 and G4) are essentially plutonic and the remainder (G2 and G3) migmatitic or anatectic. The granitic and deformational events are generally accompanied by a metamorphic phase.

Post-Archean events are confined to the major phase of faulting of the area which is essentially synchronous with the intrusion of late/post-karroo dyke swarms and later by the deposition of the Kalahari Beds (M. Litherland, 1975). The Kalahari Beds and superficial sediments cover mainly the western part of the project area.

Three major metalliferous zones are recognised at Vumba, Timbale and Matsitama North.

Vumba province is an Archean "Gold Belt" and there are various old abandoned gold prospects which were explored or mined by ancients, European prospectors and modern mining companies.

Gold/sulphide mineralization is found in quartzose bands in amphibolite. Mineralized rocks show pyrite, pyrrhotite, arsenopyrite and chalcopyrite disseminated in amphibolitic zones and growing sparsely but in greater masses in the quartz. Somerset mine is the largest and most extensively developed of the site. Old workings extend over 200 m on quartz veins that strike north-northeast. The veins have an average thickness of about 1 m and the vein material assays at about 5 g/t Au. Two of these sites were drilled by the Anglo-American Group without significant results.

Intense geophysical, geological and geochemical surveys including heavy mineral sampling have covered almost the whole of Vumba province as well as the old abandoned gold prospects. Two of geophysical anomolies were discovered by Geoterrex Limited in this area and the sites were drilled by the Anglo-American Group but yielded only light sulpfide mineralization at depth.

The mineralization of Tinbale Province is coincident with Tinbale granite and aureole. The Anglo-American Group's sample concentrates revealed the mineralization of rare elements in the pegmatites dipping towards the central granite and follow-up semi-reconnaissance soil sampling by the same group revealed intense anomalies which are apparently geologically controlled by underlying dolerite intrusion. The following metals are involved: vanadium, nickel, copper, yttrium, niobium, molybdenum, tin, tungsten, gold and lead. Where I.P. surveys showed anomalies, drilling (two-holes) was carried out but no mineralization was intersected.

Matsitama North province is situated on the northwestern margin of the Matsitama basin which is currently believed to represent an ancient somewhat atypical schist belt which probably constitues part of Rhodesian craton. The schist belt comprises a sequence of mafic schists, amphibolites, quartzites, limestones and banded iron stones. All have metamorphic amphibolite facies (Bennett 1968).

The sulfides appear to be spatially associated with calcareous host rock (varying from siliceous limestone to calcareous quartzites) and biotite schists and probably of syngenetic origin. The discovery of ancient copper workings in the Matsitama schist belt by the Anglo-American Group in 1962 was followed by considerable exploration work at the main centre of mineralization in the region, and about 8 million tonnes averaging about 2.2 % Cu including copper oxide were indicated at two principal deposits (Baldock 1977).

Prospecting in the region was suspended in 1968 when the main effort was transferred to the Phikwe sector.

Recent exploration has been directed towards the Bushman lineament, a major zone of cataclastic deformation northwest of the Matsitama basin. Although copper deposits are particularly concentrated in the southwestern part of the Matsitama basin, the northern part is still within the lower portion of the copper horizon in which some copper showings have been found.

DETAILED REMARKS

1. Geological Survey

1-1 Introduction

The survey was conducted for the purpose of selecting, promising areas of about 700 km^2 out of the entire 5,300 m^2 area for detailed survey in the following years. Because of this particular nature of the survey, the limited period of investigation and small staff, and also in consideration of the local topography, it was thought most advisable to adopt the grid method to perform geochemical investigation primarily and geological survey supplementally. Therefore, the geological survey simply summarized existing data in each area, LANDSAT data analysis, geological survey results along the geochemical traverse lines. No regular survey covering all rivers and streams in the area was conducted. As a result, correlation of the two schist belts of Vumba and Matsitama, the most important question in the survey area, had to be relegated to future investigation. After overall evaluation of the results of the geological and geochemical survey, it was decided that northern Matsitama required further investigation in the following year.

1-2 LANDSAT data Analysis

1-2-1 Purpose

The Analysis was carried out for the purpose of providing basic data for exploration of mineral resources in the survey area by interpreting the data acquired from the earth resources observation satellite LANDSAT concerning geological units and geological structures there.

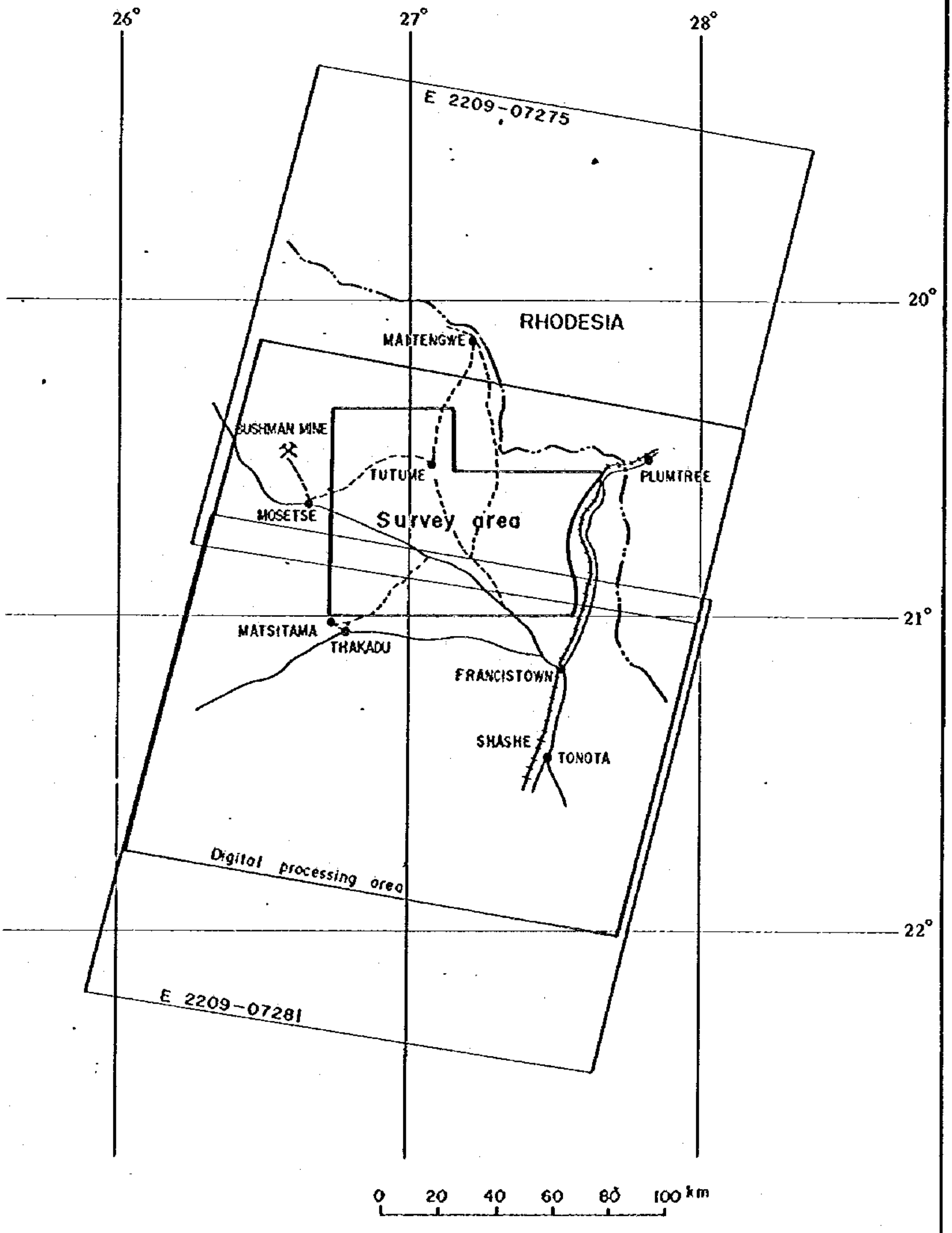
1-2-2 Data Used

The Analised area was included in two scenes. The CCT used were as follows:

I.D. No. E2209-07275

Date:	Aug. 19, 1975
Scene center point:	(S20°80'00", E027°20'00")
Corner point #1	(S19°29'58", E028°24'37")

Fig. 3 Index map of LANDSAT images



Corner point	#2	(S19°14'01", E026°42'19")
	#3	(S20°45'41", E026°14'53")
	#4	(S21°01'50", E027°58'09")

I.D. No. E2209-07281

Date:	Aug. 19, 1975
Scene center point:	(S21°34'00", E026°59'00")

Corner point	#1	(S20°55'59", E028°04'15")
	#2	(S20°39'56", E026°20'59")
	#3	(S22°11'37", E025°53'13")
	#4	(S22°27'55", E027°37'33")

The Analised area and range covered by these CCTs are shown in Fig. 3.

