Ph.D. Geology

BLECHA : THE ORIGIN OF THE BRETON BRECCIA BATCHAWANA AREA, ONTARIO.

ABSTRACT

The Breton breccia forms a Precambrian breccia pipe of a type which has not, so far, been found elsewhere in Canada.

The pipe is oval in shape, underlies an area of 1,350 by 250 feet, and extends to a depth of at least 1,600 feet. The breccia consists of a variety of fragments embedded in a quartz and carbonate matrix. The entire breccia is mineralized with chalcopyrite and pyrite, with minor amounts of sphalerite, galena and molybdenite.

The ore zones are domal in shape, and are enveloped in halos of altered rock characterized by the presence of sericite, chlorite and clay minerals.

Experimental data on the effects of the heating of chalcopyrite containing exsolution bodies of sphalerite indicate that the chalcopyrite formed at temperatures above 500°C.

It is proposed that the breccia formed by a collapse of rocks due to removal of support caused by the withdrawal of a felsic magma at depth.

THE ORIGIN OF THE BRETON BRECCIA
BATCHAWANA AREA, ONTARIO

by

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fulfillment of the requirements for
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INTRODUCTION

General Statement.

Mineralized breccia pipes, particularly those in the southwestern United States and Mexico, contain some of the largest base metal deposits in the world. The vast majority of breccia pipes, however, are relatively small structures, notorious for the erratic distribution of primary ore minerals. This often defies the use of selective underground mining methods. Breccias of this type are usually mined in their entirety or along contact areas in which mineralization is commonly concentrated.

The breccia described in this thesis is one of the rare examples of mineralized breccia pipes in the Canadian Precambrian Shield. The initial examination of the breccia gave the impression that the structure consists of a heterogeneous mass of randomly distributed rock fragments embedded in a quartz-carbonate matrix with erratically distributed sulphides. Although the total copper content of the breccia was obviously large, the average grade seemed too low for profitable mining.

Detailed geological studies of the breccia gradually revealed a certain degree of ordering of the fragments within the breccia, which could be directly related to the distribution of sulphide mineralization. This thesis provides a detailed description of the breccia, and its internal structure, the recognition of which ultimately enabled selective mining of high grade zones. Possible explanations of the available facts are discussed at some length.

Location and Access.

The Breton breccia is located on the property of the Tribag Mining Company Limited, in Township 28, Range 13, approximately 40 miles north of Sault Ste.Marie, Ontario.

The mine is accessible by an all-weather gravel road which connects the property to the Trans-Canada Highway No. 17 North, over a distance of 17 miles.

Topography.

The Batchawana area belongs to one of the most scenic parts of Canada. Rugged hills with steep cliffs formed by resistant diabases rise high above Lake Superior, giving a local relief in excess of one thousand feet. The most prominent are Mamainse Hill, and Batchawana Mountain which rises to an elevation of 2,142 feet and ranks second in Ontario. The granites generally form a gentle rolling highland with less prominent ridges. On the shore of Lake Superior the Keweenawan volcanics form a rugged landscape due to uneven erosion of the interbedded lavas and conglomerates. In places where volcanics are absent, the shore is smooth, and the bays are lined with wide sandy beaches.

The area is drained by three main streams, all of which flow almost due south. Batchawana River, the largest of these streams, drains the central part of the area, and is flanked by Pancake River to the west, and Harmony River to the east.

History.

The Batchawana area is one of the oldest mining centres in Canada. While the presence of copper was probably known to Jesuit missionaries at the beginning of the eighteenth century, much earlier mining attempts were made by the natives, as witnessed by old "Indian diggings" near Sand Bay, not far from the presently producing Coppercorp Mine. The first recorded discovery of copper was made by David Thompson, an explorer, during his visit to Mamainse in 1798. The similarity of the local geology to that of the Michigan copper deposits attracted much attention throughout the latter part of the nineteenth century. Among the companies engaged in exploration were the Montreal Mining Company, (1856-57), Ontario Mineral Lands Company, (1882-84), Canada Lands Purchase Company, (1890), and the Nipigon Mining Company, (1892). During that period several shafts were sunk at various places and a large mill was erected at the Mamainse mine between Mica Bay and Mamainse Island. All of these mining ventures concentrated on the exploitation of chalcocite-filled fractures in the Keweenawan flows and conglomerates, or deposits of native copper in amygdaloids and fragmental flow tops. These deposits, however, invariably proved uneconomic, and all mining attempts ultimately met with failure. On examining the old mining camps, Moore, (1926, p.81) remarked that "...prodigal expenditures of money seems to have been a characteristic of many of the operations of the region..."

Serious exploration of the Batchawana area was resumed by Calumet-Hecla Company of Michigan, which in 1906-08 had a series of diamond drill holes bored in an attempt to find a repetition of the Michigan copper deposits. The drilling results, described by Lane, (1911), did not warrant further work at that time, and all operations were suspended.

In post-war years the old copper showings located on the Montreal Company Sand Bay location were re-examined by C. C. Huston, mining engineer for Macassa Mines Limited. On his recommendation the company carried out a diamond drilling programme but lost interest in the property in 1950. The exploration was taken over by C. C. Huston and Associates in 1951-52, and in 1955 the ground was acquired by Coppercorp Mines Limited. The portion of the property which included the known ore was leased to Vauze Mines Limited in 1964, and subsequently purchased by Sheridan Geophysics Limited, who started production in 1965.

The discovery of the Tribag deposit was made in 1954 by Aime Breton, a prospector, in the bed of small creek which runs through the present mine site. The showing was optioned to Sylvanite Gold Mines Limited, who after having drilled 22 holes totalling 8,331 feet, relinquished the option in 1956. During the same time some trenching and diamond drilling was also done about one mile east of the showing, in the area presently known as the East Breccia.

The name of the company that did the work is not known, and the claims lapsed.

Work on the original Tribag showing was resumed in 1961, when three holes were drilled by private individuals. Tribag Mining Company Limited obtained control of the property in 1962, and immediately started an exploration programme, involving geological mapping, geophysical surveying, and diamond drilling. The exploration concentrated on the Breton Zone where, by the end of 1963, sufficient copper mineralization was outlined to warrant underground development. In the summer of 1964 a three compartment shaft was sunk to a depth of 765 feet, and lateral development was started on three levels. Encouraging results prompted the decision to deepen the shaft to its present 1,251 feet, and by the end of 1965 three new levels were established.

In September 1965 Noranda Mines Limited volunteered an agreement whereby it would expend funds on further development. After additional drilling, Noranda chose not to exercise the option.

In August 1966 an agreement was reached with Teck Corporation Limited to provide funds and management to bring the mine into production. On March 10, 1967 power was brought to the property, and by the end of April most of the construction, including a 400 tons per day copper concentrator, was completed.

On May 10, 1967, thirteen years after the original discovery, and after an estimated expenditure of over five million dollars, the production of copper concentrate was started. The concentrate is trucked to the Algoma Central Railroad yards in Sault Ste.Marie, and shipped by rail to Noranda for smelting.

The underground workings, including raises, drifts and cross-cuts, total 17,884 feet. The underground diamond drill hole footage to June 1, 1967 totalled 92,470 feet. Total surface diamond drilling was 138,588 feet.

The ore reserves were estimated to be 600,000 tons of proven ore grading 2.20 per cent copper. The mine is scheduled to produce 500,000 pounds of copper per month.

Previous Geological Work.

Geological reconnaissance of the Batchawana area was started in 1863 by William Logan, then Director of the Geological Survey of Canada. Certain portions of the area were subsequently described by Thomas MacFarlane, (1863), Robert Bell, (1890), and A. P. Coleman, (1899). First systematic mapping of the area was done by Moore, (1926), on a scale of one inch to two miles. Detailed description of the Keweenawan series in the Mamainse Point area is given in a report by J. E. Thompson, (1953). Geological study of the area was resumed in 1963 when a systematic mapping programme of the townships on a scale of one inch to ½ mile was started by the Ontario Department of Mines.

The first description of the Tribag deposit was given by the writer in an address at the Annual General Meeting of the Canadian Institute of Mining and Metallurgy in 1965. This description, based on eighteen months of field work, was subsequently published, (Blecha, 1965). A second account of the geology is included in a paper by Giblin, (1966). A study of the wall rock alteration and paragenesis at the Tribag deposit was done by Armbrust, (1967).

The writer worked at the mine from September 1963 until March 1968. During that time he had the opportunity to log approximately 90 per cent of all the surface and underground drill core, map the underground workings, and carry out detailed geological mapping of the critical areas on a scale of 1 inch to 50 feet. The surface geological maps of the property, as well as all level plans and sections included with this thesis are the result of his work.

Acknowledgements.

The writer wishes to express his thanks to the directors of the Tribag Mining Company Limited for the permission to conduct this study, and for granting and financing the leaves-of-absence during which the laboratory work was carried out.

The thesis was written under the direction of Dr. J. E. Gill, Dawson Professor of Geology at McGill University. The writer is very grateful for his encouragement and criticism.

The study of the Tribag deposit was suggested by Dr. S. E. Malouf, consulting geologist, who introduced the writer to the Batchawana area in 1963. For this, the author is most grateful.

Many thanks go to the Ontario Department of Mines for kindly furnishing the chemical analyses included in this thesis, and particularly to Dr. P. E. Giblin, Resident Geologist in Sault Ste.Marie, for his help and fruitful discussions.

At McGill University, the writer received advice and assistance from many professors and fellow graduate students. He wishes to thank particularly Dr. W. H. MacLean for introducing him to various laboratory techniques, Dr. L. A. Clark for the use of the laboratory apparatus, and general advice, and to Dr. R. Doig for kindly providing the K-Ar age determination of the Tribag granite.

Lastly, the writer wishes to extend his thanks to Mr. W. T. Swensen, vice-president of Anaconda American Brass Limited, for permission to examine the breccia pipes in Cananea, Mexico. Mr. C. C. Brown, chief geologist of Compania Minera de Cananea, and Dr. P. Gilmour, resident geologist for Texas Gulf Sulfur Corporation in Tuscon kindly offerred to guide the author on his field trips in Mexico and Arizona.

Contribution to Knowledge.

The writer claims the following of his findings as his contribution to knowledge:

1. The recognition and description of a Precambrian breccia pipe of a type which is new to Canada.

2. Recognition and description of the structural control of the ore present in the breccia pipe.

3. Additional experimental data on the effects of the heating of chalcopyrite containing exsolution bodies of sphalerite, and their bearing on the geothermometry of the ore in the breccia.

4. Proposal of a new theory explaining the origin of the breccia, its structure, and the origin of the ore.

GENERAL GEOLOGY

REGIONAL SETTING.

The Batchawana area lies in the south-central part of the Superior Province of the Canadian Precambrian Shield. The Superior Province, first recognized by Gill, (1948), on the basis of dominant structural trends, and by Wilson, (1949), from isotopic dates, is characterized by east-west trending Archean belts of volcanic and sedimentary rocks, separated by large masses of granites and gneisses, (Plate 1).

The Tribag property is located at the north contact of an Archean belt which extends from the east shore of Lake Superior northeastward over a distance of 50 miles, (Plate 2). In the west it is overlain by rocks classed as "Keweenawan Series" and presumed to form part of the eastward extension of the great Lake Superior syncline. The location of the Batchawana area in relation to other mining areas of the Superior Province suggests that it belongs to the large metallogenic Province which extends from Chibougamau south-westward toward Sudbury, and probably continues westward to include the copper deposits of Michigan.

GEOLOGY OF THE BATCHAWANA AREA.

The following discussion deals with the geographic distribution of the formations and their mutual relationships. It is based largely on a survey of literature, and on personal communication with Dr. P. E. Giblin, Resident Geologist for the Ontario Department of Mines in Sault Ste.Marie. The

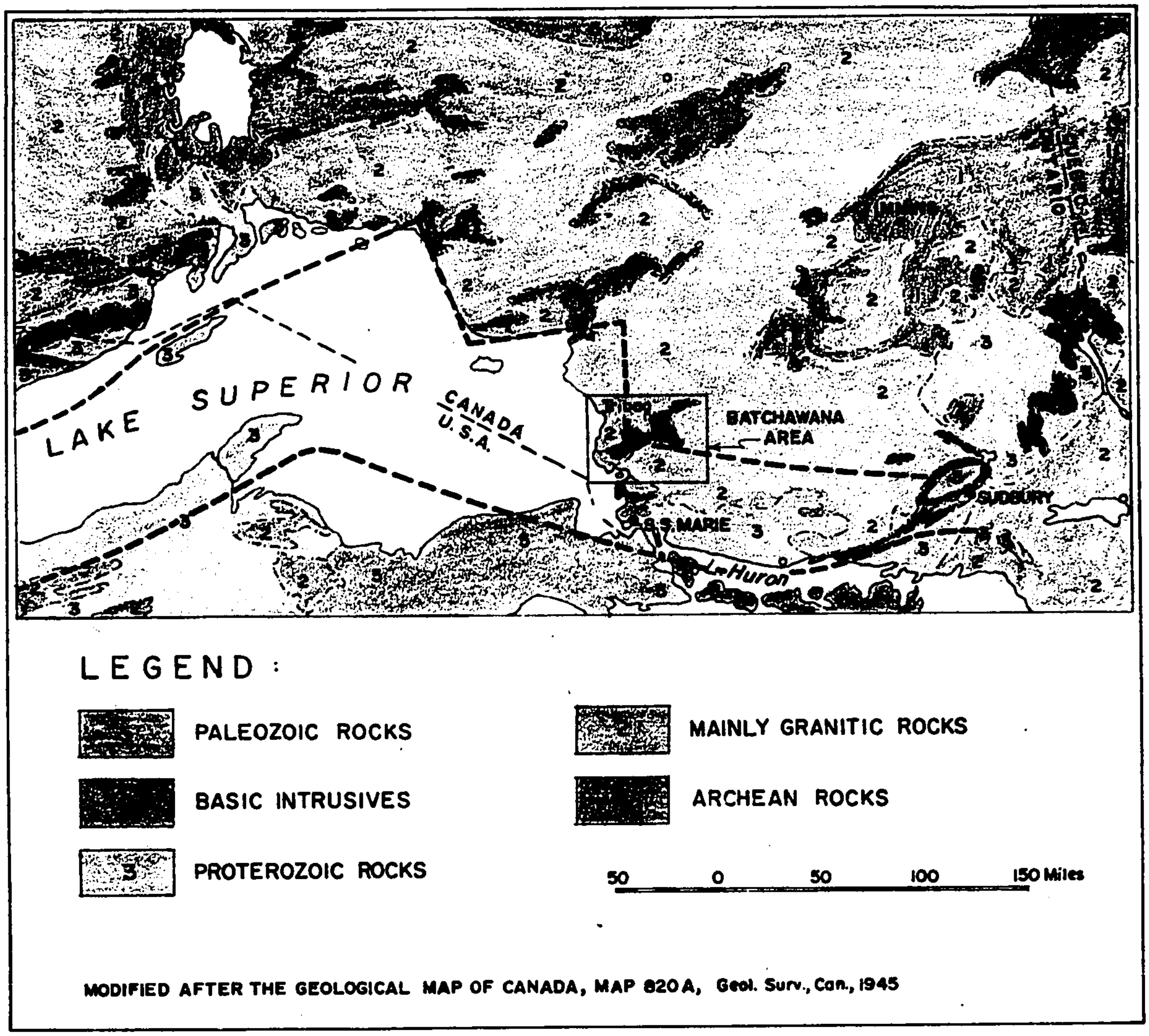


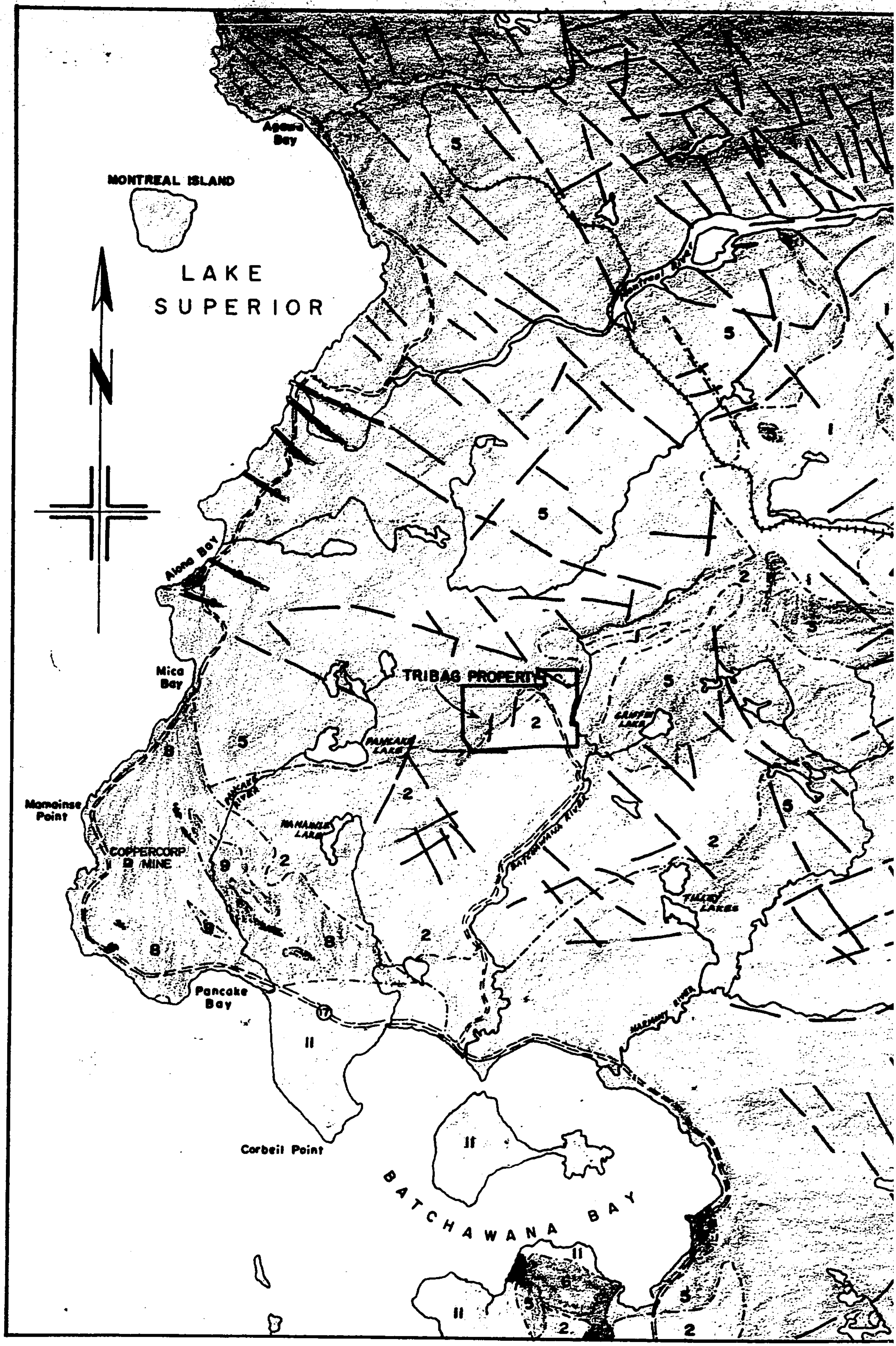
Plate 1. Regional Setting of the Batchawana Area.
Heavy, broken lines represent zones of predominantly normal faulting, according to Kumarapeli and Saull, (1966, Fig. 5).

writer's contribution is restricted to observations made during detailed mapping of parts of the Tribag property. Detailed petrographic descriptions will be given in the section on the geology of the Mine area.

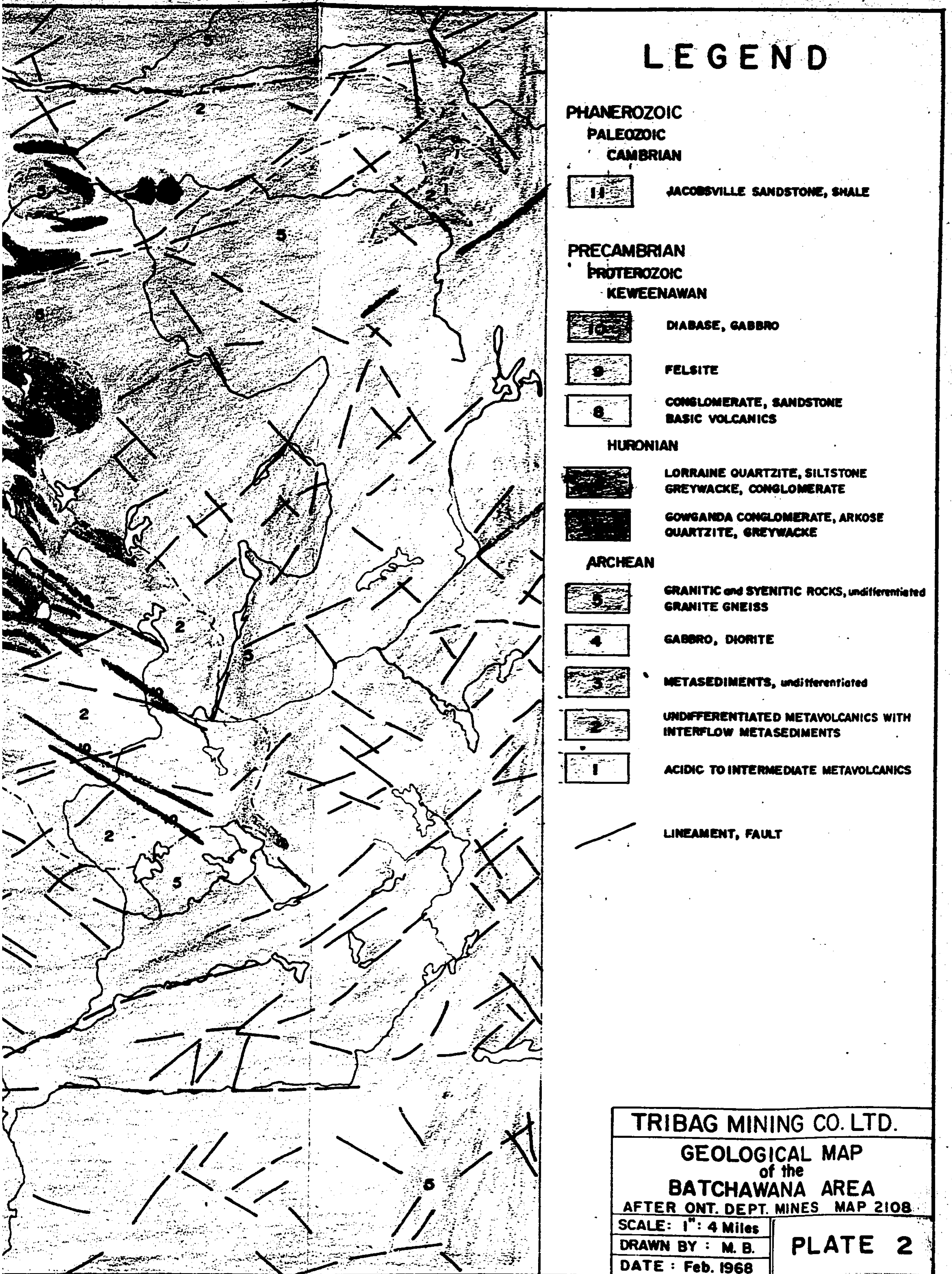
The Batchawana area is underlain by a variety of rocks which can be conveniently divided into four main groups. These are: 1. The Archean belt, 2. the granitic and gneissic rocks, 3. the Keweenawan Series, and 4. the Paleozoic sedimentary rocks, (Plate 2).

1. The Archean Greenstone Belt.

The Archean greenstone belt underlies an area of an average width of six to seven miles. Moore, (1926), subdivided the belt into two distinct units: the older "Batchawana Series" in the east part, and the intrusive "Mamainse Formation" in the west. The Batchawana Series was described as a "series of complex, highly metamorphosed interbedded lavas, mostly rhyolites and felsites, and sediments, chiefly arkose and greywacke." (p.59). The term Mamainse diabase was given to rocks extending over several townships in the west part of the belt, and forming the most prominent hills in the area. These rocks were described as a "monotonous formation, consisting of great masses of diabase and gabbro, grading into diorite in places." (p.60). Several occurrences of banded iron formations within the areas underlain by the Mamainse formation were cited as evidence for the former greater distribution of the Batchawana Series.


MONTREAL ISLAND
LAKE SUPERIOR
Agawa Bay
Alona Bay
Mica Bay
Mamainse Point
COPPERCORP MINE
TRIBAG PROPERTY
PANCAKE LAKE
Pancake Bay
Corbeil Point
BATCHAWANA BAY
Montreal River
17

HARMONY RIVER


LEGEND
PHANEROZOIC
PALEOZOIC
CAMBRIAN
11
JACOBSVILLE SANDSTONE, SHALE
PRECAMBRIAN
PROTEROZOIC
KEWEENAWAN
10
DIABASE, GABBRO
9
FELSITE
8
CONGLOMERATE, SANDSTONE
BASIC VOLCANICS
HURONIAN
LORRAINE QUARTZITE, SILTSTONE
GREYWACKE, CONGLOMERATE
GOWGANDA CONGLOMERATE, ARKOSE
QUARTZITE, GREYWACKE
ARCHEAN
5
GRANITIC and SYENITIC ROCKS, undifferentiated
GRANITE GNEISS
4
GABBRO, DIORITE
3
METASEDIMENTS, undifferentiated
2
UNDIFFERENTIATED METAVOLCANICS WITH
INTERFLOW METASEDIMENTS
1
ACIDIC TO INTERMEDIATE METAVOLCANICS
LINEAMENT, FAULT
TRIBAG MINING CO. LTD.
GEOLOGICAL MAP
of the
BATCHAWANA AREA
AFTER ONT. DEPT. MINES MAP 2108
SCALE: 1": 4 Miles
DRAWN BY : M. B.
DATE : Feb. 1968
PLATE 2

Recent geological mapping, as well as data provided by diamond drilling indicate that the west part of the belt is a far more heterogeneous complex of rocks than had originally been thought. On the Preliminary Geological maps of Townships 27 and 28, Range XIII, (Ont.Dept.Mines, 1964), the areas previously mapped as underlain by the Mamainse formation are shown as comprised of predominantly mafic to intermediate volcanics, with minor coarse grained flows or intrusive rocks. On the basis of detailed geological mapping, and examination of drill core from the Tribag property, the author estimates that these areas are underlain by approximately equal amounts of mafic volcanics, and mafic intrusives. At least 50 per cent of the intrusives are later diabase dykes, which are megascopically indistinguishable from the older, (Mamainse), diabases. The original impression that the west part of the belt was underlain chiefly by the "monotonous" Mamainse diabase was probably caused by the fact that the older diabases were the most resistant to erosion, and formed most of the hills and outcrops in the areas.

At the present state of knowledge, the geology of the greenstone belt can be briefly summarized as follows: The entire belt is a highly folded complex of metamorphosed sedimentary and volcanic rocks with associated (Mamainse) diabases, cut by swarms of late Keweenawan diabase dykes. The metasediments and the felsic metavolcanics are restricted to the east part of the belt, whereas the mafic metavolcanics with

Table 1.

TABLE OF FORMATIONS

CENOZOIC		
	Pleistocene	Glacial deposits
PALEOZOIC		
	Cambrian	Lake Superior sandstone
PRECAMBRIAN		
	Proterozoic	Felsic dykes and stocks; olivine diabase.
		Keweenawan Series: amygdaloidal basalts and associated amygdaloidal and "grey" dykes; interbedded conglomerates and minor sandstones
		Breccia pipes
		Felsic intrusions; composite dykes.
		Diabase dykes, porphyritic and non-porphyritic.
	Archean	Granites and gneisses.
		Mafic volcanics and associated intrusives and iron formations; felsic volcanics and associated arkose and greywacke.

associated iron formations predominate in the west.

2. Granitic Rocks.

The Archean greenstone belt is surrounded by large masses of granitic rocks in the north, east and south. Several granitic stocks occur in the north part of the belt. The relation between the granites and the other rocks can be observed in several places. In one locality described by Moore, (1926, p.61), "the granite is found cutting the older (Mamainse) diabase, cut by the latest dykes in the region...and overlain by the Upper and Middle Keweenawan sediments and lavas." The relationship between the granite and Archean metavolcanics can be seen on the Tribag property, approximately 1,400 feet north-northeast of the shaft. Here, in one outcrop distinct xenoliths of the metavolcanics, ranging in size from a few inches to one foot, are enclosed in the granite a short distance from the sharp contact. The contact, well defined by diamond drilling in the vicinity of the breccias, dips uniformly at 50° south.

The granites are mostly massive in structure, but may locally grade into gneisses, particularly near their contacts northeast of the Tribag property. The colour of the granite ranges from salmon-red to grey, and the texture is locally porphyritic, with coarse, round quartz phenocrysts. The mafic minerals are mainly biotite, but hornblende and pyroxene have also been noted. Several intersections of syenitic phases have been observed in diamond drill core.

These variations in structure, texture and composition raise the question as to whether the granitic masses are all of one age or whether intrusions of several ages are present, a possibility noted by McConnell, (1926), when studying an area 24 miles north of Sault Ste.Marie. Although there is so far no direct geological evidence for this, recent isotopic age determinations suggest that the granitic rocks are not as homogeneous as present geological maps would seem to imply.

A K-Ar age determination on a core sample of granite taken from a point 2,500 feet northeast of the shaft, carried out in the laboratories at McGill University, gave 1,606$\pm$ 40 million years. The next nearest sample, a granodiorite collected about 20 miles northwest of the Tribag property yielded a K-Ar age of 2,340 million years, (Lowdon, 1963). Weakly corroborative evidence of the presence of more than one intrusion of granitic rocks is provided by magnetic surveys which indicate a relatively wide range of magnetic intensities in areas shown as underlain by granitic rocks. This is also supported by the occurrence of several large outcrops of a felsic porphyry, noted by the writer during his reconnaissance mapping north of the Tribag property.

3. Keweenawan Rocks.

Diabase Dykes. The Archean rocks of the Batchawana area are cut by swarms of diabase dykes and irregular intrusions of at least two ages. The dykes, commonly attaining widths of up to 100 feet, cut the formations of the greenstone belt as well as the granites but are not found in the Keweenawan Series. Moore therefore classified them as Lower Keweenawan. From field evidence alone, however, it is impossible to say how much time elapsed between the emplacement of the dykes and the extrusion of the Keweenawan lavas.

Distinct cross-cutting relationships of two diabase dykes, both of which cut the granite, have been noted in several drill holes on the Tribag property. The dykes are indistinguishable from each other as well as from the older (Mamainse) diabase, except where containing porphyritic phases. These have been noted by the writer in several places, particularly north of the West breccia. The porphyritic phases are characterized by coarse zoisitized feldspar phenocrysts which range up to 1½ inches in diameter, and comprise 5 to 10 per cent of the rock. Geophysical surveys indicate that the dykes differ in their magnetic properties. Whereas the non-porphyritic dykes give rise to high magnetic anomalies, the porphyritic diabases are not expressed on magnetometer survey maps. Although no cross-cutting relationships have been observed directly, the outcrop pattern suggests that the porphyritic dykes are older.

Keweenawan Series. Unconformably overlying the greenstone belt and the surrounding granites are rocks commonly correlated with the "Keweenawan Series." These rocks, well exposed on the shore of Lake Superior, consist of interbedded amygdaloidal basalts and sedimentary rocks, chiefly conglomerates, with minor shales and sandstones. The estimates of the total thickness range from 8,500 feet to 17,000 feet, depending on the interpretation of the dips, and of the effects of faulting. The formations strike northwest, and dip west at an average angle of 30°, forming the east part of the great, basin-shaped Lake Superior syncline.

A sample of the Keweenawan basalts taken from the mouth of Harmony River yielded a K-Ar age of 915 ± 140 million years, (Wanless, 1966). This is comparable to the generally accepted age of the Duluth gabbro, (1,120 m.y.), which is intrusive into the Middle Keweenawan rocks, (Goldich, 1957). Paleomagnetic work on samples of volcanics from Alona Bay, (Plate 2.), however, suggests that the volcanics from that locality can be correlated with the Logan sills in the Nipigon area. This would indicate that the period of volcanic activity in the Lake Superior basin began early in Keweenawan time, approximately 1,400 million years ago, (DuBois, 1962).

An interesting feature of the Batchawana area is an amygdaloidal dyke which cuts the Breton breccia. The dyke, averaging 10 feet in thickeess, is petrographically and chemically similar to the Keweenawan volcanics, and probably represents a feeder emplaced during the last stages of the volcanic activity.

Felsic Intrusions. A number of felsic dykes and irregular intrusions occur throughout the Batchawana area. Some cut the Keweenawan Series along the shore of Lake Superior. These were described by J. E. Thompson, (1953), as fine, banded felsites, and quartz porphyries with a tendency to form contact breccias consisting of fragments of invaded rocks. These intrusives do not cut the Paleozoic sedimentary rocks, and have been therefore classed as Late Keweenawan.

On the Tribag property numerous dykes, both porphyritic and non-porphyritic, have been observed in outcrops, as well as in diamond drill core. A small stock of quartz-feldspar porphyry, weakly mineralized with molybdenite and chalcopyrite has been discovered by drilling on the Jogran property in Ryan Township, just west of Mamainse Lake. The stock has a minimum extent of 600 feet by 400 feet, and has been traced to a depth of 650 feet, (Giblin, 1966). Felsic fragments are found in the breccia pipes, and are therefore older than the breccia. The Breton breccia is cut by the previously mentioned amygdaloidal dyke, believed to be related to the Keweenawan volcanics. The volcanics, in turn, are clearly cut by the felsic dykes. Felsic intrusions of similar descriptions occur also in Michigan in the vicinity of the Keweenaw fault. The occurrence of felsitic fragments in the Copper Harbor conglomerate of Michigan indicates that the period of felsic intrusions must have begun early in Keweenawan time. It probably continued intermittently throughout the Keweenawan period, judging by the deformation of the latest known Keweenawan rocks which is attributed to the felsic intrusion, (Butler, 1929).

If this is so, and if the felsic intrusives of Michigan can be correlated with those in the Batchawana area, then the latest felsic intrusions must be younger than the Tribag breccias, and the fact that the Breton breccia is not cut by any felsic dykes must be regarded as fortuitous. This reasoning is supported by the fact that felsic porphyry dykes cut the East breccia whose age is probably the same as that of the Breton breccia.

Olivine Diabase. Intrusive into the lavas and conglomerates of the Keweenawan Series are a number of dykes of olivine diabase. The dykes are not found in the areas underlain by the Paleozoic sediments, and their mutual time relationship is therefore uncertain, (Moore, 1926).

4. Paleozoic Sedimentary Rocks.

Overlying the Keweenawan Series with an angular unconformity are patches of flatly lying or gently dipping sandstones and basal conglomerates. At Mica Bay these rocks attain a thickness of fifteen feet. The formations contain no fossils, and their age has been a matter of controversy. They were placed into the Upper Keweenawan by Moore, (1926), but later classified as Cambrian by Thompson, (1953). More recently, tho rocks have been regarded as Upper Keweenawan, and correlated with the Freda sandstone exposed in Michigan, (Hamblin, 1958). At present, the formation is considered to be Cambrian, (Giblin, personal communication).

Breccias. Irregularly distributed along the north contact of the Archean greenstone belt, in the central part of the Tribag property, is a cluster of four breccia bodies, known as the West, East, South, and Breton breccia. The breccias contain fragments of the Archean metavolcanics, granite and later diabase, as well as fragments of a variety of felsic intrusive rocks. Another breccia, resembling those of the Tribag property occurs five miles to the southwest, in the central part of the Archean belt, (Giblin, 1966).

The similarity of the breccias, and their field relationships with the adjacent rocks indicate that all were formed during the same period of disturbance. A sample of muscovite from the Breton zone yielded a K-Ar age of 1,055 $\pm$ 35 million years, (Roscoe, 1965). This age is comparable to that of the Keweenawan basalts on the east shore of Lake Superior.

Although the petrological environment, and the mineral assemblage are of a different type, it is interesting to note that the indicated age of the Breton breccia corresponds to one of the main chronological groups of carbonatite complexes in Ontario. These were dated at 125 m.y., 565 m.y., 1,075 m.y., and 1,700 million years, (Gittins et al, 1967).

<u>Structural Geology.</u>

The Lake Superior basin, long regarded as of glacial origin, has recently been considered to be the result of an ancient rift structure, (Smith et al, 1966). Kumarapeli and Saull, (1966), have traced zones of predominantly normal faulting from the St.Lawrence valley westward into the Lake

Superior region, and suggested that the carbonatite complexes north of Lake Superior may be related to the Lake Superior rift structure. Although this suggestion was later criticized, (Gittins et al, 1967), it is interesting to note that the Tribag breccias occur at an intersection of two major zones of normal faulting, (Plate 1). If the Lake Superior rift system is of Precambrian age, as is indirectly suggested by radiometric dating of some of the carbonatite complexes, then the spatial relationship of the Tribag breccias to the normal faults assumes importance. It is not suggested here that the breccias may be related to the carbonatites. It is tempting, however, to draw a parallel with the regional structural setting of some of the porphyry coppers and associated breccias in the southwestern United States, which have been postulated to lie at intersections of major lineaments.

While the above considerations are in the realm of speculation, it is certain that structurally, the Tribag breccias occur in an area characterized by normal faulting. The area is cut by three sets of faults which strike north, northeast, and northwest, (Plate 3). One major east-west fault occurs along the south boundary of the property. The north-striking faults are the most prominent, and it may be significant that these represent the only north-striking structures in the entire Batchawana area, (Plate 2). Each of the faults is characterized by fault breccia, and each is well expressed on aerial photographs.

The Breton breccia lies immediately south of an intersection between two faults. One of these strikes north, and extends southward toward the West breccia, which it probably offsets, causing a left-hand separation, (Plate 3). Its age relationship with the Breton breccia is, however, uncertain. The other fault strikes northwest, and is pre-breccia in age.

Whether or not the association of the breccias with one of more faults is significant is open to question. The idea that the breccias were formed along zones of weakness provided by intersections of extension faults is attractive, but exploration of such areas south of the Tribag property by other companies proved unsuccessful.

Folding. As with most greenstone belts, the folding in the Batchawana Archean metavolcanics and metasediments is intense. The absence of distinct marker horizons and flow structures, however, makes the determination of the folding pattern extremely difficult. In general, the foliation of the metavolcanics, as well as the contacts between the metavolcanics and diabases dip vertically or steeply south, and strike predominantly northwest. Locally, however, variations in core angle of graphitic horizons, and chlorite schists, as well as the tight folding of the iron formations, indicate that the folding pattern is complex, (Figure 1).

Figure 1. Folding in an iron formation, 1,400' southwest of the Tribag shaft.

Armbrust, (1967), noted that primary structures, as well as the foliation of the Archean volcanics are generally parallel to the granite contact, suggesting that the granite intruded concordantly. In the immediate vicinity of the Breton breccia, however, the foliation of the metavolcanics does not appear to be related to the granite contact in any particular way, (Plate 4). The parallel orientation of the foliation of the volcanics and the breccia contact in one outcrop suggests that at least in part, the emplacement of the breccia was controlled by the structure of the metavolcanics, (Figure 2).

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Figure 2. Sharp contact between the Breton breccia and the Archean metavolcanics. Note parallel orientation of the contact and foliation of volcanics.

Economic Geology.

The Batchawana area contains copper deposits of three types, (Giblin, 1966):

1. Breccia Pipe Deposits, located on the Tribag property, are cavity-filling deposits containing chalcopyrite as the principal ore mineral. Molybdenite, galena and sphalerite occur in minor quantities. The breccias are similar in character, and each is regarded as containing potential ore bodies. Of these, only the Breton breccia is currently in production.

2. Copper deposits in the Keweenawan Series are exploited by the Coppercorp Mine of Sheridan Geophysics Limited, located on the original Montreal Mining Company Sand Bay Location. The deposits are fissure-filling calcite-quartz veins controlled by faults parallel and transverse to the Keweenawan series. The principal mineral is chalcocite, with minor quantities of bornite, chalcopyrite and native copper.

The Keweenawan volcanics also contain minor amounts of native copper in fragmental flow tops and in amygdules, but these have not proved to be economic so far.

3. A porphyry copper type of deposit has been outlined on the Jogran property, west of Mamainse Lake. It consists of minor quantities of disseminated chalcopyrite and molybdenite in a quartz and feldspar porphyry stock.
The average grade of the deposit is too low to be economic at present.

In addition to the copper deposits, the Batchawana area contains a number of iron formations associated with the Archean metavolcanics. Several uranium showings occur in the north part of the area, near the shore of Lake Superior. None of these deposits have proved to be of economic proportions so far.

GEOLOGY OF THE MINE AREA

The property of the Tribag Mining Company Limited lies along the north contact of the northeast-trending greenstone belt, (Plate 2). The contact between these Archean rocks and the granites to the north trends in a N50°E to N60°E direction, and bisects the property into equal parts. The area under consideration straddles the contact, and occupies the central part of the property*.

The oldest rocks in the area are steeply-dipping metavolcanics with minor interbedded iron formations. Intrusive into them are irregularly distributed masses of (Mamainse) diabase and gabbro, locally grading into diorites. These are cut by batholithic masses of granites in the north. The granites are in turn cut by Keweenawan diabases, and felsic dykes. Irregularly distributed along the granite contact are four breccia bodies which contain fragments of all the above-noted rocks. The youngest consolidated rock in the area is the amygdaloidal dyke which cuts the Breton breccia.

PETROLOGY.

Metavolcanics.

The metavolcanics in the mine area are mafic rocks, dark green in colour, aphanitic to fine grained, and generally

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* The base line of the mine grid system strikes N60°E, roughly parallel to the granite contact. All mine maps and sections included in this thesis are base on this grid. It should be noted that the grid north lies 30° west of true north.

massive to slightly foliated. Pillow structures are rare, and have been observed in only few outcrops, particularly half-way between the Breton and East breccias.

In the field, the metavolcanics are characterized by extensive epidote alteration, which forms streaks and patches, and peculiar rounded structures, up to 10 mm in diameter. These "eyes" commonly contain specks of chalcopyrite with associated carbonate, and may represent remnants of amygdules.

In most thin sections foliation of the rock is marked by sub-parallel orientation of hornblende shreds, which make up about 60 per cent of the rock. The hornblende grains, partly altered to chlorite, average 0.2 mm in length, rarely exceeding 0.5 mm, except in sheared phases, where they form coarse, euhedral crystals. The pleochroism of the hornblende is X = yellowish green, Y = pale green, and Z = dark green. Plagioclase, comprising about 30 per cent of the rock, is present in fine, anhedral grains, rarely forming subhedral laths. It is partly replaced by sericite, and its composition could not be determined. In coarser grained phases of the rock indistinct ophitic texture may sometimes be observed in thin sections as well as in hand specimens. In these cases the metavolcanics can be distinguished from diabase only if pillow structures are present.

Fine grained epidote is distributed throughout the rock, forming streaks parallel to the preferred orientation of the amphibole. Minor secondary quartz and calcite with associated fine grains of magnetite are usually concentrated near late quartz stringers.

Several sheared tuffaceous layers have been noted by the writer north of the East breccia. The tuffs average six to seven feet in thickness, and can be traced over several hundreds of feet.

Iron Formation.

Although iron formations are common in the Batchawana area, only one small remnant has been found in the vicinity of the breccias. It occurs about 1,400 feet southwest of the shaft in contact with granite. The iron formation is highly folded, (Figure 1), and consists of beds of magnetite averaging 0.5 inches in width, interlayered with thicker beds of cherty rock. It has not been studied under the microscope.

Granite.

In the mine area, the granite is a pale grey rock, grading to pink, and locally salmon-red, (Figure 3). The rock has a medium grained, hypidiomorphic granular texture with local porphyritic phases characterized by medium to coarse, round, anhedral grains of quartz, which range in size up to 6 mm.

Microscopic examination of fifteen thin sections showed a considerable range in the relative amounts of the rock-forming minerals, (Table 2). The main constituents are plagioclase and quartz. Microcline is present only in some specimens. In the vicinity of the mine, biotite was the only

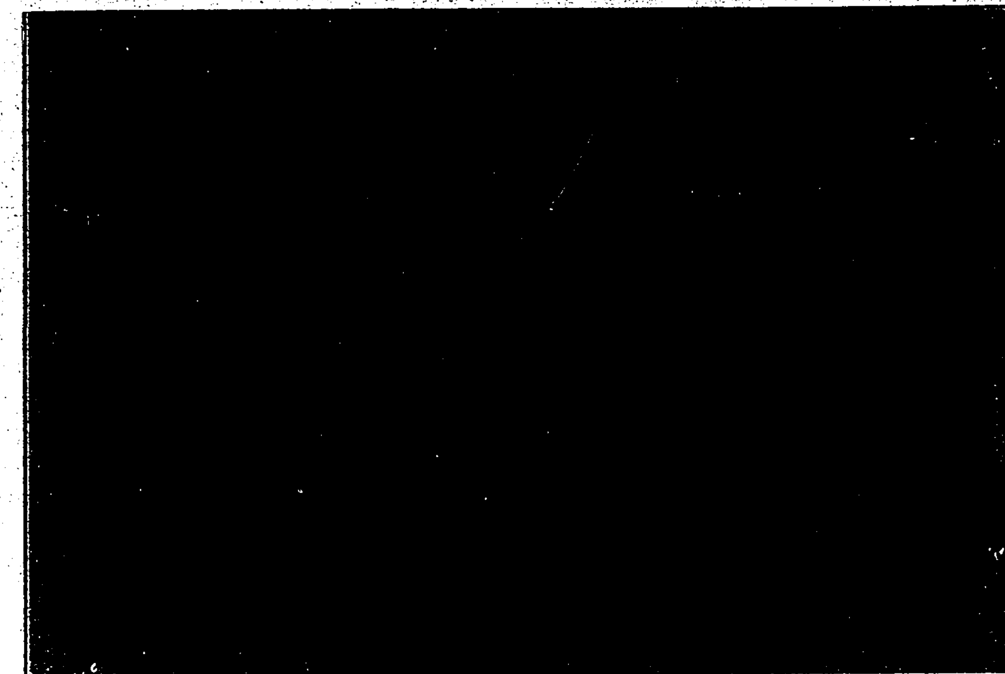


Figure 3. Granite near the shaft on the 1,050 level.

Figure 4. Granite, plane light, x4.

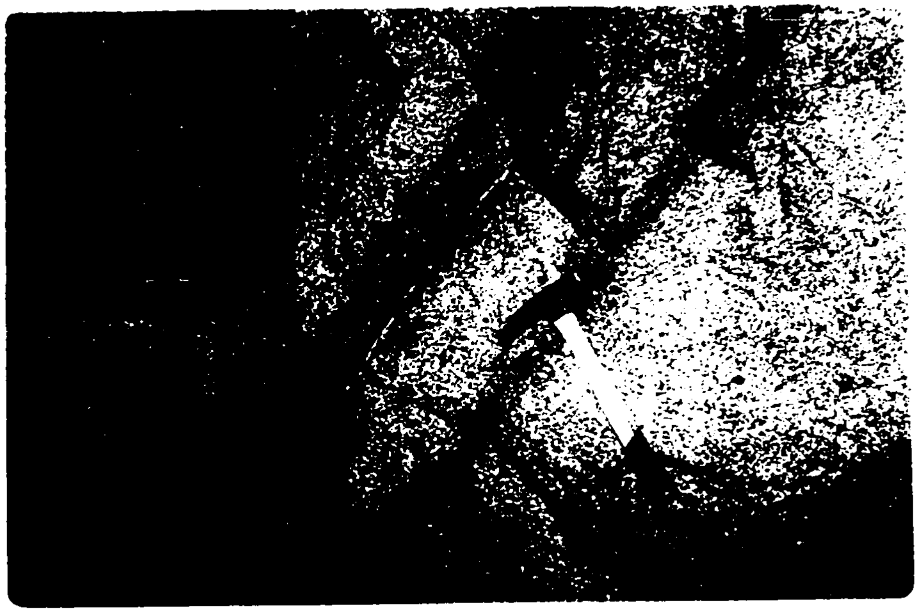


Figure 3. Granite near the shaft on the 1,050 level.

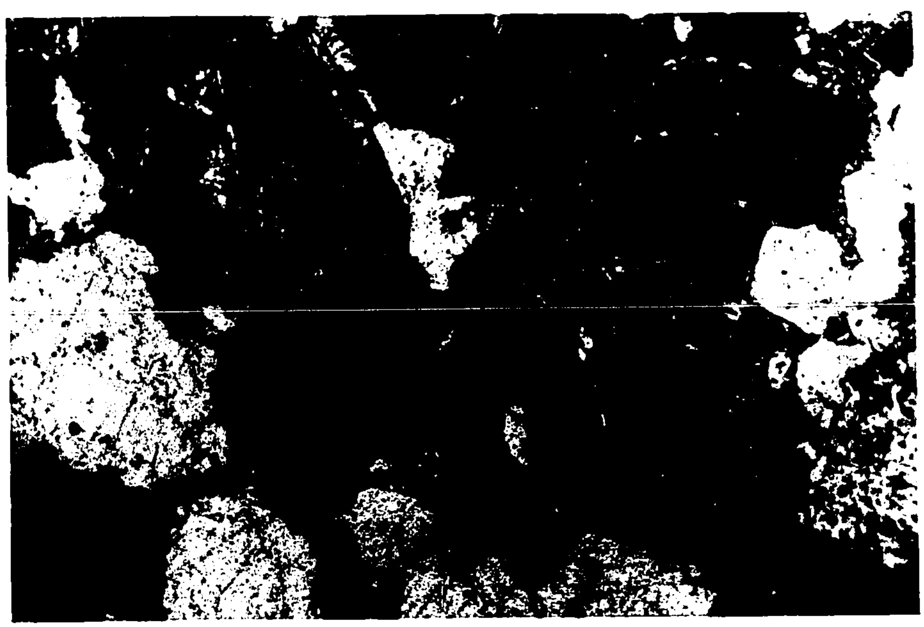


Figure 4. Granite, plane light, x4.

primary ferromagnesian mineral. Epidote and sphene are accessory minerals. Traces of disseminated pyrite occur locally.

Plagioclase. Universal stage determinations of the anorthite content indicate an average composition of An12 to An13. The plagioclase grains are anhedral to subhedral, show well developed albite and carlsbad twinning, and range in size from 0.5 to 4 mm. An interesting feature of the plagioclase is the high sericite alteration concentrated in the central part of the grains. Along the rims the sericite is absent, leaving distinct rims of clear, white plagioclase. Armbrust, (1967), noted that the anorthite content of the rims shows a decrease to An2.

Quartz occurs interstitially between the plagioclase crystals as anhedral grains ranging in size from 0.1 mm to 5 mm in diameter. A few of these show undulatory extinction.

Microcline, when present, occurs interstitially between euhedral plagioclase crystals. Grains range in size from 0.20 to 2 mm, and are easily identifiable by typical twinning. (Figure 5).

Biotite occurs as shreds and subhedral crystals ranging in size from 0.1 to 2 mm. The mineral is strongly pleochroic with a formula X - yellow, and Y = Z - reddish brown. In all specimens the biotite is partly replaced by chlorite which shows an anomalous blue interference colour.

Table 2.

Modal Analyses of Granite

	2865	6	469	101	102	103	104	105	106	107	108	109
Quartz	35.3	36.5	32.0	19.3	29.2	38.0	22.1	28.6	25.8	22.0	31.1	24.9
Plagioclase	49.7	49.6	48.5	46.9	57.7	51.1	59.2	59.3	55.7	59.4	50.1	73.6
K-feldspar	9.2	7.4	11.2	20.2	---	4.3	8.6	4.7	12.2	15.0	15.1	---
Biotite	2.0	2.4	----	10.4	9.5	4.3	7.6	6.1	6.0	3.2	3.5	0.7
Chlorite	2.4	1.6	8.0									
Epidote	1.0	2.5	----	2.8	3.6	2.3	1.8	0.9	----	0.2	----	----
Pyrite	0.4	----	----	0.4	----	----	0.7	0.4	0.3	0.2	0.2	0.1

Note: Modal analyses of samples 2865, 6, and 469 were done by the writer.

Modal analyses of samples 101 to 109, inclusive, are by Armbrust, (1967).

Sample locations are entered in Table I in the Appendix.

Figure 5. Microcline in the Tribag granite: X-nicols, x4.

Red Alteration of the Granite. The red colour of the granite is restricted to the immediate vicinity of fractures, (Figure 3). Near the mine, where fractures are abundant, the red alteration halos coalesce, and the granite is uniformly red in colour. Numerous outcrops of red granite have also been noted, however, at considerable distances from the Breton breccia, and it is doubtful that the colour could be used as a guide in exploration for breccia pipes.

Microscopic examination of the granite shows that the red colour is due to staining of the plagioclase grains by hematite, which is restricted to the centres of the grains, leaving the rims clear, (Figures 6 and 7). Microcline has not been affected by the hematite alteration.

Armbrust, (1967), believes that the clouding of the plagioclases occurred during regional metamorphism of the granite,

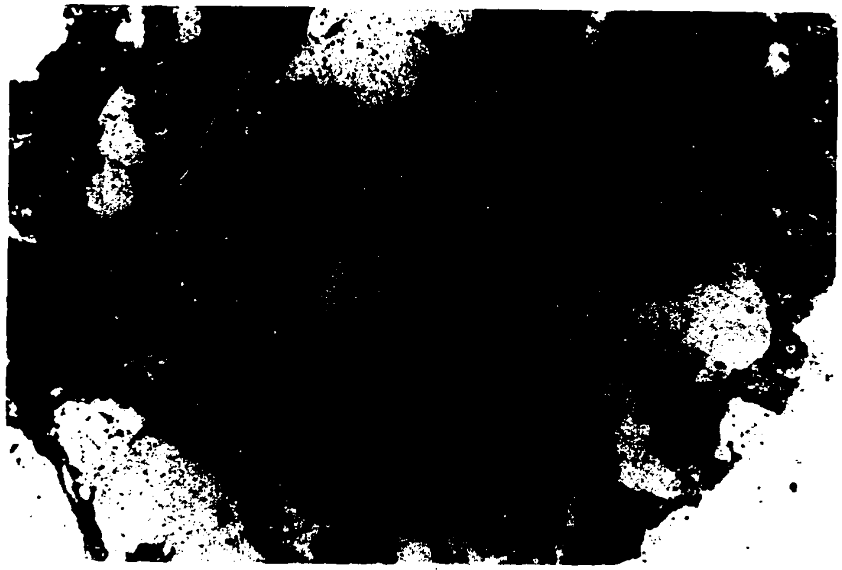


Figure 6. Granite with red, hematite alteration of plagioclase. Note clear, narrow rims of the plagioclase grains. Plane light, x 7.

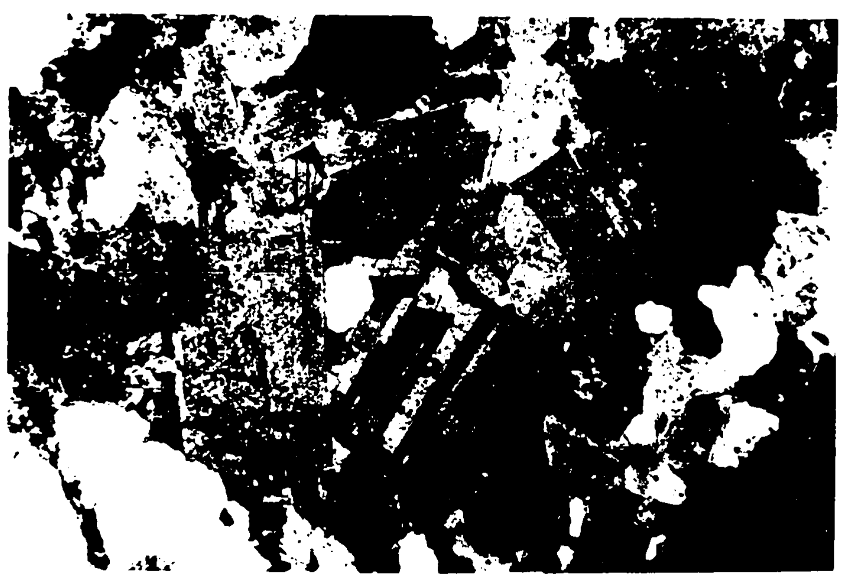


Figure 7. Granite, same as in Figure 6, but with crossed nicols, x 7.

and that the iron was freed during the breakdown of primary ferromagnesian minerals.

The fact that the red alteration is restricted to the vicinity of fractures, however, suggests an external rather than an internal source of the iron.

Classification of Granite. Modal analyses of the granite are given in Table 2. C.I.P.W. norms and complete chemical analyses are shown in Tables 3 and 4, respectively.

The granite is mineralogically and chemically similar to trondhjemite, and has been so classified by Armburst, (1967), on the basis of feldspar ratios.

Table 3

C.I.P.W. Norms of Granite
(in weight per cent)

	2865	2868
Q	36.1	25.2
or	14.5	14.0
ab	31.0	48.0
an	10.0	3.5
C	3.8	2.8
mt	0.6	0.3
en	1.8	3.0
fs	1.2	1.6
il	0.4	0.4
cc	0.4	1.0
py	0.3	0.3

2865 - Grey, fresh granite, (1,200 level near shaft)

2868 - Red, fresh granite, (DDH V-30 @ 700'; 10,800E)

Table 4.

Chemical Analyses of Granite

	2868	2865	M-1	Trondhjemite
SiO_2	71.0 %	74.0 %	68.0 %	69.30 %
Al_2O_3	15.2	15.4	13.9	16.81
Fe_2O_3	0.31	0.50	0.03	0.28
FeO	1.48	1.35	3.45	1.26
MgO	1.09	0.62	3.16	1.08
CaO	1.22	2.25	0.68	3.30
Na_2O	5.32	3.45	0.16	6.00
K_2O	2.35	2.45	6.02	1.39
H_2O+	0.48	0.84	2.65	0.50
H_2O-	0.18	0.12	1.27	----
CO_2	0.35	0.15	0.02	0.15
TiO	0.26	0.27	0.17	0.23
P_2O_5	0.06	0.06	0.10	0.03
S	0.10	0.12	0.36	
MnO	0.03	0.03	0.04	Tr
Total	99.43	101.61	100.41	100.37
Ba	300 ppm	800 ppm	200 ppm	
Sr	200	600	30	
Cr	10	20	10	
Co	20 -	40	30	
Ni	60	40	20	
Cu	800	200	800	
Pb	10	10	10	
Zn	100	100 -	100	
Ag	2	2	5	
Sn	10	10 -	10	
Mo	20 -	20 -	200	
Ga	30	40	30	
V	50	50	50	
Zr	200	100	100	
S.G.	2.63	2.65	2.63	

2868 - Red, fresh granite, (DDH. V-30 @ 700'; 10,800E)
2865 - Grey, fresh granite, (1,200 level, near shaft)
M-1 - Highly altered granite, (DDH. V-32 @ 500'; 10,900E)
Trondhjemite - Trondhjem, Norway, (Turner and Verhoogen, 1960)

Diabase.

Three diabase dykes occur in the immediate vicinity of the mine, (Plate 4). The dykes are pre-breccia in age, and their fragments are contained in the breccia pipe.

One of the dykes occurs 320 feet east of the shaft, and is found on every level of the mine. It strikes N30°W, dips uniformly 80° west, and has an average thickness of 40 feet. Its contact with the breccia is gradational, and near mineralized zones is cut by fractures, filled by pyrite and chalcopyrite (Figure 8).

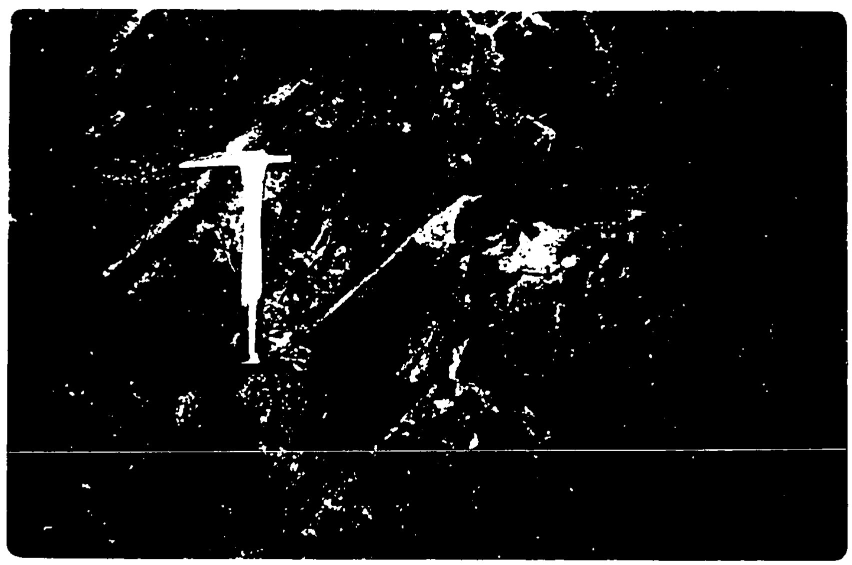


Figure 8. Diabase dyke in contact with breccia on the 625 level. Note the transition from fractured to brecciated diabase.

The second dyke outcrops 1,150 feet east of the shaft, where it attains a width of 130 feet. The dyke strikes N30°W, and is cut sharply by the eastern extremity of the breccia.

The third dyke outcrops 150 feet north of the shaft. It strikes N45°E, dips steeply to the south, and is cut by the central part of the breccia.

The diabase dykes are dark grey in colour, medium grained, and have a well defined ophitic texture. The rock is generally massive and fresh, and shows distinct chilled margins. It consists of 50 per cent plagioclase, 25 to 30 per cent augite, partly altered to hornblende, and occasional grains of quartz and biotite. The plagioclase forms well-twinned, euhedral and subhedral laths, averaging two millimeters in length. U-stage measurements indicated a range in composition from An_{46} to An_{52}. The augite occurs interstitially

Figure 9. Diabase, crossed nicols, x4.

between the plagioclase grains. It is commonly twinned, and has an extinction angle of $c \wedge Z = 50°$.

Felsic Intrusives.

Felsic dykes are widely distributed in the entire Batchawana area. In the vicinity of the mine, a number of felsic dykes have been encountered in diamond drilling, but only a few have been noted in outcrops. The felsic dykes cut the granite and diabases, and their fragments are found within the breccia pipes. The dykes range in width from a few inches to several feet.

All of these dykes are pink in colour, but show a wide range in texture and composition. A petrogrographic study of these rocks to permit detailed comparison with the felsites that cut the Keweenawan series, and with the mineralized porphyry stock on the Jogran property, would be a worth while project. At this time only brief descriptions of the three most common rock types will be presented.

1. Felsites are pink, aphanitic, siliceous rocks, consisting predominantly of plagioclase and quartz, with lesser amounts of potash feldspar, and minor chlorite and epidote. The felsites are mostly equigranular, but plagioclase and quartz show a tendency to form coarser grains, thus providing a complete range from felsites to felsophyres. As with the granite, the pink colour of these rocks is the result of staining of the feldspars by fine hematite.

2. Felsophyres are more abundant than felsites. On the basis of the composition of the phenocrysts, three main types are distinguished. These are quartz felsophyres, feldspar felsophyres, and quartz-feldspar felsophyres, (Figures 10 and 11). The phenocrysts are embedded in an aphanitic matrix which is composed of approximately equal amounts of quartz and feldspar, with minor biotite and epidote.

Plagioclase phenocrysts are mostly euhedral, and range in size up to 7 or 8 millimeters. In some dykes they show distinct oscillatory zoning with the composition ranging from An20 to An45, (Figure 11). Quartz forms anhedral, rounded phenocrysts, averaging 2 millimeters in diameter. The felsophyres, as well as the felsites, commonly contain up to 10 per cent finely disseminated pyrite, and traces of magnetite.

Table 5 shows a comparison of the chemical compositions of a quartz-feldspar felsophyre and a composite sample of felsites collected from various locations in the Keweenawan series. The felsophyre has a lower silica content, and is higher in Al_2O_3, FeO, MgO, CaO, as well as in Na_2O, and K_2O. Considering the great variety of the felsic intrusives in the Batchawana area, however, a great number of chemical analyses would be required before significant comparisons of the various rock types could be made.

3. Aplite. Several aplitic dykes, averaging a few inches in width have been noted in diamond drilling. The aplites are pink, and differ from the felsites and felsophyres

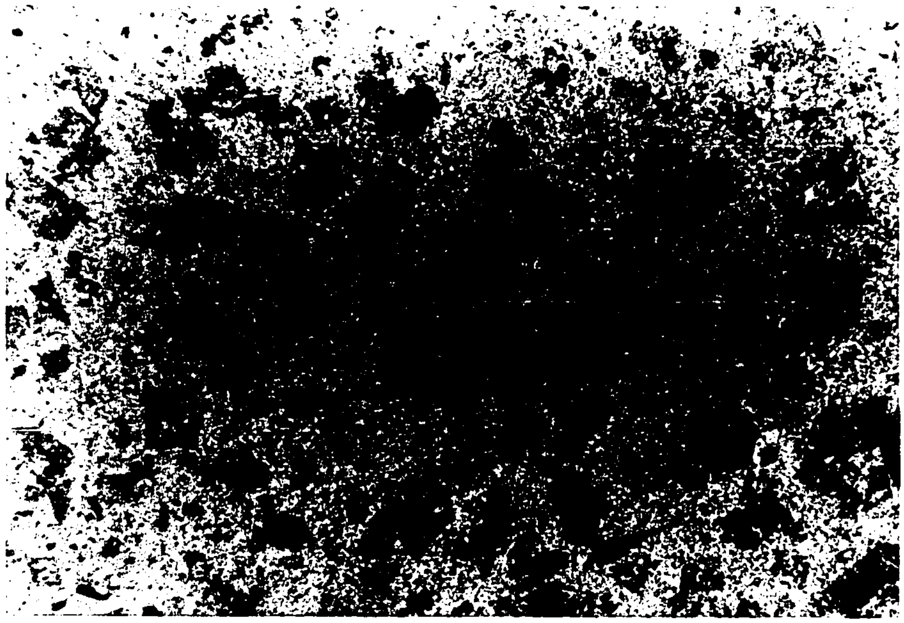


Figure 10. Feldspar felsophyre, plane light, x 4.

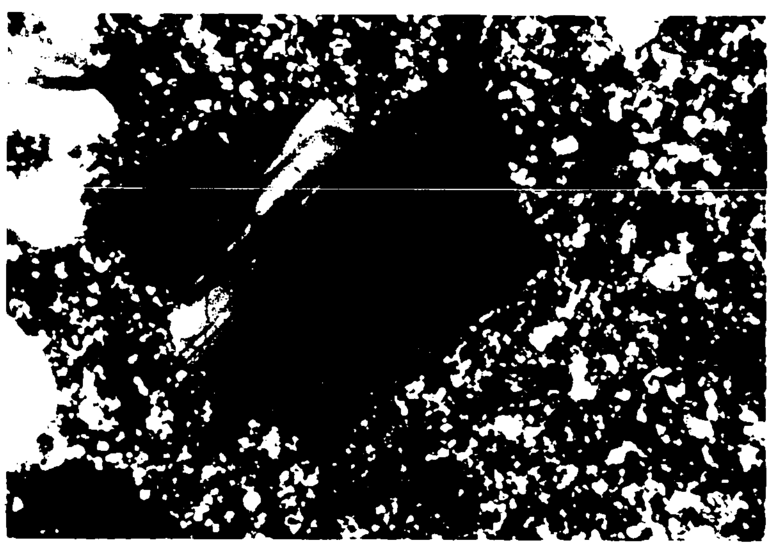


Figure 11. Zoned plagioclase in a quartz-feldspar felsophyre; crossed nicols, x 7.

Table 5.

Chemical Analyses of a Porphyry Dyke and Keweenawan Felsites.

	Porphyry Dyke (2878)	Keweenawan Felsites
SiO_2	71.0 %	77.50 %
Al_2O_3	15.2	13.46
Fe_2O_3	0.64	0.58
FeO	1.58	0.82
MgO	1.49	0.01
CaO	0.78	1.05
Na_2O	3.55	0.50
K_2O	5.88	2.82
H_2O+	0.66	2.90
H_2O-	0.11	0.40
CO_2	0.30	0.70
TiO_2	0.18	0.09
P_2O_5	0.07	0.04
S	0.31	
MnO	0.03	0.06
Total	100.88	100.93

2878 - Porphyry dyke from drill hole V-65, at 295.0'. Location: 12,300E, 10,460N, (Plate 4).

Keweenawan Felsites - A composite sample of felsites taken from 6 locations near the shore of Lake Superior, (Thompson, 1953).

by a coarser, typically sugary texture. No thin sections of these rocks have been prepared.

Composite Dykes.

Two remarkable dykes occur in the immediate vicinity of the Breton breccia. They are parallel in attitude, and occur 900 feet and 1,150 feet east of the shaft, respectively. The dykes strike N15°W, and dip uniformly at 50° west. They have been traced by diamond drilling over a strike length of 1,300 feet, and to a depth of 1,200 feet.

Each of the dykes is composed of a pink, siliceous member sandwiched between two identical, mafic dykes. The composite width of the dykes averages 20 feet, with the inner part ranging from a few inches to 8 feet. In several places the felsic dyke cuts across the upper mafic dyke, and extends over a limited distance as a separate single dyke.
The contact between the central and outer dykes is sharp but not chilled. On the 1,200 level the felsic dyke contains a number of rounded xenoliths of the mafic dyke, which average 3 - 4 inches in diameter.

The central dyke is a quartz porphyry consisting of rounded, anhedral quartz phenocrysts and anhedral green spots embedded in an aphanitic matrix. Under the microscope, the matrix is seen to be composed of approximately 60 per cent feldspar, mainly plagioclase with minor potash feldspar, and of 40 per cent quartz, with approximately 2 - 3 per cent chlorite showing anomalous blue interference colours. The green spots represent clusters of fine epidote crystals. The rock contains 2 - 3 per cent of disseminated pyrite.

The outer, mafic dykes show a well developed ophitic texture, with narrow laths of plagioclase averaging 3 millimeters in length, and ranging in composition from An48 to An50. Interstitial to the plagioclase is fine, green amphibole, almost completely altered to chlorite, and minor amounts of biotite and quartz. The rock is strongly magnetic, containing 10 - 12 per cent fine magnetite grains. It is megascopically distinguishable from other diabases by peculiar, fine, rounded grains of a reddish mineral, which occurs sparsely, but consistently throughout the rock, at an average frequency of three to four grains in one square foot. They were not found in thin sections.

Dykes of this type are usually regarded as products of a multiple intrusion of two or more magmas, or as a result of a separation of two magmas in place, either by the processes of differentiation or by liquid immiscibility. The cross-cutting relationships between the outer and inner members of the dyke, as well as the occurrence of xenoliths of the mafic dyke in the central, felsic member clearly indicate that the individual dykes were intruded in succession, and that the central dyke is younger. The remarkable spatial relationship of the two rock types can best be explained by postulating that the intrusion of the younger dyke was controlled by a zone of weakness in the central part of the mafic dyke.

Figure 12. Composite Dyke; outer, mafic member. Plane light, x7.

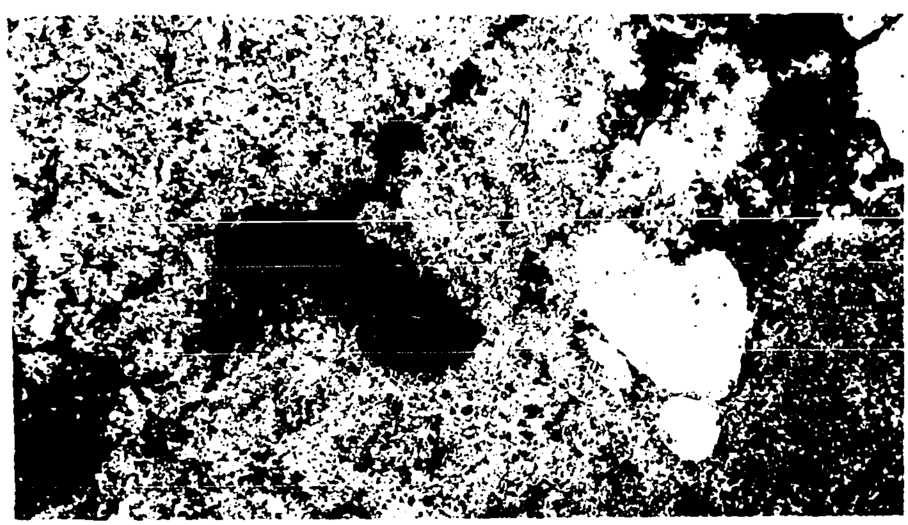


Figure 13. Composite Dyke; inner, felsic member. Plane light, x7.

Such a zone could have been present in the form of the unconsolidated core of the basic dyke which was still in the process of cooling at the time of the intrusion of the felsic dyke. This would account for the absence of chilled margins in the younger dyke.

One of the problems concerning the origin of dykes of this type, is the genetic relationship of the two types of magma which intruded into the same fracture within a relatively short period of time. Two views are generally advanced. According to one, both rock types are differentiates of a single parent magma. The opposing view is that the two rock types are the products of two entirely separate magma chambers which existed at approximately the same time. In the case of the composite dykes described here, the second theory has more merit, considering that it is unlikely that one magma could differentiate into two chemically entirely different rock types within a short period of time, (Table 6).

The composite dykes provide easily recognizeable markers from which the position of their fragments within the breccia pipe can be used to deduce the amount and the sense of movement within the breccia. Another important fact is that the dykes do not show any offsetting across the breccia pipe. These relations will be discussed in some detail in the last chapter dealing with the origin of the breccia pipe.

<u>Amygdaloidal Dyke.</u>

The amygdaloidal dyke is one of the most remarkable geological features of the Tribag property. The dyke strikes

Table 6.

Chemical Analyses and Norms of the Composite Dyke.

	2866	2871
SiO_2	51.5 %	74.7 %
Al_2O_3	15.6	14.0
Fe_2O_3	3.80	0.20
FeO	8.26	1.17
MgO	5.26	0.56
CaO	7.43	0.90
Na_2O	2.16	2.16
K_2O	1.50	6.80
H_2O+	1.50	0.43
H_2O-	0.08	0.09
CO_2	0.10	0.25
TiO_2	1.88	0.16
P_2O_5	0.01	0.04
S	0.16	0.04
MnO	0.20	0.02
Total	99.44	101.52
Ba	100	4000
Sr	600	100
Cr	100	10
Co	100	20
Ni	100	60
Cu	200	1000
Pb	10	20
Zn	100-	100
Ag	1-	5
Sn	10	10
Mo	20-	20-
Ga	30	30
V	300	30
Zr	300	200
S.G.	2.93	2.60

	2866	2871
Q	8.2	30.7
or	9.5	40.5
ab	20.0	19.5
an	24.5	3.0
C		2.1
wo	5.4	
mt	4.2	0.2
en	15.2	1.6
fs	7.5	1.1
il	2.8	0.2
cc	0.2	0.6
py	0.5	0.8

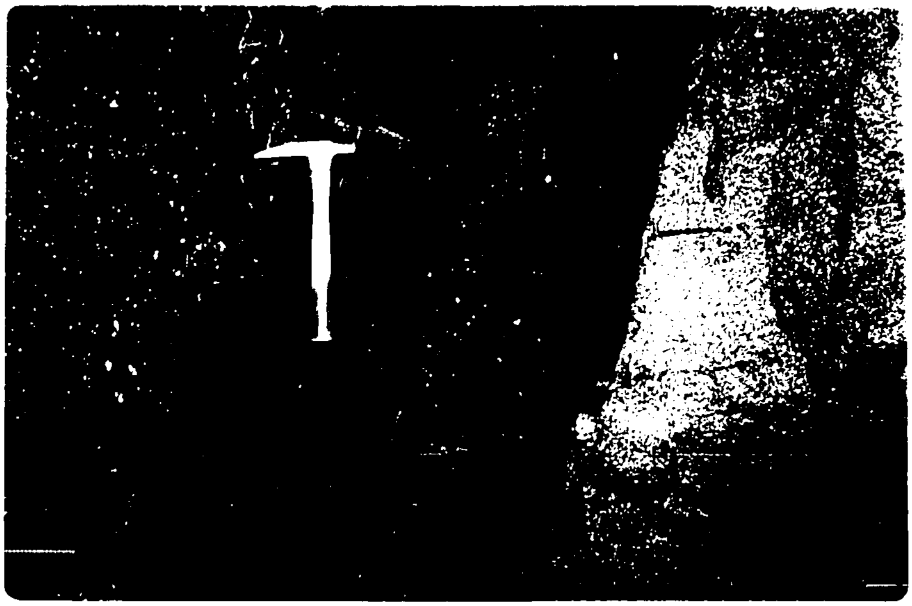
2866 - Mafic, outer member of composite dyke

2871 - Felsic, central member of composite dyke due north, and ranges in dip from 58° to 85° west, changing to 60° east on the 1,200 level. It occurs on every level of the mine, near the shaft where it cuts the granite, (Figure 14).

Figure 14. Amygdaloidal dyke cutting the granite on the 375 level.

and the diabase dykes, and extends to the north, cleanly cutting across the entire breccia pipe. The dyke ranges in width from 4 to 12 feet, and has several branches that gradually narrow down and pinch out a short distance from the main dyke.

Within the breccia, the dyke cuts indiscriminately across rock fragments as well as across the quartz-carbonate matrix. The contacts are sharp, and are marked by distinct chilled margins, paler in colour that the central part of the dyke. The due north, and ranges in dip from 58° to 85° west, changing to 60° east on the 1,200 level. It occurs on every level of the mine, near the shaft where it cuts the granite, (Figure 14).



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Within the breccia, the dyke cuts indiscriminately across rock fragments as well as across the quartz-carbonate matrix. The contacts are sharp, and are marked by distinct chilled margins, paler in colour that the central part of the dyke. The chilled margins locally contain narrow carbonate veinlets that follow the contact for considerable distances.

The dyke is characterized by the presence of round amygdules ranging in diameter from 1 to 12 millimeters. The amygdules are largest, and most abundant in the central part of the dyke, where they constitute as much as 20 per cent of the rock. They consist mainly of calcite, but some are filled with a pistachio green, soft, chloritic mineral, identified by the writer as thuringite, ($8FeO.4(Al,Fe)_2O_3 6SiO_2.9H_2O$), a mineral common in the Lake Superior region of Michigan.

In several places, particularly on the 375 level of the mine, the dyke appears to consist of three separate intrusions, (Figure 14). The central part is stained red by hematite, and contains abundant amygdules. The outer parts average 2 feet in width, are dark grey in colour, and contain relatively few amygdules which are concentrated in a zone about 10 inches from the granite contact. The contacts between the individual parts of the dyke are sharp and irregular, and contain no chilled margins.

The dyke has a distinct ophitic texture. Euhedral to subhedral laths of plagioclase are enclosed by augite, chlorite, and biotite, (Figure 15). The plagioclase laths range in length from 0.2 to 1 millimeters, and U-stage determinations indicate an average composition of An_{48}. The dyke is strongly magnetic, containing 10 per cent of fine grained magnetite grains. A modal analysis of the rock is presented in Table 7.

Figure 15. Amygdaloidal dyke; plane light, x4.

Table 7.

Modal Analysis of the Amygdaloidal Dyke.

Plagioclase	48.7 per cent
Augite	14.5 per cent
Chlorite	15.9 per cent
Magnetite	9.9 per cent
Biotite	10.8 per cent

In addition to the amygdules, the dyke contains coarse, reddish inclusions of feldspar up to one inch in diameter. No thin sections showing these inclusions have been observed by the writer, but Armbrust, (1967, p. 40), identified them as microcline, and suggested, that they are residua from granite fragments, after resorption of plagioclase and quartz by the mafic magma.

The dyke is petrographically similar to the Keweenawan amygdaloidal flows that outcrop on the east shore of Lake Superior, and probably represent one of the feeders. A complete chemical analysis of the rock is presented in Table 8. This shows it to be similar to the Keweenawan volcanics except for its higher potash content. This may be partly due to microcline inclusions mentioned above.

Grey Dykes.

A number of fine grained, grey dykes occur both inside as well as outside of the Breton breccia. The dykes range in thickness from a few inches to over 12 feet, and cut the granites, locally enclosing large, angular blocks of the intruded rock, (Figures 16 and 17). Inside the breccia pipe, they appear to have squeezed their way between the rock fragments without cutting across them. The grey dykes show important structural relationships with the ore zones in the Breton breccia. These will be discussed in a separate paragraph in the chapter dealing with economic geology.

Megascopically, the dykes resembles the chilled margins of the amygdaloidal dyke, and can be distinguished from it only by the presence of euhedral pyrite cubes, concentrated in layers in the central parts. The pyrite cubes range in size from a fraction of a millimeter to almost one inch, and in several places in the mine, particularly on the 625 level, at 10,390E, 10,215N, in the vicinity of ore, they make up as much as 30 per cent of the rock.

Under the microscope, the dykes show a great variety of textures and compositions. In most thin sections the texture is ophitic, with fine laths of plagioclase and interstitial chlorite, (Figure 18). The laths range in length from 0.1 to 1.0 millimeters, and show a preferred orientation sub-parallel to the attitude of the dyke. Occasional subhedral plagioclase phenocrysts with a composition of An_{70} are present in the rock.

In other thin sections, the rock has a pseudoporphyritic texture characterized by anhedral grains of quartz, and clusters of fine epidote crystals, (Figure 19). Elsewhere, particularly on the 225 sub-level, in the vicinity of late fractures, the rock is completely chloritized, and contains large growths of secondary quartz crystals which attain up to two inches in length.

A complete chemical rock analysis of the grey dyke is presented in Table 8. The rock is chemically comparable to the amygdaloidal dyke and to the Keweenawan amygdaloidal flows to which it is probably related. However, considering the great textural and mineralogical variety indicated by microscopic examinations of relatively few thin sections, an analysis of one specimen may be misleading.

Figure 16.

Grey dyke intruding granite on the 1,050 level. Note large granite blocks enveloped by the dyke. (Photo by Giblin)

Figure 17.

Grey dyke intruding granite on the 1,050 level. Note control of the dyke by fractures. (Photo by Giblin)

Figure 18. Grey dyke; ophitic texture with parallel orientation of plagioclase laths, and plagioclase phenocrysts; plane light, x 46.

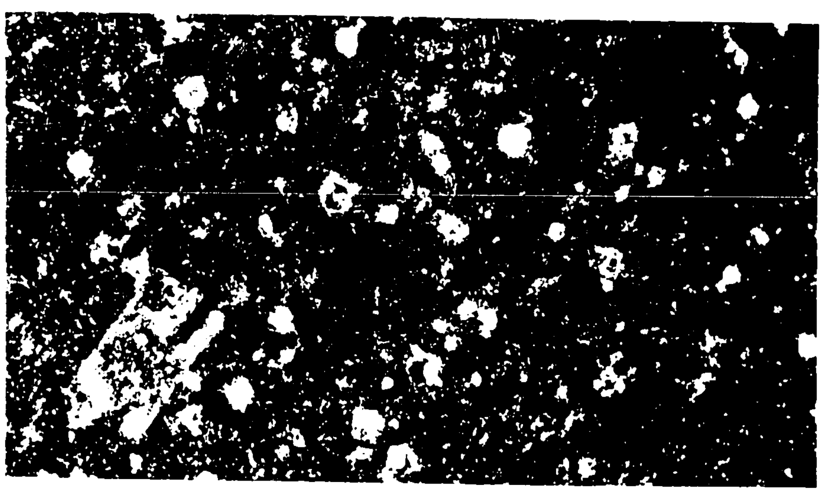


Figure 19. Grey dyke; pseudoporphyritic texture with grains of secondary quartz; plane light, x 7.

Table 8.

Chemical Analyses of Amygdaloids and Grey Dyke.

	Amygdaloidal Dyke (2869)	Amygdaloidal Volc.	Amygdaloidal Volc.	Grey Dyke (2870)
SiO_2	48.3 %	41.94 %	41.62 %	47.1 %
Al_2O_3	17.0	17.33	12.44	15.9
Fe_2O_3	3.43	2.87	10.82	3.00
FeO	5.55	6.28	2.51	8.14
MgO	2.16	5.40	4.55	5.06
CaO	7.57	9.76	9.74	8.24
Na_2O	3.18	3.79	4.48	1.83
K_2O	5.24	0.75	1.05	1.62
H_2O+	1.86	4.24	2.37	3.26
H_2O-	0.42	0.35	0.35	0.19
CO_2	4.25	5.41	7.25	3.24
TiO_2	1.51	2.30	2.06	2.14
P_2O_5	0.32	0.23	0.23	0.01
S	0.11			0.26
MnO	0.13	0.48	0.24	0.17
Total	101.03	101.13	99.71	100.10
Ba	2000 ppm6	300 ppm		300 ppm
Sr	1000			500
Cr	10			50
Co	100			100
Ni	60			100
Cu	200	200 ppm	100 ppm	200
Pb	10			10
Zn	100			100
Ag	2			1-
Sn	10-			10
Mo	20-			20-
Ga	20			30
V	400			300
Zr	200			300
S.G.	2.76			2.83

Analyses of the amygdaloidal volcanics: Thompson, (1953).

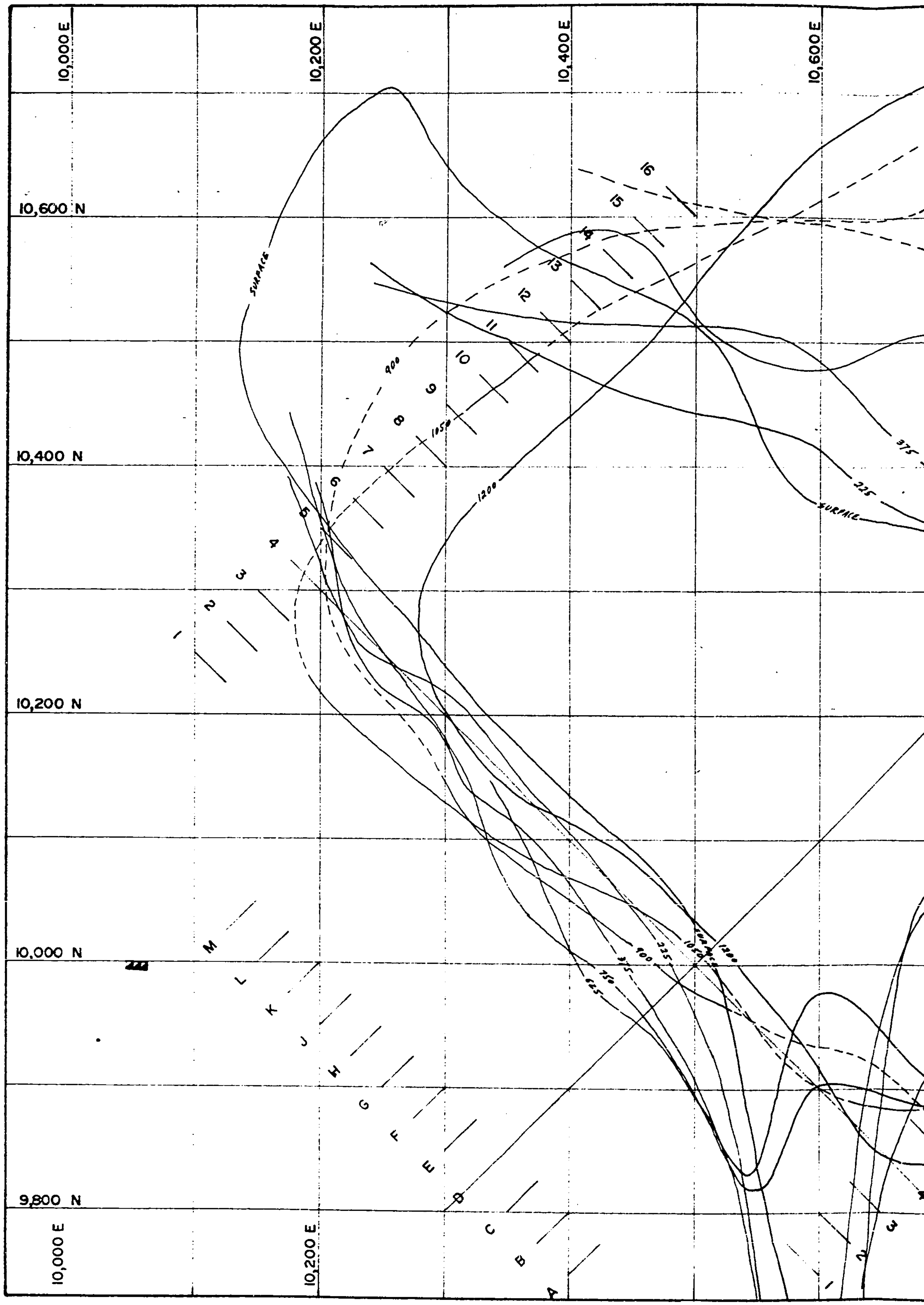
GEOLOGY OF THE BRETON BRECCIA

Structure.

The Breton breccia is a heterogeneous mixture of a variety of rock fragments embedded in a matrix composed primarily of coarsely crystalline quartz and carbonate. It forms a pipe-like body, underlying an area 1,350 feet in length, with an average width of 250 feet. Its outline in horizontal sections changes from an elongated oval on the surface to a more circular outline on the 1,200 level, (Plate 5). The depth of the breccia is unknown. It has been encountered to a depth of at least 1,600 feet, and the comparison of the surface plan area, (340,000 square feet), with the area on the bottom level, (350,000 square feet), does not indicate bottoming out.

Despite the relatively large amount of surface and underground drilling, the exact shape of the breccia is not well known. Although its full limits appear to have been determined on the surface and on the bottom level, several irregularities in its shape suggest that at some horizons the breccia may extend over greater areas than is presently known.