1-2-3 Method

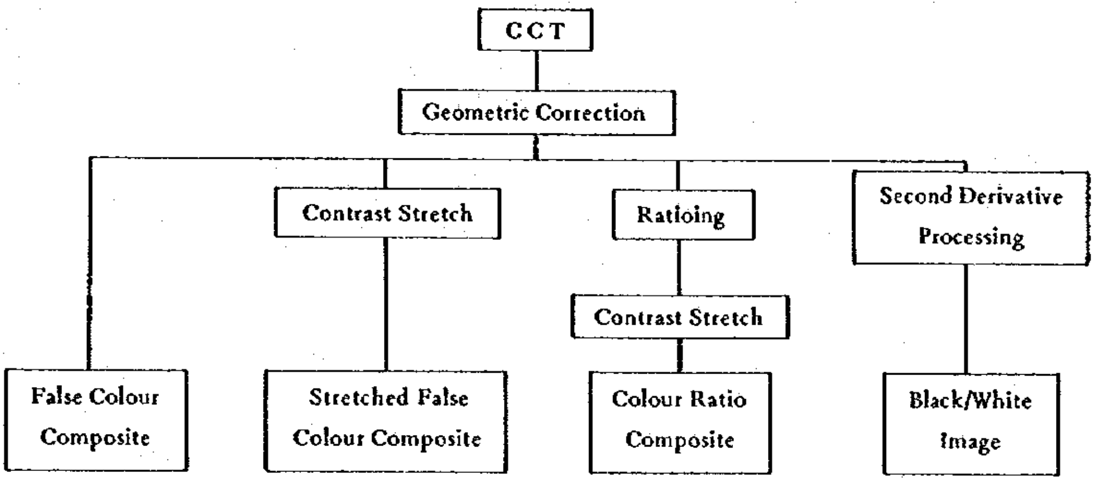
As shown in Fig. 3, the LANDSAT CCTs containing the Analised area extend over two scenes. The two CCTs were therefore connected to produce a one-scene CCT that centers on the survey area. The produced one-scene CCT was used for analysis.

LANDSAT images are originally given as digital data, which are processed at the EROS data center in the U.S. to produce photo images and CCTs (magnetic tapes) for the users.

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. 5):

Fig. 5. Flow Chart of Digital Processing



1-2-4 Digital Analysis Procedure

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

Details of the analytical procedure are described in the report referred to above.

(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 knwon. 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 from 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) Ratioing

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

1-2-5 Analysis

Images obtained from CCT through its digital processing are as follows:

1) Geometrically corrected false color composite image (band 4: blue, band 5: green, band 7: red)

2) Black/white image of each band

3) Contrast stretched false color composite image (band 4: blue, band 5: green, band 7: red)

4) Contrast stretched ratio composite image (band 4 / band 5: blue, band 5 / band 6: green, band 6 / band 7: red)

5) Edge enhanced image

(The scale of the above-mentioned images is 1/400,000 respectively.)

In the analysis of the above-mentioned images, black/white image of each band and false color composite image produced through photographycal processing were used supplementarily.

On the process of the analysis, following geological units have been extracted.

G_1: grey - pale grey tone, flatly distributed in ellipse shape with dendritic drainage patterns, having clear boundaries with neighbouring rocks.

G_4: black - dark brown tone, having coarse and rugged texture with dendritic drainage patterns, having vague boundaries with neighbouring rocks.

G_{4s}: dark brown tone, distributed in uplifted circular shape, having clear bounderies with neighbouring rocks.

U: dark brown tone, distributed in the shape of elongated uplift.

Am: pale brown - pale greenish grey tone with banded form, flatly distributed (This unit is useful for the analysis of geological structure of the survey area).

D: dark grey tone, with linear distribution, easily distinguishable from other units.

Bt: dark grey smooth tone, flatly distributed. (This unit shows the evidence of alluvial fans).

A large amount of structural informations such as fault, folding, and lineation has been obtained mainly from the edge enhanced images and false color composite images.

However, the mineralized zones such as Vumba, Timbale and Matsitama have not been discriminated by this analysis.

It seems that the evidence of these mineralized zones is too small for the LANDSAT data analysis to be applied to directly.

1-2-6 Results of Analysis

Analysis was attempted by digital processing of LANDSAT computer compatible tapes (CCT) and more accurate information was obtained in larger quantities than by analysis with images from 70 mm films alone. As for geological units, formations could not be distinguished as clearly as we had hoped, presumably because they were distributed over small areas. Nevertheless, the overall geological structure was grasped.

Concerning some granitic rocks, ultramafic, and basic rocks which occur in this area, we had expected that the weathered rocks, forming reddish brown soil, would stand out against leucocratic granitic rocks and be easy to recognise. This contrast in tone, however, did not always reflect on the images.

Ultramafic rocks can easily be detected owing to their topographic feature: they form narrow ridges rising from flat land. There are two types of them, serpentinite and metapyroxenite, but they could not be differentiated because of limited distribution.