The most prominent of these irregularities is an apparent "protrusion" of the breccia to the south, as indicated by underground drilling on sections 10,550E, and 10,600E, (Plate 4). The east-west extent of this protrusion is yet to be determined. A second, and equally significant irregularity is the widening of the breccia to the north, indicated on section 10,800E. It is not yet known whether this is due to the flatt-


10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
SURFACE
900
1050
1200
375
225
750
625
1
2
3
4
5
6
7
8
9
10
11
12
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14
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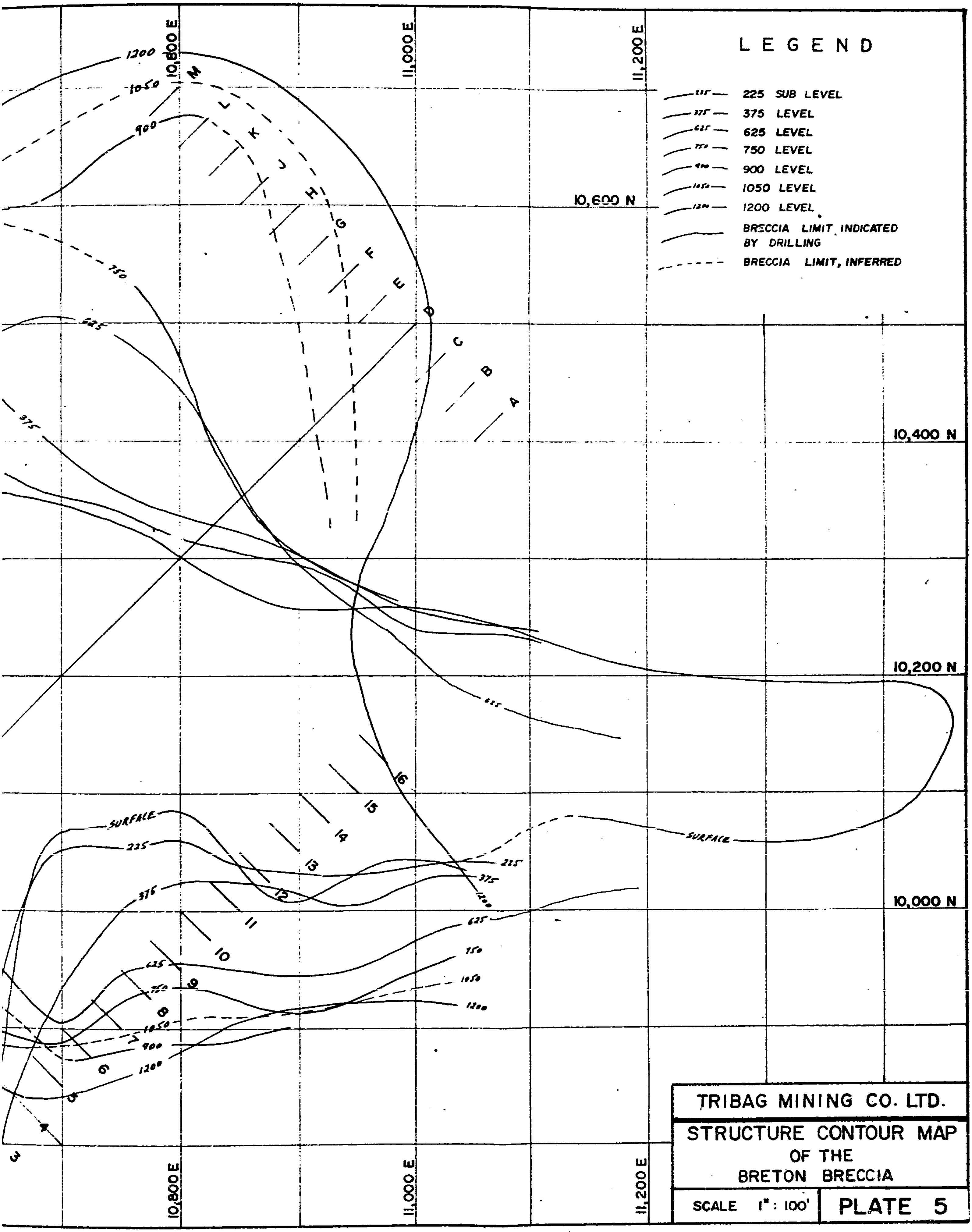
LEGEND
225 SUB LEVEL
375 LEVEL
625 LEVEL
750 LEVEL
900 LEVEL
1050 LEVEL
1200 LEVEL
BRECCIA LIMIT INDICATED BY DRILLING
BRECCIA LIMIT, INFERRED
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
SURFACE
TRIBAG MINING CO. LTD.
STRUCTURE CONTOUR MAP
OF THE
BRETON BRECCIA
SCALE 1" : 100'
PLATE 5

ening of the north contact, or to repetition of the breccia by faulting.

Several huge, massive granite fragments are present within the breccia boundaries. The largest of these occurs between the 625 and 750 levels in the eastern part of the breccia, (Plate 26). It is conceivable that other similar fragments are present, and that they are being mistaken for the massive granite wall rock. Such misinterpretation could lead to underestimating of the extent of the breccia in places, but major changes in the size and shape of the breccia by future development are doubtful.

A second breccia body occurs at a distance of 400 feet east along the strike of the Breton breccia. The two breccias are petrologically similar, and it is possible that they are connected at depth.

Composition of Fragments.

The fragments are composed of rocks found in the immediate vicinity of the breccia. In order of abundance, the fragments are granites, diabases, mafic metavolcanics, felsites, felsophyres, and pieces of the composite dykes. No fragments foreign to the area have been observed.

Single fragments may, however, be composed of more than one rock type. Fragments of this type are usually composed of granite cut by diabase or felsite dykes, or of breccias made up of fragments of diabase or mafic metavolcanics embedded in a felsite or granite, (Figure 31). These are described as "primary breccia", and are thought to have been derived from brecciated contact zones.

Distribution of Fragments.

In general, the predominance of fragments of a particular rock type reflects the nature of the massive wall rock. Thus, in the east where the breccia cuts across mafic metavolcanics and diabases, the fragments are predominantly mafic. Correspondingly, in the central and western part of the breccia granitic fragments predominate.

In the central part of the breccia to a depth of about 350 feet, however, most fragments are mafic. This suggests that the fragments have been derived from mafic metavolcanics which overlay the granite prior to brecciation, and which subsequently slumped down to their present position.

An important feature of the breccia is the relatively high proportion of felsitic and felsophyric fragments. The writer estimates that these felsic rocks form only a fraction of one per cent of all the outcrops on the Tribag property. Yet, within the breccia, fragments of these rocks amount to at least 5 per cent, and locally may even predominate over fragments of all other rock types combined.

Although these generalization apply on a large scale, locally the distribution of fragments of various rock types may be erratic. Thus, for example, in several places where the breccia is in contact with massive granite, the fragments are predominantly diabasic, (Figure 20). Instances of the reverse relationship have also been observed, particularly on the 375 level.

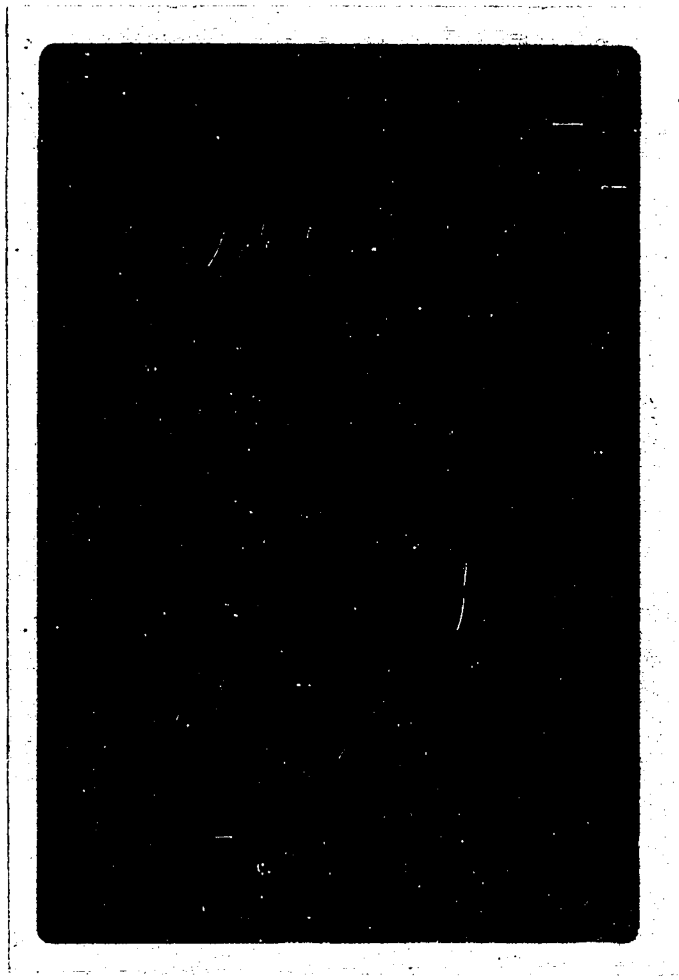

Figure 20. North breccia contact. Note predominance of diabasic fragments opposite a granitic wall rock.

<u>Size of Fragments.</u>

The fragments range in size from a few millimeters to about 20 feet. The commonest sizes are between three inches and three feet. Several fragments, measuring over 100 feet, are present, but few, if any, occur in the 20 to 100 foot range.

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An interesting feature of the breccia is the absence of comminuted material. This has important implications in relation to the origin of the breccia.

Small fragments averaging two or three inches in diameter predominate in the east part of the breccia, and in the central part, to a depth of about 350 feet. There appears to be no correlation between size and composition or distance from the outer boundaries.

Known ore zones are all associated with relatively fine fragments, whereas the weakly mineralized parts of the breccia are characterized by coarse fragmentation. In zones of sulphide mineralization, the footwall contacts between the fine and coarse phases of fragmentation are usually gradational, and the hanging wall contacts are sharp, (Figure 29).

It should be emphasized, however, that although these sorting patterns are readily recognizeable, the degree of sorting is generally poor. Zones of fine brecciation invariably contain some large fragments, (Figure 26), and in the coarser phases, large fragments may be separated by fragments of much smaller size.

Shapes of Fragments.

Regardless of their size, the majority of fragments are highly angular, with only a small proportion showing slight rounding of corners, (Figure 43). The shapes of the fragments as seen in two dimensions in the underground workings are irregularly rectangular or triangular. Elongated , slab-like fragments are common. These generally show a parallel orientation, and their attitude is mostly horizontal or gently dipping, (Figure 32).

Matrix.

The matrix of the breccia is composed mainly of quartz and calcite, with minor amounts of dolomite, fluorite and laumontite, with traces of biotite. The total amount of these matrix minerals ranges from less than 5 per cent to over 90 per cent of the breccia, averaging an estimated 15 per cent of the rock. The abundance of the matrix is directly proportional to the amount of sulphide mineralization, and has been carefully noted in underground mapping, and in diamond drill logs.

The matrix is generally coarse grained and vuggy, particularly in the vicinity of ore, (Figure 21). The vugs are usually a few inches in diameter, although larger ones, measuring several feet are not exceptional. These are commonly lined with well-formed crystals of quartz, calcite, and occasional fluorite.

The boundaries between the matrix and the rock fragments are mostly sharp, and the shapes of the fragments are clearly distinguishable. In areas of coarse brecciation, where little movement of the fragments has taken place, major irregularities in the walls of the fragments can be matched with those in the adjacent fragments. Matching of finer irregularities in detail, however, is not always possible. This led to the suggestion that partial replacement of the rock fragments by the quartz present in the matrix has taken place. Microscopic

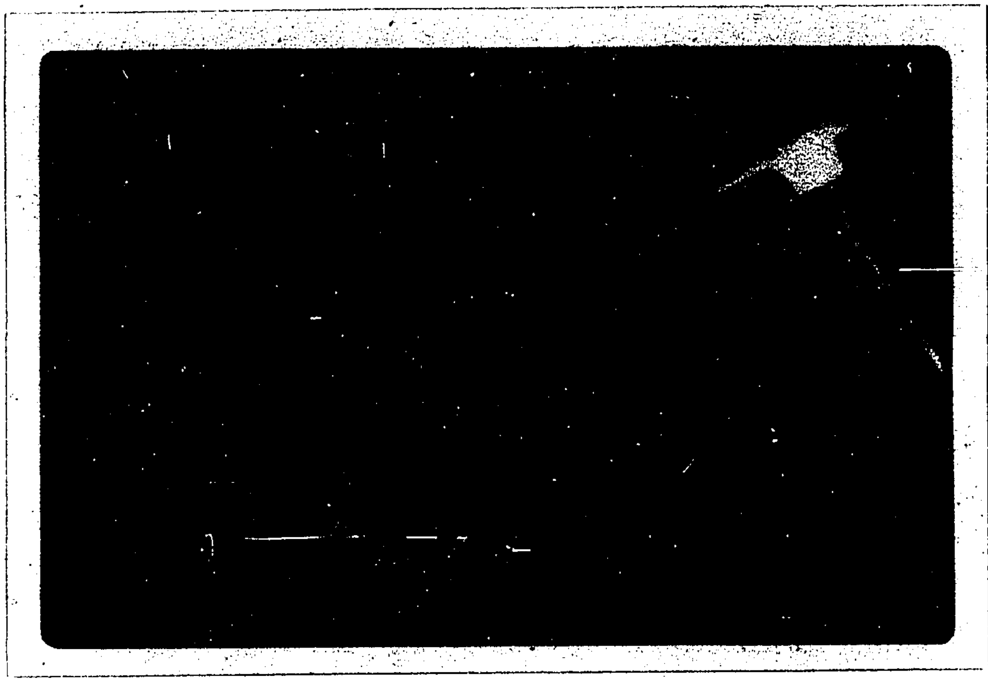


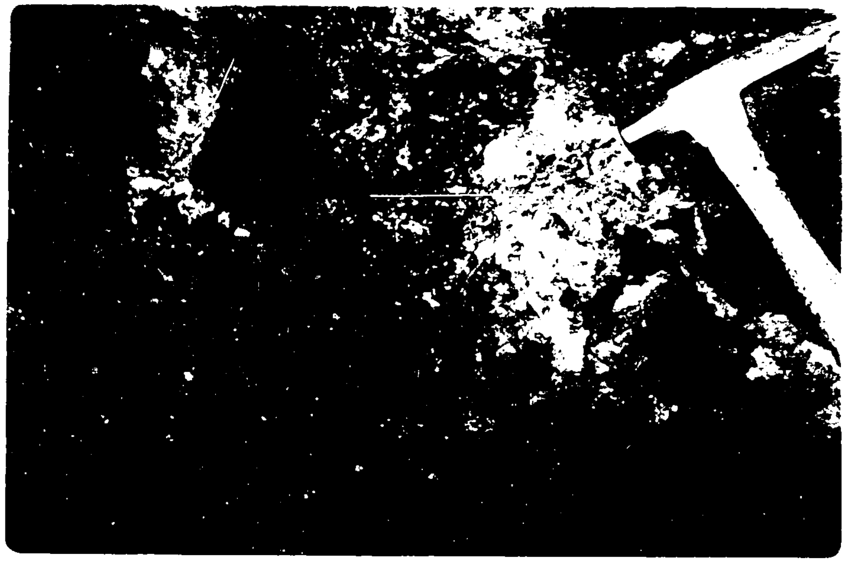
Figure 21. Mineralized breccia with coarse, vuggy matrix. 750 level, at 10,650E, 10,305N.

examination of finely brecciated rock confirmed this, but the amount of replacement is very minor.

Quartz. In the matrix, quartz is by far the most common mineral. It is estimated that it predominates over calcite by a ratio of 20:1. Local variations of the relative proportions of these two minerals are considerable, but do not appear to have any significance with regard to sulphide mineralization.

Several generations of quartz are clearly distinguishable in hand specimens.

1. The oldest quartz occurs in narrow stringers which cut the granites and diabases, and obviously pre-dates brecciation. The quartz is milky white in colour, but may be faintly stained blue by the presence of finely disseminated



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molybdenite.

2. Clear, coarsely crystalline quartz forms the bulk of the breccia matrix. Here one finds intricately intergrown crystals of quartz up to four or five inches in length intimately associated with sulphides. Perfect crystals are often found in vugs in which they developed to an almost optical quality.

3. Fine, white, milky quartz is found locally in the form of a thin, (½ - 1 mm), coating on crystals of sulphides, as well as on crystals of older quartz.

Late, quartz occurs also in narrow stringers which cut across the fragments, as well as across the matrix of the breccia, (Figure 30).

<u>Calcite.</u> Calcite is mostly white or pale pink, and rarely clear. It is later than the second generation of quartz, and was probably introduced before the quartz of the third generation, and at the same time as chalcopyrite. Well-formed crystals of clear calcite are often found to contain, as well as to be coated by tiny, euhedral sphenoids of chalcopyrite, and fine pyrite cubes.

A second generation of calcite occurs in late veins which cut across the breccia fragments. These have been observed on the 900 and 1,050 levels, in the north-central part of the breccia, (Figure 22). The veins are several inches thick, and characteristically contain yellow sphalerite, schalenblende, galena, and minor chalcopyrite.

Figure 22. Late carbonate vein cutting steeply across the breccia on the 1,050 level. Scale is 6 inches long. (Photo by Koskitalo)

Dolomite. Dolomite was identified by the writer by X-ray diffractometer in one drill core specimen, and later noted in several places in the mine workings. The mineral is found in the matrix in association with calcite, from which it can be easily distinguished by differential etching with hydrochloric acid. The dolomite is characterized by a botryoidal structure with concentric layers ranging in colour from pale greyish yellow to brown and green. The mineral is clearly later than the second generation of quartz, but

Figure 22. Late carbonate vein cutting steeply across the breccia on the 1,050 level. Scale is 6 inches long. (Photo by Koskitalo)

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Fluorite. Fluorite is found in small quantities throughout the breccia. It occurs in finely crystalline masses, as well as in well formed, large, single crystals, mostly octahedrons, occasionally combined with cubes. Green and violet varieties are most common. Both of these colours may be present in a single specimen, and show distinct bands parallel to the cube faces. Deep violet, almost black fluorite was noted on the 750 level, and white cubic crystals are found occasionally. Crystals of fluorite are usually less than one inch in size, although several specimens measured over 2½ inches.

Fluorite is associated with quartz and carbonate, but does not bear any particular relationship to the abundance of sulphides. Its age relationship to the quartz is uncertain. However, the presence of calcite crystals on top of crystals of fluorite can be considered as good evidence that the calcite is later.

Laumontite*, $CaAl_2Si_4O_{12}.4H_2O$, a mineral belonging to the zeolite family, is common in the east part of the breccia which is characterized by the predominance of diabasic and mafic volcanic fragments. Locally, it forms as much as 10

* Laumontite was first recognized megascopically by B.Gosling, an undergraduate student of geology at the Michigan Technological University. Subsequently, the identification was confirmed by X-ray diffraction, and spectrographic analysis carried out by the Ontario Department of Mines.

per cent of the matrix, occurring interstitially between quartz and carbonate. It is pale orange in colour, and forms aggregates of euhedral crystals which average two or three millimeters in diameter.

It is important to note that the mineral occurs in large amounts in association with the copper deposits of Michigan, where its presence invariably signifies a decrease in copper mineralization. Although the east part of the Breton breccia is insufficiently explored to justify such a generalization for the area, preliminary investigations indicate that the relationship here may be similar.

Laumontite is also common in the West breccia on the Tribag property, where, as in the Breton breccia, it occurs in association with mafic volcanic, and diabasic fragments.

<u>Amphibole (?).</u> Needles of a dark greenish mineral, up to 20 millimeters in length, have been noted at several places in the vicinity of ore zones. The needles are wholly enclosed by quartz, and are commonly arranged in a distinctly radial pattern. The mineral resembles amphibole in its rhombic cross section, and amphibole-type cleavage, but X-ray examination by the Ontario Department of Mines identified it as muscovite. Examination under the microscope confirmed this, showing fine grained aggregates of sericite. Spectrographic analysis indicated a relatively high potassium and aluminum content, (Table 9), again confirming the identification.

Table 9.

Semi-quantitative Spectrographic Analysis of Amphibole (?) Needles.

(Analyst: Ontario Department of Mines)

Si	over 15 per cent
Al	5 - 15 per cent
K	0.5 - 5 per cent
Ca	0.5 - 5 per cent
Mg	0.5 - 5 per cent
Na	0.1 - 1 per cent

The shape and the cleavage of the acicular crystals suggest that the mineral was originally amphibole, and was later replaced by fine grained muscovite.

The mineral does not occur in sufficiently large quantities to be of importance as a guide to ore, but serves as an aid in correlation of drill hole data.

Biotite. Biotite is widely distributed throughout the breccia, but it is restricted to quartz stringers cutting across diabasic fragments, (Figure 23). Microscopic examination of the breccia also revealed the presence of fine biotite crystals that formed along the interfaces of mafic rock fragments and the quartz matrix, (Figure 24).

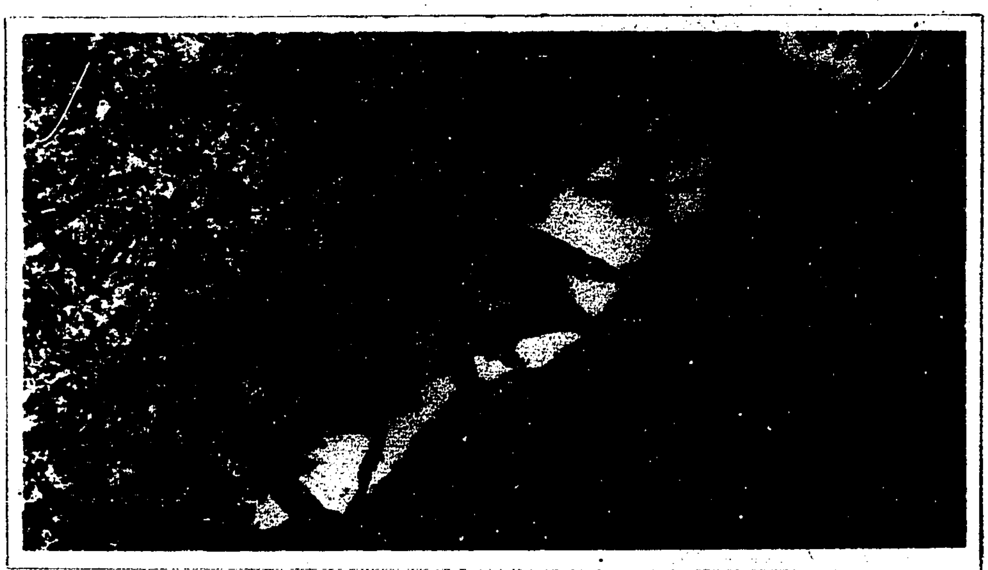

Figure 23. Crystals of biotite and magnetite in a quartz stringer cutting across a mafic fragments. Plane light; 4 x.

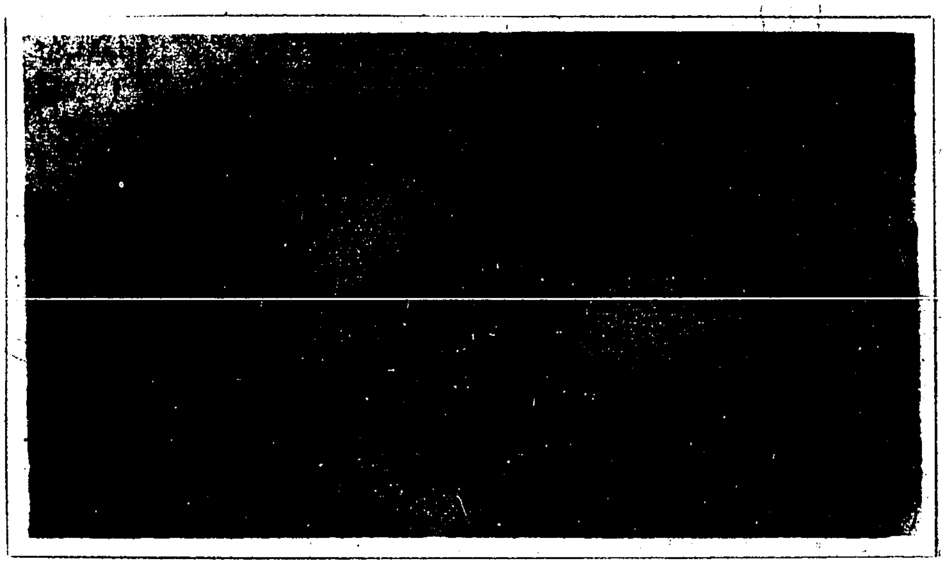

Figure 24. Biotite crystals formed along interfaces of diabasic fragments and quartz matrix. Plane light; 7 x.

Figure 23. Crystals of biotite and magnetite in a quartz stringer cutting across a mafic fragments. Plane light; 4 x.

Figure 24. Biotite crystals formed along interfaces of diabasic fragments and quartz matrix. Plane light; 7 x.

CLASSIFICATION OF BRECCIAS WITHIN THE BRETON PIPE.

Detailed studies of the various types of breccia within the Breton pipe were undertaken in the hope that some structural pattern would emerge that would be useful in locating ore. Three classifications were devised, based on:

1. The compositions of the fragments.
2. The physical character of brecciation.
3. The intensity of alteration.

1. Classification based on Compositions of Fragments.

This classification is based on visual estimates of the relative amounts of fragments of various rock types. The visual estimates have been noted consistently in drill logs and in underground mapping, and have been expressed in terms of percentages. Thus, certain phases of the breccia may be described, for example, as consisting of X per cent granitic fragments, Y per cent diabasic fragments, and Z per cent felsitic fragments. In order to streamline this type of description, and at the same time to reduce the element of error in estimating the percentages, it has been found both convenient and satisfactory to express the relative amounts of fragments in more general terms, such as "predominantly" granitic, or heterogeneous breccia.

The classification is presented diagrammatically in the following illustration, (Figure 25).

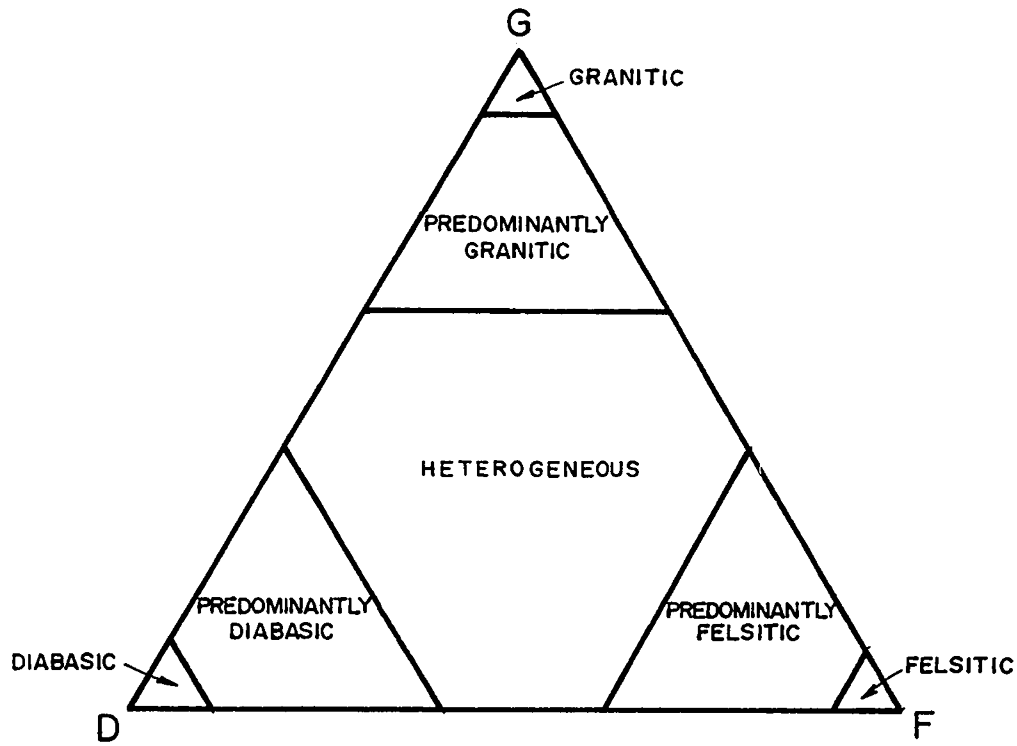

Figure 25. Classification of breccia on the basis of composition of fragments.

2. <u>Classification Based on the Physical Character of the Breccia.</u>

The physical character of the breccia is described in terms of the type and abundance of the matrix, the size, shape and attitudes of the fragments, and their mutual relationship. The following types of breccia have been recognized within the Breton pipe.

Table 10.

Classification of the Breccia Based on its Physical Character.

I. Matrix-rich Breccia, (quartz-carbonate matrix > 10%)

  a. Disordered

   1. Fragments of Single Size Range
   2. Fragments of Dual Size Range

  b. Ordered

  c. Vein Breccia

II. Matrix-poor Breccia, (Quartz-carbonate matrix < 10%)

  a. Marginal

  b. Internal

   1. Hanging Wall Breccia
   2. Deep Breccia

III. Breccia with Igneous Matrix

  a. Diabase or Felsite Matrix

  b. "Grey" Dyke Matrix.

I. Matrix-rich breccia is characterized by rock fragments distinctly embedded in a quartz and carbonate matrix constituting at least 10 per cent of the breccia, (Figure 26). The relative amount of the matrix is governed by the degree of packing of the fragments, and their average size. As a rule, the amount of the matrix is inversely proportional to the average size of the fragments. Matrix-rich, or "open" breccia containing over 25 per cent quartz and carbonate usually consists of relatively small fragments, averaging only a few inches in diameter.

On the basis of the attitude of the fragments, two types of matrix -rich breccia are distinguishable.

a. Disordered Breccia. In this type of breccia, individual fragments may be completely enclosed by the matrix and are arranged at random, so that matching of walls of adjacent fragments is not possible.

The fragments are usually of a single size range, measuring between 3 inches and 3 feet, with a few larger fragments present occasionally.

Breccia with fragments of a dual size range is relatively rare. It consists of large, angular fragments separated by quartz and carbonate matrix containing fine, angular fragments of another rock type. Most commonly, the coarse fragments are granite, whereas the fine fragments embedded in the intervening matrix are felsites.

b. Ordered Breccia is a peculiar type of brecciation, characterized by parallel or sub-parallel orientation of slab-like fragments separated by guartz-carbonate matrix, (Figure 27). The best example of this type of breccia occurs on the 225 sublevel, where the breccia is mineralized with 2 to 3 per cent chalcopyrite and 3 to 4 per cent pyrite, concentrated in layers parallel to the attitude of the fragments, which is mostly horizontal or gently dipping.

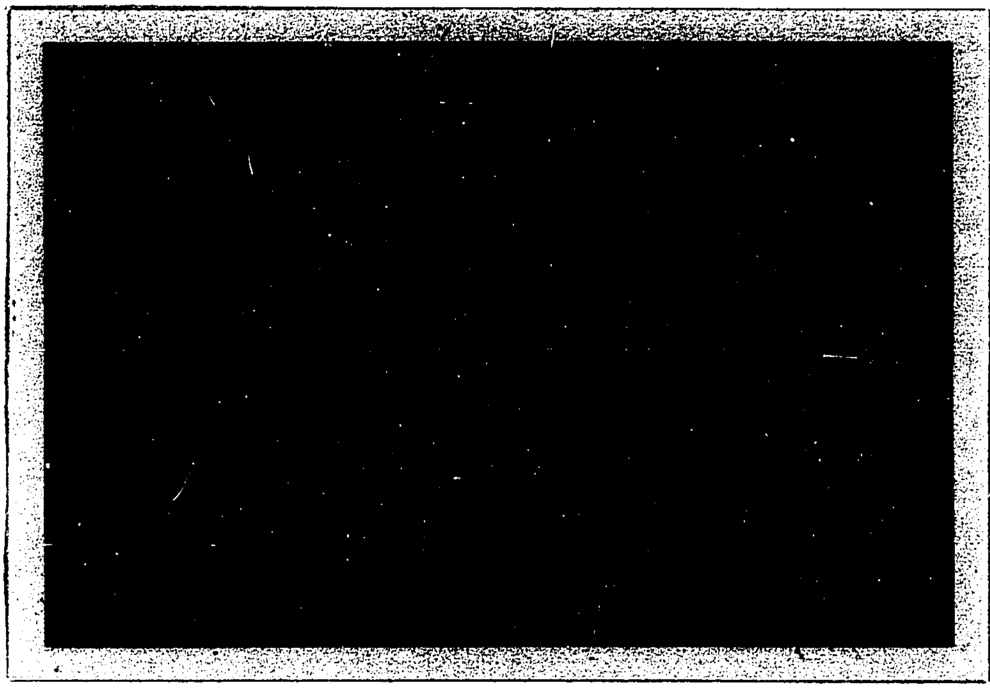

Figure 26. Matrix-rich breccia. Note large, angular fragment in the upper part of the picture. 375 level, in the northeast part of breccia. (Photo by L.O.Koskitalo)

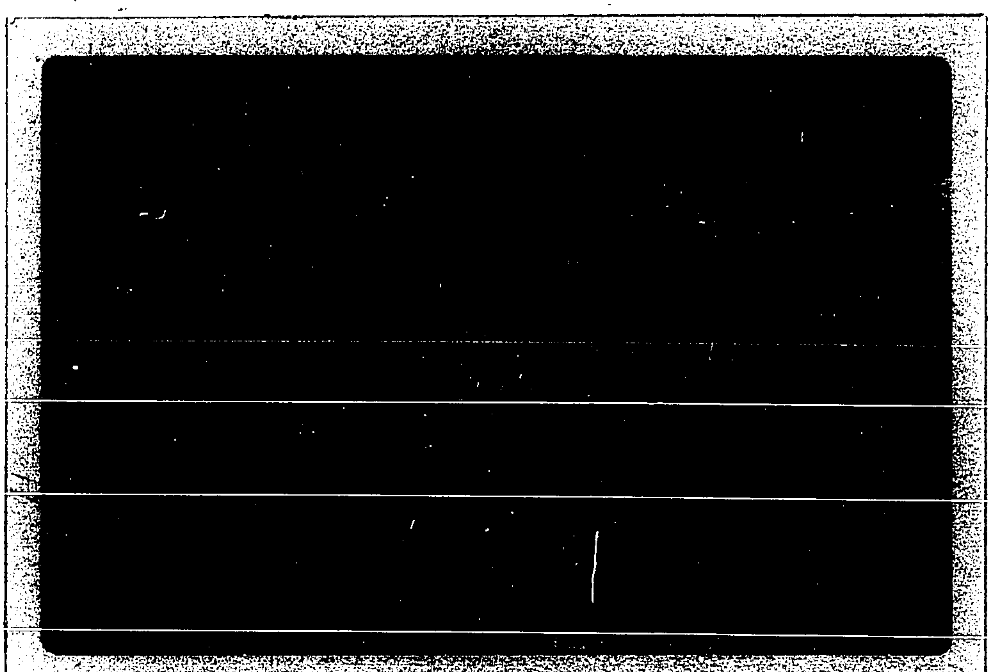

Figure 27. Ordered breccia, characterized by sub-parallel orientation of slab-like fragments. 625 level, 10,800E, 10,100N.

Figure 26. Matrix-rich breccia. Note large, angular fragment in the upper part of the picture. 375 level, in the northeast part of breccia. (Photo by [illegible] Koskitalo)

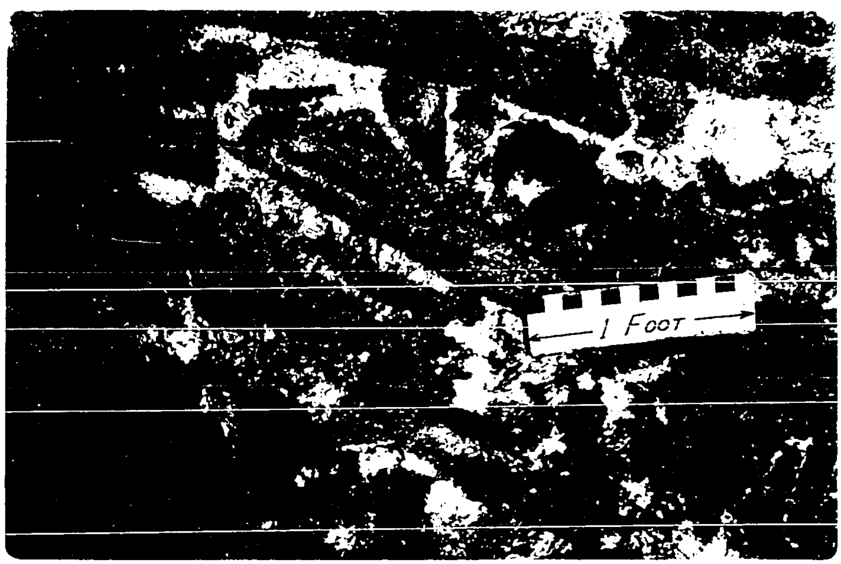

Figure 27. Ordered breccia, characterized by sub-[illegible] orientation of slab-like fragments. [illegible] level, [illegible]

Parallel orientation of elongated fragments is fairly common throughout the Breton breccia. It is interesting to note that in the vicinity of mineralized zones, the attitude of the fragments is not necessarily conformable to the attitude of the ore.

c. Vein Breccia. This type of breccia occurs in vein-like structures which cut across older breccia, and which are composed of quartz and carbonate containing fine, angular rock fragments. These are petrologically foreign to the immediate vicinity of the vein, and seem to have been transported to their present position from depth, (Figure 28).

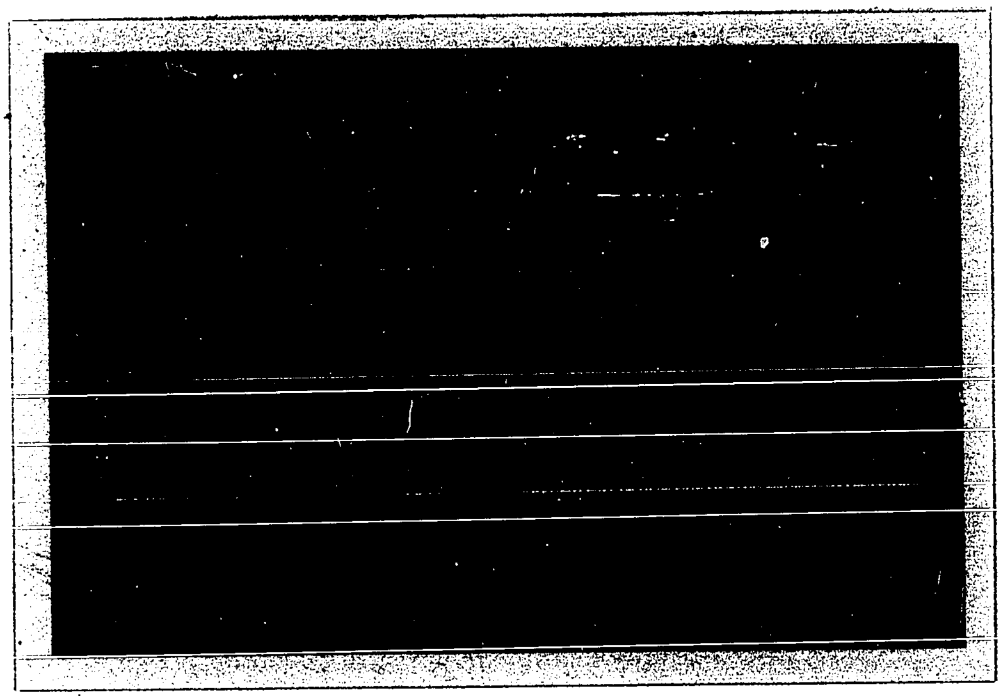

Figure 28. Vein breccia cutting across older breccia. 900 level at the west breccia contact. (Photo by L.O.Koskitalo)

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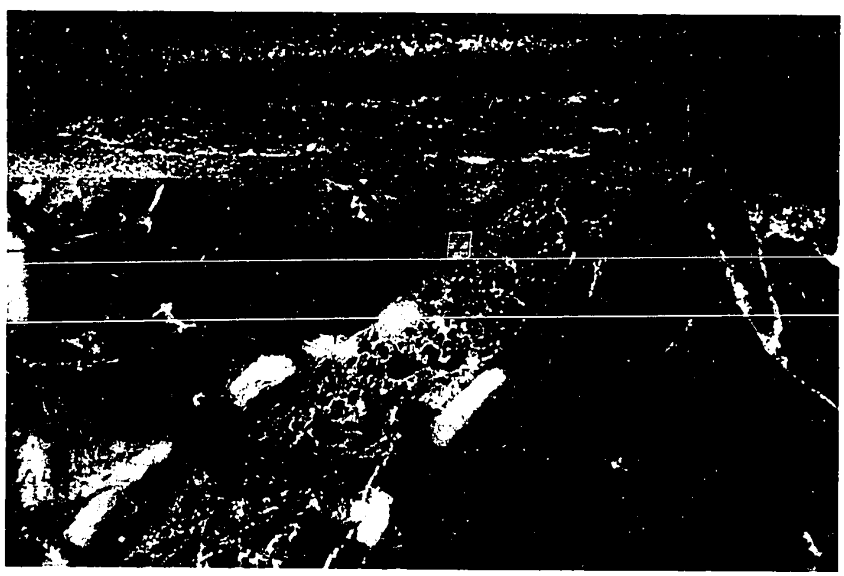


Figure 28. Vein breccia cutting across older breccia.
900 level at the west breccia contact.
(Photo by [illegible].Koskitalo)

II. Matrix-Poor Breccia, or "tight" breccia contains less than 10 per cent quartz-carbonate matrix. Although there is a complete gradation between matrix-rich and tight breccia, each has a sufficiently characteristic appearance to be considered as a special type. Several types of tight breccia are recognized, mainly on the basis of their positions within the Breton pipe.

a. Marginal Breccia. Tight breccia of this type occurs at the east and west extremities of the Breton breccia. It can be observed at the east contact on the 1,200 level, (Figure 29), and at the west contact on the 625 and 375 levels. In each case, the breccia is composed exclusively of fragments derived from the adjacent, massive wall rock. The fragments are tightly packed, and are cemented with less than 10 per cent quartz-carbonate matrix. The tight breccia extends for a distance of 20 to 30 feet from the contact, and it is marked by progressively higher amounts of matrix toward the centre of the breccia pipe. The contacts with the matrix-rich breccia are gradational, and the increase in the amount of matrix is accompanied by an increase in the amount of other rock fragments.

b. Internal, matrix-poor breccia has two modes of occurrence within the Breton pipe.

1. Hanging wall breccia is a relatively tight, but heterogeneous breccia which forms the hanging walls of many ore zones. It is particularly well exposed in the main north cross-cut on the 750 level, at 10,550E, where tight, barren

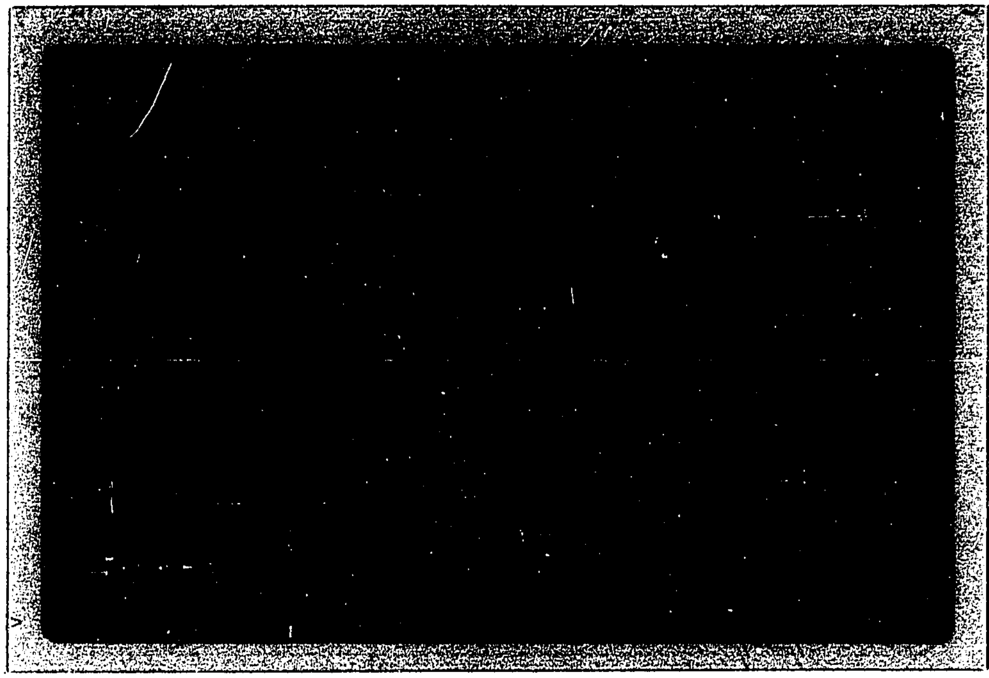


Figure 29. Marginal breccia at the east contact of the Breton pipe, on the 1,200 level, at 10,150N, 11,065E, looking south. Note gradational contact between the breccia and the massive granite wall rock.

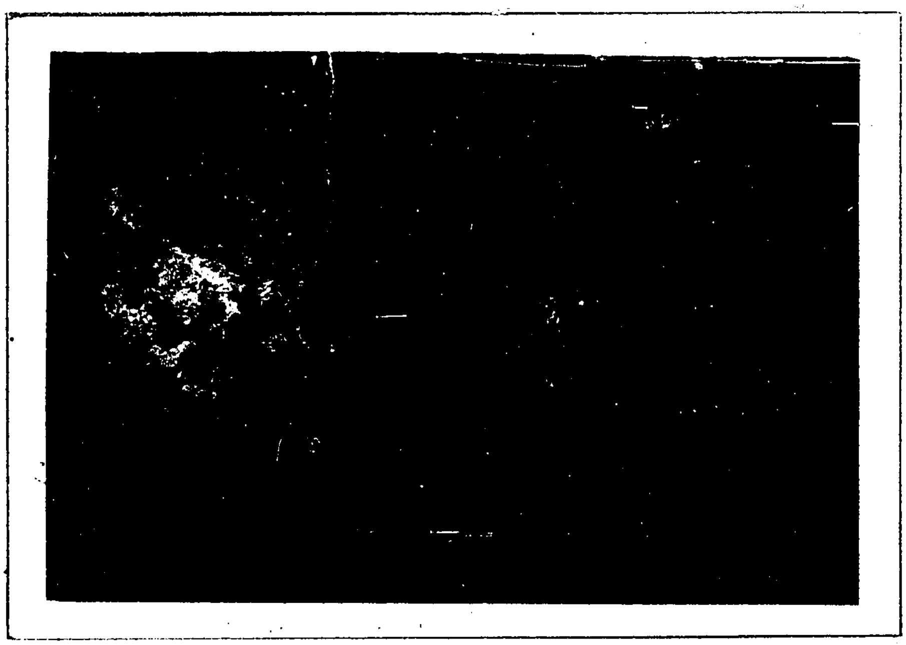


Figure 30. Sharp contact between "open", mineralized breccia, and "tight", barren breccia on the 750 level at 10,350N, 10,550E, looking west. Note the late quartz stringer cutting across the contact.

Figure 29. Marginal breccia at the east contact of the Breton pipe, on the 1,200 level, at 10,150N, 11,065E, looking south. Note gradational contact between the breccia and the massive granite wall rock.

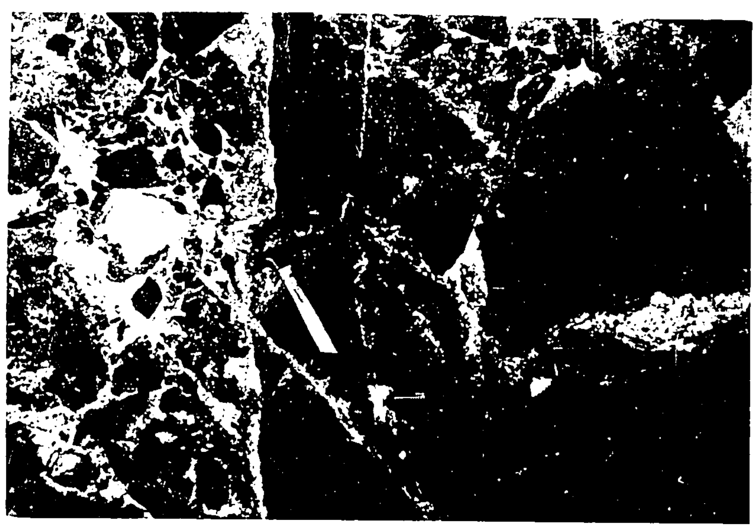


Figure 30. Sharp contact between "open", mineralized breccia, and "tight", barren breccia on the 750 level at 10,350N, 10,550E, looking west. Note the late quartz stringer cutting across the contact.

breccia is in sharp contact with "open", mineralized breccia, (Figure 30). This is of importance from the mining viewpoint, since the sharp contacts permit the mining of ore with minimum dilution.

2. Tight breccia at depth occurs in large areas on the 1,050 and 1,200 levels. It consists of tightly packed fragments whose boundaried are obscured by alteration to the extent that their shapes are difficult to distinguish, (Figure 31). The colour of the rock is greyish green, due to green sericitization and chloritization, and carbonatization of granitic fragments. The occurrence of this type of breccia at depth was at one time considered to be a sign of the bottoming out of the breccia

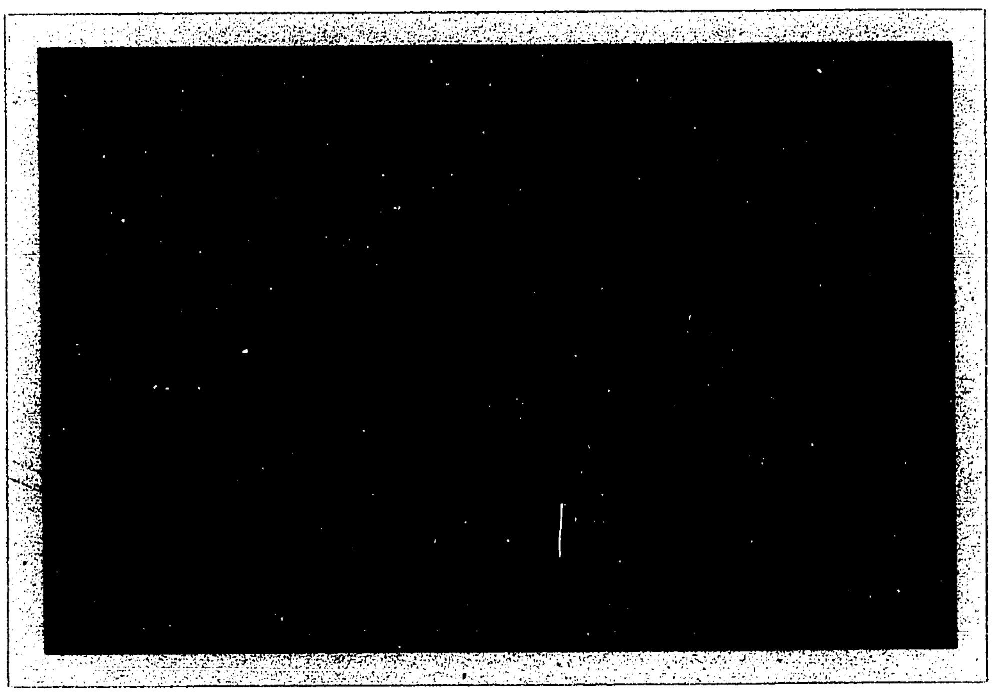


Figure 31. Tight, breccia on the 1,050 level. Outlines of fragments are obscured by high alteration. (Photo by L.O.Koskitalo)

breccia is in sharp contact with "[illegible]", [illegible] breccia, (Figure 30). This is of importance from [illegible] viewpoint, since the sharp contacts permit the mining of ore with minimal dilution.

2. [illegible] breccia at depth occurs in [illegible] on the 3,[illegible] and [illegible] levels. It consists of tightly packed fragments [illegible] obscured by alteration to the extent that their [illegible] are difficult to distinguish, (Figure 31). The colour of the rock is greyish green, due to [illegible] sericitization and chloritization, and carbonatization of [illegible] fragments. The occurrence of this type of breccia at depth may at once be considered to be a sign of the bottoming out of the breccia

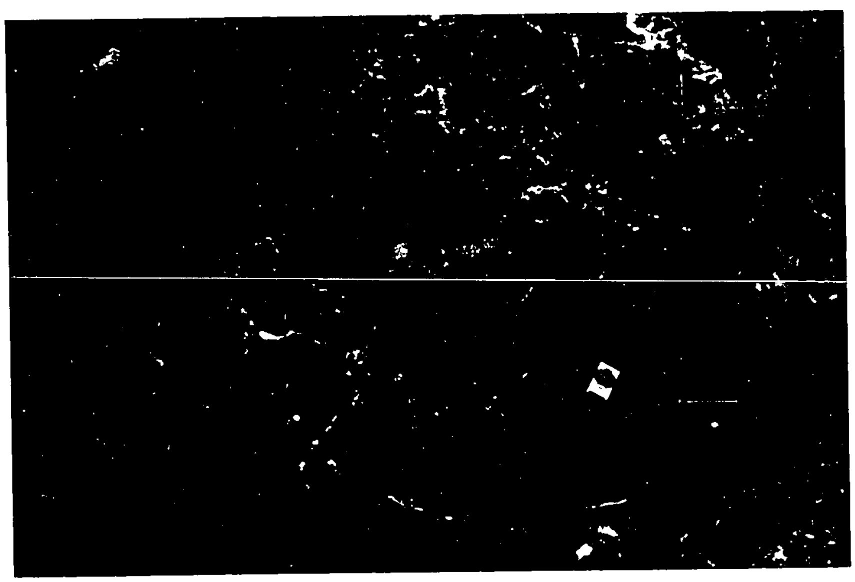


Figure 31, [illegible], breccia on the 1,050 level. Outlines of fragments are obscured by [illegible] alteration. (Photo by [illegible]) pipe. More recently, however, several drill holes penetrated through it into "normal", matrix-rich breccia.

III. Breccia with Igneous Matrix

a. Breccia with granitic, felsitic or diabasic matrix occurs rarely. It is found in large fragments which themselves consist of smaller fragments of felsite or granite, embedded in diabase or felsite without any intervening quartz or carbonate, (Figure 32). This "brecciated breccia" is relatively rare, and occurs mainly on the 750 level in the central part of the Breton pipe, and above the 375 level near 10,700E. The breccia is considered to represent older brecciated contact zones between granites and diabases or felsites.

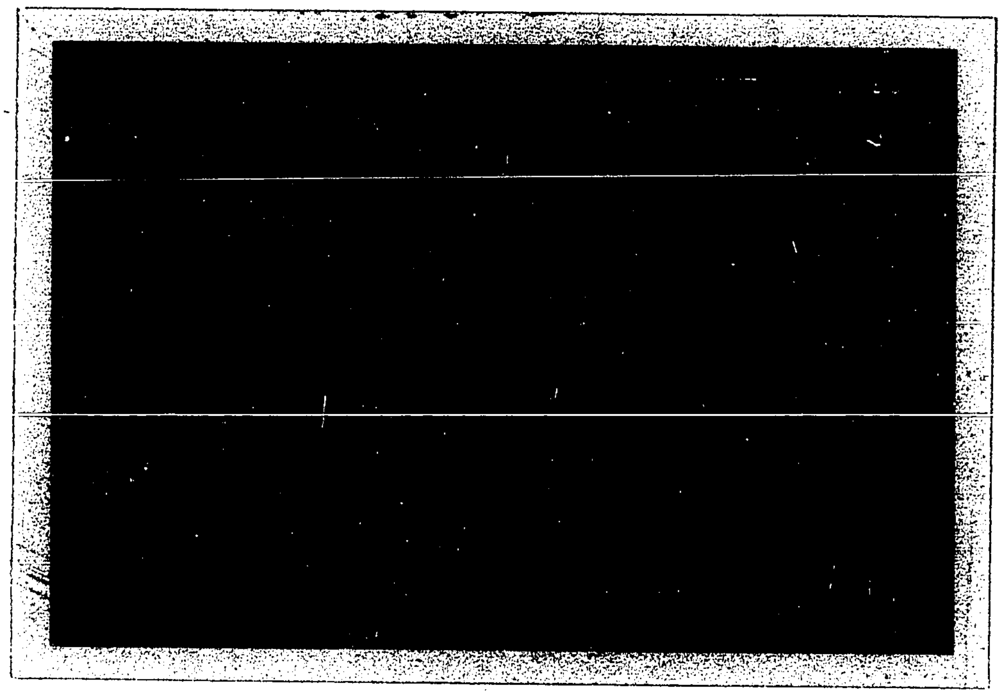
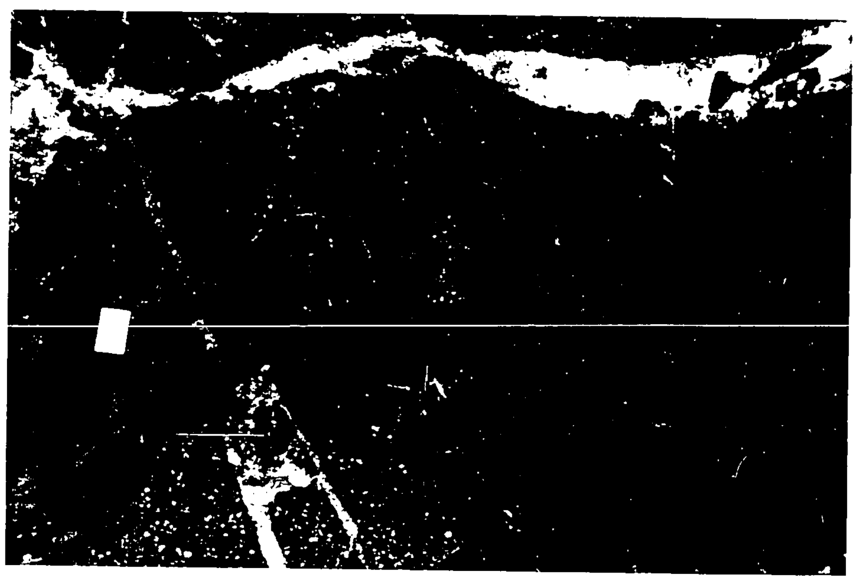


Figure 32. "Primary" breccia, consisting of angular fragments of granite embedded in diabase without any intervening quartz or carbonate. 750 level, 10,650E, 10,320N. (Photo by L.O.Koskitalo)

[illegible], [illegible], [illegible] [illegible] breccia.

[illegible]

[illegible] central part of the [illegible] breccia [illegible] to represent older brecciation contact [illegible] [illegible] dikelets of felsites.



[illegible] breccia, [illegible] granite [illegible] in diabase [illegible] [illegible]

b. Breccia consisting of rock fragments embedded in a matrix composed of the grey dyke material is rare. It is best exposed in a small area on the 625 level, at 10,800E, 10,125N. The fragments are fine, angular and highly altered, and the matrix locally contains large growths of secondary quartz crystals, (Figure 33).

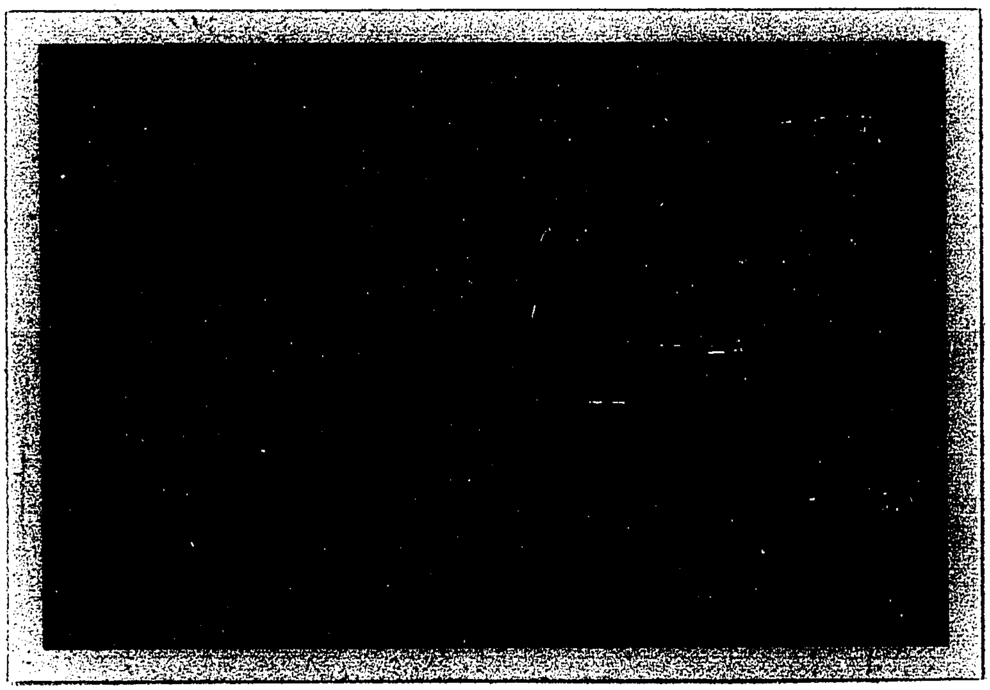
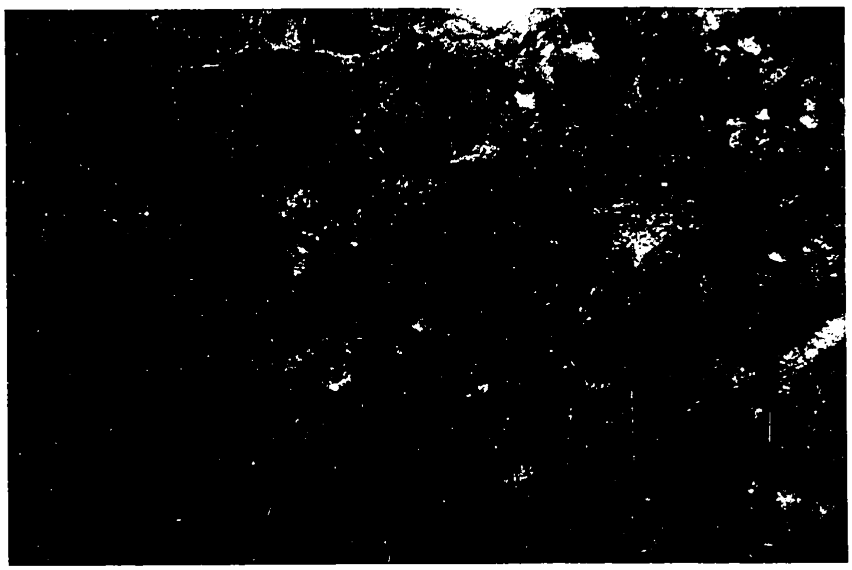


Figure 33. Igneous breccia, consisting of rock fragments embedded in a matrix composed of the grey dyke material. Note large growths of quartz crystals within the grey dyke. 625 level, at 10,800E, 10,125N.

3. <u>Classification of Breccia based on Alteration.</u>

The hydrothermal alteration in the Breton breccia consists of sericitization, clay mineral alteration, chloritization, and minor carbonatization. Since the type of alteration depends

b. Breccia consisting of rock fragments embedded in a matrix composed of the grey dyke material is rare. It is best exposed in a small area on the 625 level, at 10,800E, 10,125N. The fragments are fine, angular and highly altered, and the matrix locally contains large growths of secondary quartz crystals, (Figure 33).



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625 level, at 10,800E, 10,125N.

3. <u>Classification of Breccia based on Alteration.</u>

The hydrothermal alteration in the Breton breccia consists of sericitization, clay mineral alteration, chloritization, and minor carbonatization. Since the type of alteration depends largely on the petrological nature of individual rock fragments, each of these alteration products may be present in a heterogeneous phase of the breccia. As a result, it was found convenient for the purpose of classification, to distinguish between overall intensities of alteration rather than between alteration types.

On this basis, five classes of alteration are distinguished in the Breton breccia. These have been consistently noted in drill logs as well as in underground mapping, and have helped greatly in defining the complex structural pattern within the breccia pipe.

The criteria for recognition of the various intensities of hydrothermal alteration are the colour of granitic and felsitic fragments, and the hardness and colour of fragments of diabase, and mafic metavolcanics.

1. Relatively Fresh. The breccia is composed exclusively of fresh rock fragments. It is characterized by the distinct red colour of granitic and felsitic rock fragments, and by the hardness and dark green colour of diabase.

2. Low Alteration. The breccia contains a small proportion of acidic rock fragments bleached to a pale, pinkish green colour due to sericitization and kaolinization of the feldspar, but in general, the original colour of the granite predominates, (Figure 44).

3. Medium Alteration. The breccia is predominantly greenish grey and soft, with only occasional remnants of the

original red colour present, (Figure 43). Fragments of basic rocks are soft due to high chloritization.

4. High Alteration. The breccia is characterized by a complete absence of the original red colour of the felsic fragments. The rock is greyish green, very soft, and the distinction between felsic and mafic fragments is often impossible megascopically, (Figure 21).

5. Extreme alteration. The breccia is marked by an almost complete disintegration of individual rock fragments due to intense clay mineral alteration, and particularly the presence of illite. In most cases it is impossible to identify the original composition of individual fragments. Zones of intense alteration usually border joints and faults, and may have sharp boundaries with adjacent, relatively fresh phases of the breccia.

The contacts between the zones of the first four degrees of alteration may be sharp or gradational. In uncertain cases, intermediate descriptions such as "medium-high" or "medium-low" alteration have been used, and the correlation of the rocks is then established more definitely by other means.

An example of a brief description of the various types of breccia in terms of the three main criteria is given in a typical diamond drill hole log in the Appendix.

ECONOMIC GEOLOGY

ORE MINERALS.

Chalcopyrite and pyrite are the main ore minerals. Galena and sphalerite are locally abundant, but their overall amounts in the breccia are not sufficient for economic recovery. Pyrrhotite, marcasite, molybdenite, scheelite and magnetite are rare.

Chalcopyrite.

Chalcopyrite occurs in coarsely crystalline aggregates, as well as in single crystals in association with the quartz-carbonate matrix, (Figures 21, 43, 44 and 46). Single chalcopyrite grains average over 5 millimeters in diameter, rarely exceeding 30 millimeters. Several large, single, well twinned but deformed crystals have been found associated with kaolinite masses inside large vugs. Euhedral sphenoids 1 - 2 millimeters in size, have been noted rarely, mostly inside crystals of clear calcite, and in small vugs.

Microscopic examination of polished sections of chalcopyrite revealed the presence of myriads of star-shaped ex-solution bodies of sphalerite, ranging in size from 0.05 to 0.1 millimeters. These commonly cover areas estimated to be 1 to 2 per cent of that occupied by chalcopyrite, (Figure 34, 35 and 37). The skeletal bodies show a parallel orientation within individual chalcopyrite grains, and are elongated in the (111) plane of the chalcopyrite, (Edwards, 1954, p. 100). Etching of the chalcopyrite with a 1:1 solution of H_2O_2 and NH_4OH revealed that some of the sphalerite bodies are pseudo-skeletal structures which formed along the interfaces between individual chalcopyrite grains. These probably represent

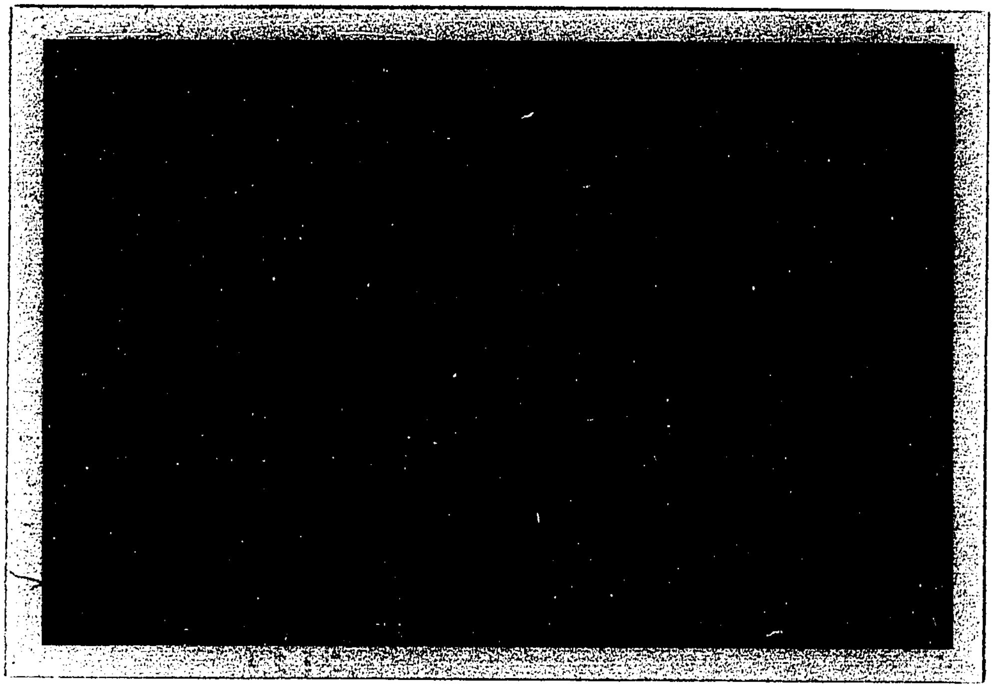


Figure 34. Skeletal ex-solution bodies of sphalerite in chalcopyrite. Note parallel orientation of the ex-solution bodies. (x290)

Figure 35. Skeletal ex-solution bodies of sphalerite greatly enlarged. (x1200)

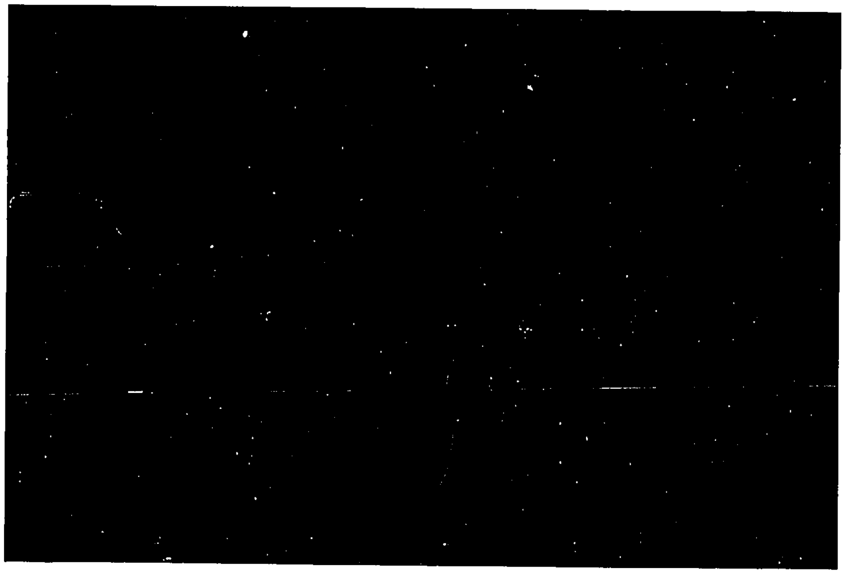


Figure 34. Skeletal ex-solution bodies of sphalerite in chalcopyrite. Note parallel orientation of the ex-solution bodies. (x290)

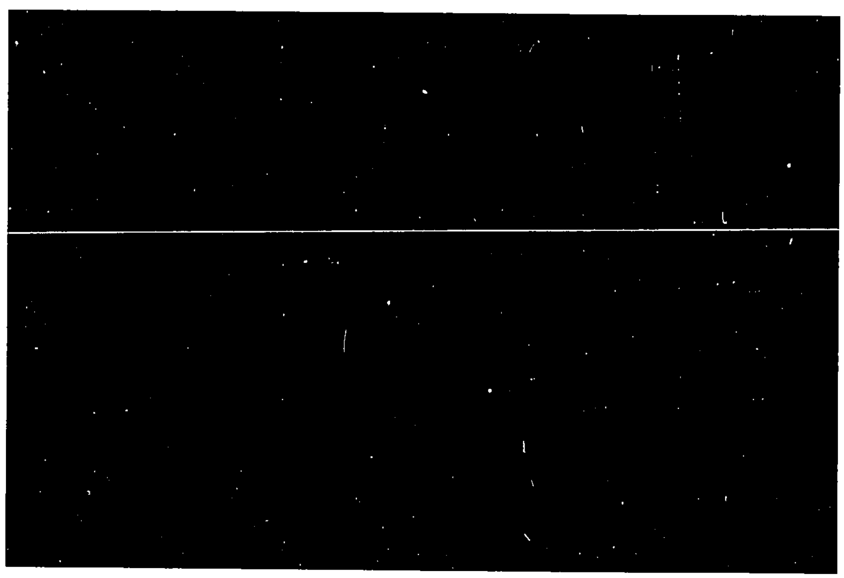


Figure 35. Skeletal ex-solution bodies of sphalerite greatly enlarged. (x1200)

Figure 36. Pseudo-skeletal bodies of sphalerite formed along interfaces of chalcopyrite grains. (x290)

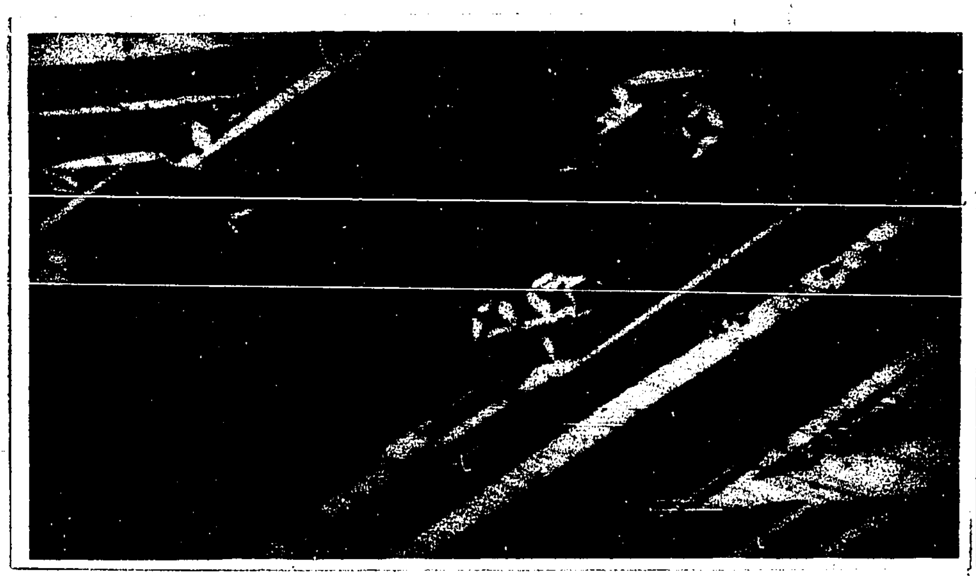


Figure 37. Deformation twinning of chalcopyrite caused by the ex-solution of sphalerite. (x120)

Figure 36. Pseudo-skeletal bodies of sphalerite formed along interfaces of chalcopyrite grains. (x290)

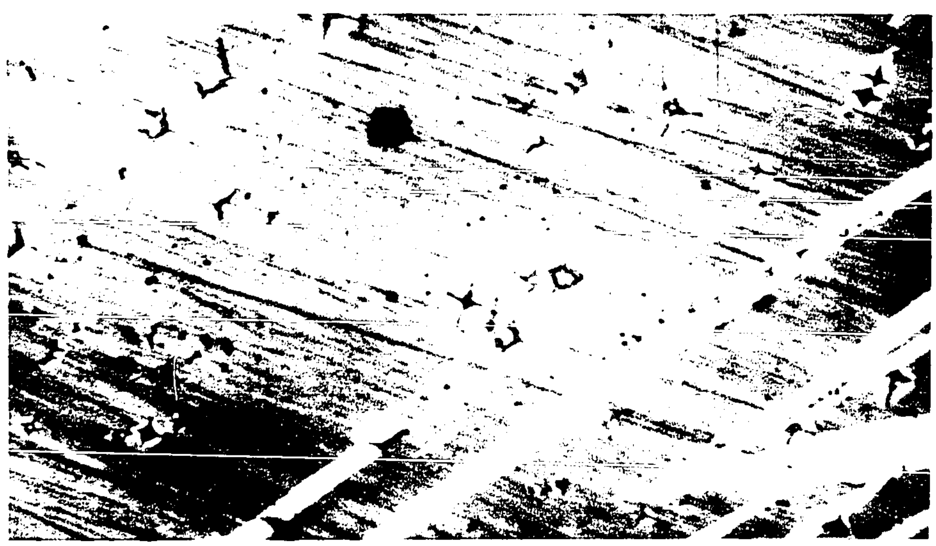


Figure 37. Deformation twinning of chalcopyrite caused by the ex-solution of sphalerite. (x120)

ex-solution bodies seggregated into surfaces of weakness, provided by the contacts between the individual grains, (Figure 36). True skeletal ex-solution bodies invariably occurring inside the grains, are associated with deformation twinning in the chalcopyrite, as shown in Figure 37.

The ex-solution bodies of sphalerite were used by the writer in an attempt to determine the temperature of formation of chalcopyrite. This will be discussed in a separate paragraph later.

Pyrite.

Next to chalcopyrite, pyrite is the most common mineral. It is estimated that the two minerals occur in approximately equal proportions, although in ore zones, chalcopyrite predominates over pyrite. Pyrite-rich zones, with only minor chalcopyrite, occur in several places, particularly on the 375 level.

Pyrite occurs in coarse grained aggregates, as well as in individual crystals which attain up to 2 inches in size. The cube is the most common crystal form, but pyritohedrons, and combinations of cubes and pyritohedrons have been noted in many zones.

Aggregates of pyrite occur mostly as masses, separated from other sulphides by gangue minerals. In places where pyrite grains are in contact with other sulphides, pyrite invariably shows its own crystal outlines. Individual pyrite crystals are commonly fractured, and the fractures may be filled with galena, chalcopyrite and sphalerite.

A later generation of pyrite occurs as finely crystalline coating on crystals of calcite and fluorite. Occasionally, pyrite is found replacing fragments of mafic metavolcanics but this is considered to represent pre-breccia mineralization.

Galena.

Galena occurs in association with sphalerite and chalcopyrite. It forms aggregates of coarse, euhedral crystals, most commonly showing cubic or octahedral faces, or a combination of both. Individual crystals may reach up to one inch in size.

In polished sections, the galena, easily identifiable by its softness and typical triangular pits, shows mutual boundaries with chalcopyrite and sphalerite, and occasionally contains isolated islands of these minerals. Inclusions of chalcopyrite are usually oriented parallel to the cleavage direction of the galena, (Figure 38). In several specimens, both galena and chalcopyrite occur along the interfaces of sphalerite grains, (Figure 39).

In some massive sulphide veins, galena occurs in narrow stringers which cut across all other sulphides, as well as the grey dyke with which the massive sulphides may be associated.

Sphalerite.

The distribution of sphalerite is similar to that of galena. Three varieties of the mineral have been identified within the Breton breccia. These are: 1. black sphalerite,

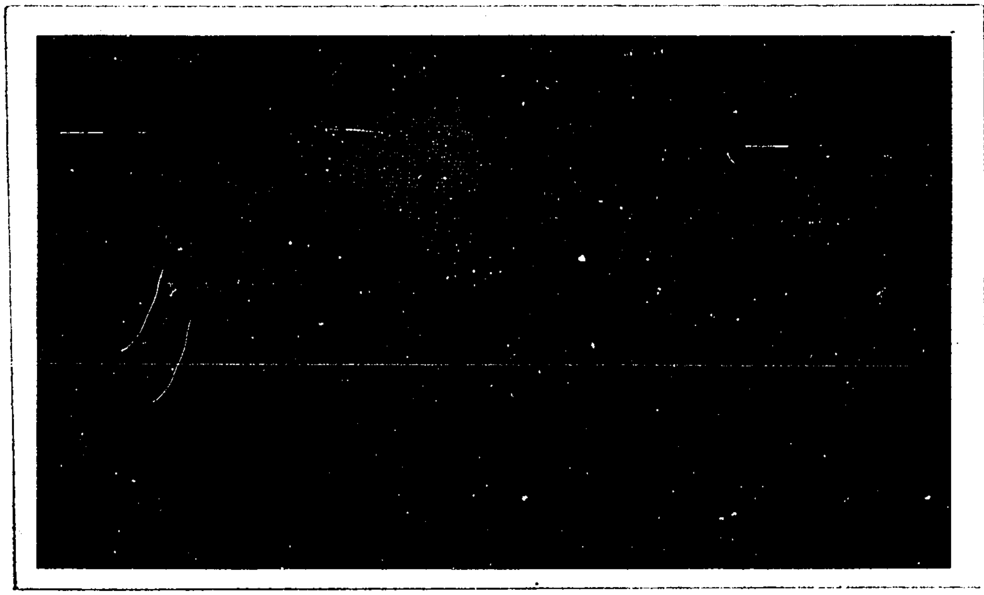


Figure 38. Galena containing isolated islands of chalcopyrite oriented parallel to a direction of cleavage. (x120)

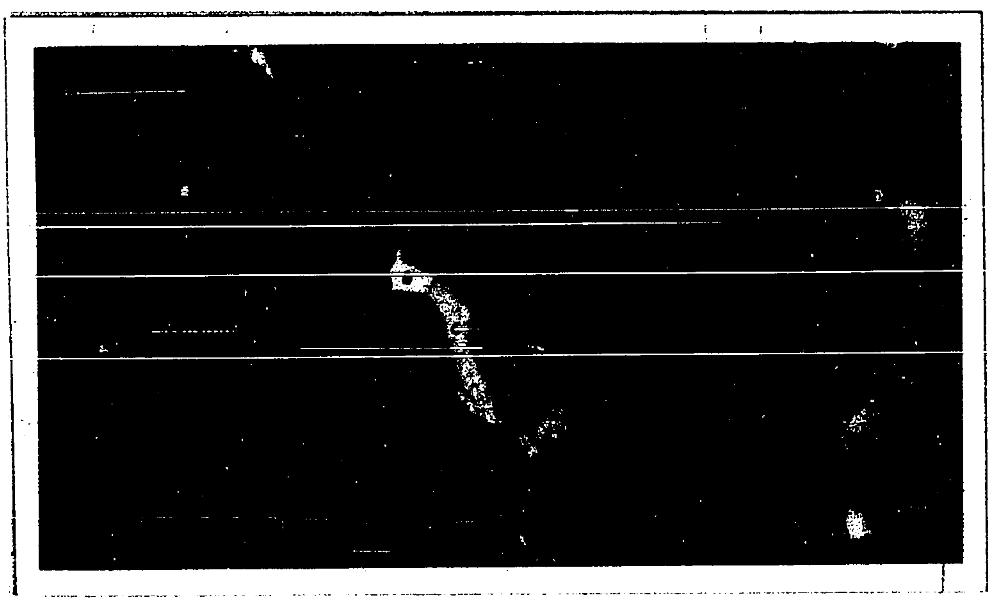
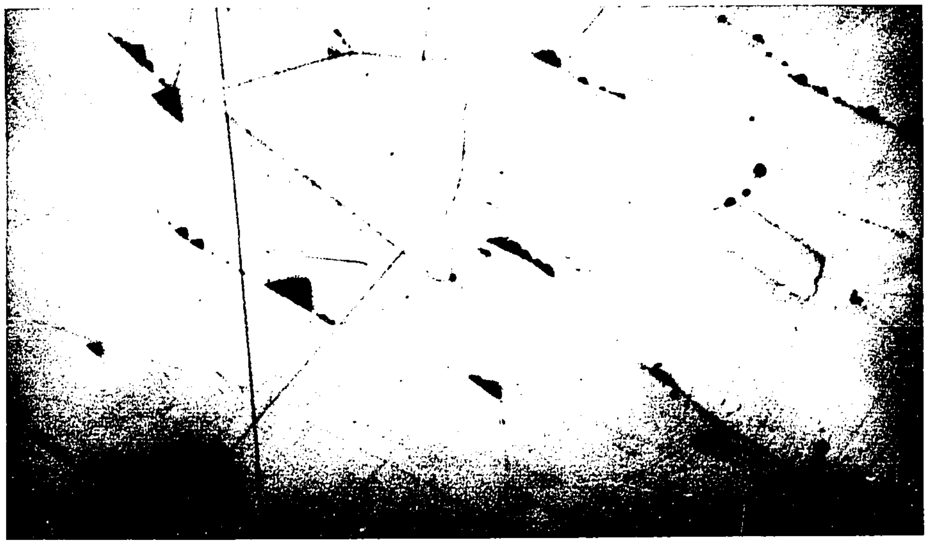


Figure 39. Galena and chalcopyrite formed at the interfaces of grains of sphalerite. Note well developed emulsion texture along the grain boundaries of the sphalerite. (x120). S-sphalerite, G-galena, C-chalcopyrite.



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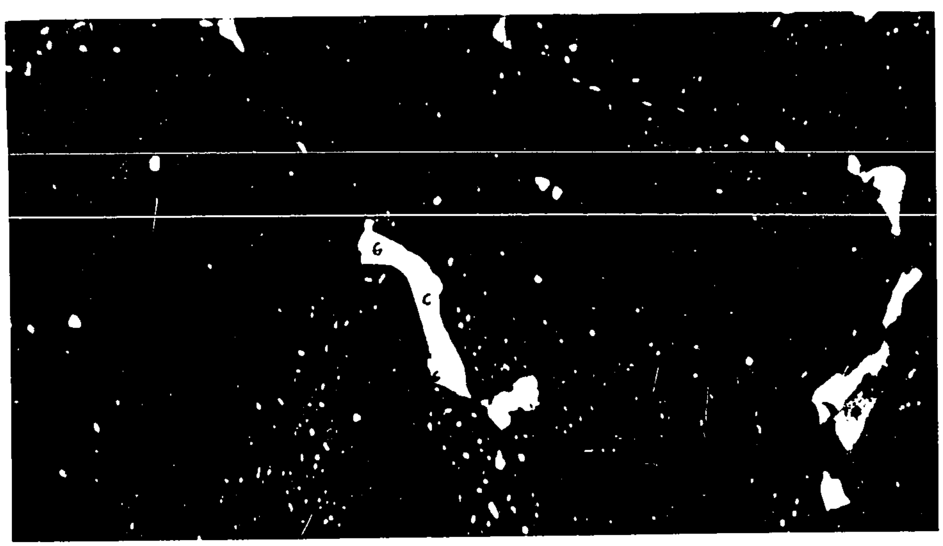

Figure 39. Galena and chalcopyrite formed at the interfaces of grains of sphalerite. Note well developed emulsion texture along the grain boundaries of the sphalerite. (x120). S-sphalerite, G-galena, C-chalcopyrite.

2. yellow sphalerite, and 3. schalenblende.

The black variety is the most common one, and occurs particularly in the "North" and "Outer" zones*. The sphalerite occurs in masses that are usually separated from other sulphides by quartz and carbonate. In matrix-rich portions of the breccia, the sphalerite tends to form narrow roughly concentric layers around aggregates of chalcopyrite.

In polished sections, sphalerite shows an excellent emulsion texture formed by ex-solved blebs of chalcopyrite, concentrated near grain boundaries, (Figure 39). The emulsion texture is present not only in grains adjacent to chalcopyrite, but also in areas where chalcopyrite is absent.

The pale yellow variety of sphalerite occurs mostly in large vugs in association with coarse galena, particularly on the 750 level, in the central portion of the breccia.

Schalenblende was identified in polished sections of specimens taken from late, steeply dipping carbonate veins on the 900 level. The mineral consists of roughly concentric layers of black and yellow sphalerite with intimately associated galena, and contains fine, colloform marcasite in the centre, (Figure 40).

<u>Marcasite.</u>

Apart from its occurence in schalenblende, marcasite is present in narrow stringers cutting across masses of

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* The North and the Outer zones will be described on pages 98-100, inclusive.

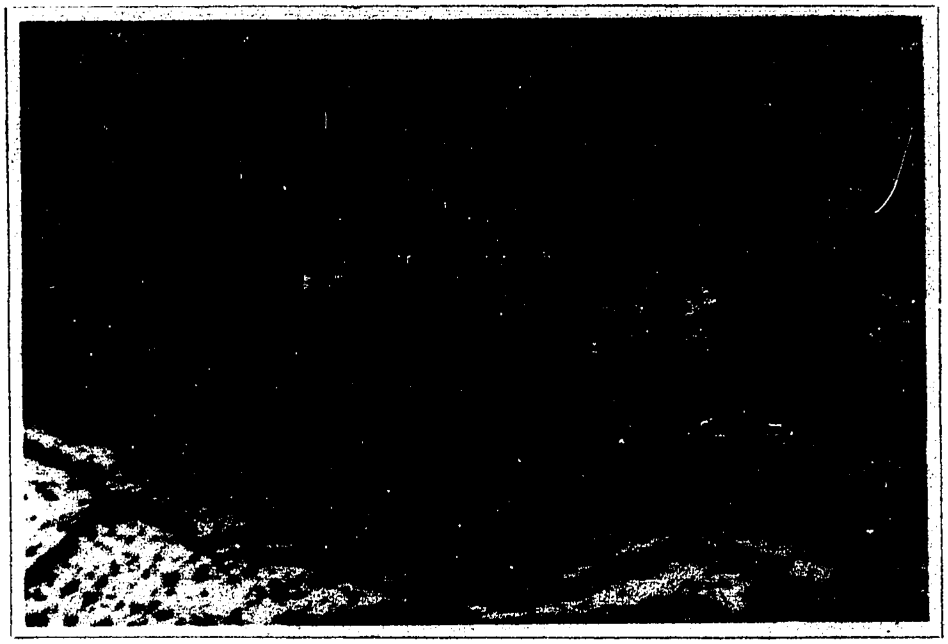

Figure 40. Colloform marcasite in the centre of concentric bands of schalenblende. (x 150)

Figure 41. Pyrrhotite formed between grains of sphalerite and chalcopyrite. (x 120)

Figure 40. Colloform marcasite in the centre of concentric bands of schalenblende. (x 150)

Figure 41. Pyrrhotite formed between grains of sphalerite and chalcopyrite. (x 120)

chalcopyrite and pyrite. This relationship may be observed in polished sections as well as in hand specimens, particularly in zones of massive sulphides, in which marcasite stringers extend for a length of several inches, mostly at small angles to the strike of the zone.

Pyrrhotite.

Pyrrhotite is a rare mineral in the Breton breccia. It was first detected in polished sections in which it occurs in the form of narrow, worm-like bodies between chalcopyrite, grains, or between grains of sphalerite and chalcopyrite, (Figure 41). In the recent development drilling of the South zone, pyrrhotite has been noted megascopically in association with chalcopyrite and pyrite.

Scheelite.

Scheelite occurs in small quantities throughout the mineralized portions of the Breton breccia. An indication of its abundance is provided by analyses of composite bulk samples which averaged 0.03 per cent WO_3.