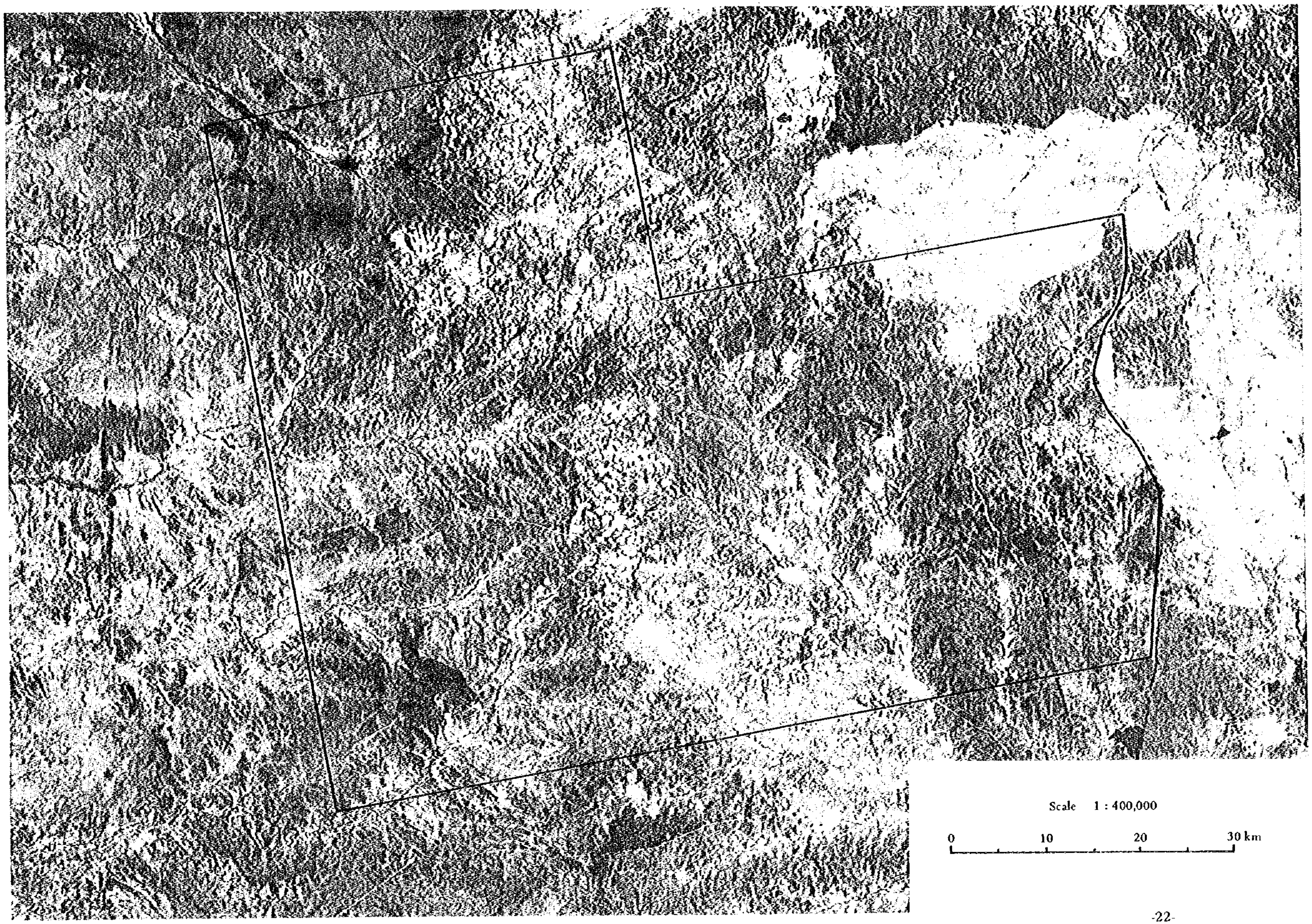
Amphibolite, a basic rock, occurs extensively in the Vumba area and is also distributed in belts surrounding the area, reflecting the local geological structure. It does not form ridges. Weathered amphibolite forms lateritic soil, wich shows a pale greyish brown color. On the image, occurrence is detected only in the northern area, with scant vegetation, but not in the center of the Vumba schist relic in the central part because of the black turf, intrusive rock bodies, and vegetation there.

The Tutume arkose group also has several intercalated belts of amphibolite, which however do not show clearly on the image. One reason may be vegetation. Another possible reason is that, as shown in the geological map, the amphibolite belts alternate with meta-arkose and G_{2g}.

As for granitic rocks, G_1 and G_4, Myshawe pluton can be distinguished by tone, but Shashe drift pluton and Kalakamate pluton cannot because of the complicated condition in which they intrude into amphibolite and receive intrusion of Dombashaba pluton (G4). Kalakamate monzonite is weathered and presents a reddish brown color, making it more difficult to recognise these rock bodies.

The Shechele stock in the G4 rock body can be recognised by color although it is small. Timbale granite forms ridges but the extent of its distribution is not clear.

Fig. 4. LANDSAT Image of Survey Area



Scale 1 : 400,000

0 10 20 30 km

Fig. 6-1 Originl histogram (Band 4)

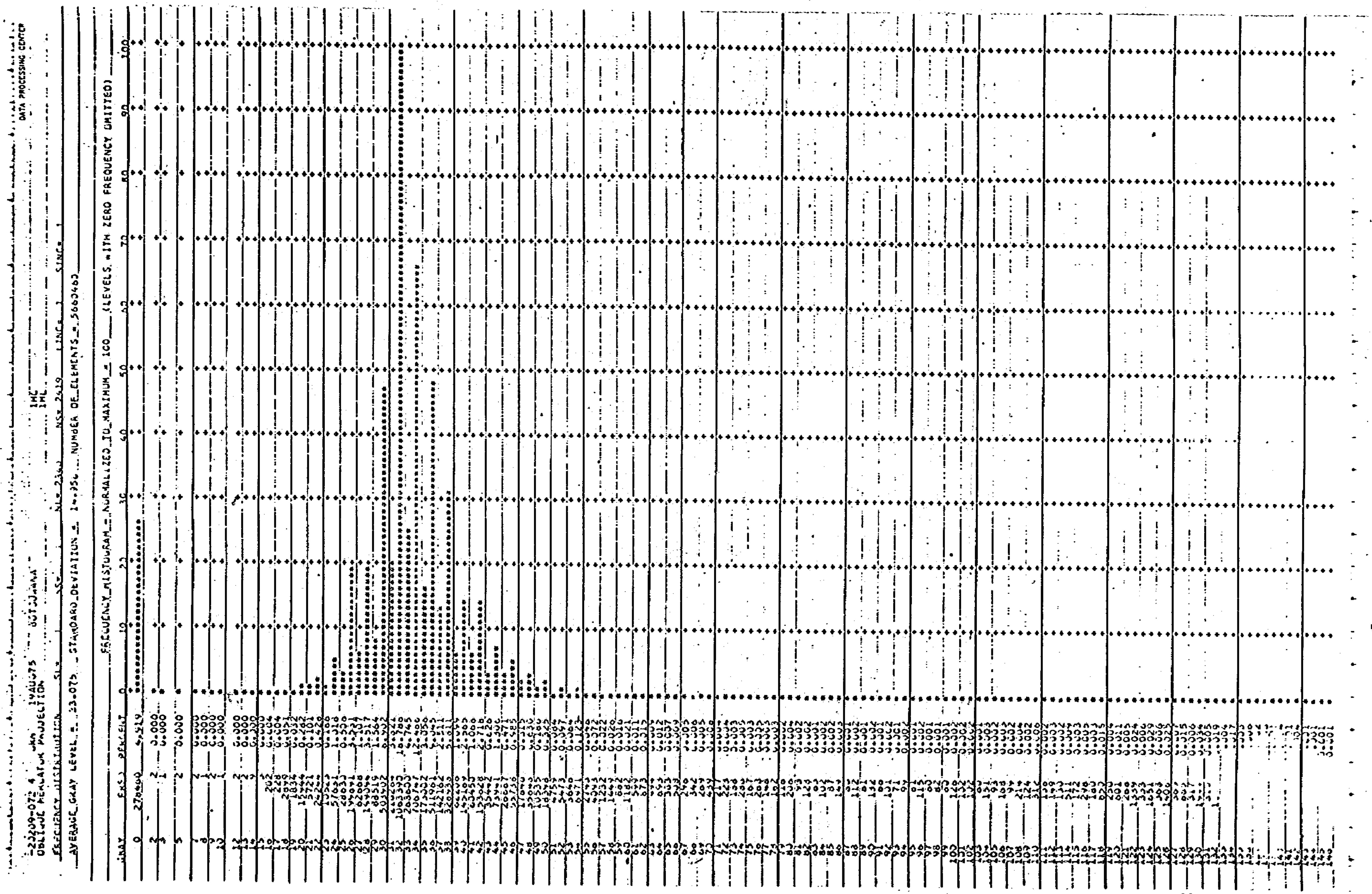


Fig.6-2 Original historam (Band 5)