The mineral was first noted under ultraviolet light which revealed that the scheelite occurs in small specks concentrated in narrow veins in the quartz-carbonate matrix. The relation of scheelite to sulphides was observed only in one polished section. In it the scheelite occurs adjacent to sphalerite, which seems to invade it along a fracture, (Figure 42).

Molybdenite.

Unlike all other ore minerals described so far, molybden-

Figure 42. Scheelite, invaded by sphalerite. (x 120)

ite is not associated with the quartz-carbonate matrix in the Breton breccia. Instead, it occurs mainly along the periphery of the breccia, in narrow quartz stringers and fractures that cut the massive granite wall rock. Granitic fragments containing these molybdenite-bearing fractures are occasionally found within the breccia.

A second generation of molybdenite occurs in late faults and fractures that cut the Breton breccia. Locally, these fractures also contain traces of graphite.

Molybdenite does not occur in recoverable quantities, although several zones, particularly south of the breccia on

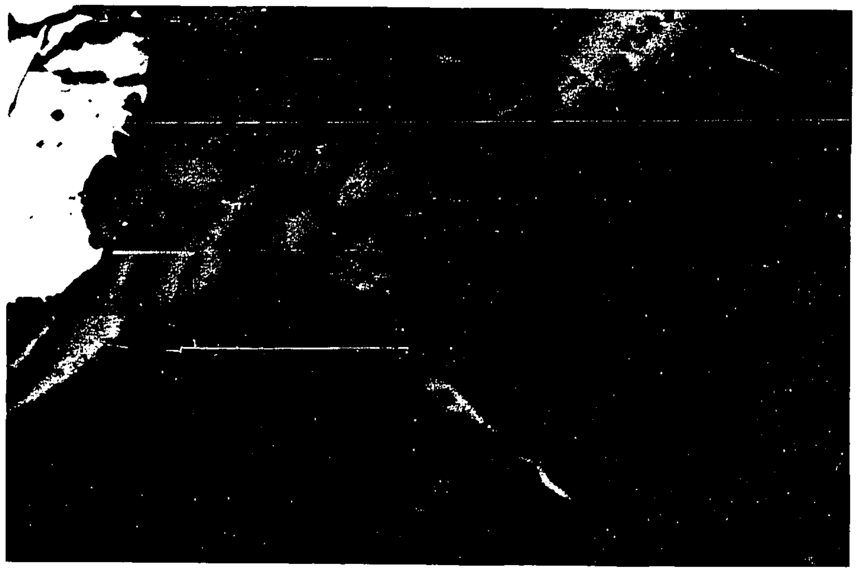

Figure 42. Scheelite, invaded by sphalerite. (x 120)

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A second generation of molybdenite occurs in late faults and fractures that cut the Breton breccia. Locally, these fractures also contain traces of graphite.

Molybdenite does not occur in recoverable quantities, although several zones, particularly south of the breccia on the 1,200 level, approach ore grade.

Magnetite.

Apart from its occurrence in diabasic fragments and late mafic dykes, magnetite is present in trace quantities in association with biotite in quartz stringers that cut fragments of diabase, (Figure 23).

PRECIOUS METALS.

Silver.

Recoverable quantities of silver are consistently present in the mineralized zones, but no silver mineral has been identified. A search for the source of silver led to good evidence that the metal is present in the chalcopyrite.

A compilation of silver and cooper assays from more than 100 samples showed that the concentration of silver is directly proportional to copper in a ratio of approximately 0.20 oz/ton Ag to 1.0 per cent copper, (Plate 6). Similar compilation of the silver values with lead and zinc have not shown significant correlations.

The only minerals consistently associated with chalcopyrite are pyrite, and the ex-solution bodies of sphalerite present in chalcopyrite. The possibility of the association of the silver with pyrite was eliminated by the fact that the silver content of the concentrate increased abruptly as the pyrite was depressed in the flotation process. This narrowed down the possible source of silver to the ex-solution bodies of sphalerite, and to the chalcopyrite itself.

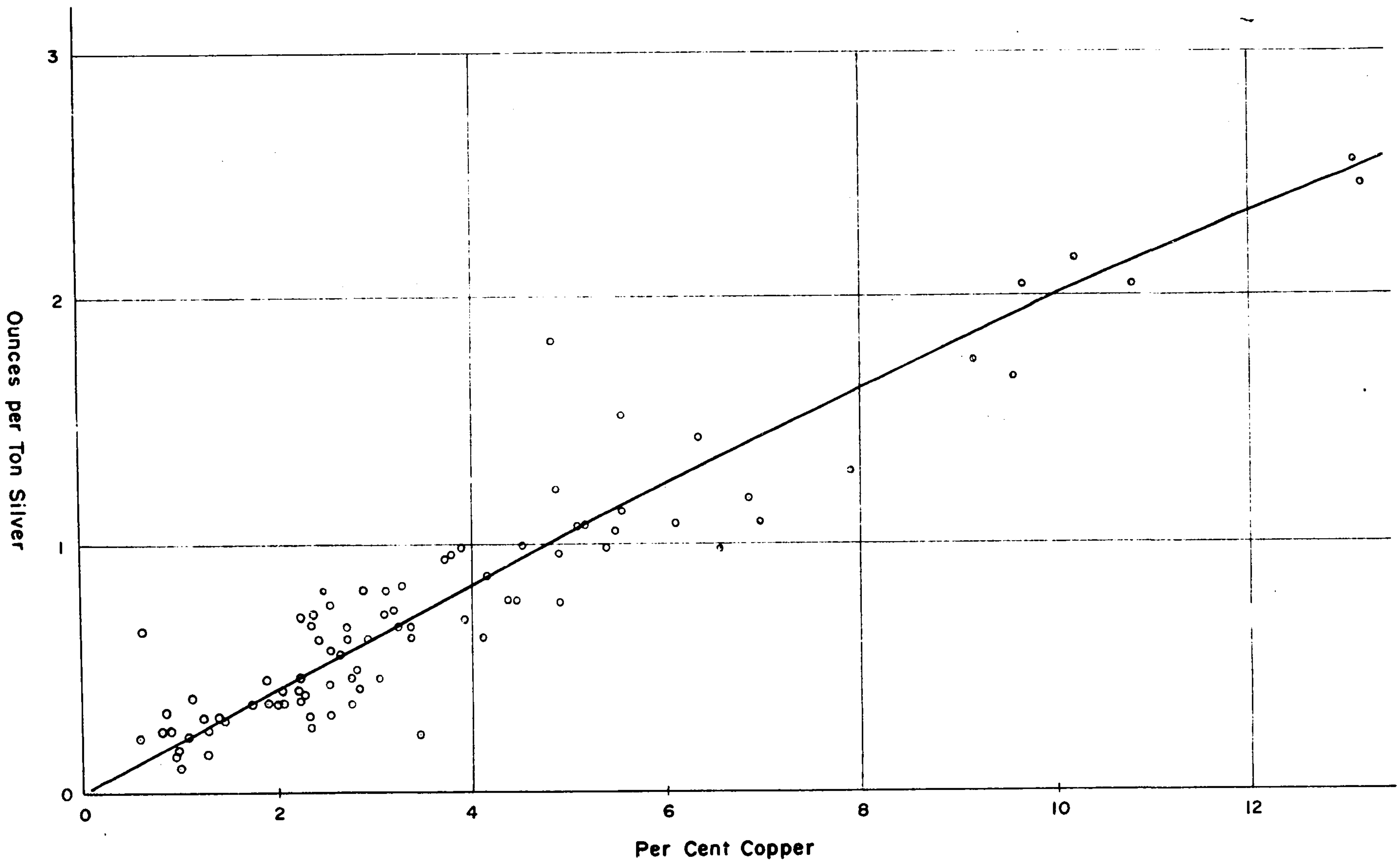


Plate 6. Graph, showing correlation of copper and silver values.

In order to determine in which of the two minerals the silver was present, the writer examined a polished section of chalcopyrite with the electron microprobe, in the laboratories at McGill University.

Considering that the average silver content of the concentrate is aproximately 5 ounces per ton, the chalcopyrite would have to contain approximately 200 ppm Ag, in order to account for the silver, according to the following, approximate calculation:

$$(1) \quad \frac{5}{14.58 \times 2000} \times 100 = 0.0171 \,\%\, Ag = 171 \text{ ppm Ag}$$

Since the ex-solution bodies of sphalerite constitute approximately 1 per cent of the chalcopyrite, the concentration of silver in the sphalerite would have to be at least one hundred times as high as that in the chalcopyrite, in order to account for the silver in the concentrate.

No signs of silver have been detected by the electron microprobe either in the chalcopyrite or in the sphalerite. The electron microprobe should detect 17,100 ppm silver in the sphalerite, but would not detect 171 ppm Ag in the chalcopyrite.

Conclusive evidence of the presence of silver in the chalcopyrite was provided by an analysis of the polished section, which revealed a concentration of 170 ppm silver*.

* Analysed by Swastika Laboratories Limited, by the fire assay procedure with an estimated accuracy of 5 per cent.

Significant amounts of silver are also present in the galena. An analysis of a galena crystal indicated a concentration of 10.78 oz/ton, (= 370 ppm Ag)*. Since, however, the concentrate averages approximately one per cent lead, which corresponds to 1.2 per cent galena, the silver content of the concentrate due to galena is approximately only .129 oz/ton, according to equation (2).

$$(2) \qquad \frac{10.78}{100} \times 1.2 = .129 \text{ oz/ton Ag}$$

From the above considerations it can be concluded that the bulk of the silver is present in the chalcopyrite, and that the scatter of the Ag : Cu ratios, (Plate 6), is probably due to the varying amounts of galena present in the analysed samples.

Gold.

While only traces of gold have been detected in the majority of all samples analysed for gold, recoverable amounts of gold, rarely exceeding 0.010 oz/ton, are occasionally present in the concentrate. Data on the occurrence of gold are not sufficient to permit the determination of its source, but preliminary indications are that the distribution of gold does not parallel that of silver.

* Fleischer, (1955), reports maximum contents of silver in sulphides as follows: 2,300 ppm Ag in chalcopyrite, 30,000 ppm Ag in galena, and 10,000 ppm Ag in sphalerite.

PARAGENESIS.

As with most other deposits, the determination of the sequence of deposition of minerals in the Breton breccia is difficult. To some extent, however, it is facilitated by the absence of any evidence of post-ore deformation, and by the presence of large, well-formed crystals which enable the study of their mutual relationships megascopically rather than under the microscope.

A convenient starting point of the study of paragenesis is provided by the relationship of various minerals to quartz, of which at least three generations have been recognized, (p. 61).

The first generation of quartz pre-dates brecciation, and was followed by the deposition of molybdenite, which is found as disseminations in the early quartz.

The second generation of quartz forms the greater part of the breccia matrix. It contains within its interstitial spaces calcite and dolomite, and the bulk of all other sulphides representing the main period of deposition. The determination of the sequence of deposition of the sulphides within this period can be postulated on the basis of their textural relationships observed in polished sections.

The ex-solution relationship of chalcopyrite and sphalerite clearly indicates their contemporaneity. In the matrix-rich portions of the breccia, however, sphalerite and associated galena form concentric layers surrounding masses of chalcopyrite, which indicates that at least some of the sphalerite and galena are later than the chalcopyrite.

Well-formed crystals of pyrite adjacent to chalcopyrite, galena and sphalerite, as well as fractures in the pyrite filled by these minerals, led Armbrust, (1967, p.57), to conclude that the pyrite was the first mineral to form. In view of the well known force of crystallization of pyrite, as well as the great mobility of the other sulphides under raised temperature and pressure, such evidence, however, seems inconclusive. Nevertheless, the consistent association of pyrite and chalcopyrite does suggest that these two minerals are probably closely related in time.

A second generation of sulphides can be observed in large vugs in the mineralized quartz-carbonate matrix. The vugs are lined with euhedral crystals of calcite, which commonly contain chalcopyrite. Tiny sphenoids of chalcopyrite are, however, also found on top of the calcite crystals, as well as on top of laumontite and galena. Reverse relationships of these minerals found elsewhere, however, indicate that the deposition of minerals in vugs was a continuous process in which the formation of various minerals overlapped in time.

One of the latest minerals to form was fluorite, which is invariably found on top of quartz and calcite. Some of the fluorite crystals, however, are coated with finely crystalline pyrite, which probably represents the last stage of the second period of deposition.

Third, and possibly fourth periods are represented by the schalenblende, and associated galena, marcasite and chalcopyrite found in the late carbonate veins, and by molybdenite and graphite in late faults and fractures.

In summarizing, it can be said that the minerals contained in the Breton breccia are the result of at least three or four periods of mineral deposition. On the basis of available evidence, it is impossible to postulate the order of deposition within each of the periods.

STRUCTURAL CONTROL OF THE ORE.

Sulphide mineralization in the Breton breccia is ubiquitous. Chalcopyrite and pyrite occur in small specks and coarser aggregates which are distributed in the quartz-carbonate matrix in an apparently erratic fashion, (Figures 21, 43, 44, and 46). The grade of copper depends on the concentration of the aggregates rather than on their size. With the mine operating on a one per cent cut-off grade, the minimum required concentration of chalcopyrite is three per cent. Outlining of such zones over mineable widths has been the greatest single task of the geologist at the Tribag mine.

The key to this problem was provided by the recognition of the internal structure of the Breton breccia.

All ore within the Breton breccia is controlled by a single structure.* The structure is a dome, located in the

* For the remainder of this chapter, the reader is referred to the level plans and vertical sections included in the Appendix.

central part of the breccia consisting of relatively "open", matrix-rich breccia. The ore is concentrated in the top part of the dome, as well as in the narrower, steeply-dipping limbs.

The dome contains two, possibly three major ore zones, and a number of subsidiary branches which "peel off" from the steeply-dipping limbs of the dome toward the centre of the breccia. The zones are not consistently mineralized with mineable grade of copper, but their continuity is always indicated by either the presence of quartz-carbonate-rich breccia, or by high alteration, or by the occurrence of the grey dyke, or by any combination of these features.

The ore zones range in width from three to fifteen feet, but may converage along strike or down dip, thus locally providing mineable widths of much grater proportions. The tracing of each individual zone through an area of such convergence is difficult. It can be accomplished only by careful noting of certain characteristic associations, such as the lead and zinc content, quartz:carbonate ratio, the presence of amphibole (?) needles, or the predominance of fragments of a particular rock type.

In general, the ore zones are characterized by sharp hanging wall contacts between the mineralized, "open" breccia and the relatively "tight", barren breccia on the outer side of the structure. Footwall contacts of the ore zones are gradational, and the decrease in grade is accompanied by a corresponding decrease in the amount of the quartz-carbonate matrix.

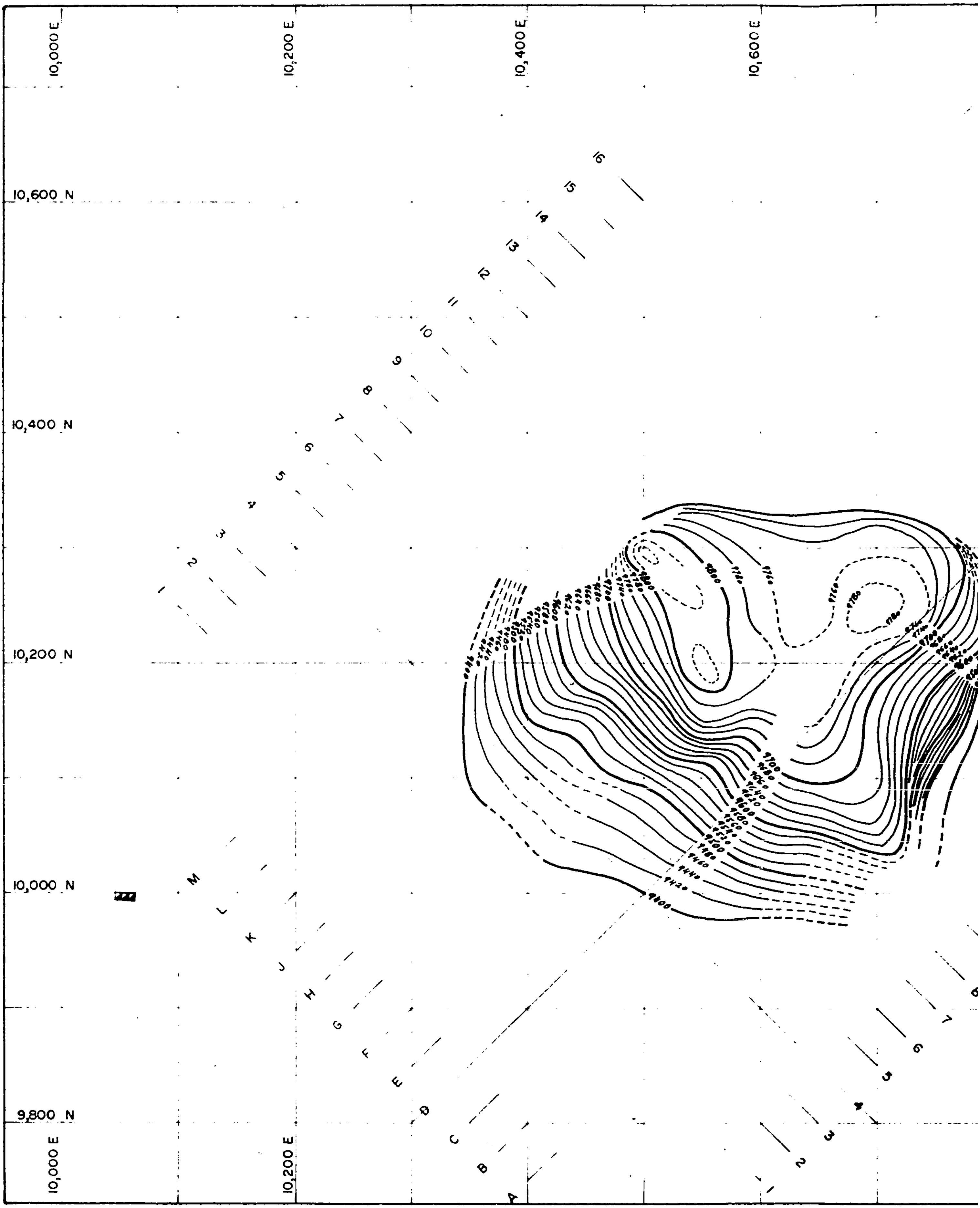
In narrow, steeply dipping zones, both contacts may be relatively abrupt.

Description of the Ore Zones.

1. The "Outer" Zone, is irregularly oval-shaped in plan, and saddle-shaped in vertical section through any plane. The zone has been outlined in sufficient detail to permit structural contouring if its hanging wall, (Plate 7). The top of the zone is located in the central part of the breccia between the 375 level and the 225 sub-level. The southwest limb of the zone dips irregularly 45° to 80° southwest, and extends down to approximately 50 feet above the 750 level, where it is cut off by the granite contact. The east limb dips 60° to 80° east, and has been traced down to the 750 level, where it extends for a length of 230 feet, striking N 10°E. On the 750 level, the mineralization of the east limb decreases to the southwest, but the structure continues to the 10,000 N co-ordinate, where it turns abruptly to the west, and terminates at the granite contact.

The north limb of the zone dips vertically or steeply north, and has been traced to the 1,050 level. On the 750 level, the structure abuts against the granite contact on the west, and joins with the east limb in the east, in the vicinity of 10,800E, 10,275N.

It is important to note that the projection of the north and south limbs beyond the granite contact to the southwest and west, respectively, passes through an area characterized


10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
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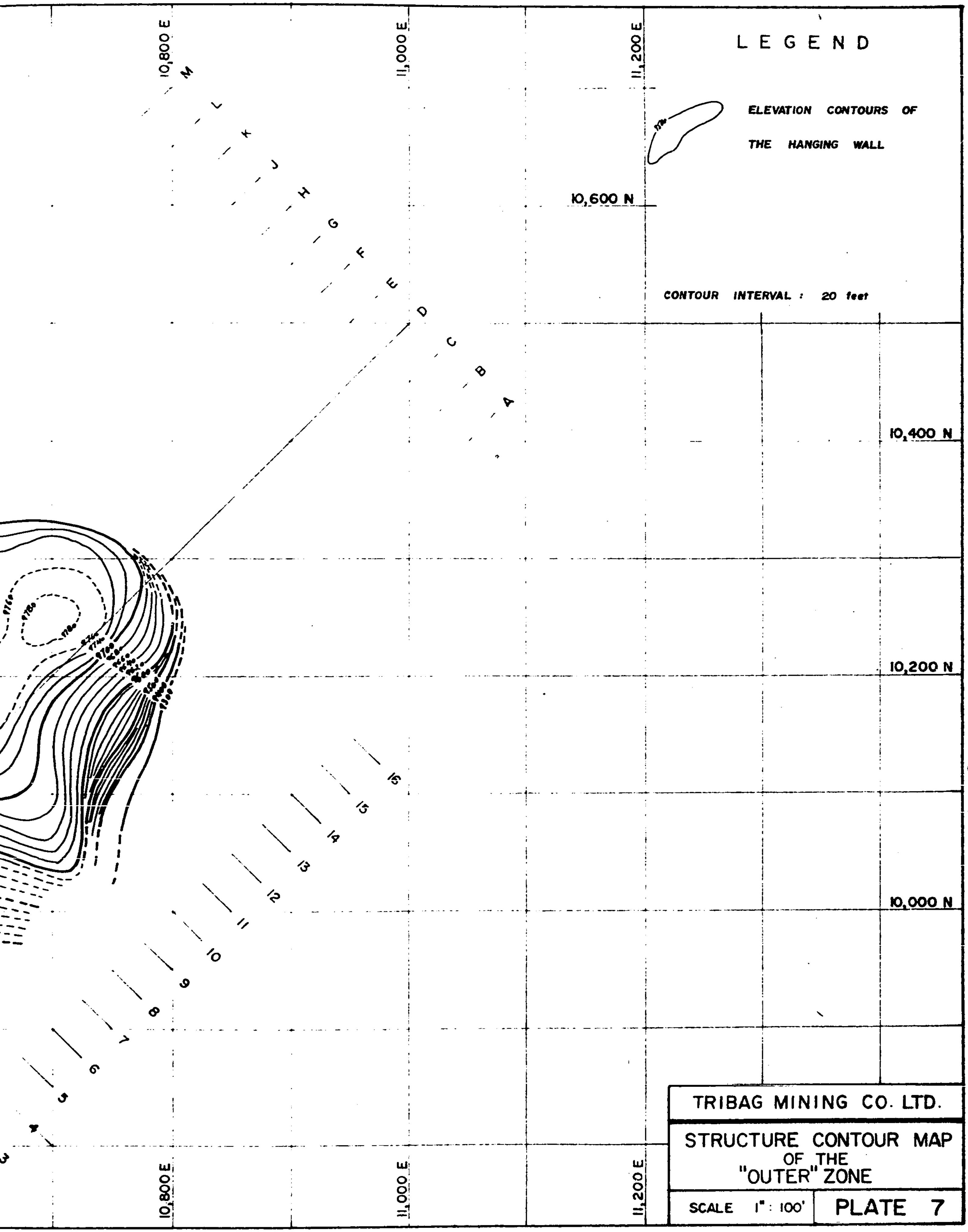
9440
9460
9480
9700



LEGEND
ELEVATION CONTOURS OF THE HANGING WALL
CONTOUR INTERVAL : 20 feet
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
M
L
K
J
H
G
F
E
D
C
B
A
16
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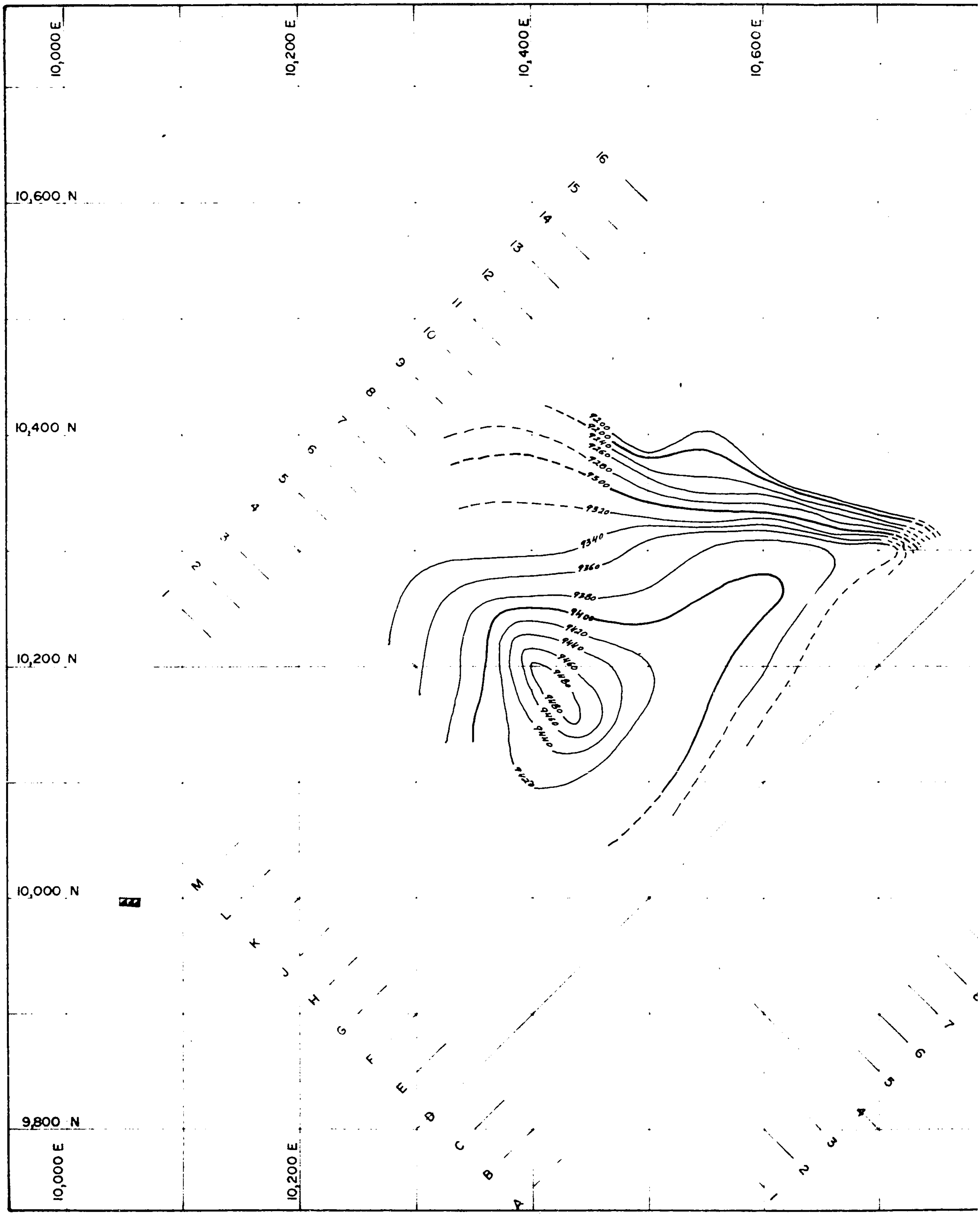
TRIBAG MINING CO. LTD.
STRUCTURE CONTOUR MAP OF THE "OUTER" ZONE
SCALE 1" : 100'
PLATE 7

by strong fracturing of the massive granite wall rock. The attitude of the fractures is conformable to the attitude of imaginary projections of the Outer zone in that area, (Plate 13).

2. The "Inner" Zone. The top of the Inner zone lies at 10,420E, 10,175N, approximately 30 feet above the 625 level, (Plate 8). On the 625 level, the zone is oval-shaped, and its long axis trends in a northwesterly direction. Its limbs dip outward in all directions, relatively flatly to the southwest, and steeply to the north and northwest. The north limb of the Inner zone merges with the north limb of the Outer zone, as well as with a minor subsidiary zone above the 750 level, thus forming a wide zone, which is currently mined by the blasthole stope method.

Both the Inner and the Outer zones are characterized by their association with the grey dyke, and by the occurrence of massive sulphides. Both of these are particularly well developed in the Outer zone, between the 375 and 625 levels.

The zone of massive sulphides ranges is width from 0.5 to 5 feet, and consists of approximately 85 per cent sulphides of which at least 75 per cent consists of chalcopyrite, (Figure 43). The massive sulphides represent the core of each of the ore zones, and tend to be located either in their centres or near their hanging wall contacts. The massive sulphides are irregular in places, locally changing their strike and dip, and they may pinch out or widen within a distance of a few feet. In spite of local interruptions, the zone shows a remarkable



10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E
1
2
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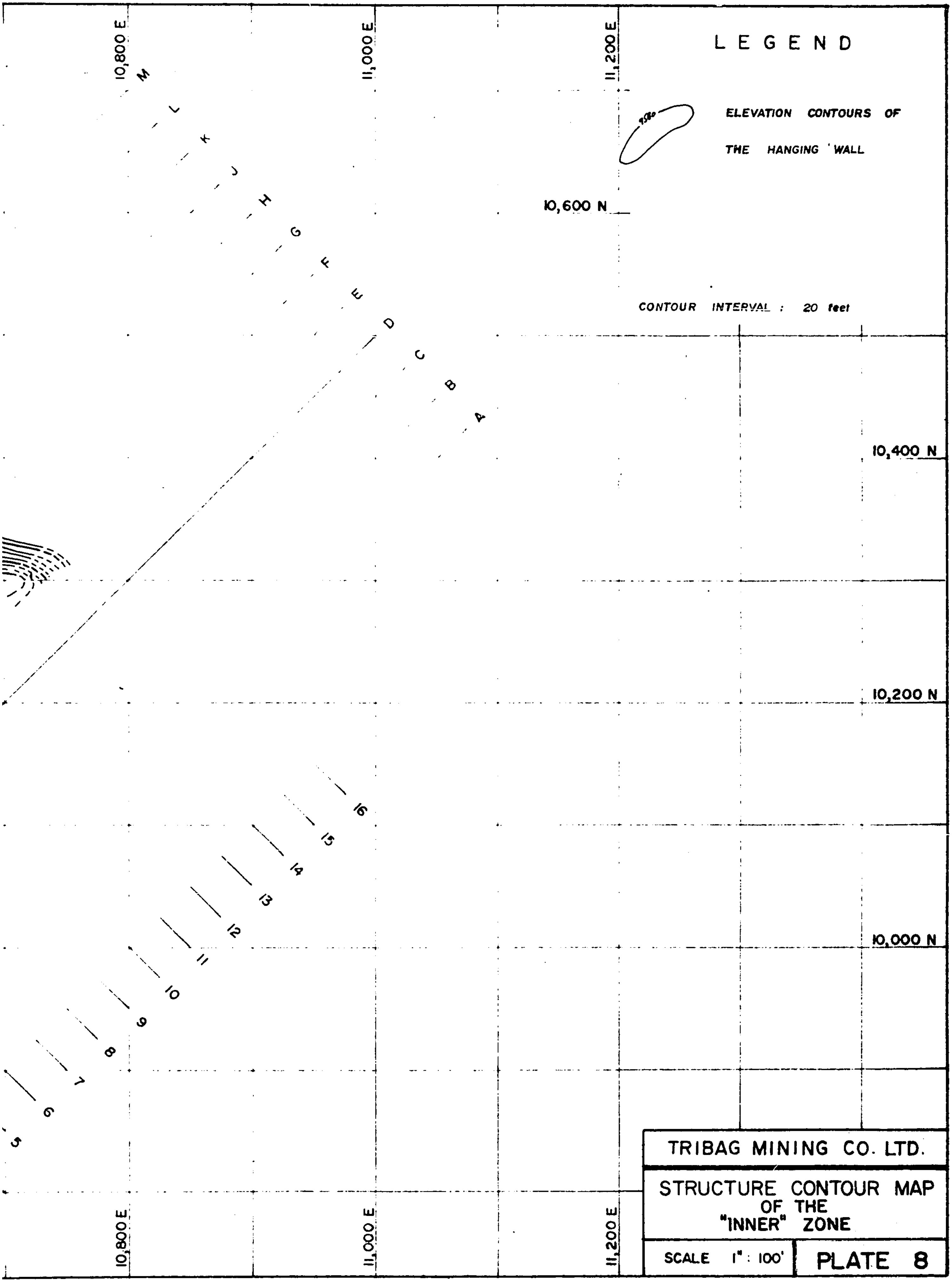
LEGEND
ELEVATION CONTOURS OF THE HANGING WALL
CONTOUR INTERVAL : 20 feet
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
M
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K
J
H
G
F
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TRIBAG MINING CO. LTD.
STRUCTURE CONTOUR MAP OF THE "INNER" ZONE
SCALE 1" : 100'
PLATE 8

continuity over a strike length of 500 feet, particularly on the 750 level.

Owing to their irregular shapes, the mutual structural relationship of the Outer and Inner zones is difficult to establish. Considering the positions of their peaks, however, a line joining the highest points of each peak would plunge at 65° to 70° in a S 35° - 80° W direction, depending on the exact position of the peak of the Outer zone. The projection of this line to lower levels would leave the breccia pipe above the 750 level.

3. <u>The North and South Zones.</u> Both the North and the South zones are in part controlled by the granite-breccia contact.

The North zone strikes N 80° W, and extends from the surface to the 375 level, between the 10,600E and 10,900E co-ordinates. In longitudinal section, the zone exhibits a steep easterly plunge, and probably continues down to the 900 level, east of the 10,900 E co-ordinate.

This zone ranges in width from 2 to 30 feet, and its greater part lies immediately adjacent to the granite contact, (Plate 15). In the west, however, the zone moves away from the contact, leaving the contact area relatively barren. A similar trend is observed in section, particularly on 10,800E, (Plate 25), where the dip flattens above the 225 sub-level, and the zone "rolls over" toward the centre of the breccia pipe.

The South zone extends from the 375 level to the 900 level between the 10,700E and 11,100E co-ordinates. It consists of two main branches. One branch lies adjacent to the granite contact, strikes due east, and dips 70° south. As with the North zone, it shows the tendency to leave the granite contact as it approaches higher horizons, (Plate 17, 26 and 27).

The second branch of the South zone, shown on sections 10,800E to 11,000E, (Plates 25 - 27), departs from the granite contact below the 625 level, and flattens toward the centre of the breccia, forming a saddle-shaped body, with its crest just above the 625 level.

The close association of the North and South zones with the granite contact, and the "peeling off" effect noted at shallower horizons suggest that the two zones may represent parts of a single structure, possibly the outermost zone contained in the dome, the top of which may have been removed by erosion. It is probable that the two zones join in a large arc connecting the east end of the North zone on the 375 level with the east end of the South zone on the 625 level. The inferred continuity of the two zones in section is shown in Plate 25.

As with the Outer zone, it is again important to note that the predominant attitude of fractures in the granite exposed in a drift at 10,800E and 10,500N on the 750 level is conformable to the attitude of the projection of the two zones into that area, (Plate 13).

Unlike the Outer and Inner zones, the North and the South

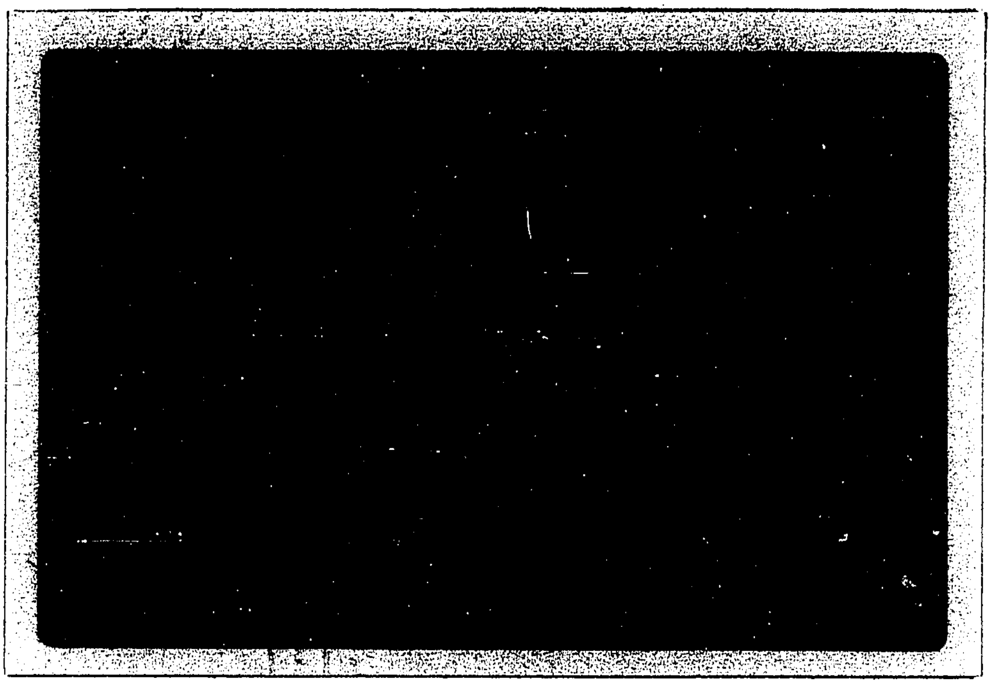


Figure 43. A zone of massive sulphides in the Outer zone on the 750 level.

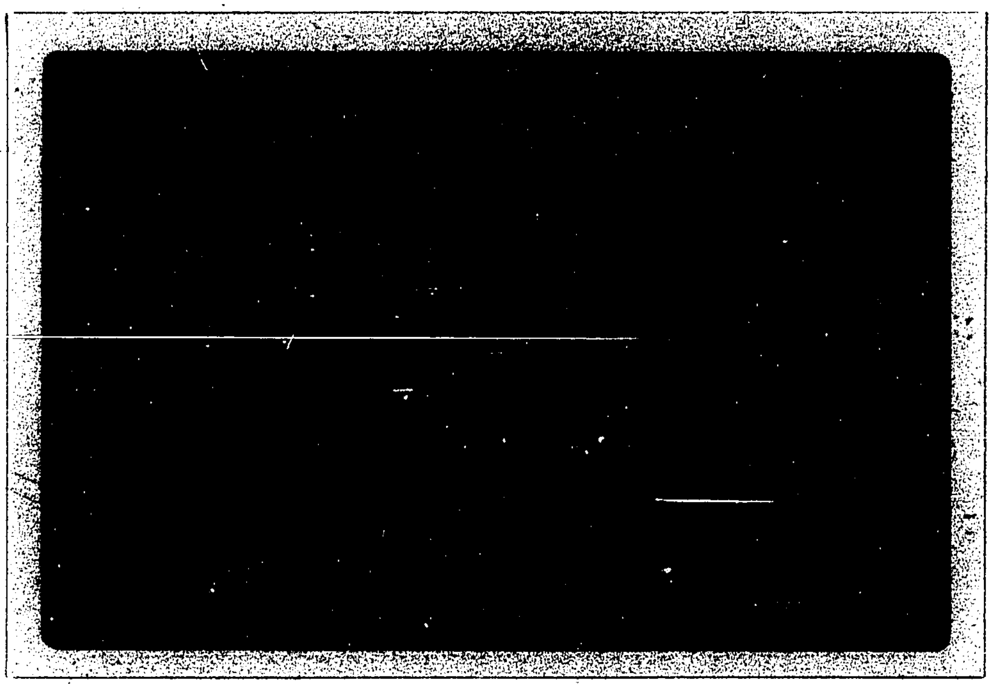
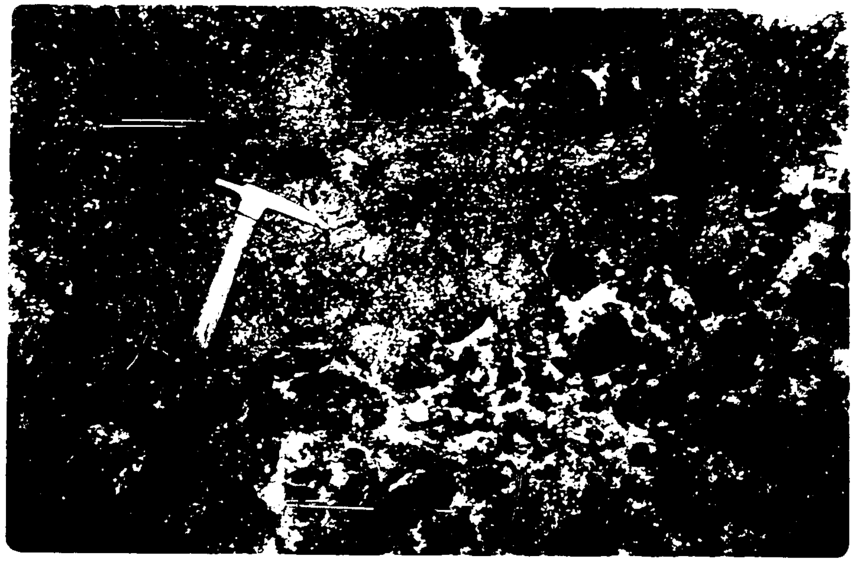


Figure 44. Chalcopyrite in the South zone, characterized by "low alteration breccia".



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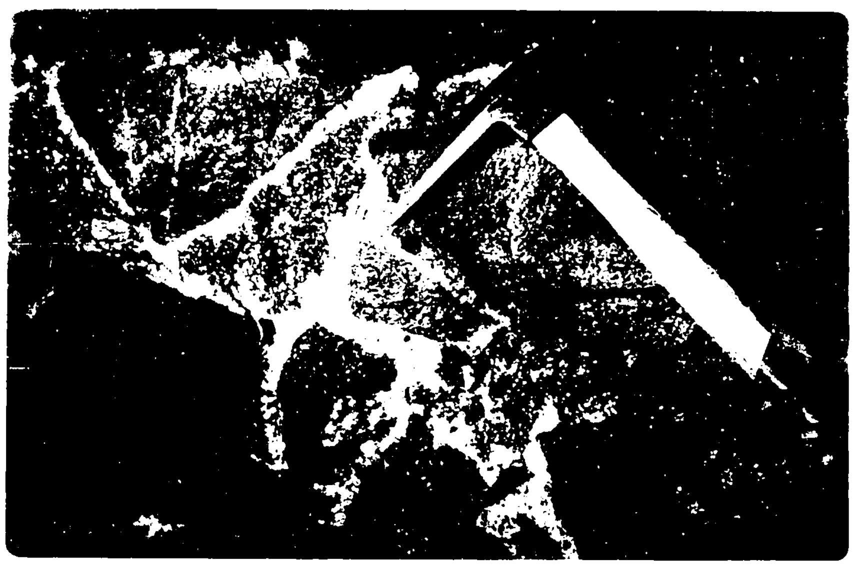

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zones are not associated with the grey dyke, and do not contain massive sulphides. Sulphide mineralization is fairly uniform, showing some degree of concentration at the granite contacts, and decrease in mineralization toward the footwall. Both zones are characteristically associated with fragments of diabase and basic metavolcanics, and none of the zones is enveloped in a high alteration aureole.

The two zones differ, however, mineralogically. The North zone is characterized by a relatively high galena and sphalerite content, particularly between 10,800E and 10,700E above the 375 level. The South zone is the only zone containing megascopically identifiable pyrrhotite.

4. Subsidiary Zones. Each of the ore zones described so far has one or more minor subsidiary zones, which merge with one of its steeply dipping limbs, and as a rule, flatten toward the central part of the breccia at shallower horizons. While some of these subsidiary zones may be marginal in grade, their overall economic importance is considerable, particularly in places where they merge with other zones, thus adding to their widths.

5. Low Grade Zones. In addition to zones of mineable grade, the Breton zone contains several broad zones of low grade mineralization, the exact boundaries of which are difficult to define. The most important of these is the "Open Pit" zone which occurs in the central part of the breccia, and extends from the 375 level to the surface. The zone is associated with

ordered breccia, and the sulphides are conformable to the predominantly horizontal attitude of the elongated fragments.

Another low grade zone extends from the 1,050 to the 900 level, between the 10,300E, and 10,450E co-ordinates. The mineralization is associated with relatively tight but highly altered breccia, but its full extent is not as yet known.

Large tonnages of low grade mineralization are also present beneath the peak of the Inner Zone, at the 625 level. These mineralized areas represent extensions of the Inner zone, and their mutual boundaries are artificially determined by assay cut-offs.

6. Cross Structures. Several narrow, quartz-rich, vein-like structures, mineralized mostly with sub-marginal grade of copper occur in several stopes. These structures strike predominantly at right angles to the strike of the rich ore, dip steeply, and appear to radiate from the central part of the dome. Their extent, and distribution pattern are not known in detail, but the structures are probably the results of the same stresses which resulted in the formation of the dome.

7. Granite Zone. In comparison to all other ore zones described so far, the Granite zone is an anomaly. As its name implies, the zone occurs in the granite, and it is characterized by the replacement of the mafic constituents by chalcopyrite.

Mineralization of this type was first encountered in surface hole V-49, (10,500E, 10,000N), below the 900 level, and subsequently in hole V-76, (10,100E, 10,500N), close to the surface, (Plate 4). The occurrence of similar but low grade mineralization in surface holes drilled immediately southwest of the Breton breccia suggests that the zone may extend continuously along the southwest contact of the breccia, and plunge to the southeast.

The granitic host rock is highly sericitized, and contains approximately 5 per cent of fine grained, grey, rounded inclusions, which average two inches in diameter. A narrow grey dyke occurs at the top of the intersection encountered in hole V-49.

Post-Ore Faulting and Fracturing.

The Breton breccia is cut by relatively few faults. These cause only minor displacement of the ore, and pose no problems in mining. The faults are surrounded by narrow zones of extreme alteration, and are occasionally filled with fault gouge. The faults range in dip from 30° to 90°, and it is interesting to note that regardless of their attitude, slickensides observed in the fault planes are mostly horizontal, seldom exceeding a plunge of 15 or 20 degrees.

The only fault along which considerable movement has taken place occurs west of the breccia, and has been noted on every level of the mine. The fault strikes N 65° W, dips 70° north, and offsets the amygdaloidal dyke, causing a right-hand strike separation of 90 feet, (Plate 17).

A number of strong fractures surrounded by haloes of strong alteration or bleaching have been observed throughout the breccia, (Figure 45). Detailed mapping of the fractures, however, revealed no evidence of movement.

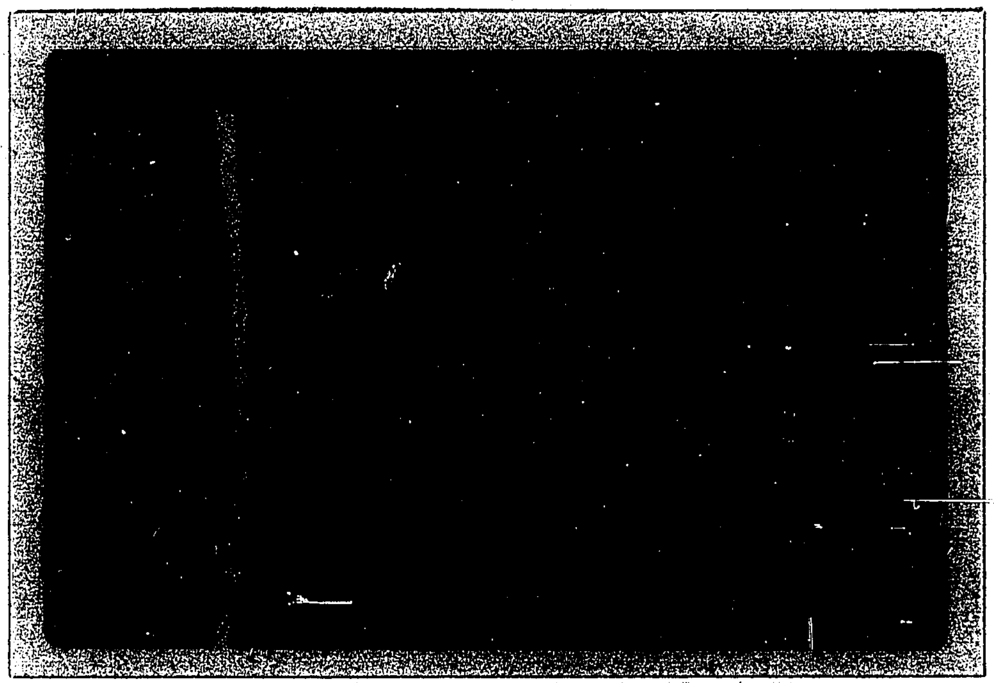


Figure 45. ~~A zone~~ of bleaching of a series of dykelets surrounding a fracture on the 1,200 level.

It may be important to note that the frequency of fractures appear to increase with depth. This is particularly obvious in the massive granite wall rock, exposed on every level of the mine, between the shaft and the west contact of the breccia. The possible significance of this observation will be discussed in the final paragraph of this thesis.

band strike separation of 60 feet, (Plate 17).

A number of strong fractures surrounded by haloes of strong alteration or bleaching have been observed throughout the breccia, (Figure 45). Detailed mapping of the fractures, however, revealed no evidence of movement.

Figure 45. A zone of bleaching of a series of dykelets surrounding a fracture on the 1,200 level.

It may be important to note that the frequency of fractures appear to increase with depth. This is particularly obvious in the breccia [illegible] wall rock, exposed on every level of the mine, between the shaft and the [illegible] contact of the breccia. The possible significance of this observation will be discussed in the final [illegible] of this thesis.

Grey Dyke - Its Relation to Ore.

The recognition of the grey dyke as a guide to ore has helped enormously in tracing out the ore zones in the Breton breccia. Yet, its presence alone does not necessarily indicate the proximity of ore, and neither are all zones associated with it. The main significance of the grey dyke lies in the fact that its occurrence along the projected strike of a seemingly terminated ore zone, invariably indicates continuance of the mineralized structure.

Within the breccia, the dyke is an apparently discontinuous intrusion, which widens and narrows down erratically,

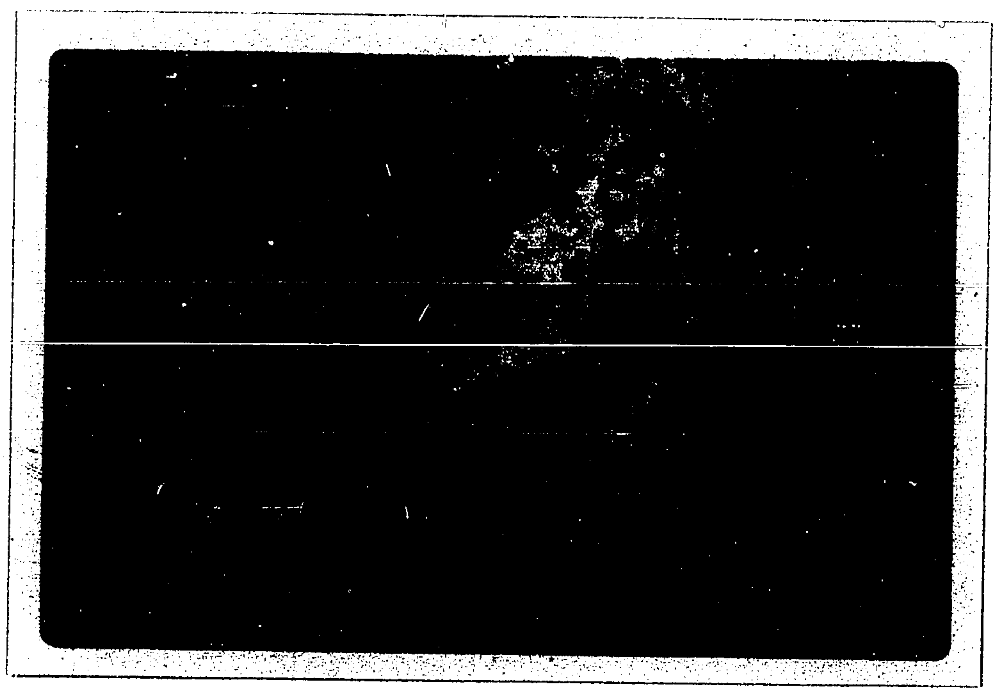


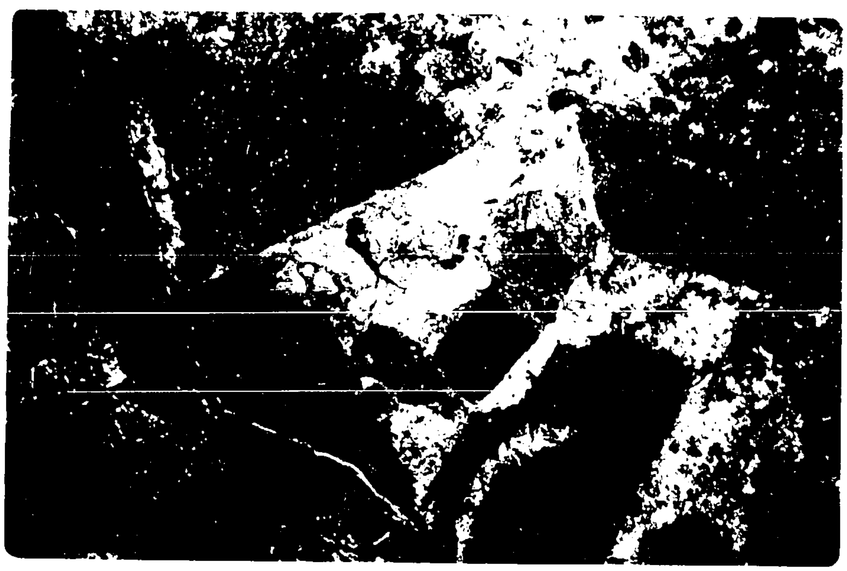
Figure 46. Grey dyke following the outlines of angular rock fragments. Note also the occurrence of chalcopyrite on top of the fragments.

[illegible] - [illegible].

[illegible] of the [illegible] as a guide to ore [illegible] but the ore zones in the [illegible] breccia. [illegible], its presence alone does not necessarily indicate [illegible] ore, [illegible] are all [illegible]

[illegible]. [illegible] of the [illegible] lies in the fact that its occurrence along the [illegible] of [illegible] indicates [illegible] of the [illegible] structure.

[illegible] in the breccia, the [illegible] is [illegible] discontinuous intrusion, which pinches and [illegible] erratically,



[illegible]. [illegible] following the outlines of [illegible] rock fragments. [illegible] also the occurrence of [illegible] of the fragments.

occasionally leaving only a few inconspicuous traces in the quartz-carbonate matrix. The dyke does not cut across the rock fragments, but appears to avoid them, closely following their outlines, (Figure 46).

In steeply dipping, narrow ore zones, such as in the north limb of the Outer zone, the grey dyke is present fairly consistently. It may occur in the hanging wall or the footwall of the ore, or it may be "sandwiched" between massive sulphides. In the flat-lying, upper portion of the zone, however, the dyke splits into innumerable narrow, discontinuous dykelets which roughly follow the trend of the ore, occupying an overall width in excess of thirty or forty feet.

At the top of the Inner zone, above the 625 level, the grey dyke forms a wide "roof" over near-massive sulphides, locally attaining a thikness of over 12 feet. The occurrence of sulphides above the dyke, however, indicates that the dyke did not restrict the ascent of the metal-bearing solutions by acting as a dam, but that its intrusion merely followed the same paths.

In the "stratified" breccia exposed on the 225 sub-level the grey dyke intruded conformably between the gently-dipping elongated fragments, thus behaving like a sill rather than a dyke. Elsewhere, however, traces of the dyke are present in fractures and faults which cut across the breccia fragments.

Pre-Ore or Post-Ore? The age relationship of the grey dyke and sulphide mineralization is uncertain.

1. Contact between the grey dyke and massive sulphides are extremely sharp.

2. Microscopic examinations indicate that the grey dyke is partly replaced by chalcopyrite. The replacement is restricted to a narrow zone immediately adjacent to the contact, and which rarely exceeds two inches in width. Within the zone, the amount of chalcopyrite decreases markedly away from the contact.

3. The dyke is cut by minute fractures, some of which are mineralized with chalcopyrite.

4. Large, irregular masses of the grey dyke are occasionally enclosed by massive sulphides.

5. The intensity of the alteration of the grey dyke in the vicinity of ore is not consistent, and may range from relatively low to high.

6. The grey dyke may occur both in the footwall or the hanging wall of an ore zone, as well as in its centre. No damming effects have been observed.

7. Microscopic examinations of polished sections of chalcopyrite revealed that the skeletal exsolution bodies of sphalerite contained in the chalcopyrite are invariably distorted or destroyed in the vicinity of the grey dyke.

While none of these observations provides conclusive evidence, the writer feels, mainly on the basis of the last two point that the emplacement of the dyke took place after the deposition of the sulphides.

WALL ROCK ALTERATION.

Study of the wall rock alteration was the subject of a doctoral thesis entitled "Wall Rock Alteration and Paragenesis of the Tribag Mine", by Armbrust, (1967). His findings are summarized in the following paragraphs.

Sericite, or fine grained muscovite are the most abundant alteration products. The principal mineral subject to sericitization is plagioclase, which is replaced by sericite particularly along cleavage and twin planes. In fragments of mafic metavolcanics, sericite replaces the calcic plagioclase, whereas the mafic minerals are chloritized. Sericitized grains of plagioclase are commonly associated with secondary quartz which can be distinguished from primary quartz by lack of undulatory extinction, and by lack of apatite inclusions, which are commonly present in primary quartz.

Armbrust, (p.49), distinguished three important associations of chlorite in the Breton breccia. In the first of these, chlorite, characterized by anomalous extinction colours, replaces biotite grains. The second type of chlorite is isotropic, and replaces rims of plagioclase. The third type, distinguishable by first order grey interference colour, is found in stringers in granite, which cut across plagioclase containing chlorite of the second type.

In addition to chlorite and sericite, Armbrust, (p.50), identified kaolinite by X-ray diffraction. The kaolinite replaces plagioclase, producing a cloudy effect. Masses of kaolinite, have also been found, however, in large vugs, particularly at the east end of the breccia, on the 750 level.

Carbonatization, according to Armbrust, (p.50), is most pronouced in mafic volcanic rocks, in which it affects plagioclase, and hornblende. The writer noted extensive carbonatization also in the amygdaloidal and grey dykes, as well as in the granite, particularly on the lower levels.

Illite is the principal alteration product in zones of extreme alteration which surround late faults and fractures.

A striking feature of the alteration is the presence of alteration rims found in granitic fragments throughout the Breton breccia. The rims consist of fresh-looking granite,

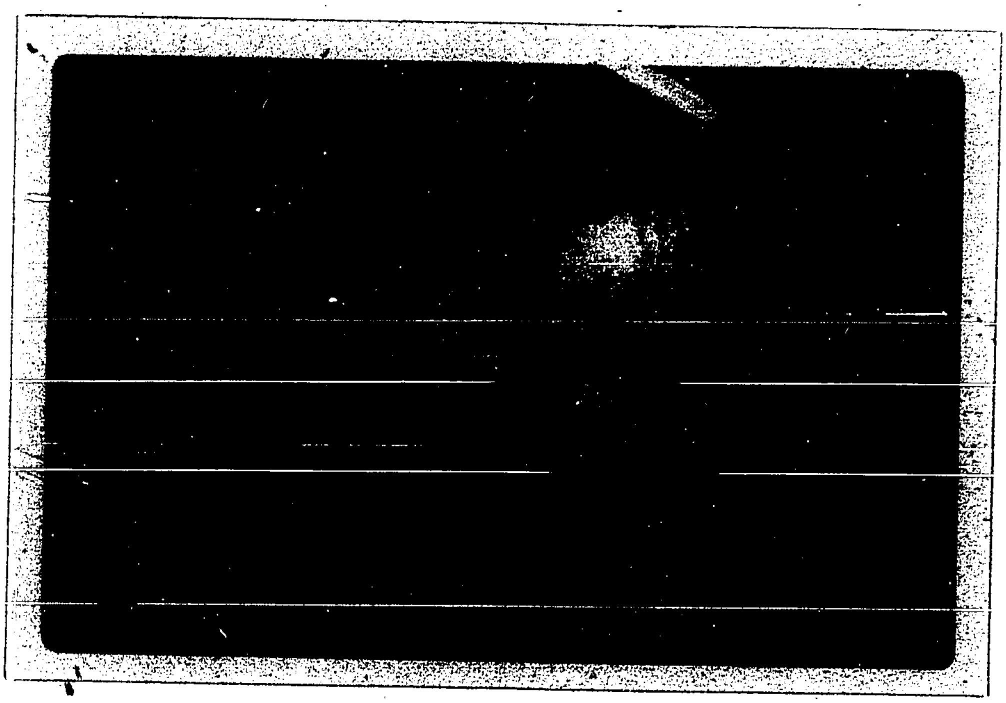
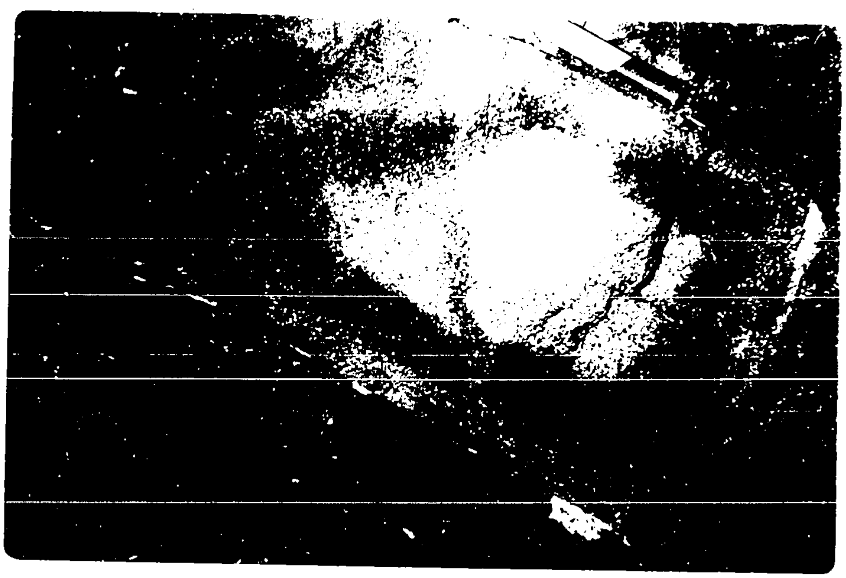


Figure 47. Zones of alteration in a granitic fragment.

maf



whereas the centres of the fragments are intensely altered and bleached to a pale yellow colour. Occasionally, a third zone may be present, (Figure 47), which consists of chloritization between the fresh-looking rim and the altered core of the fragment.

The cause of this peculiar zoning is not understood. Examination of thin sections by Armbrust, (p.56), revealed that in the central part of the fragments, the plagioclase is completely replaced by kaolinite, and by lesser amounts of sericite and chlorite. In the fresh-looking rim, the alteration consists mainly of sericite, while kaolinite alteration is minor.

Alteration as a Guide to Ore.

The examination of vertical sections and level plans included in the Appendix reveals that most ore zones are enveloped by broad haloes of alteration.* Their recognition significantly reduced the exploration targets, and the alteration has been successfully used as a direct guide to ore throughout the development of the Breton breccia.

The broadest zone of alteration occurs in the central part of the breccia, in which it surrounds the Outer and Inner zones, including a number of their subsidiary branches. In general, the medium and highly altered zones roughly parallel the distribution of the "open", matrix-rich breccia. In the

* The "altered breccia" indicated on the level plans and sections represents both high, and medium alteration.

footwalls of ore zones the intensity of alteration decreases gradually away from the ore, whereas in the hanging wall, the contact between high and low alteration is usually abrupt, and commonly coincides with the boundary between open and tight breccia. This is particularly noticeable in the steeply-dipping north limb of the Outer zone, where the alteration halo in the hanging wall is narrow, and locally absent, (Plate 24).

Just as with many other guides to ore, however, the alteration zones in the Breton breccia have to be regarded with caution. The presence of high alteration alone does not necessarily herald the proximity of ore, and conversely, not all ore zones are associated with it. A striking example of this occurs in the central and west-central parts of the breccia on the 1,050 and 1,200 levels, where high alteration is present in a broad zone of relatively tight and barren breccia, (Plates 19 and 20).

In an attempt to determine whether the change from relatively fresh, tight and barren breccia to an open, altered and mineralized breccia is reflected chemically, the writer sampled a diamond drill hole which intersected the north limbs of the Outer and Inner zones. The samples were taken at irregular intervals avoiding basic fragments to reduce the chemical variation due to the original composition of the rock, and were subsequently analysed for 16 trace elements. The results of the analyses are shown both graphically and in tabular form in the Appendix.

With the exception of strontium, which has a somewhat higher background in the relatively fresh, barren breccia, no element shows any significant variation which could be related to the proximity of ore.

GEOTHERMOMETRY.

Heating Experiments.

In an attempt to estimate the temperature of formation of chalcopyrite, the writer carried out a series of nine experiments modelled after earlier work of Japanese and Germnn research workers. The experiments involved the heating of polished specimens of chalcopyrite containing exsolution bodies of sphalerite, and of subsequent observation of the changes in the exsolution textures. The work was done on the assumption that the temperature at which the exsolution bodies became absorbed in chalcopyrite provided evidence that the temperature of formation of the chalcopyrite was higher than the temperature of homogenization.

The specimens were collected on the 750 level, and are representative of the mineralization found in the north limb of the "Outer" zone. The polished sections averaged 15 x 6 x x 4 mm in size, and were composed of two or more coarse grains of chalcopyrite, each containing approximately 1-2 per cent skeletal sphalerite bodies, and occasional small fields of sphalerite. No other minerals were present in the specimens.

The specimens were heated in evacuated silica tubes in furnaces at controlled temperatures. After a certain period of time each specimen was quenched in water, allowing the temperature to drop to room temperature within approximately five seconds. Most of the specimens shattered on quenching, and had to be re-polished before a microscopic examination could be made. The effects of the heating are summarized in Table 11.

Table 11

Effects of Heating on Sphalerite Exsolution Bodies in Chalcopyrite.

Run No.	Temperature (°C)	Time (hours)	Observations
1	302	112	No change
2	394	72	No change
3	497	72	Incipient absorption of sphalerite noted in some exsolution bodies.
4	600	70½	Exsolution bodies of sphalerite completely disappeared.
5	500	137½	Same as in run No. 3
6	600	137½	Exsolution bodies of sphalerite completely disappeared. Well developed domains in chalcopyrite observed on etching.
7	550	148	Exsolution bodies of sphalerite completely disappeared. Several irregular fields of sphalerite partly absorbed in chalcopyrite.
8	525	275	Same as in run No. 7
9	500	672	Exsolution bodies of sphalerite completely disappeared. Perfect development of domains observed in chalcopyrite even before etching.

Discussion of the Results.

The absorption of exsolution bodies of sphalerite was complete in all runs carried out at temperatures above 500 °C. This temperature of homogenization falls within the range of temperatures indicated by previous experiments. Borchert, (1934), noted the absorption of sphalerite in chalcopyrite at 550 °C. Nakamo, (1937), described the same effect after a three-hour experiment at 480 °C. More recently, Sugaki and Tashiro, (1957), found that skeletal sphalerite disappeared at temperatures ranging from 480 °C to 515 °C.

It has been suggested that the unmixing of sphalerite may take place when the chalcopyrite is cooled through the temperature of inversion (T_c) from the high, disordered state to the low, ordered state. Considering that disorder enhances solid solution, and that some minerals unmix completely at the inversion temperature, (Ramdohr, 1938), this suggestion has much merit.

Inversion of pure, synthetic chalcopyrite takes place at 547 ± 5 °C, (Yund and Kullerud, 1961). Experimental data on inversion temperatures of natural chalcopyrite, however are varied, and range up to 580 °C ± 20 °C, (Cheriton, 1952). There is no doubt that the inversion temperatures are influenced by the chemical composition of the mineral, (Kullerud, 1956), and to a lesser degree on pressure, (Cheriton, 1952; Krishnamurthy, 1967). Moreover, it is probable that the T_c depends also on the chemical environment at the time of the formation of chalcopyrite, just as the T_c of quartz was found to have been influenced in experiments carried out in the presence of various metals, (Keith and Tuttle, 1952).

In runs Nos. 8 and 9, conducted at temperatures of 525°C and 500°C respectively, the exsolution bodies were completely absorbed in chalcopyrite. As these temperatures are well below the experimentally determined T_c of chalcopyrite, it would seem that the homogenization is not necessarily due to the inversion to higher state. It is important to note, however, that neither the exact composition of the chalcopyrite, (apart from its known high silver content), nor the chemical environment in which it was formed, is known. With this in view, it is not inconceivable that the homogenization of the chalcopyrite-sphalerite assemblage might indeed be the result of inversion, which could take place at an unusually low temperature in the examined specimens. The surprising appearance of domains in experiment No. 9, could be regarded as evidence that the chalcopyrite attained the high, disordered state at a temperature of 500°C or lower.

Domains, representing inversion twinning have been recognized by Frueh, (1958), on X-ray diffraction records, and first observed under the microscope by Krishnamurphy, (1967). The domains appear on etching with a 1 : 1 solution of H_2O_2 and NH_4OH, or with acidic $K_2Cr_2O_7$. They were observed in run No. 6 after etching with H_2O_2 and NH_4OH, (Figure 48). In experiment No. 9 no staining was necessary to show up the domains distinctly. Since in none of the specimens similar twinning was observed before heating, there is no doubt that the domains represent inversion twinning rather than twinning caused by other forces.

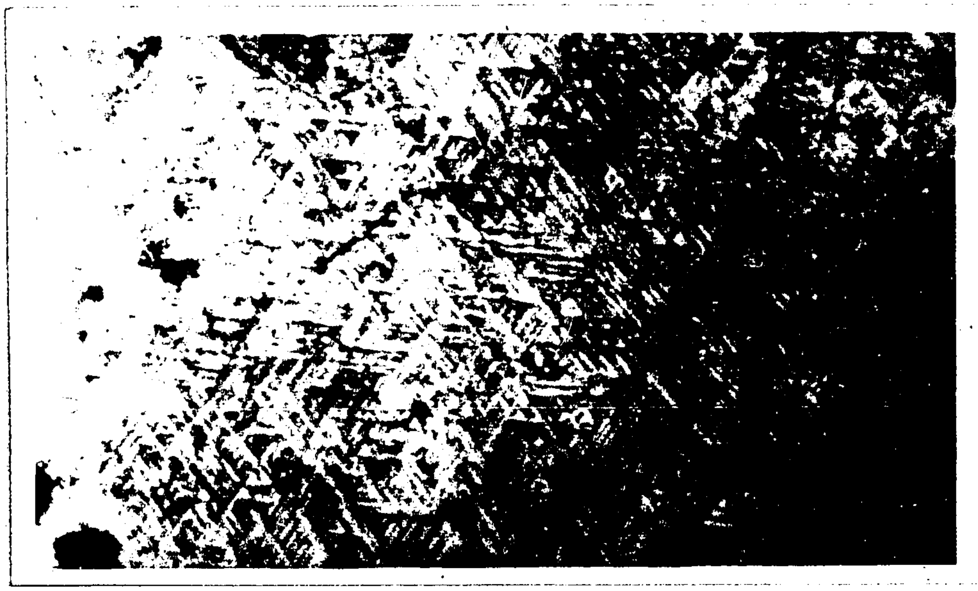


Figure 48. Domains in chalcopyrite. (x 120)

The question arises as to why the domains were not observed in runs Nos. 4, 5, 7, and 8, which were carried out at temperatures of 500 °C and higher. The answer may lie partly in the variation of the rate of quenching, and partly in the length of time of heating. Since disorder can be "frozen in" provided that the rate of quenching is sufficiently rapid, it is possible that the specimens in runs Nos. 4, 7 and 8 did not re-order on cooling, and that no inversion twinning could therefore be observed. In run No. 5, however, (500 °C for 137½ hours), only incipient absorption of sphalerite was noted in some exsolution bodies, and it is improbable that the chalcopyrite reached a disordered state. Possibly, the length of heating is an important factor that may influence the inversion to a higher state at lower temperatures.

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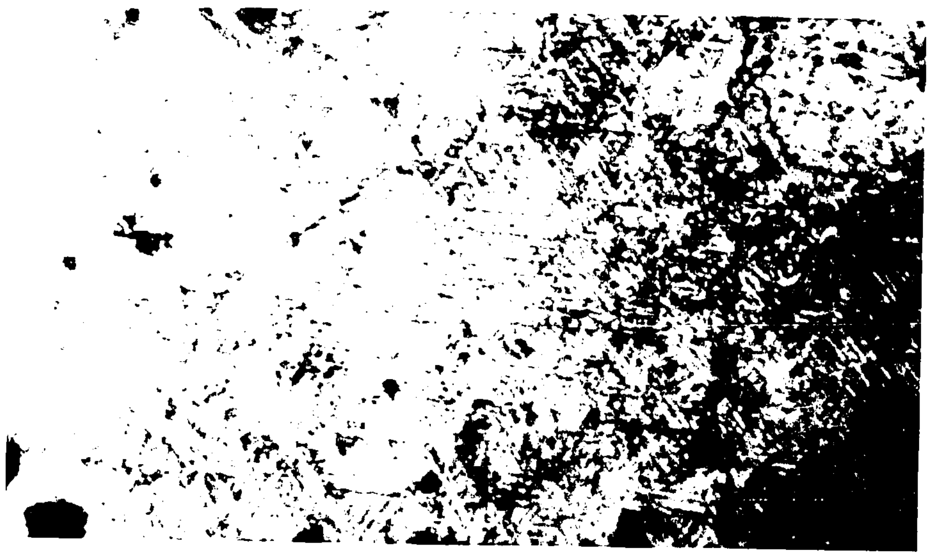

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Since it is not the purpose of this thesis to study the rates and temperatures of inversion of chalcopyrite, further work in this direction was not pursued. Whether the absorption of sphalerite exsolution bodies into chalcopyrite is the result of inversion or not, the fact that the skeletal bodies disappeared in all runs above 500°C and remained in runs below 500°C suggests that the chalcopyrite formed at temperatures above 500°C. Whatever the effects of vapour pressure of sulphur and water may have been in nature, it may be concluded on a more qualitative basis that the chalcopyrite was formed at relatively high temperatures.

It had been noted earlier, (p. 93), that the mineral deposition in the Breton breccia proceeded in at least three or four successive stages. There are indications that these were characterized by successively lower temperature conditions.

The chalcopyrite on which the heating experiments were carried out is representative of the main period of deposition. A later generation of chalcopyrite occurs in the form of fine sphenoids which have grown on top of well-formed crystals of calcite in vugs of the quartz-carbonate matrix. Microscopic examinations of these sphenoids revealed that the skeletal exsolution bodies of sphalerite are absent. This suggests that the chalcopyrite was formed under lower temperatures which did not promote the formation of the solid solution of chalcopyrite and sphalerite.

Corroborative evidence of deposition under successively lower temperature conditions is provided by the presence of such generally recognized low temperature minerals as laumontite and schalenblende, which occur in vugs in the matrix, and in late carbonate veins, respectively.

DISCUSSION.

The history of the development of the Breton breccia, reconstructed on the basis of available evidence, includes four main events: (1) formation of a pipe-like structure composed of unconsolidated fragmental material; (2) cementation of the fragmental mass by quartz and carbonate; (3) formation of domal fractures and re-brecciation; (4) sulphide mineralization.

Search of literature, and personal communication with many geologists familiar with breccia pipes revealed the existence of the following theories that have been advanced to account for the origin of these structures: (1) tectonic activity; (2) igneous intrusion; (3) intrusion of non-silicate solutions; (4) solution and replacement; (5) explosive activity; (6) collapse of rocks.

The following discussion examines these theories, and their applicability to the origin of the Breton breccia.

1. Brecciation by Faulting.

Faulting was one of the first processes to be invoked in explaining the formation of the Breton breccia. The breccia was regarded as a shatter zone, located at the intersection of two or more faults, one of which was thought to coincide with the long axis of the breccia. The proximity of normal faulting characterized by intense brecciation seemed to support this argument.

The main objection to this explanation is the absence of any evidence of faulting coincident with the long axis of the breccia. Any such faulting would have been noted, particularly east of the breccia where outcrops are abundant, (Plate 4). One would also expect to find evidence of displacement of the excellent markers provided by the composite dykes on either side of the breccia. The absence of such evidence limits the possibility of faulting to a zone parallel to the dykes. None is present, and if one did exist, the formation of localized breccia masses could not be explained by fault movement on such a single zone.

The possibility that the position of the breccia may have been influenced by the presence of faults or fractures cannot be denied. Other processes must, however, be invoked to explain the main features of the breccia.

2. Brecciation by Igneous Intrusion.

Brecciation by igneous intrusion is the result of injection of a magma into zones of weakness in the invaded rock, and by subsequent isolation and complete envelopment of the fragments of the older rock by the invading magma. The chief characteristic of breccia of this type is the presence of an ingeous matrix crowded with angular or rounded xenoliths.

Two types of breccia with an igneous matrix have been recognized in the Breton pipe. In one of these, the fragments are embedded in the grey dyke, (Figure 33). Field relations indicate, however, that the grey dyke is post-breccia in age, and that it merely filled spaces between breccia fragments. The second type of breccia with an igneous matrix occurs in fragments composed of xenoliths embedded in a matrix of granite, felsite or diabase, (Figure 32). These form only a small part of the Breton breccia. Since the greatest part of the Breton breccia is characterized by a quartz and carbonate matrix, brecciation by igneous intrusion cannot be accepted as an explanation for the origin of the pipe.

<u>3. Brecciation by Fluid Intrusion.</u>

Brecciation by intrusion of fluids of magmatic origin, or fluidization, as distinct from an intrusion of a more viscous magma, was recently proposed to account for the formation of intrusive breccias in the Warren District of Arizona, (Bryant, 1968). The process involves suspension and transportation of fragmental material, and as will be shown in the final chapter, can account for many of the features in the Breton breccia. It is doubtful, however, that fluidization is capable of producing initial fragmentation of rocks, as was recognized by Bryant, (1968, p.10), who postulated that the initial fragmentation of the intrusive breccias was produced by earlier faulting.

<u>4. Solution and Replacement.</u>

Breccia pipes formed by solution of fractured rocks and by subsequent replacement of the fragmental material by later minerals are characterized by matrices containing no comminuted material. This is, however, where all the similarity of breccias of this type to the characteristics of the Breton breccia ends. The fragments of breccias produced by solution and replacement are modified in situ, and as a result, show little evidence of having been transported or greatly re-oriented. The opposite is true with the Breton breccia. Moreover, detailed studies of the relationship of the fragments to the matrix of the Breton breccia indicate that only a very minor degree of replacement took place.

5. Brecciation by Explosion.

Brecciation of massive rocks by violent explosions has been described in many papers dealing with breccia pipes. The explosions are usually attributed to violent liberation of gases from a magma at a level where the partial vapour pressure of the ascending magma exceeds the lithostatic pressure of the overlying rocks. There is no doubt that explosions of gases at great depths, blowing through to the surface are capable of producing breccia pipes structurally similar to the Breton breccia. The intensity of brecciation present in the Breton breccia led the writer to suggest this mechanism in an earlier paper, (Blecha, 1965). Additional evidence turned up at the mine, and the study of pertinent literature, has since convinced the writer that explosion alone does not provide a satisfactory explanation for all the field evidence.

Diatreme breccias are characterized by a thorough mixing of fragments derived from the country rock as well as from great depths. In the Breton breccia, however, local predominance of fragments of a particular rock type generally reflects the nature of the nearest massive wall rock. This suggests that the movement of the fragments was limited to a smaller degree than would be expected to take place during violent explosions. Moreover, all fragments found within the Breton breccia are derived from rocks found in the immediate vicinity of the pipe, and no fragments have been found that could be suspected of a deep seated origin.

The matrix of diatreme breccias is usually composed of a variety of fragments, including a large proportion of fines. It seems unlikely that the washing action of ascending solutions postulated to have taken place in the Breton breccia would completely remove as large an amount of comminuted material as could be expected to result from violent explosions.

Another significant feature commonly found in diatreme breccias is the widening of the pipe near surface, caused by lower rock pressure at shallow depths, or by inward sliding of the vent walls subsequent to the formation of the pipe. No such widening is present in the Breton breccia.

Subsidence that often follows the formation of diatremes generally results in inward dips of the material contained in the upper parts of the pipe. Although downward movement of fragments undoubtedly took place in the Breton breccia, no inward dips have been observed.

Recent studies of the effects of underground nuclear explosions at relatively shallow depths have revealed the presence of two or more well defined zones characterized by different degrees of intensity of fragmentation, depending on the distance from the centre of the explosion. It has been demonstrated that the distance from the origin of the explosion to the zone characterized by a thorough mixing of fragments, (domain of mixing), is a function of the total energy released, (Shoemaker, 1960). There is no evidence of any such zoning in the Breton breccia.

6. Brecciation by Collapse of Rocks.

Brecciation of rock by collapse subsequent to removal of support is a generally accepted method of rock fragmentation, and has been applied to many breccia pipes. The removal of support is usually explained by the dissolving of the underlying rocks by hypogene solutions, (Locke, 1926), or more rarely by shrinkage accompanying the oxidation of sulphides, (Wisser, 1927). More recently, Perry, (1961), advocated the proposal that collapse of rocks is the result of a decrease in pressure at localized points above an intruding batholith caused by the withdrawal of magma below.

The collapse theory has many attractive features, but it alone cannot entirely explain all the features of the Breton breccia. In combination with other related geological processes, however, the mechanism of brecciation of rocks by collapse can best account for the origin of the Breton breccia, as well as for the origin and structure of the ore.

PROPOSED ORIGIN OF THE BRETON BRECCIA

The main geological processes invoked in the proposed origin of the Breton breccia are fragmentation of rocks by collapse, and cyclic pulsations of an intruding magma.

The feasibility of rock fragmentation by collapse of unsupported rocks is beyond doubt. Collapse structures in nature have been extensively described by Hundt, (1950), and the process can be directly observed in mining operations. Incontrovertible evidence that downward movement of fragments took place at one stage during the formation of the Breton breccia is provided by the presence of fragments of mafic metavolcanics below the 375 level of the mine.

The concept of magmatic pulsations, first inferred from direct observations of fluctuating levels in lava lakes, is not new. It was first proposed by Anderson, (1936), in his theory on the emplacement of ring dykes and cone sheets, and has been recently applied to the formation of breccias associated with porphyry coppers by Kent, (1961, 1963). Indirect evidence that periodic disturbances took place during the formation of the Breton breccia is provided by the re-brecciation of previously fragmented rock, and by the recognition of several stages of quartz and sulphide deposition.

The starting point of the proposed origin of the breccia is the postulation of an intrusion of a large batholith, similar in composition to the felsitic and felsophyric dykes which are present in the entire Batchawana area. The evidence that an intrusion of this type is present, is provided not only by the occurrence of these felsic dykes, but mainly by the high proportion of fragments of these rocks in each of the breccias found on the Tribag property.

It appears reasonable to assume that the magma advanced closest to the surface in areas presently occupied by the breccia pipes. Its emplacement was no doubt controlled by local zones of weakness, such as faults, joints or contacts. Magmatic pulsations are postulated to have started when an intrusion of magma into one of these zones of weakness caused the tranfer of magma from another.

As in the formation of ring dykes and cone sheets, the first failure caused by the upward pressure of magma produced tension fractures in the intruded rock. Subsequent withdrawal of magma resulted in the formation of a new set of fractures, domal in shape, and in simultaneous closing of the first set of fractures by the lithostatic pressure of the overlying rocks, (Plate 9).

The second cycle of the pulsating magma resulted in the emplacement of felsic dykes along previously formed fractures, and in the formation of a zone of low pressure, caused by the withdrawal of magma which followed. Subsequently, a sudden failure of the unsupported roof took place along steeply dipping fractures. Whether or not these fractures were part of the fracture system caused by the oscillating magma is unimportant. Their postulation is necessary, however, to account for the sharp contacts between the breccia and the massive wall rock.

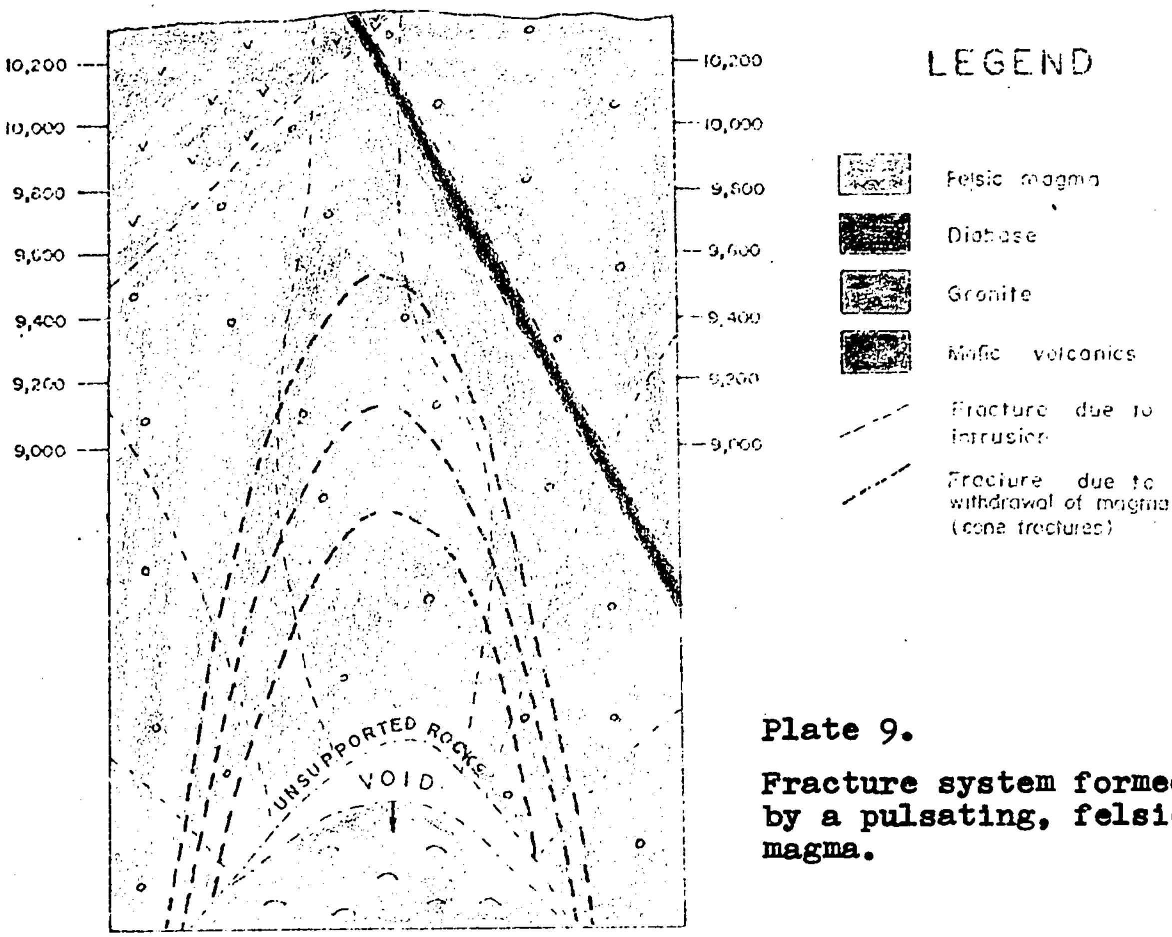
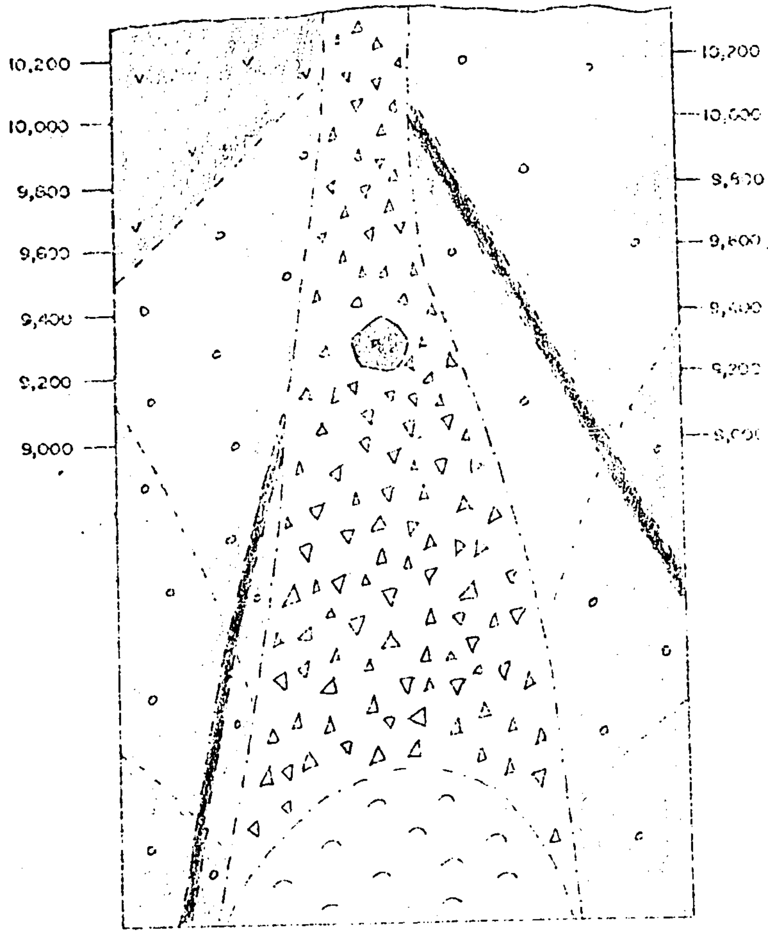


Plate 9.

Fracture system formed by a pulsating, felsic magma.

The sudden collapse of rocks resulted in the formation of a column of unconsolidated rubble, consisting of angular, unsorted fragments derived from rocks present in the immediate vicinity of the breccia, (Plate 10). The exact extent of the downward movement of the fragments is impossible to determine. Judging from the vertical distance between mafic metavolcanic and the deepest occurrence of the metavolcanic fragments within the breccia, the downward movement must have been of the order of 500 feet.

The initial fragmentation of rock was followed by surges of silica-rich, hydrothermal solutions which had separated



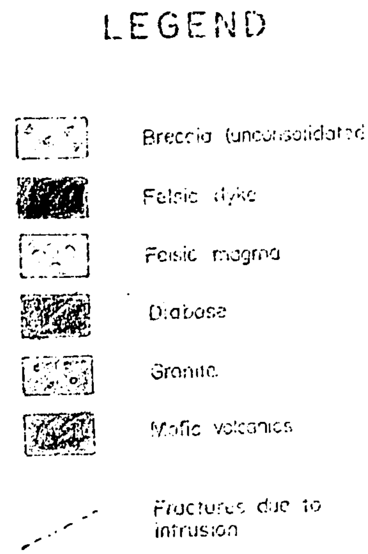


Plate 10.