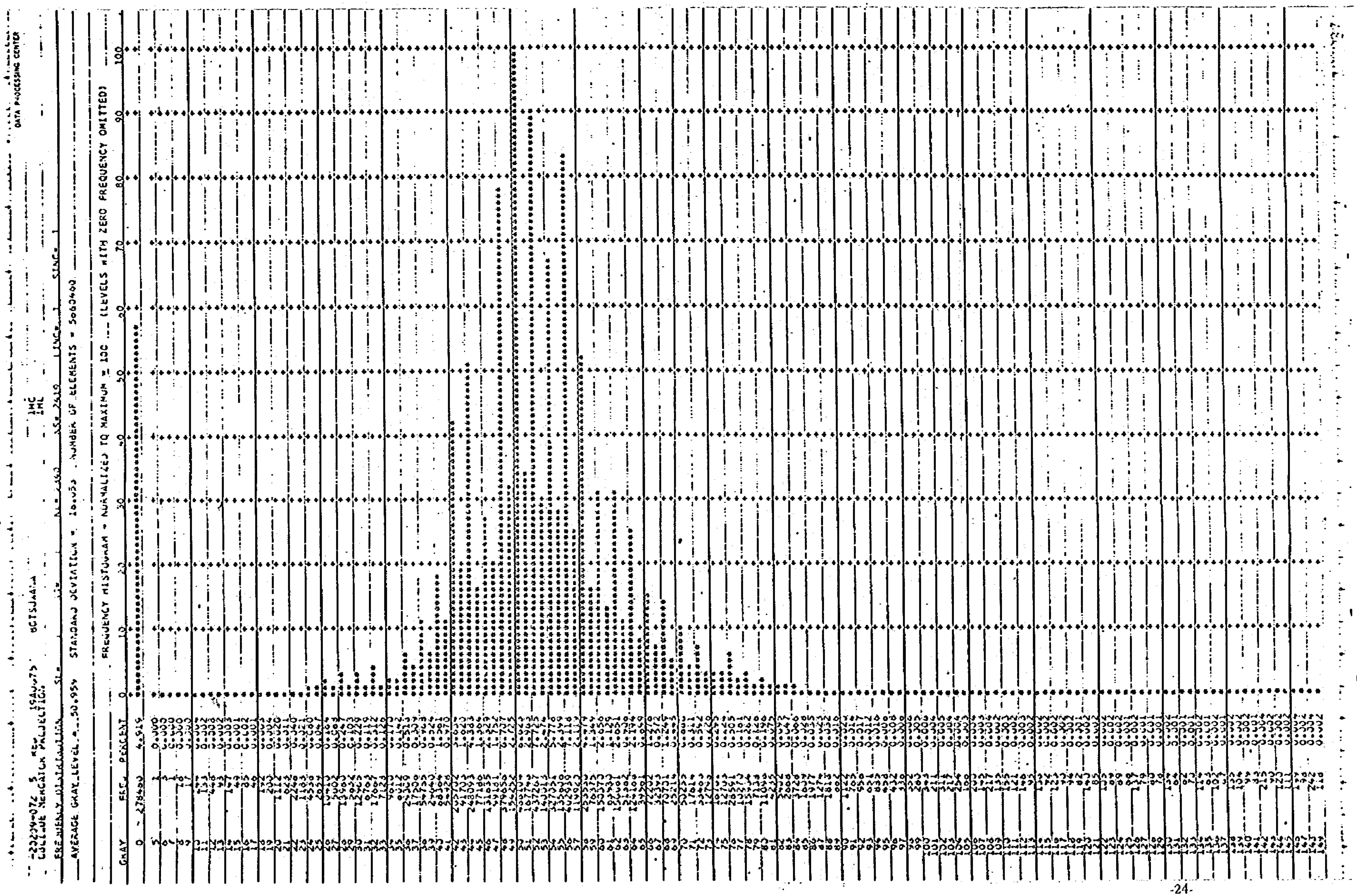


Fig. 6-3 Original histogram (Band 6)

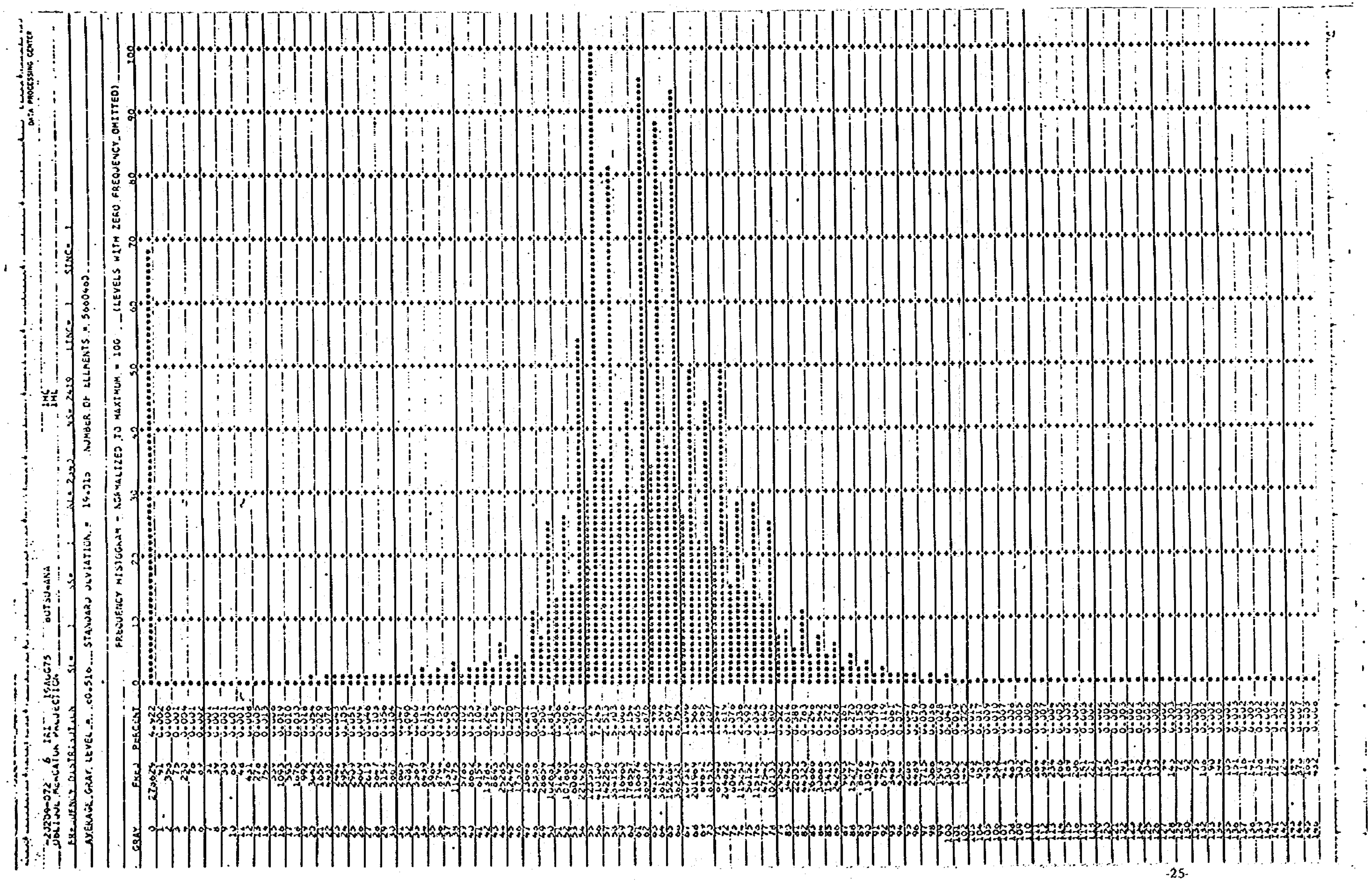


Fig. 6-4 Original histogram (Band 7)

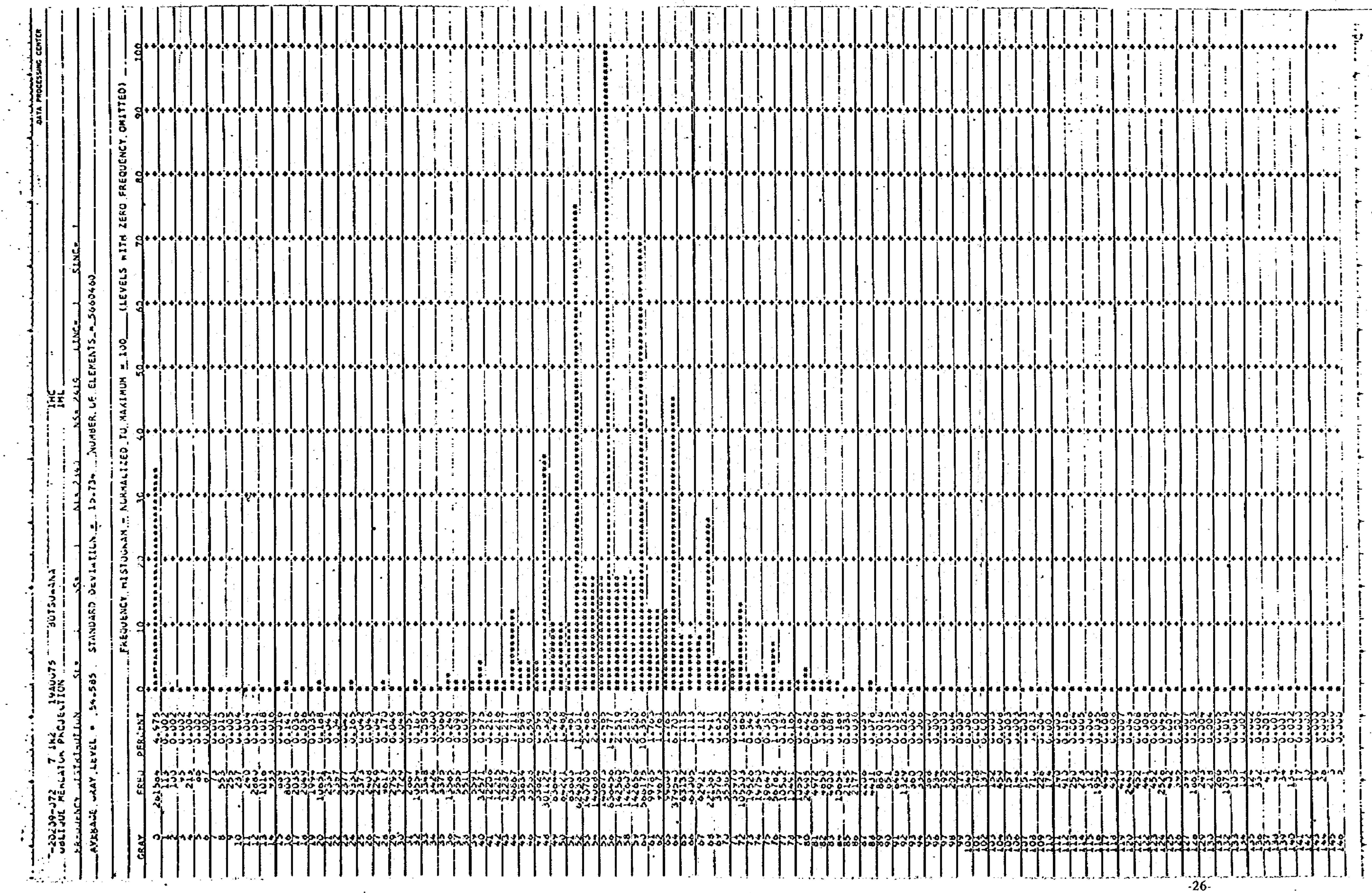


Fig. 7 Distribution map of lineament

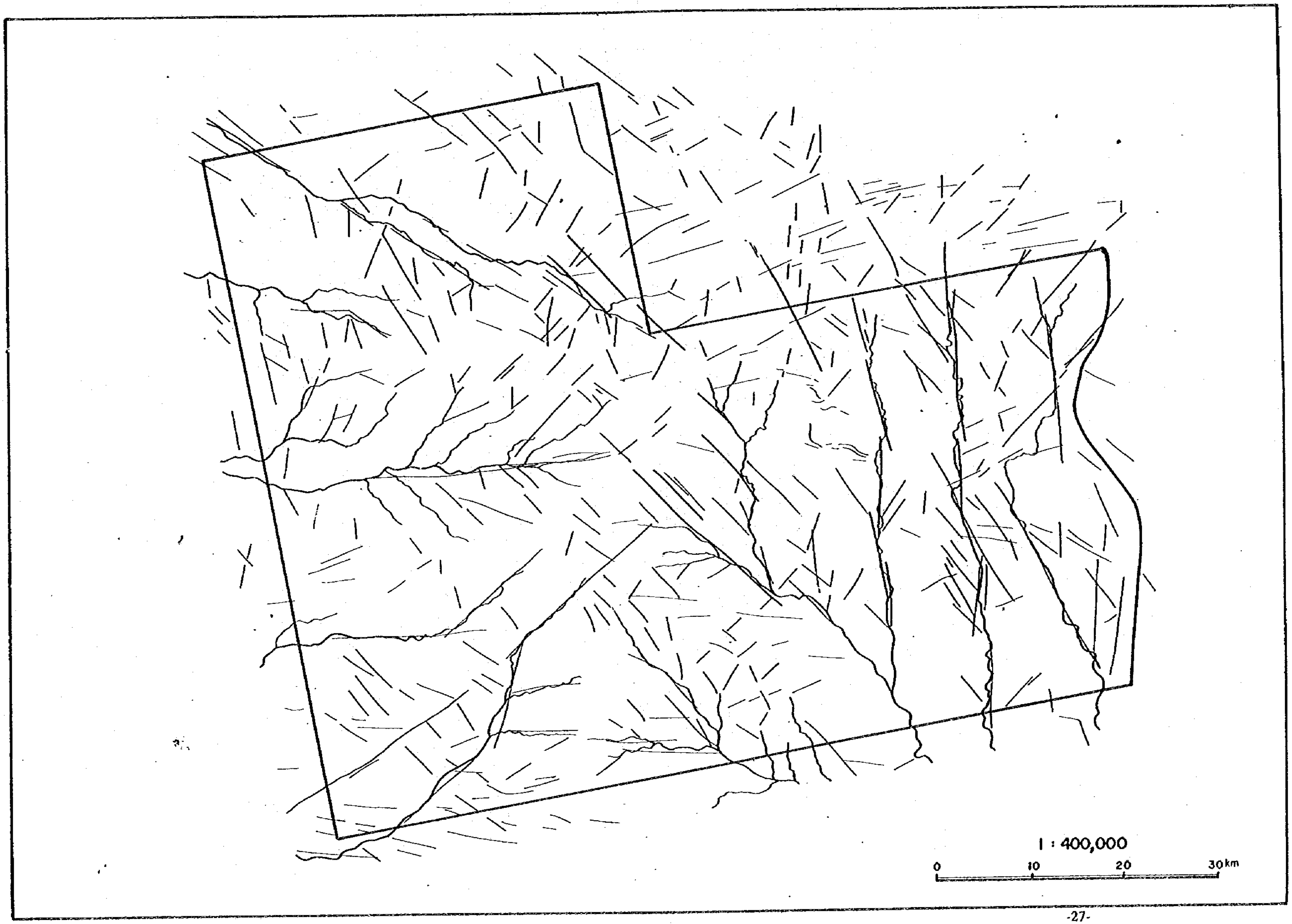
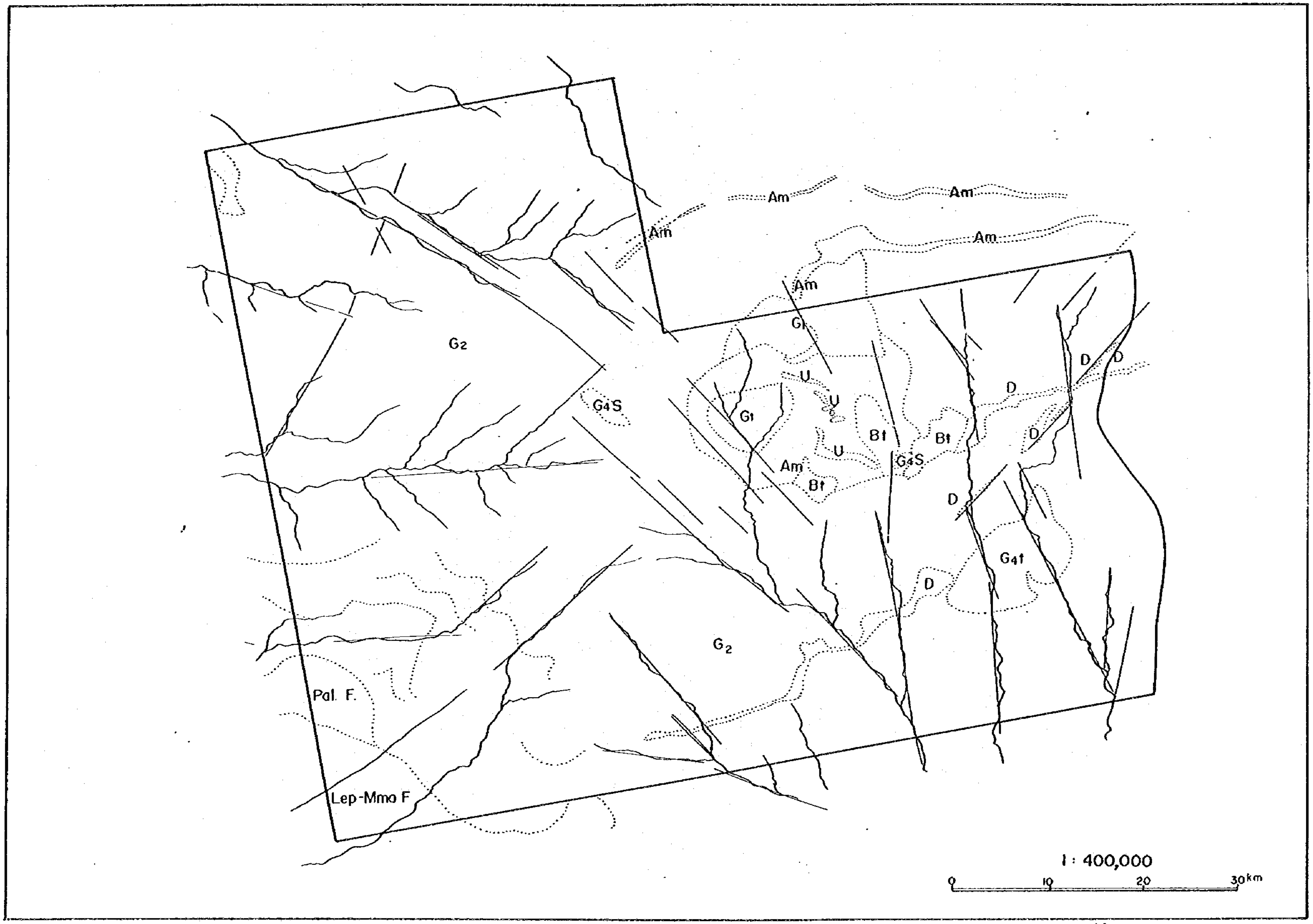