The formation of a column of an unconsolidated fragmental mass by collapse of the unsupported roof.

from the magma, and gathered at the top of the magma chamber. The solutions were driven upward under the influence of the natural pressure gradient, possibly aided by the upward push of the re-advancing magma. Streams of sulutions removed all comminuted material, and re-arranged the unconsolidated fragmental mass by rotation of individual fragments, as well as by their upward transportation.

Laboratory evidence demonstrating the ability of water to transport fragments has been demonstrated by Bryant, (1968), and need not be repeated here.

Field evidence that this type of mechanism was functioning during the formation of the Breton breccia is summarized below.

The most striking effect of the transportation of fragments by ascending fluids is the crosscutting relationship of the breccia with respect to the surrounding massive rocks. This occurs when the fluids completely fill the spaces between the fragments, and the entire breccia behaves like a fluid. Crosscutting relationship of the Breton breccia has not only been inferred from drill data, but may be observed directly underground as well as on surface. In Figure 20, (p.58), massive granite is in sharp contact with breccia composed predominantly of fragments of diabase. This implies that the diabase fragments have been transported to their present position, and such movement can best be explained by fluidization.

Perhaps an even more convincing evidence of intrusion of breccia is provided by the "vein" breccia shown in Figure 28, (p.73). Rock fragments present in the vein breccia are different from the wall rock, and their transportation to their present position could have been best accomplished in a liquid medium. A similar relationship, involving felsitic fragments present in the matrix which separates large fragments of granite has been described on page 71. Upward movement is also indicated by the positions of the fragments derived from the composite dyke; these are found not only below the projected position of the dyke in the breccia, but also above it.

The following features may be regarded as corroborative evidence of the passage of large volumes of fluids through the open spaces of the unconsolidated fragmental mass.

Elongated, slab-like fragments mostly occupy an almost horizontal position. It seems reasonable to suggest that the fragments assumed the horizontal attitude after the cessation of the upward streaming of the fluids, in a manner analogous to the deposition of platy particles in a liquid medium.

In the quartz-carbonate -rich parts of the breccia, sulphide mineralization is found mostly on top of fragments, (Figure 46). Two explanations have been suggested to account for this peculiar feature. According to one, the rock fragments were embedded in a fluid but very viscous medium, composed mainly of silica. After the cessation of movement, and prior to the crystallization of the viscous mass, the rock fragments sagged somewhat due to gravity, leaving an empty space into which the sulphides were later deposited by hydrothermal solutions.

The second hypothesis is that the sulphides were deposited in a zone of low pressure caused by eddy currents formed by the ascending solutions on encountering obstacles in the form of fragments. In view of other evidence favouring the presence of rapidly ascending solutions, this explanation is more likely.

During the ebbing stages of fluidization, precipitation of silica took place. This resulted in the crystallization of coarse quartz, and in the cementation of the rock fragments.

After the consolidation of the breccia, another withdrawal of magma took place. This resulted in the formation of a new set of domal fractures, and possibly in the re-opening of the older fractures. The fracture pattern extended into the column of fragmental material, which by now was sufficiently

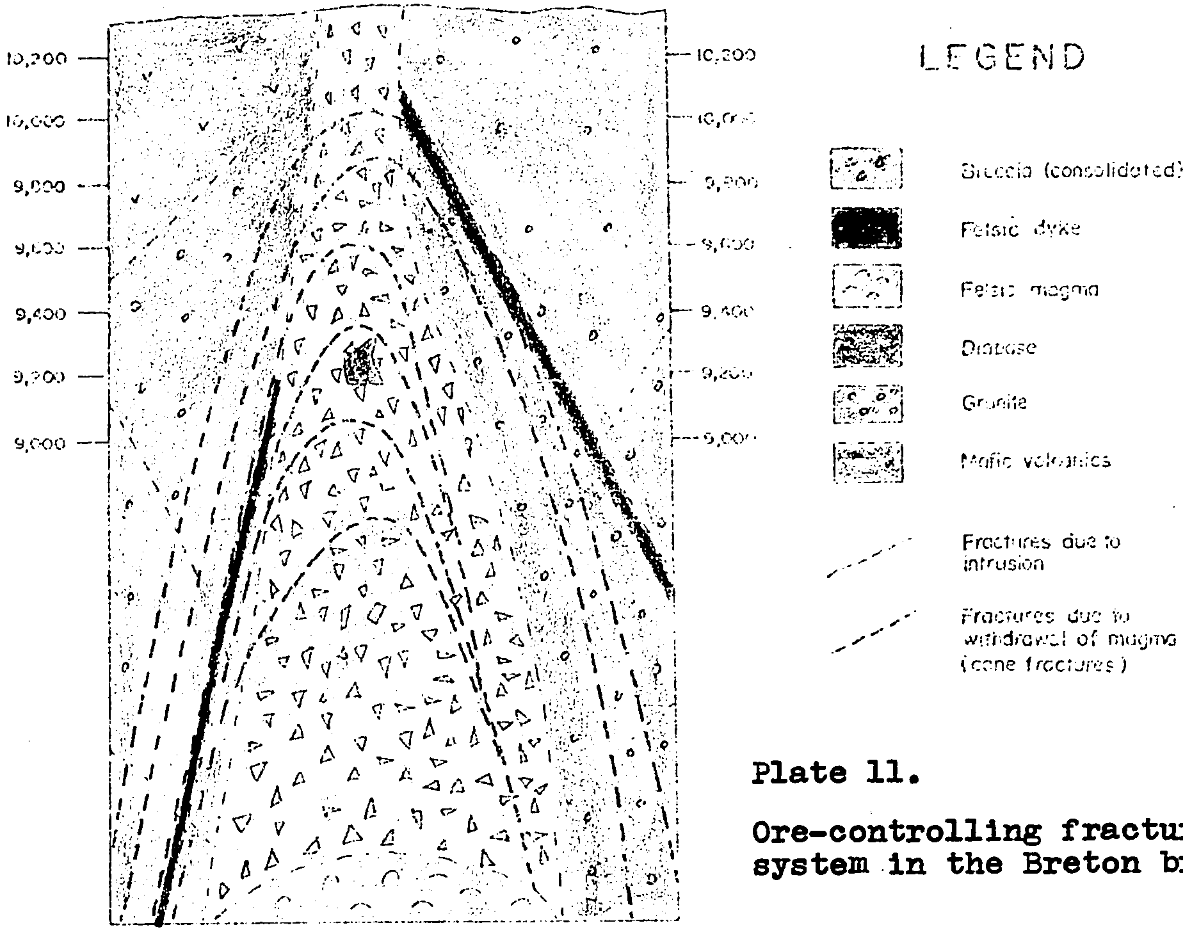


Plate 11.

Ore-controlling fracture system in the Breton breccia.

consolidated by quartz cementation to permit its fracturing, (Plate 11).

The bulk of the sulphides was deposited during subsequent fluidization. The ore-bearing solutions travelled along the channelways provided by the domal fractures in the breccia, as well as along open spaces between fragments, which were incompletely filled by quartz. The solid hanging walls of the domal fractures restricted the flow of the ascending fluids, forcing them to circulate in the footwall, particularly in the flat, upper portions of the domes. This resulted in the rebrecciation of the fragmental mass by the agitating action of the fluids, and in the formation of sharp contacts between

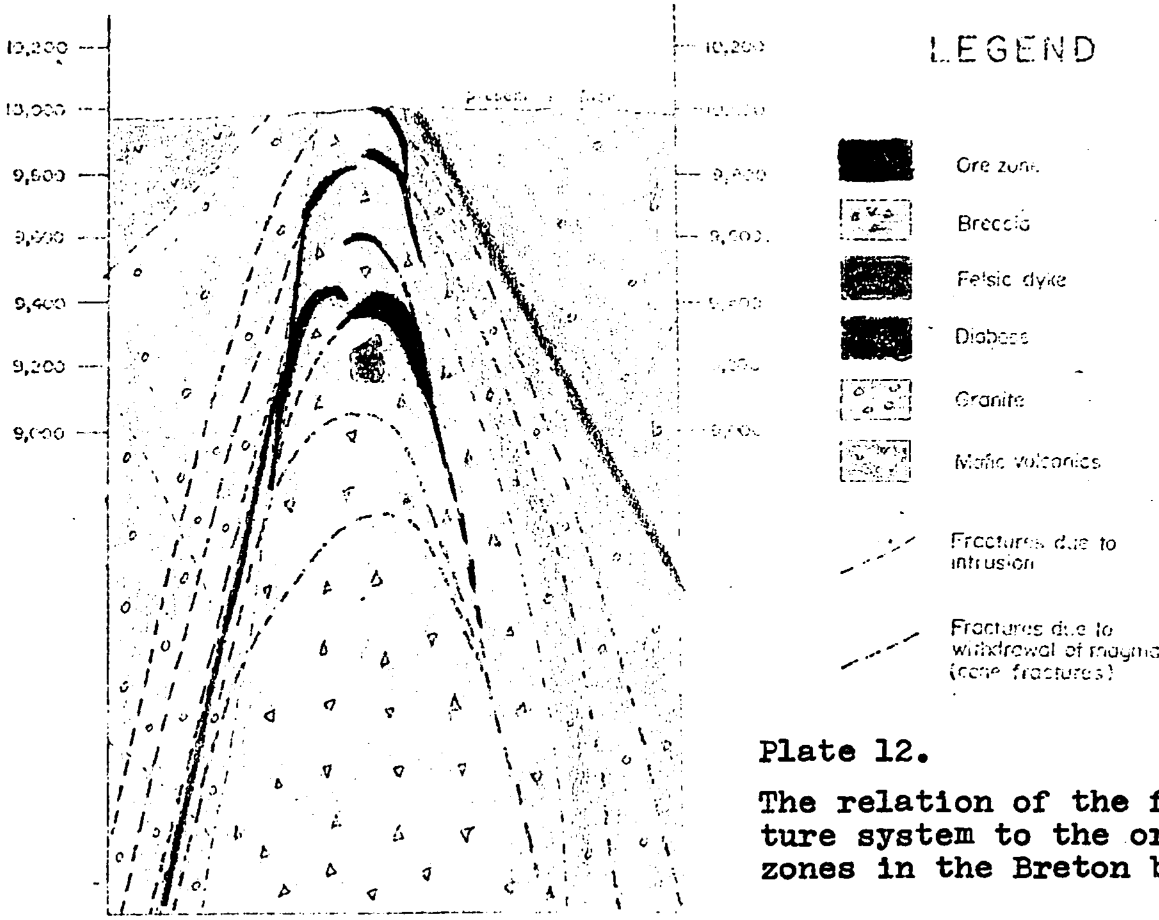


Plate 12.

The relation of the fracture system to the ore zones in the Breton breccia.

"open", mineralized breccia in the footwall of ore zones, and the "tight", relatively barren breccia in the hanging wall, (Figure 30, p.75).

An important part of the channelway system was provided by the sharp contacts between the granite and the breccia. In places where ascending solutions travelling along the contact encountered domal fractures cutting across the contact into the breccia, parts of the solutions were diverted, and precipitation of sulphides took place along the fractures in the breccia. Part of the solutions continued upward along the contact until encountering a second domal fracture at a higher horizon. The resulting ore structure is particularly well illustrated by the various branches of the South zone, on sections 10,800E, and 10,900E, (Plates 25 and 26).

An interesting, and economically important feature of the structural control of the ore is the behaviour of the mineralization in places where the domal fractures cut across the granite contact at angles close to 90°. From available data it appears that the ore stops abruptly at the contact, locally showing a tendency to spread along the contact in one or both directions, (Plate 17). The postulated projection of the ore zone into the massive granite, (assuming a constant curvature of the zone in plan), returns to the breccia contact, to join the other end of the ore zone, thus forming a large, irregular, complete circle, (Plate 13). This creates the false impression that the granite cuts across the mineralized zones. Detailed mapping of fractures in the massive rocks outside the breccia, however, revealed the presence of prominent fractures whose predominant attitude is tangential to the projected continuation of the ore zones in the massive granite. From this relationship it can be concluded that the fracture pattern in the massive granite represents the continuation of the domal fractures which controlled the ore, and that the ore-bearing solutions had an affinity to the breccia rather than to the granite. This affinity is probably of a physical rather than chemical nature, and is due to the more dilatant character of the fractures in the breccia.

The formation of the ore zones in the Breton breccia was followed by several minor, but important events whose mutual

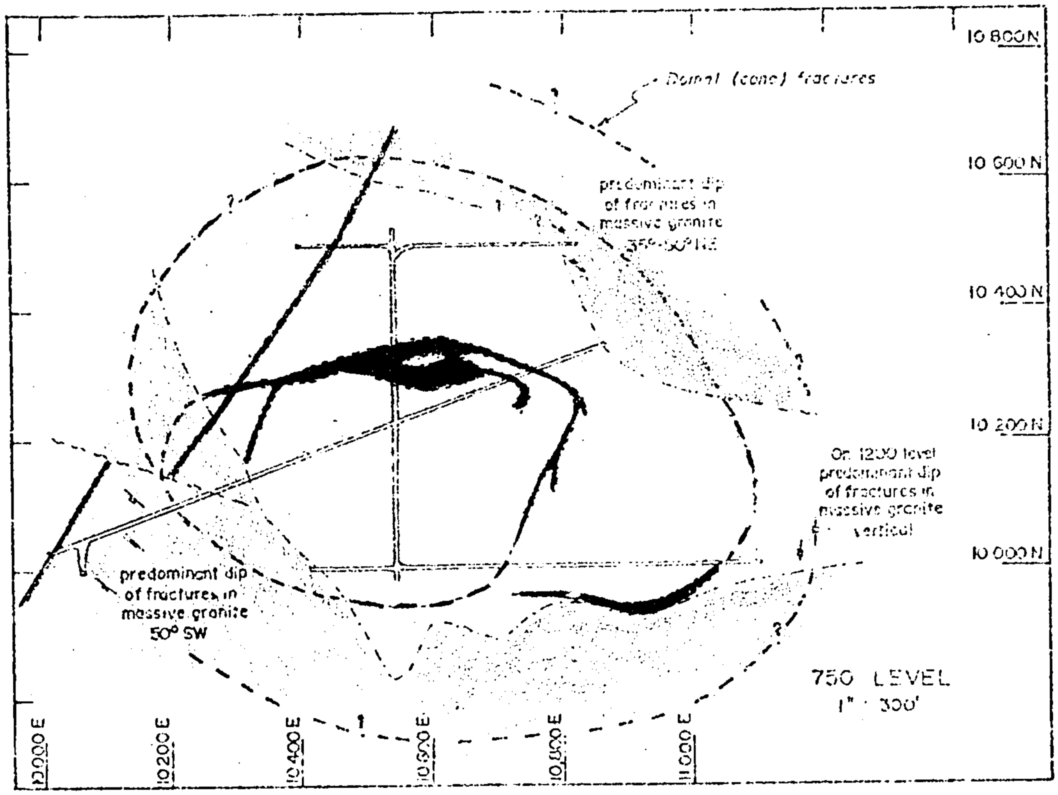


Plate 13. Generalized plan of the 750 level, showing the relation of ore zones to domal fractures.

time relationship is not entirely clear. The most important of these events were the intrusion of the amygdaloidal and the grey dykes.

These two petrologically and chemically similar rocks exhibit one major difference in their mode of intrusion. Whereas the amygdaloidal dyke cuts across the entire breccia forming a regular, tabular body, the grey dyke has the unmistakeable characteristics of a concordant intrusion, insofar as it is controlled by the internal structure of the breccia in general, and by the configuration of individual fragments in detail. This suggests that the breccia matrix offerred less resistance to the intrusion of the grey dyke than did the fragments. This, in turn implies that at the time of the intrusion of the grey dyke the breccia was in a lesser state of consolidation than during the intrusion of the amygdaloidal dyke. From these considerations it appears that the grey dyke is older than the amygdaloidal dyke, and that its intrusion was followed by another period of quartz and carbonate deposition, which resulted in the final, complete cementation of the breccia fragments. Late carbonate stringers which cut across the grey dyke appear to support this, (Figure 46, p. 107).

Minor post-breccia faulting and fracturing marked the last chapter in the complex geological history of the Breton breccia.

Finally, weathering and erosion through a great length of time, including glaciation as the penultimate stage, removed the top of the breccia pipe, and cut it down to its present surfaee, possibly eroding the tops of one or more domal zones.

Economic Implications.

The proposed origin of the Breton breccia has several important implications with respect to the exploration for additional ore within the pipe.

The most obvious of these is the possibility of the presence of additional domal ore zones within the major domel structure. Two major ore zones have been recognized so far, with the North and South zones possibly forming a third, outermost zone. Additional domal structures could occur both on the inside as well as on the outside of the presently known zones. On the currently developed levels, additional outer zones could be expected to occur at the east and west extremities of the breccia, where they would form large circles, roughly concentric with the presently known ore, (Plate 13).

Additional domes on the inside of known ore structures should be looked for at deeper horizons. This raises the important question regarding the persistence of the favourable breccia at depth.

In theory, the bottom of the breccia should occur immediately above the top of the felsic intrusion which is postulated at depth. The depth of the intrusion could, theoretically, be determined by the projection of the tension fractures down-dip. The projections should converge at the top of the intrusion. This method, however, is impractical, mainly due to the lack of available data.

The bottom parts of the breccia could be expected to be characterized by closer packing of the fragments due to greater lithostatic pressure of the overlying rocks, by intense fracturing and alteration due to the proximity of the underlying intrusion, and by the gradual appearance of am igneous matrix with depth. The presence of all of these features is indicated on the 1,200 level of the mine. However, a few deep drill holes penetrated through this type of tight, altered breccia into the "open", matrix-rich type, and the possibility of the occurrence of at least another domal ore zone below this level remains.

The bottoming of the breccia pipe, however, would not necessarily signify the bottoming of copper mineralization. If the Breton breccia is indeed underlain by a deep seated, felsic intrusion, then low grade, porphyry copper-type mineralization could be expected to occur at depth, just as it does in the famous La Colorada pipe, in the Cananea mining district of Mexico.

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APPENDIX

Table I.

Locations of Samples

Sample No.	Rock Type	Location of Sample
M-1	highly altered granite	D.D.H. V-32 @ 500.0'
6	fresh granite	D.D.H. V-54 @ 300.0'
101	sodic granite	2 miles west of Quintet Lake
102	granite	south shore Adelaide L.
103	granite	$\frac{3}{4}$ miles NW of shaft
104	granite	D.D.H. V-56 @ 200.0'
105	granite	D.D.H. V-43 @ 145.0'
106	granite	D.D.H. V-48 @ 775.0'
107	granite	D.D.H. V-71 @ 325.0'
108	granite	D.D.H. V-67 @ 925.0'
109	granite	D.D.H. V-47 @ 746.0'
469	granite	D.D.H. V-10 @ 802.0'
2865	granite	1,200 level, near shaft
2866	basic member of composite dyke	D.D.H. V-34 @ 170.0'
2868	granite	D.D.H. V-30 @ 700.0'
2869	amygdaloidal dyke	D.D.H. U-30 @ 211.0'
2878	felsophyre	D.D.H. V-65 @ 295.0'
2870	grey dyke	D.D.H. U-30 @ 147.0'
2871	central member of composite dyke	D.D.H. V-34 @ 160.0'

DIAMOND DRILL LOG

Hole Number: 6-U-77

Latitude: 10,476N
Departure: 10,600E
Level: 750
Azimuth: South
Dip: -33°
Length: 272.0'

Started: March 22, 1965
Compl'd: March 30, 1965
Logged by: Matthew Blecha

0.0	"Tight Breccia", with only 5-7% quartz-carbonate matrix; predominantly pink granitic fragments, with 10% diabase, 5% felsite, and minor occasional syenitic fragments. Note fragments of fine grained diabase at 77' - 78', and 83' - 86.5'. Very weakly mineralized with traces of pyrite, and chalcopyrite. Low altered. 128.0'
128.0	"Open Breccia", increase in quartz-carbonate to 15%; abrupt increase in alteration to medium-high. Predominantly diabasic and syenitic fragments, with minor associated biotite. Mineralized with 2-3% pyrite, and few blebs of chalcopyrite at 135' - 136'. 144.5
144.5	Mineralized Zone. 1-2% chalcopyrite, 1-2% pyrite, in medium altered, open breccia. Predominantly granitic, 15% quartz-carbonate. 162.5' Mineralization increases to 12 - 15% chalcopyrite; high alteration, quartz-carbonate 30%. 164.0' Chalcopyrite decreases to 3-4%, locally concentrated at 177.5-179.0'. Alteration remains high. 199.5'
199.5	Open Breccia, relatively small fragments predominantly granitic and felsitic; alteration medium-high; quartz-carbonate 25%. 248.0' Gradual decrease in alteration to medium; increase in diabasic fragments to 30%; quartz-carbonate 30%. Large blebs of chalcopyrite at 259.0-260.0' 272.0
272.0	End of Hole.

Table II.

Spectrographic Trace Element Analysis of Samples Collected from Drill Hole No. 6-U-77

(Analyst: Ontario Dept. of Mines)

	0	19	25	31	49	55	67	70	83
Ba	100	100	50	400	80	400	200	100	100
Sr	30	40	80	80	100	200	50	100	100
Cr	50	20	20	10	10	10	20	50	50
Mn	100	400	200	500	200	500	500	1000	800
Co	20-	20-	20-	20-	20-	20	20	20-	20
Ni	40	50	100	40	30	30	40	30	60
Cu	300	200	2000	1000	100	3000	400	400	3000
Pb	10	10	10	20	10	10	10	10	100
Zn	60	50	50	50	50	50	50	50	100
Ag	3	2	3	3	2	3	3	3	3
Sn	60	20	40	100	10	20	5	5	800
Mo	200	20-	20-	20-	20-	20	20-	20-	20-
Ga	30	30	30	30	30	40	30	30	30
Ti	6000	2000	2000	1000	2000	1000	1000	1000	2000
V	300	50	50	60	30	40	200	100	50
Zr	100	100	200	80	100	100	100	100	100
S.G.	2.65	2.56	2.59	2.61	2.61	2.60	2.62	2.62	2.65

Note: All values are expressed in parts per million

20- designates "less than" 20 ppm.

Sample numbers represent the footages of the samples in the drill hole.

(...cont'd)

Table II
(continued)

	101	108	126	131	135	144	154	159	164
Ba	50	100	100	200	100	50	400	200	300
Sr	30	80	50	20	5	30	50	50	5
Cr	50	10	100	800	10	40	20	10	10
Mn	500	1000	2000	200	20	1500	400	1000	100
Co	20-	20-	20-	30	100	20-	20-	20-	30
Ni	30	30	60	80	100	20	40	100	300
Cu	200	100	100	400	2%+	1000	600	5000	2%+
Pb	10	10	20	10	10	10	10	10	10
Zn	50	50	50	50	2000	200	100	150	10000
Ag	3	2	3	2	100	3	2	10	30
Sn	10	10	5	10	20	10	10	10-	20
Mo	20-	20-	20	20-	20	20-	20-	30	20
Ga	20	20	20	20	20	20	30	20	30
Ti	500	1000	2000	1000	1000	300	1000	2000	2000
V	40	60	100	300	10	50	50	30	30
Zr	50	100	100	50	50	30	100	200	100
S.G.	2.62	2.63	2.60	2.62	2.74	2.64	2.61	2.47	2.71

Note: All values are expressed in parts per million unless stated otherwise.

Table II
(continued)

	168	173	179	187	194	201	206	211	216
Ba	800	300	100	300	400	500	400	200	100
Sr	30	100	50	50	50	50	30	50	30
Cr	10	10	20	20	10	10	10	10	50
Mn	200	2000	500	200	60	100	200	100	500
Co	40	20	20	30	20	20-	40	20	20
Ni	80	40	50	40	50	30	50	40	100
Cu	1000	3000	200	1000	3000	100	5000	500	5000
Pb	60	20	20	10	20	10	30	20	10
Zn	200	50-	60	60	200	60	200	100	50-
Ag	4	3	3	4	5	1	3	3	4
Sn	10	10-	20	10-	10-	30	20	10-	10
Mo	20-	20-	20	20-	30	20-	20	20-	20-
Ga	50	20	20	30	30	30	30	20	20
Ti	3000	600	800	2000	2000	400	1000	2000	2000
V	100	100	60	50	50	50	50	50	50
Zr	200	50	60	100	100	50	200	100	50
S.G.	2.58	2.64	2.64	2.58	2.59	2.61	2.55	2.48	2.53

Note: All values are expressed in parts per million unless stated otherwise.

(... cont'd)

Table II
(continued)

	221	224	235	245	250	258	265	272
Ba	100	200	200	100	300	200	100	300
Sr	30	30	60	20	60	30	20	100
Cr	5	20	10	30	10	40	30	30
Co	20-	20	20	20	20-	20-	20-	20-
Mn	2000	200	200	400	300	300	500	500
Ni	20	20	30	40	30	30	20	200
Cu	300	200	4000	400	300	500	200	1000
Pb	10	10	20	10	20	20	10	20
Zn	100	100	100-	100	100	100	100-	100-
Ag	2	3	4	2	3	2	2	2
Sn	10-	10-	10-	10-	20	60	10	20
Mo	10	30	30	10-	30	20	20	30
Ti	200	800	2000	1000	1000	500	300	1000
V	130	200	50	200	100	40	50	50
Zr	30	100	100	40	100	40	20	60
S.G	2.62	2.59	2.56	2.65	2.58	2.59	2.49	2.64

Note: All values are expressed in parts per million.

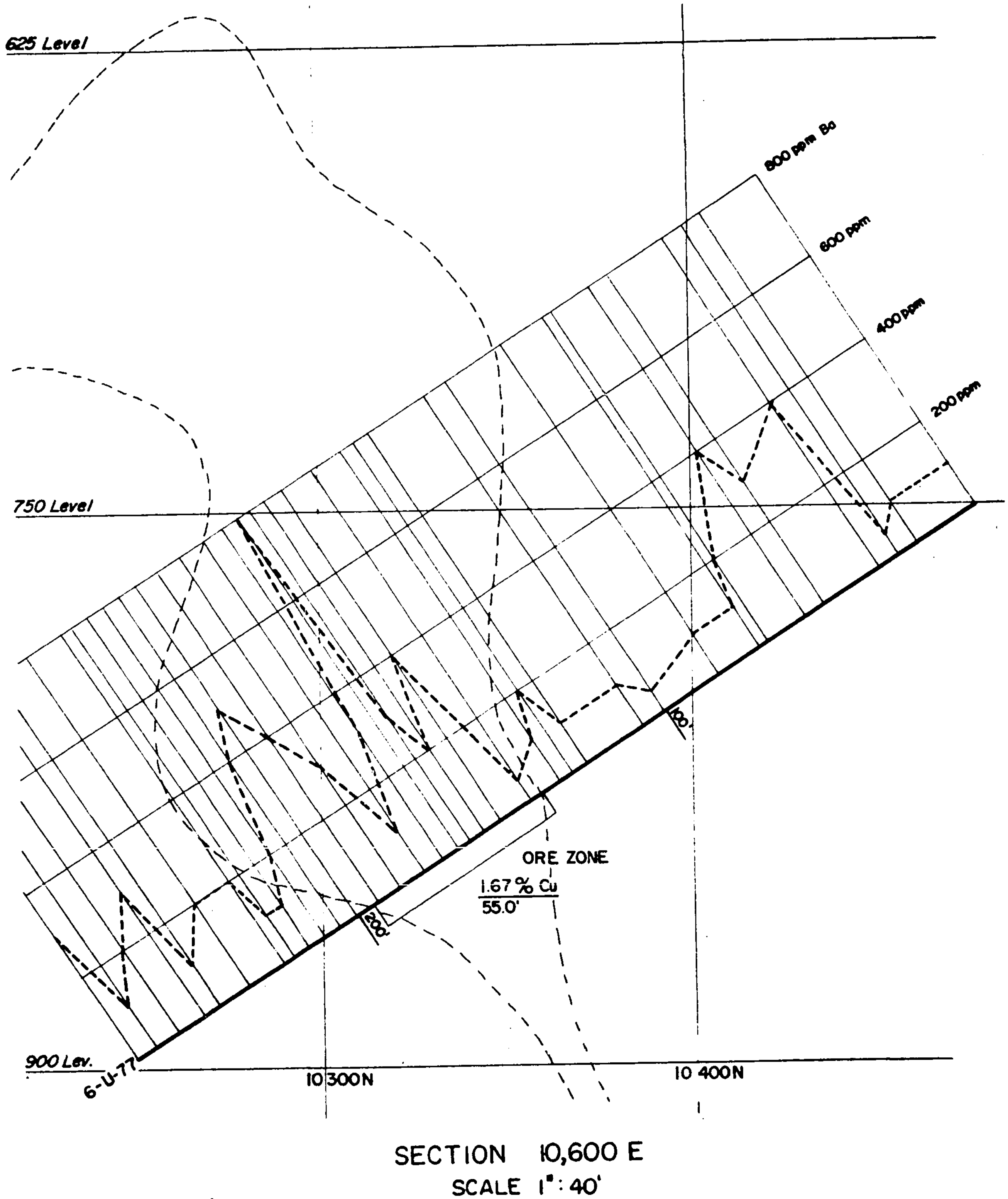
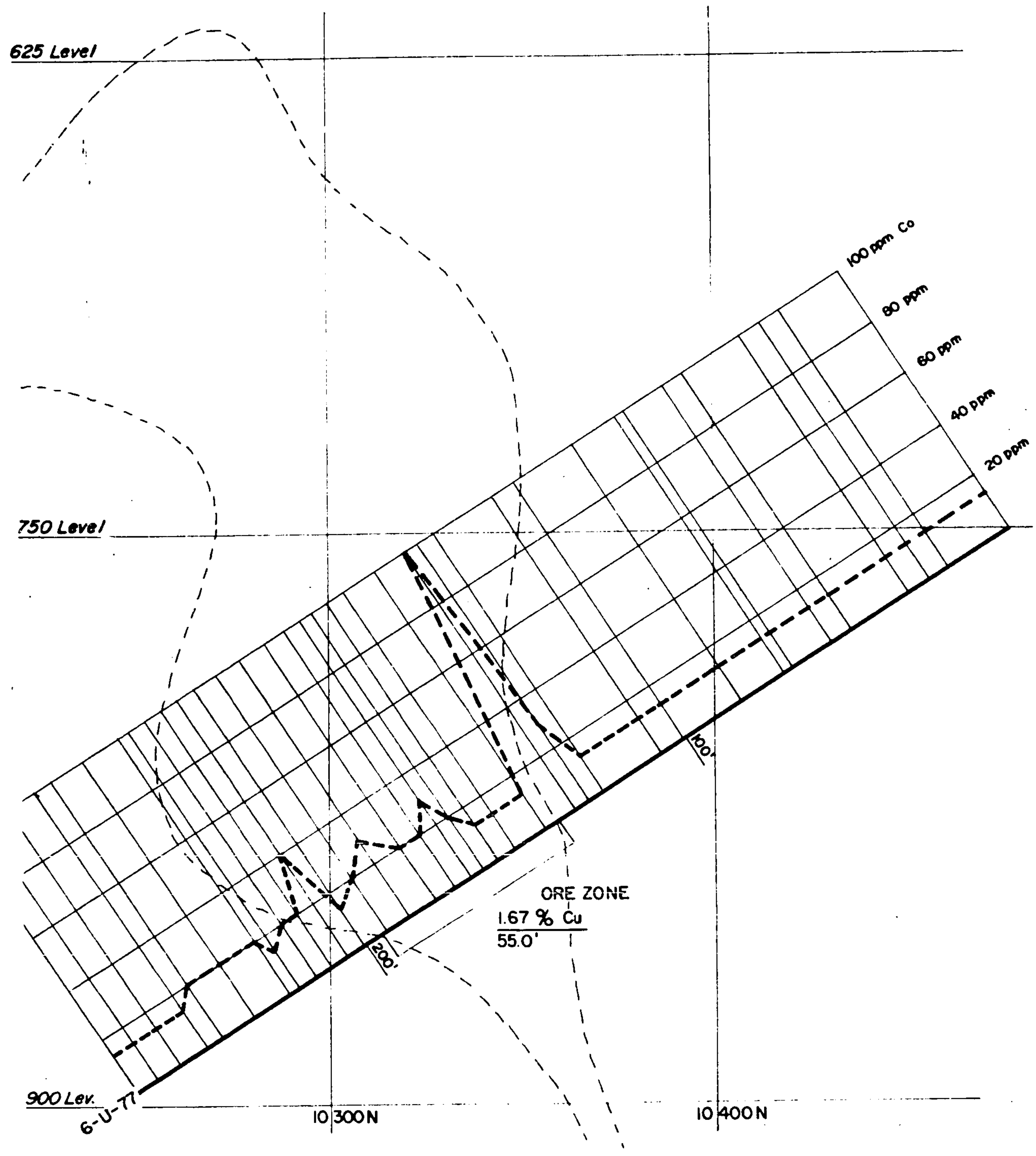


Plate 28. Graph, showing variation in barium content across an ore zone in drill hole No. 6-U-77.



SECTION 10,600 E
SCALE 1":40'

Plate 29. Graph, showing variation in cobalt content acorss an ore zone in drill hole No. 6-U=77.

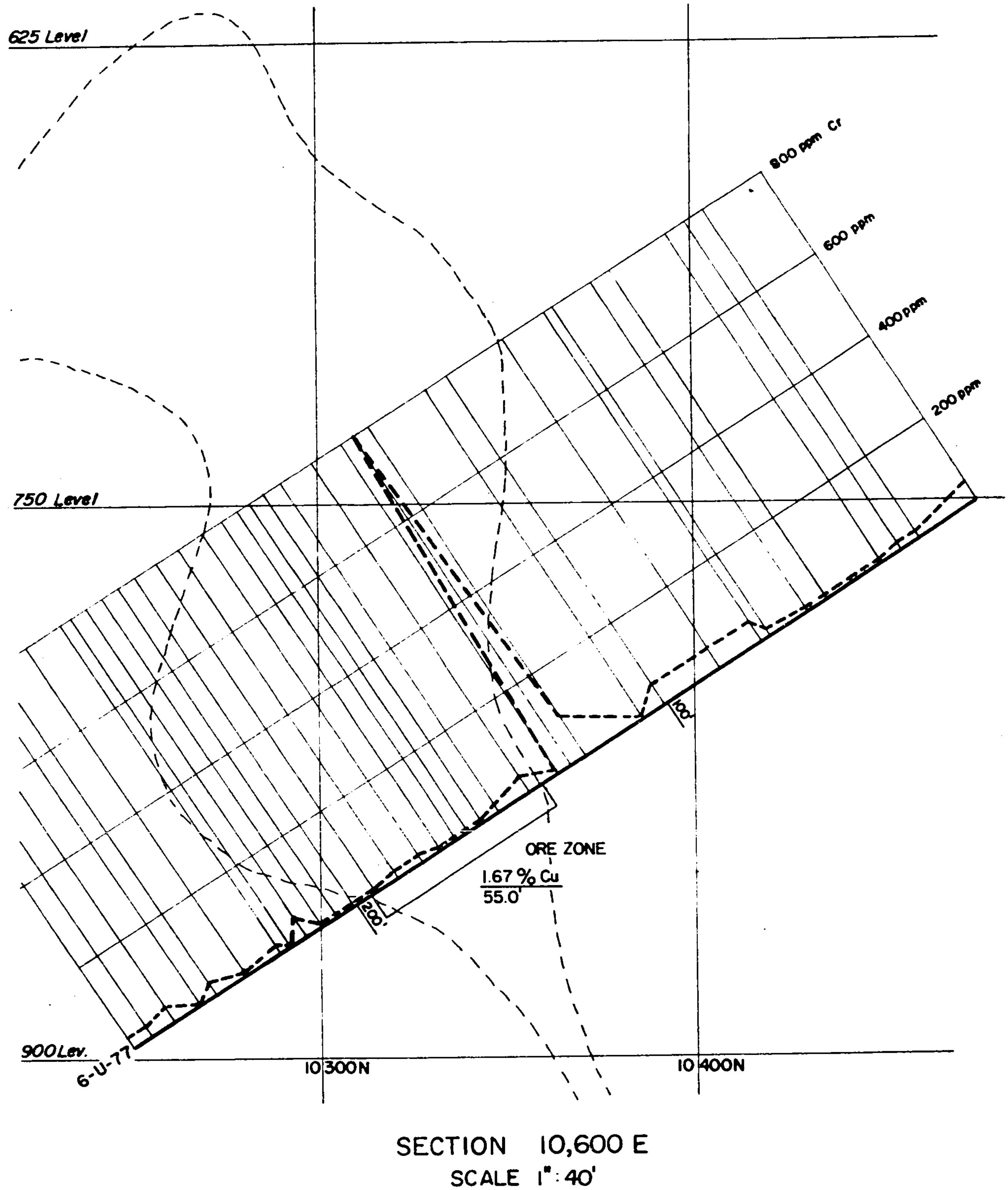
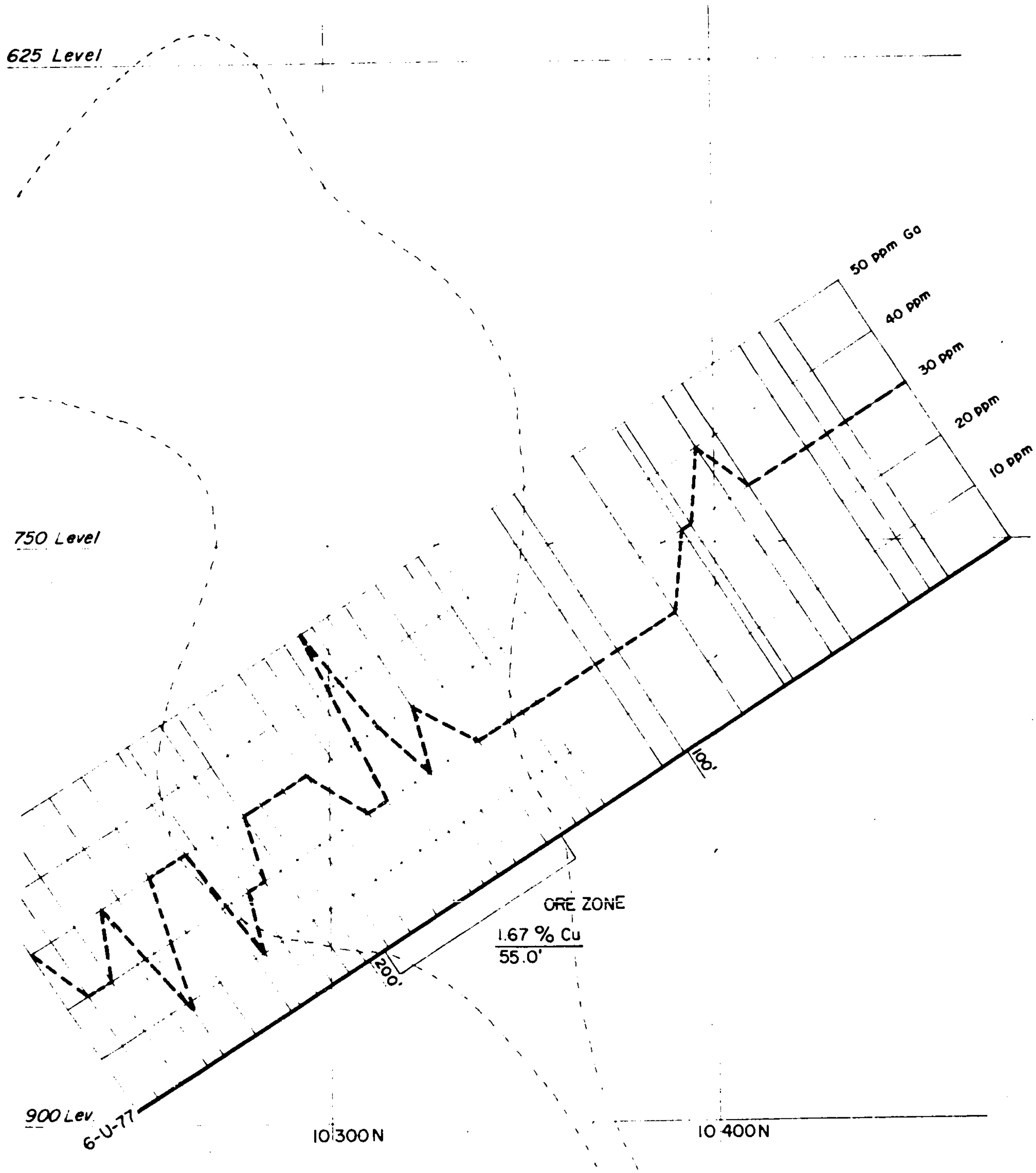
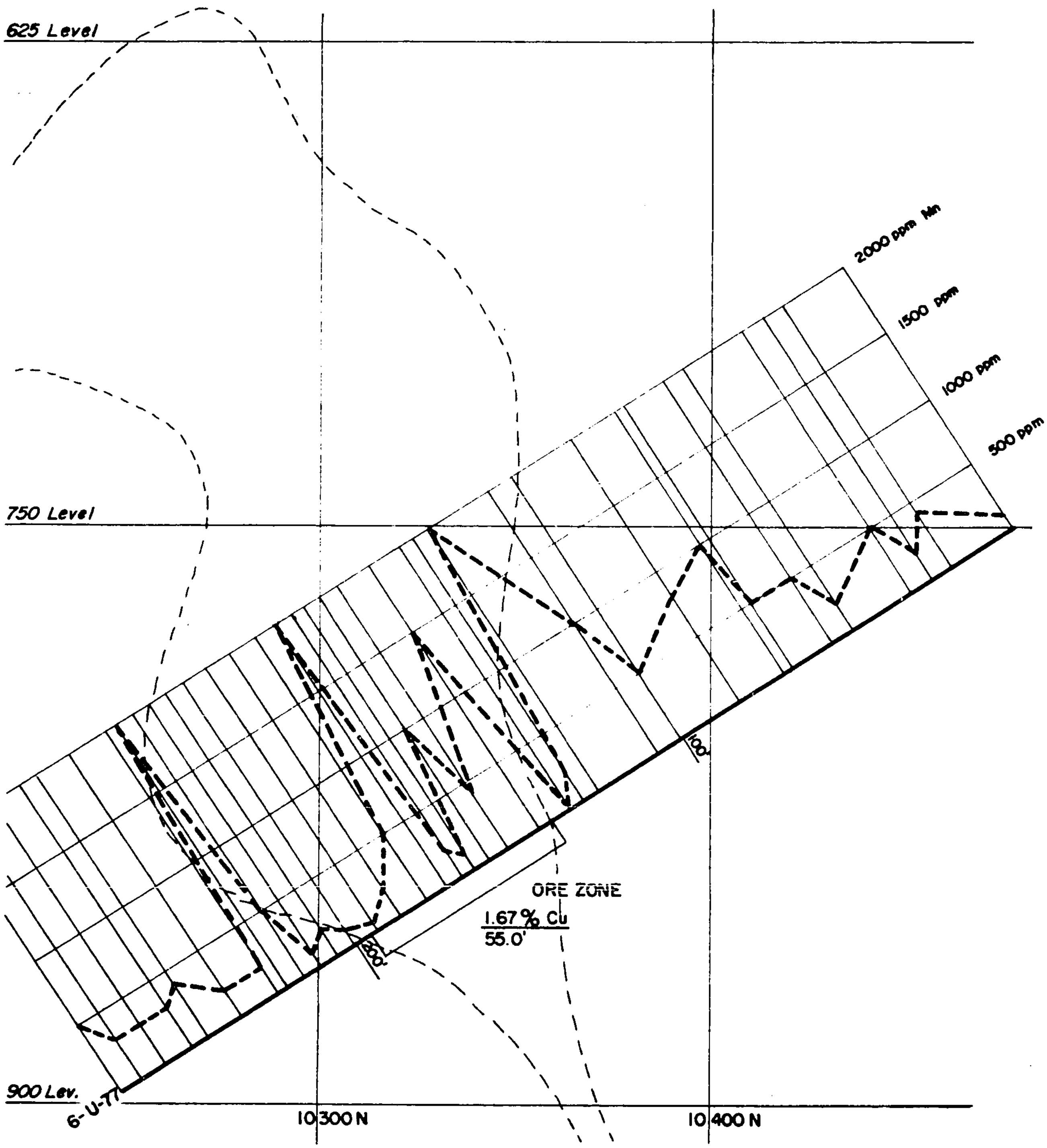


Plate 30. Graph, showing variation in chromium content across an ore zone in drill hole No. 6-U-77.