Fig.8 Interpretation map by LANDSAT image



Extensively distributed G_2 shows a grey to pale grey tone, but cannot be distinguished from G_3 tonalite because of the difference in rock facies and characteristic distribution.

Among the intrusive rocks in these rock bodies, dykes with a NE-SW trend are readily noted as they appear in clear black lines. Sheet-like rocks can be recognised because of tone.

As for geological structures, large structures can be read from difference in tone as well as from drainage pattern. On the image, the Vumba and Matsitama areas can be clearly demarcated with G_2 granite forming the border. The Vumba area is estimated as a semi-basin structure open to the east. G_1 and G_4 granitic rocks intruding into the area can be read from the difference in tone. Ultramafic rocks have minor foldings with an E-W trend axis.

In the Matsitama area, tone differences indicating strikes of formations are seen. Foldings with a NW-SE trend axis are seen and the east Wing forms part of the area. Here, formations with minor foldings and a NW-SE trend strike are seen.

Of the linear structures observed in the entire survey area, those with NW-SE, NNW-SSE and NE-SW trends are dominant.

1-3 Geological Survey

1-3-1 Introduction

The survey area may be divided largely into the Sebina-Tshesebe area covering the central to eastern part, and the Matsitama-Mosetse area in the western part. For the former and latter areas, geological maps of Litherland (1975) and Bennett (1970), respectively, are available. The geological history of the Rhodesia craton, including the survey area, has been compiled by Litherland (1975) as shown in Fig. 9.

As the present survey was conducted with emphasis placed on geological survey along the traverse line for geochemical exploration, as mentioned 1-1. So concerning geology and geological structure, therefore, we followed the views of Litherland and Bennett with only slight modifications in relation to rock facies in the Vumba sub-regional survey area.

1-3-2 Sebina-Tshesebe Area

The area is underlain extensively by basement complex consisting of schists and granitoid rocks, belonging to the Archean age. Schist belts, which cover much of the central part, are green schist belts belonging to the Archean age.

The Archean can be divided into two groups, the Tutume Meta-Arkose group and Vumba Volcanic Group.

(1) Tutume Meta-Arkose Group

This group surrounds the Vumba schist belt in several layered sequences with dominance in the western portion. It consists of stratified meta-arkose, amphibolite, and granitic gneisss.

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 is dominant in the Tutume area and vicinity. It is concordant with the meta-arkose and granitic gneiss (G_{2g}), so that it is thought to be of lava or sill origin. This rock is mainly plageoclase amphibolite of fine to medium grain. In some parts, talc-chlorite schists are intercalated with amphibolite.

(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.

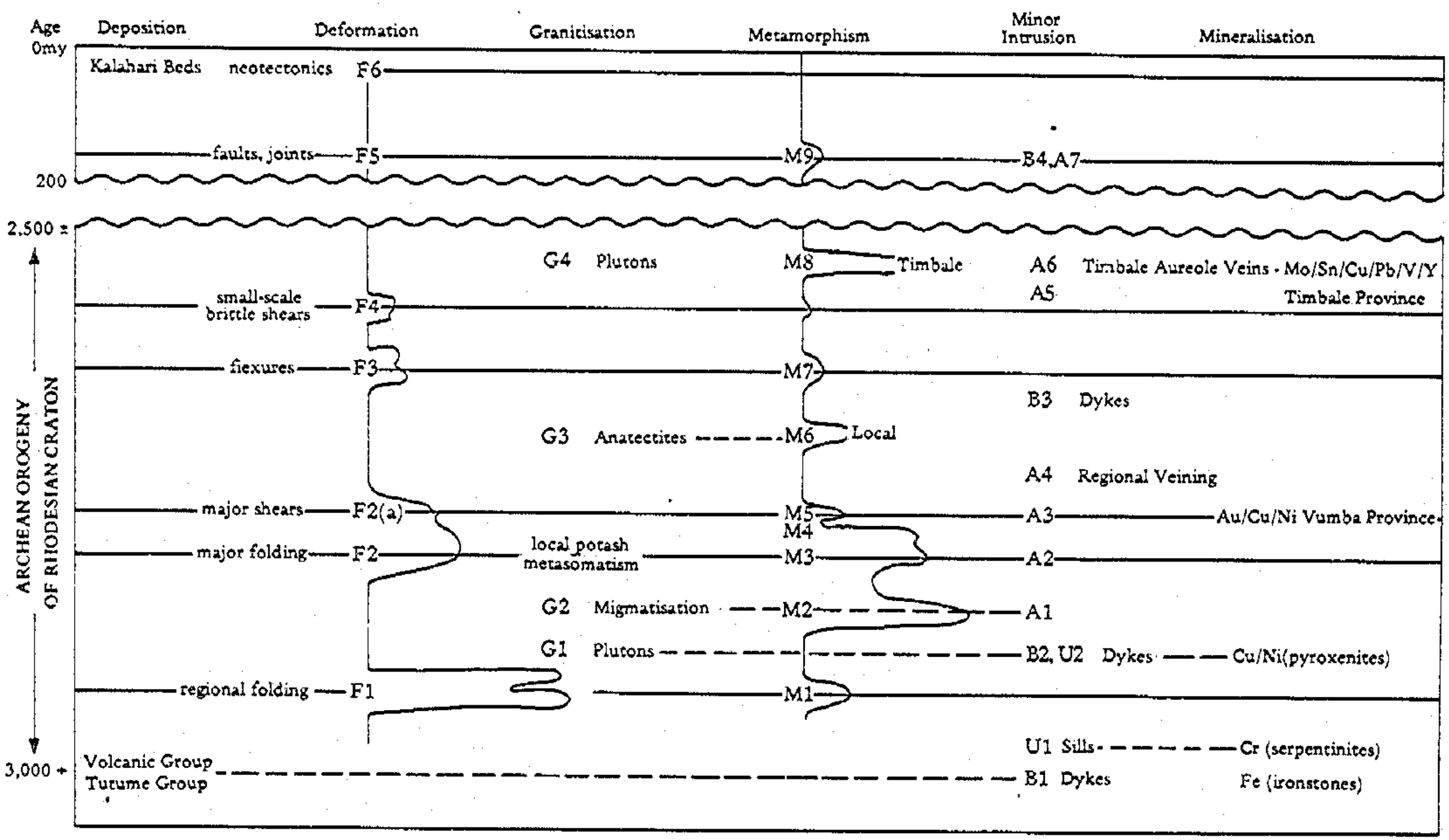


Fig. 9. Geological History (Litherland 1975)

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		

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 calcite.

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 (U_1). 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 meta-pyroxinite, 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. Presumably, they are post-F_1 intrusions because direction of intrusion is discordant to the S_0/S_1 schistosity plane. In other words, the Toteng ultramafic intrusions are thought to be due to ultramafic intrusion (U_2) in the second stage deformation (F_2).

The ultramafic rocks form kopjes in the vicinity of Tshesebe. The kopje is a large dyke intruding in the NE-SW direction into the paragneiss and Ntshe quartz diorite (G_3). It is also discordant to S_0/S_1.

The ultramafic rock intrusions in the Toteng-Tshesebe stage (U_2) are correlated with the second stage basic intrusion (B_2).

Among other small ultramafic rock bodies are: a body which has intruded in either the U_1 or U_2 stage into the quartz diorite (G_2) to the north of Vukwi Meta-arkose formaton; an isolated dark green coarse serpentinite body in the amphibolite in the Tutume Meta-arkose formation; and a meta-gabbro body correlated with U_2 because it is discordant to S_0/S_1 found in the vicinity of 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. (Apex. 3).

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) Felsic Rcoks

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 schists: These are distributed in felsic rocks in the lower Vumba felsic formation and upper Vumba felsic formation, often exposed in the small Aributary 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 4, 5, Apex. 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.

Table 4. Chemical Analysis of Rock Samples

			S-54	S-66	S-30	S-46	S-29	S-1	S-55
Rock			Q-Monzonite	Biot Granite	Granite Gneiss	Tonalite Gneiss	Granite Gneiss	Amphibolite Schist	Granite
			G_1	G_4	G_{2g}	G_{2t}	PG_{2t}		G_{1m}
Location			Kalakamate	Vumba Hills	Nshakashokwe	Makaleng	Sebinanyane	Mosope	Kalakamate
Chemical Composition	SiO_2		63.39	66.51	67.20	67.73	71.13	47.26	76.05
	TiO_2		0.77	0.50	0.50	0.43	0.29	1.94	0.03
	Al_2O_3		14.26	14.84	14.96	14.85	14.35	13.00	13.25
	Fe_2O		1.86	2.59	1.82	1.31	1.10	7.37	0.48
	FeO		2.74	1.09	1.86	2.19	1.17	7.47	0.36
	MnO		0.07	0.08	0.06	0.06	0.03	0.20	0.04
	MgO		2.33	1.42	1.30	1.52	0.72	7.12	0.07
	CaO		3.65	2.90	4.31	4.12	2.06	8.24	0.47
	Na_2O		3.45	4.29	4.39	4.05	3.95	3.19	4.87
	K_2O		5.00	2.98	1.17	1.40	4.06	0.70	4.30
	P_2O_5		0.19	0.20	0.13	0.14	0.10	0.22	0.02
	H_2O^+		0.82	1.06	0.47	0.48	0.29	0.82	0.11
	H_2O^-		0.16	0.18	0.10	0.12	0.13	0.44	0.14
	Cu (ppm)		18	44	4	64	5	54	15
	Pb (ppm)		14	14	5	15	10	13	10
	Zn (ppm)		43	56	11	43	12	46	26
	Ni (ppm)		20	35	6	21	8	42	16
	Mo (ppm)		<3	<3	<3	<3	<3	<3	<3
Total			98.69	98.64	98.27	98.40	99.38	97.97	100.35
Norm Composition	Q		14.0	26.0	26.6	27.3	27.1	0.8	27.7
	F	Or	29.5	17.8	6.7	8.4	23.9	2.3	25.6
		ab	29.4	36.2	37.2	34.1	33.6	26.7	41.4
		an	8.6	12.5	17.8	18.4	9.5	19.5	1.4
	di	wo	3.6	0.7	1.2	0.5	--	8.4	0.2
		en	2.4	0.4	0.8	0.3	—	5.9	0.2
		fo	0.9	—	0.3	0.1	—	1.7	—
	hy	en	3.4	3.1	2.4	3.5	1.8	11.8	--
		fo	1.3	—	1.1	2.4	0.7	3.3	—
	il		1.5	0.9	0.9	1.5	0.6	3.6	0.6
	mt		2.8	2.3	2.6	1.9	1.6	10.6	0.5
	hm		—	1.0	—	—	—	—	0.2
	ap		0.3	0.3	0.3	0.3	0.3	0.5	—
Total			97.7	101.2	97.9	98.7	99.1	95.1	97.8
D. I.			72.9	80.0	70.4	71.1	84.6	29.8	94.7
Dating (m.y.)			2,270 ± 114	2,020 ± 101	1,800 ± 90	1,810 ± 91	1,860 ± 93		

(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 1800 m. y. and 1860 m. y. respectively. (Tables 4, 5, Apex. 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 Makalang area gave 1810 m. y. (Tables 4, 5, Apex. 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 (G_{wt}) 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 stoks 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 S2 structure and intrudes into G3 tonalite.

The intrusive mechanism of G4 granite differs from that of G3 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 G1 pulton, forming hills. The typeical rock type is of coarse and pink potash feldspar. Marginal facies consist of banded 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 2020 m. y. The sample used in the dating, viz., S-66 had been strongly chloritised and epidotised. (Tables 4, 5, Apex. 3)

Timbale granite is of the largest scale among all G4 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) Dyke Rocks

The surveyed area has many dyke rocks, which are classified into four basic and seven acidic ones.

(i) Basic Dyke Rocks

B_1 is the earliest of all intrusive rocks. It is a fine-grained meta-basalt intruding into the Vumba valcanic group.

B_2 is a small dyke that intrudes discordantly into the S_0/S_1 fabric in the gneiss region.

B_3 is of meta-dolerite in the northern part of the surveyed area. It is a dyke swarm with a N70E direction, vertical dip, and widths ranging from several meters to several hundred meters.

B_4 is a late/post Karroo dolerite swarm. One trend is in the N70°W direction, another in the N50°E.

(ii) Acidic Dykes

A_1 is related with G_2 granitic activity and consists of quartz and feldspar.

A_2 is related to F_2 deformation; it is a quartz feldspar dyke.

A_3 is associated with the gold/sulfide mineralization.

A_4 intrusions are mainly in the form of red, pink granitic or pegmatic sheets and also occur as various faceis. They have prominent trends. One is in the N80W direction, another E-W direction.

A_5 cuts F_3 and F_4, localised in F_3 deformed areas.

A_6 is associated with Timbale granite.

A_7 is related with F_5 deformation.

A_7 is quartz and silicified veins, related with F_5 deformation.

In the southern part of the surveyed area, small-scale diorite, granite, and granodiorite veins are found.

(5) Geological Structure

Macroscopically, the geological structure of the area consists of a semicircular structure open to the east.

As for structural movements, there was folding in the Archean age and faulting in the Karroo age and later.

The Archean folding started with compression folding, which caused granitization. As a result, metamorphic base reached to amphibole hornfels facies. This was followed by folding due to tension.

In the Karroo age and later, primary wrench faults chiefly of the NNW system (Tutume fault system) and the NS system (Ramokgwebana fault system) developed, as shown in Fig. 10. These faults are accompanied by secondary NWW wrench faults.

(6) Dating

Dating in this area was performed previously for Timbale granite (G_4), which was estimated at 2,540 x m. y. (Key, 1976).

In the present survey, dating and chemical analysis were conducted for one sample each from G_1 and G_4, and three from G_2. The results are presented in Tables 4, 5, Apex. 3. The ages were 2270 m. y. for G_1; 1800, 1810, 1860 m. y. for G_2; and 2020 m. y. for G_4. These ages are much younger than previously estimated. Particularly, G_2 is the youngest and even younger than G_4.

Sample S-66 is strongly sericitized, epidotized and weakly chloritized.

Samples S-30 and S-46 are strongly epidotized, weakly sericitized and chloritized.

Sample S-54 is rather strongly sericitized, weakly epidotized and chloritized.

Sample S-29 is rather weakly sericitized, epidotized and chloritized.

The younger ages may be explained by alteration or weathering of samples,

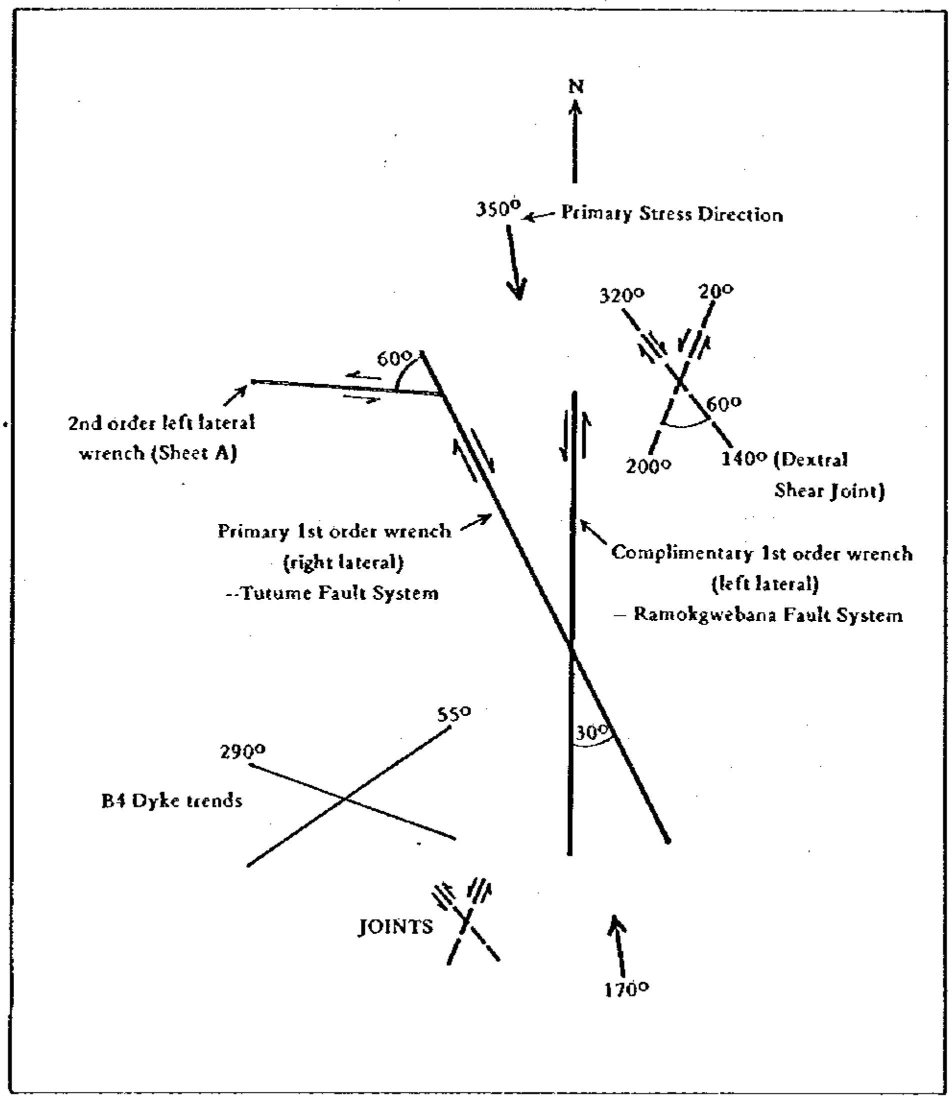


Fig. 10. F_5 Fault-Joint-Dyke Stress System (Litherland 1975)

Table 5. Data on K–Ar Isotope Dating

Sample No.	Place	Location		Rock	Age (m.y.)	Scc Ar^{40} R 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	98.0	3.71
						65.7	99.0	3.74
S - 66	Vumba Hills	27°20'29"	20°41'57"	Biotite Granite (G_4)	2,020 ± 101	86.7	98.7	5.91
						85.0	98.5	5.93
S - 30	Nshakashokwe	27°08'08"	20°46'47"	Granite Gneiss (G_{2g})	1,800 ± 90	64.7	97.0	5.23
						60.9	98.5	5.24
S - 46	Makaleng	27°17'14"	20°50'07"	Tonalite Gneiss (G_{2t})	1,810 ± 91	88.6	98.8	7.14
						84.0	98.2	7.14
S - 29	Sebinanyane	27°07'24"	20°56'54"	Granite Gneiss (PG_{2g})	1,860 ± 93	86.7	98.6	6.80
						85.5	98.3	6.85

Note: 1. The analysis was performed on biotite separated from sample.

2. Constants: $\lambda p = 4.962 \times 10^{-10} yr^{-1}$

$\lambda e = 0.581 \times 10^{-10} yr^{-1}$

$k^{40} = 1.167 \times 10^{-4}$ atom per atom of natural K.

or by rejuvenation by regional metamorphism.

1-3-3 Mosetse-Matsitama Area

This area is located in the southwestern part of the surveyed area and forms the northeastern part of Bennett's map (1970).

The area is underlain by the Archean rocks and may be divided into two groups, the Mosetse River Gneiss group and the Matsitama Schist and Metasedimentary group.

(1) Mosetse River Gneiss Group

This group, making most of the Mosetse-Matsitama area, consists primarily of granitized gneisses and has undergone regional metamorphism under amphibolite facies. Porphyroblast is well developed and schistosity is weak over a wide range, but the extent has not been confirmed.

In the upper reaches of the Mosetse and Matsitama rivers, a small amount of amphibolite rocks are distributed, with lenticular limestone scattered over them.

(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-Mmalogong 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 rocks.

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.

Geological Structure

The Matsitama area is thought to have a folding with a NW-SE trend axis. Part of the east wing of the folding is distributed in the surveyed area.

1-3-4 Correlation of Strata

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 and Vumba volcanic groups, for instance, if formation is used as the unit, the Maitengwe ultrafamic formation consisting of ultrafamic 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 and Vumba volcanic gorups, Matsitama's Sebilogae-Sebothe green schist and metasedimentary formation which consists of