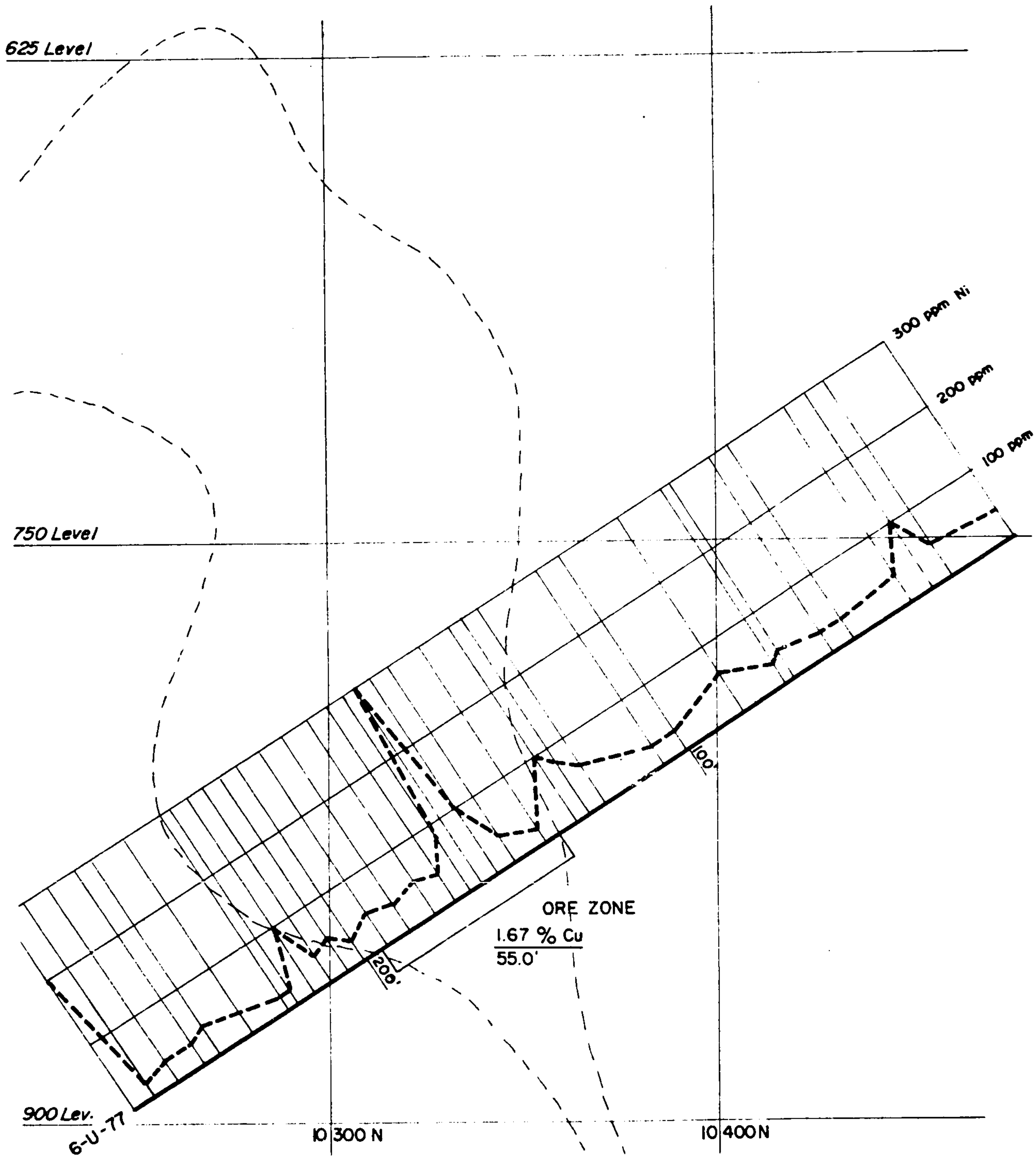
SECTION 10,600 E
SCALE 1":40'

Plate 31. Graph, showing variation in gallium content across an ore zone in drill hole No. 6-U-77.



SECTION 10,600 E
SCALE 1":40'

Plate 32. Graph, showing variation in manganese content across an ore zone in drill hole No. 6-U77.



SECTION 10,600 E
SCALE 1": 40'

Plate 33. Graph, showing variation in nickel content across an ore zone in drill hole No. 6-U-77.

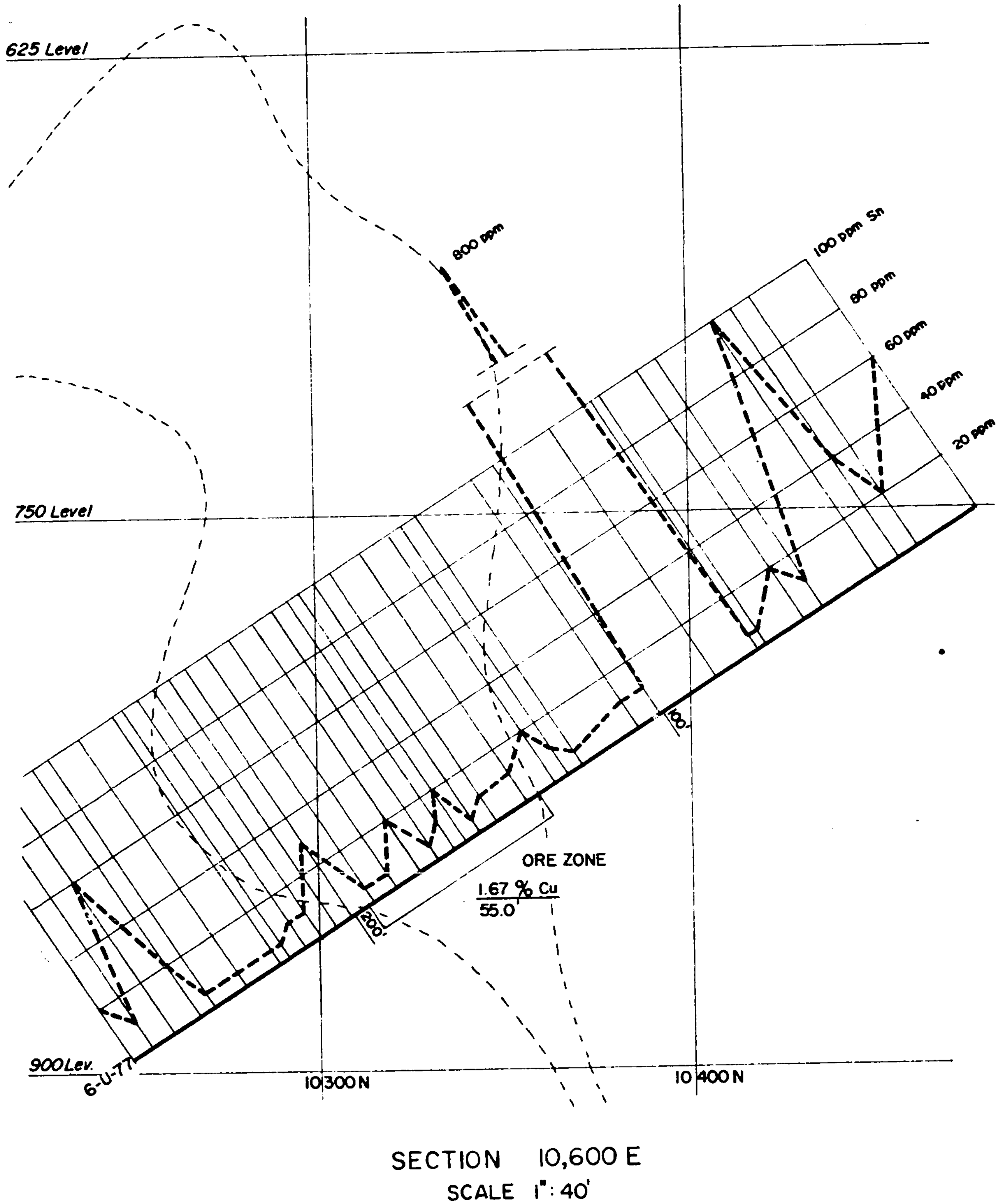
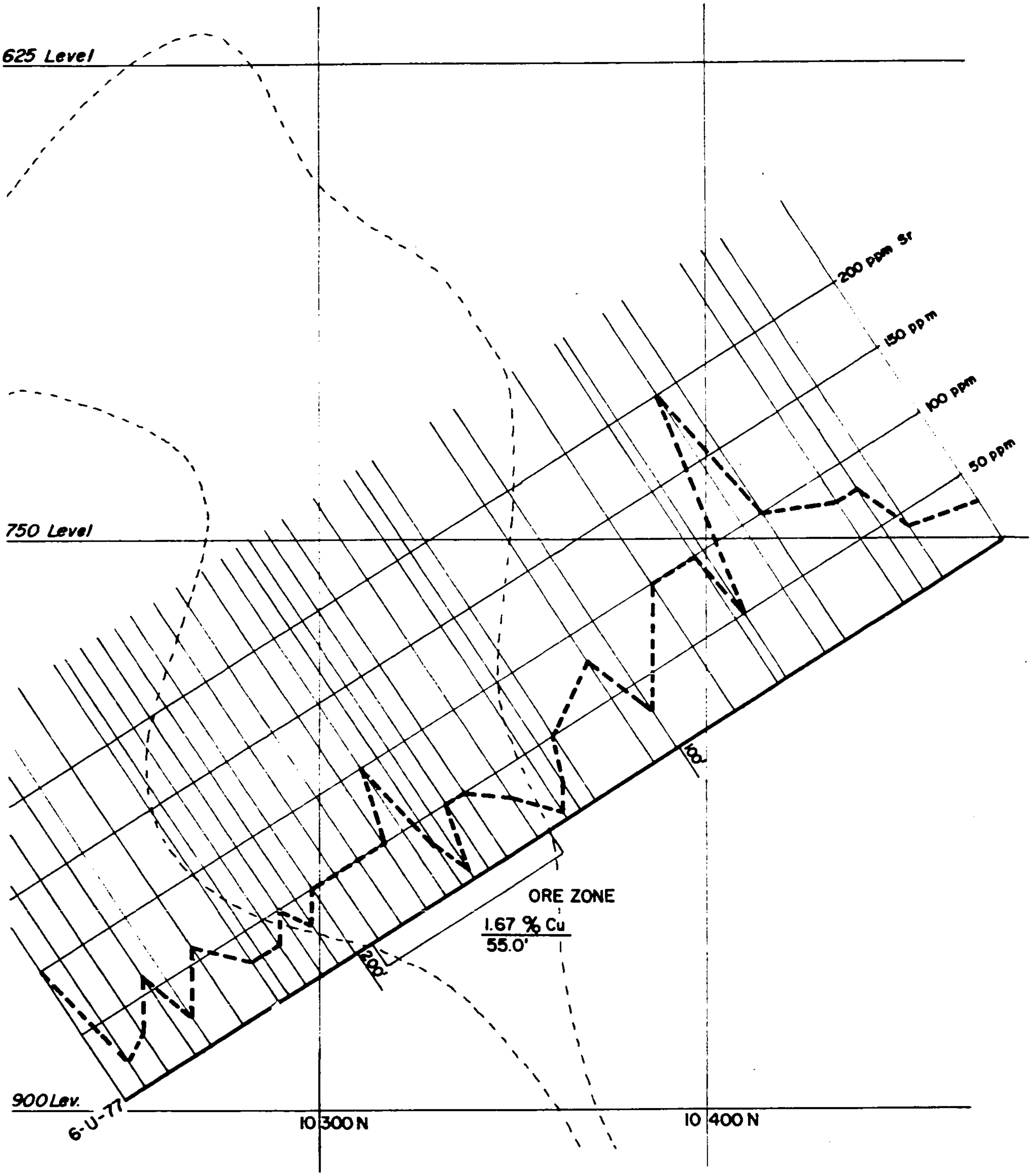
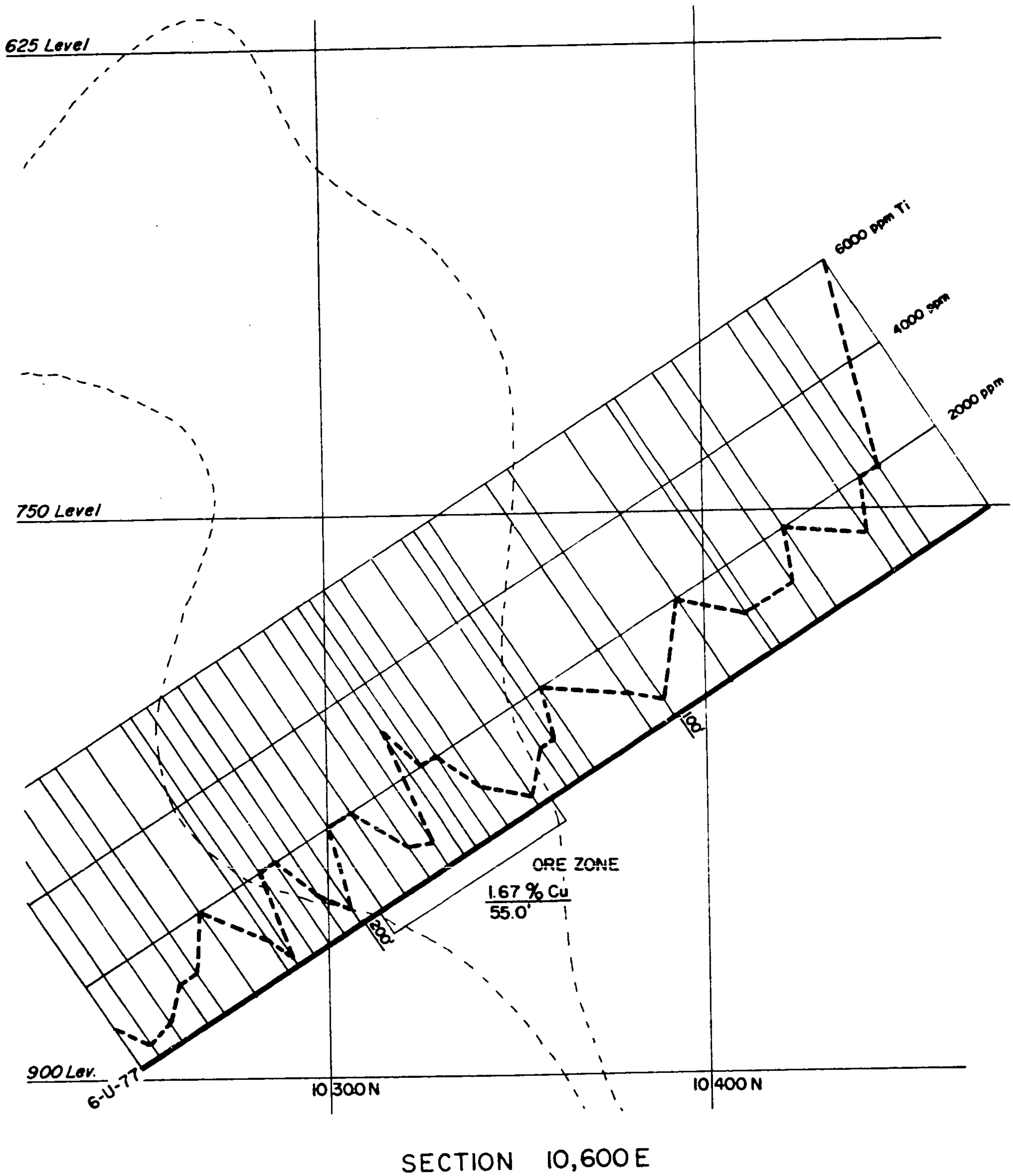


Plate 34. Graph, showing variation in tin content across an ore zone in drill hole No. 6-U-77.



SECTION 10,600 E
SCALE 1":40'

Plate 35. Graph, showing variation in strontium content across an ore zone in drill hole No. 6-U-77.



SECTION 10,600 E
SCALE 1": 40'

Plate 36. Graph, showing variation in titanium content across an ore zone in drill hole No. 6-U-77.

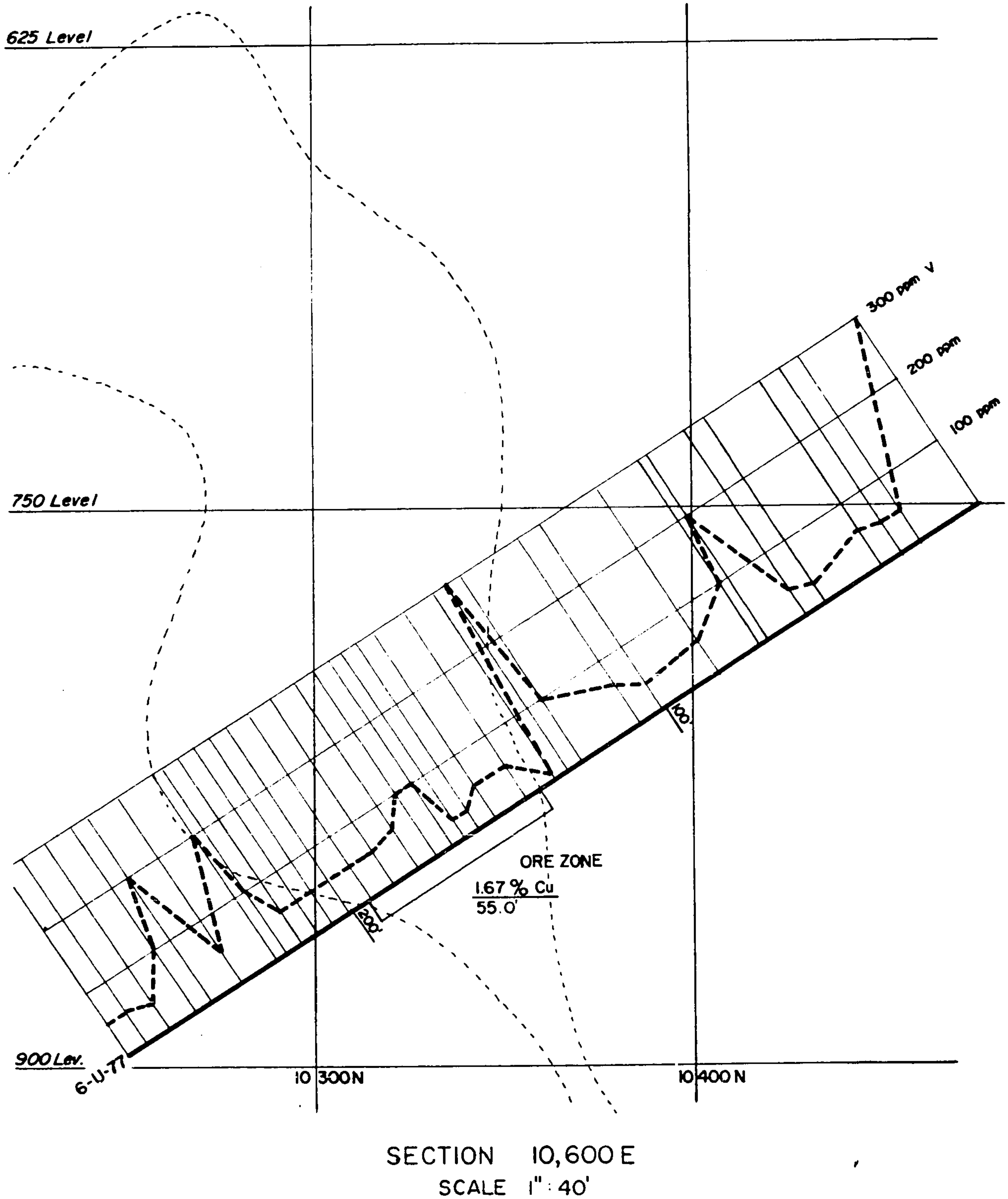


Plate 37. Graph, showing variation in vanadium content across an ore zone in drill hole 6-U-77.

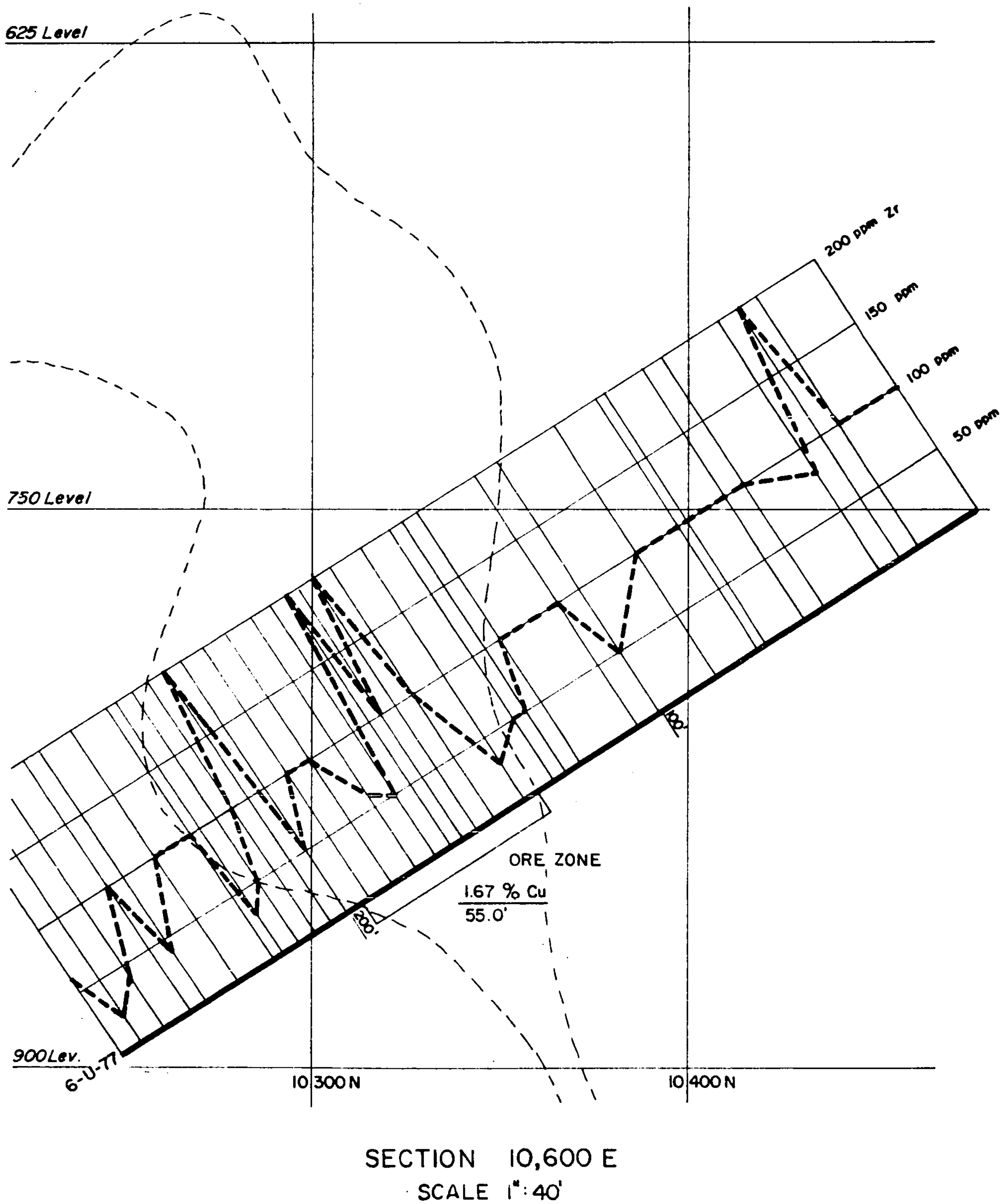


Plate 38. Graph, showing variation in zirconium content across an ore zone in drill hole No. 6-U-77.

THE ESTIMATION OF ORE RESERVES.

The description of the Breton breccia would not be complete without at least a brief account of the methods used in the estimation of the grade and tonnage of the ore.

Sampling.

The erratic occurrence of ore minerals has always posed a very serious problem in the evaluation of the Breton breccia. Already during the initial surface drilling programme it was suspected that the assay returns of drill core samples were unreliable, mainly due to the poor core recovery from the highly altered, mineralized portions of the breccia. Sampling procedures for the evaluation of the underground workings were therefore prepared with great care. Three types of samples were taken:

1. Drill core samples were provided by pilot drill holes which were drilled periodically to a depth of 100 feet, ahead of each drift and cross-cut.

2. Chip samples of the entire face were taken after each round of advance in all drifts and cross-cuts.

3. Car samples of the muck were taken both underground and on surface, and the assays were averaged.

The comparisons of the three types of samples showed a disturbing discrepancy. Assays of chip samples were highest, while muck samples gave the lowest values. This necessitated the decision to erect a bulk sampling plant, which would enable the sampling of the entire volume of rock broken in each round of advance. The sampling plant, equipped with an automatic cutter, processed muck from all subsequent underground workings. The assay results were compiled, and compared with the results of the other three sampling methods. While the comparisons of assays of individual rounds of advance were erratic, assay averages over 100-foot lengths of drifts and cross cuts showed that the drill core assays were invariably lower than the bulk samples of the corresponding areas.

As the entire deposit was evaluated mainly on the basis of drill core assays, it became of utmost importance to determine the degree of reliability of the drill core assays. Attempts were made to determine whether an up-grading factor could be applied to the drill core assays, by which the core assays could be corrected to the value indicated by bulk samples. Various statistical tests failed, however, to determine the exact numerical value of the up-grading factor.

This was followed by elaborate tests which involved the recovery of sludge, and the combining of the sludge and core assays by weighting each by theirespective weights of the recovered sample. The statistical confidence limits of the results, however, did not permit the application of any correction factor.

Apart from the poor core recovery, the main difficulty was that a drill hole of a relatively small diameter often missed the majority of the chalcopyrite blebs which made up an ore zone. The possibility of this happening is realized by the examination of Figures 44 and 46, (pp.102, and 107). Many examples can be given of holes drilled only several inches apart, each penetrating a relatively rich ore zone, and yet each giving entirely different results. In cases like these, it became necessary to take into account the nature of the host rock, the overall core recovery, and to use a great deal of intuition.

At present, with the mine in production, the trend is to rely more on visual estimates of the grade than on any sampling method.

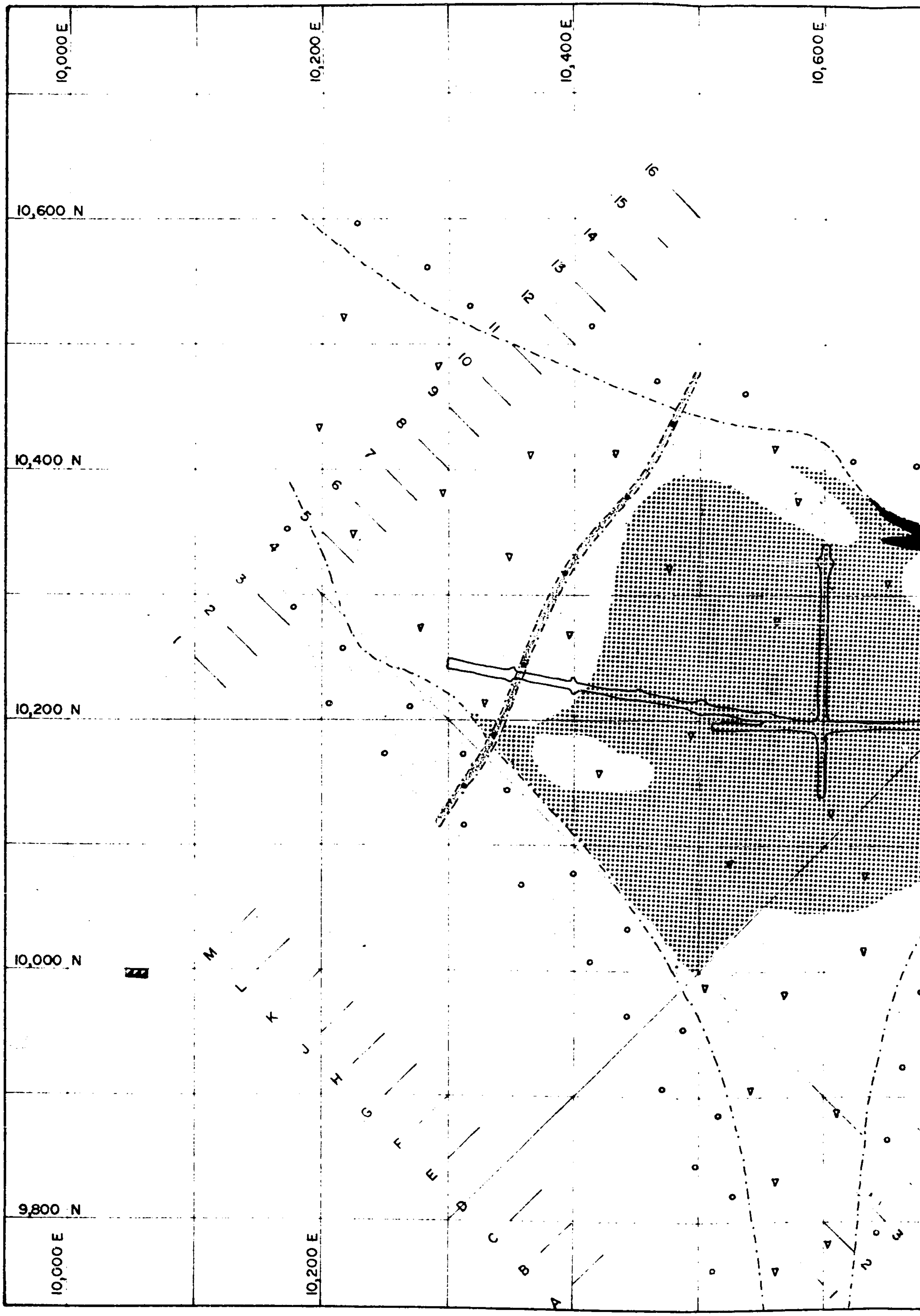
The Estimation of Ore Tonnage.

The complicated domal structure of the ore zones necessitated the use of four vertical sections, in order that every part of each zone could be shown as close to its cross-sectional area as possible. The vertical sections, indicated on the enclosed level plans, show the ore looking north, west, northwest, and northeast. The volume of each block of ore is the product of its cross-sectional area and the distance between the adjacent sections. In the case of flat-lying zones, the volumes are calculated by the polygonal method.

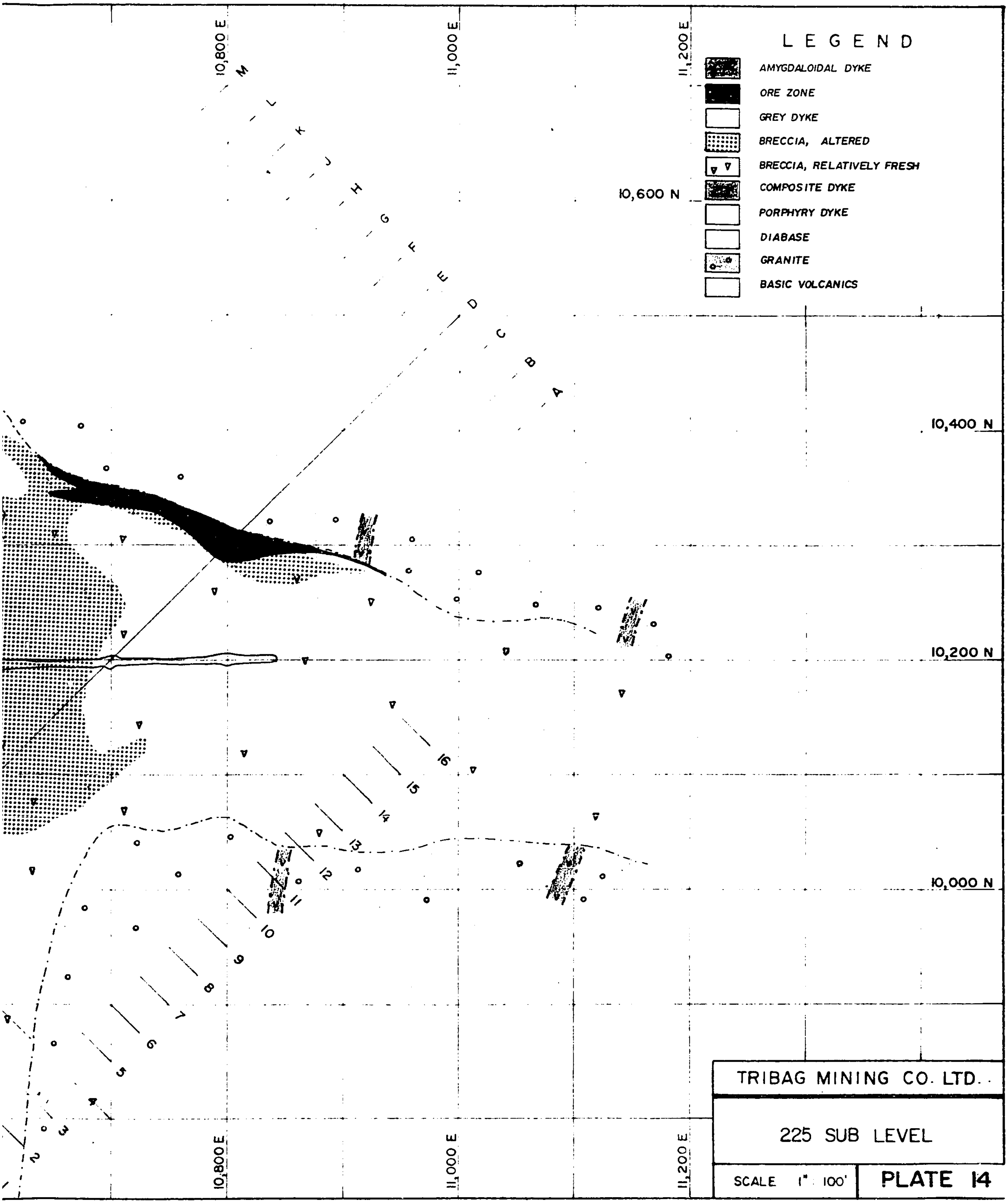
Specific gravity determinations of breccia mineralized with various amounts of sulphides indicated the usage of the following tonnage conversion factors:

Table III.
Tonnage Conversion Factors

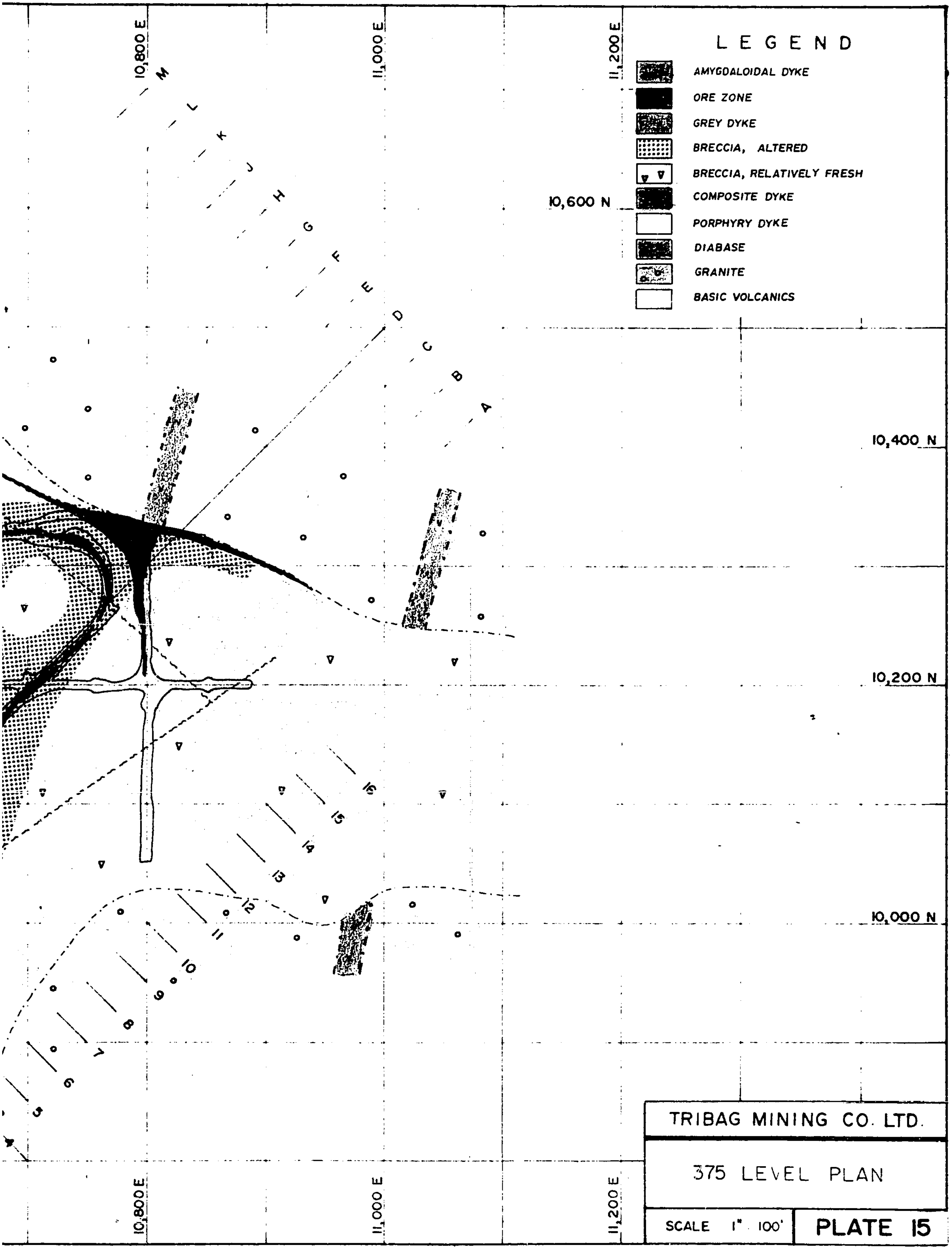
-% Cu	cu ft/t	% Cu	cu ft/t
0.0 - 0.99	12.25	5.0 - 5.99	11.00
1.0 - 1.99	12.00	6.0 - 6.00	10.75
2.0 - 2.99	11.75	7.0 - 7.99	10.50
3.0 - 3.99	11.50	8.0 - 8.99	10.25
4.0 - 4.99	11.25	9.0 +	10.00

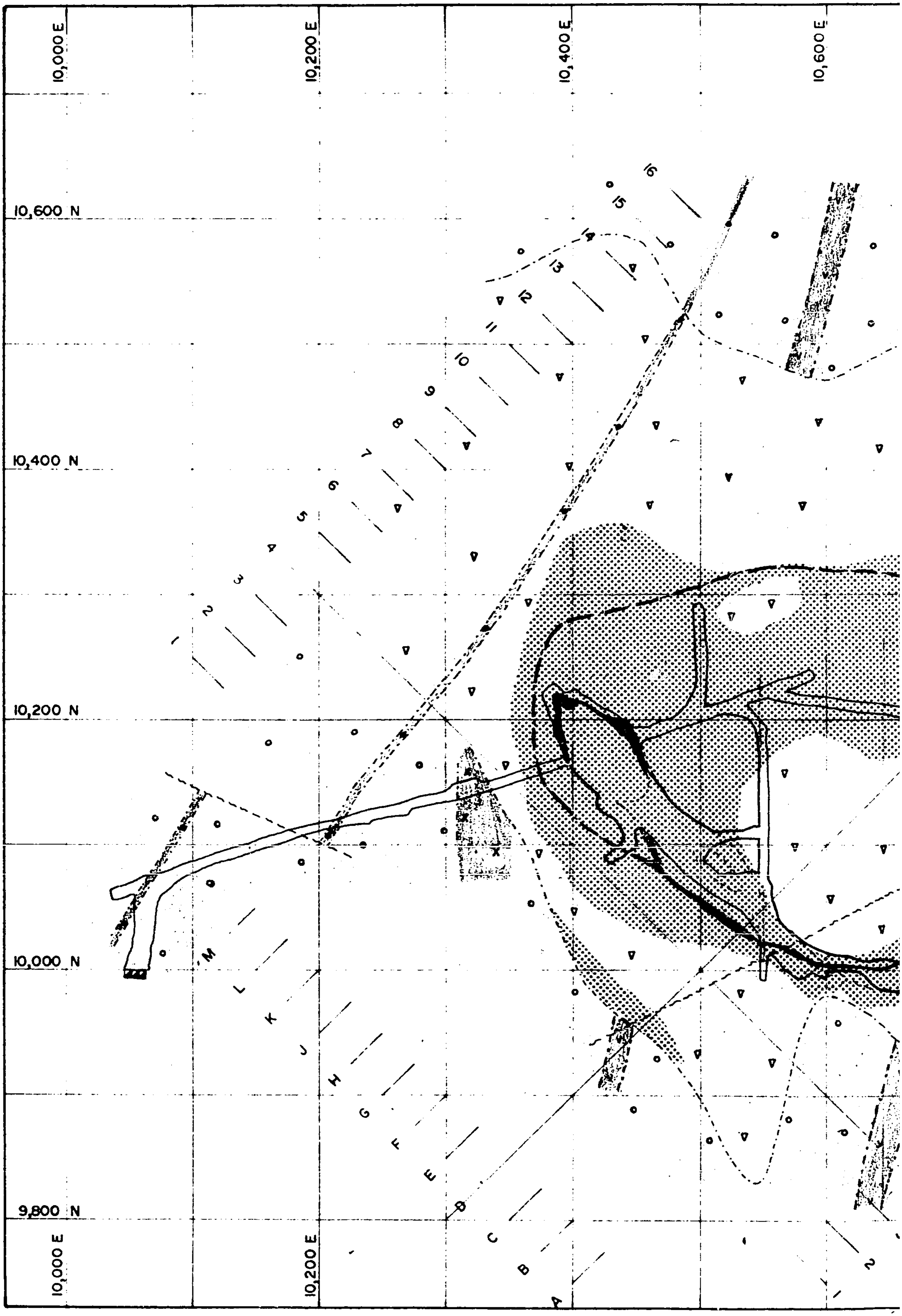


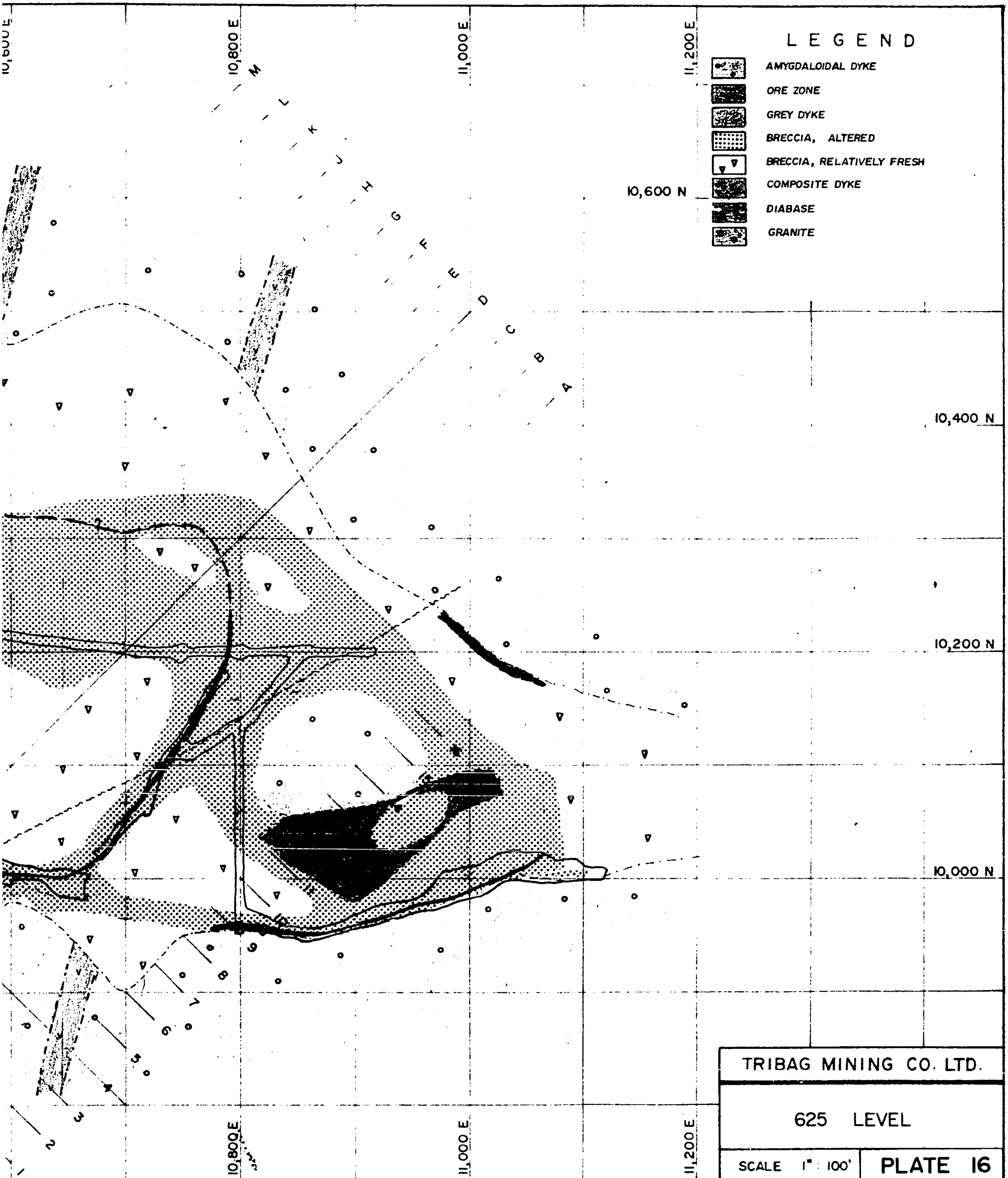
10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
A
B
C
D
E
F
G
H
J
K
L
M

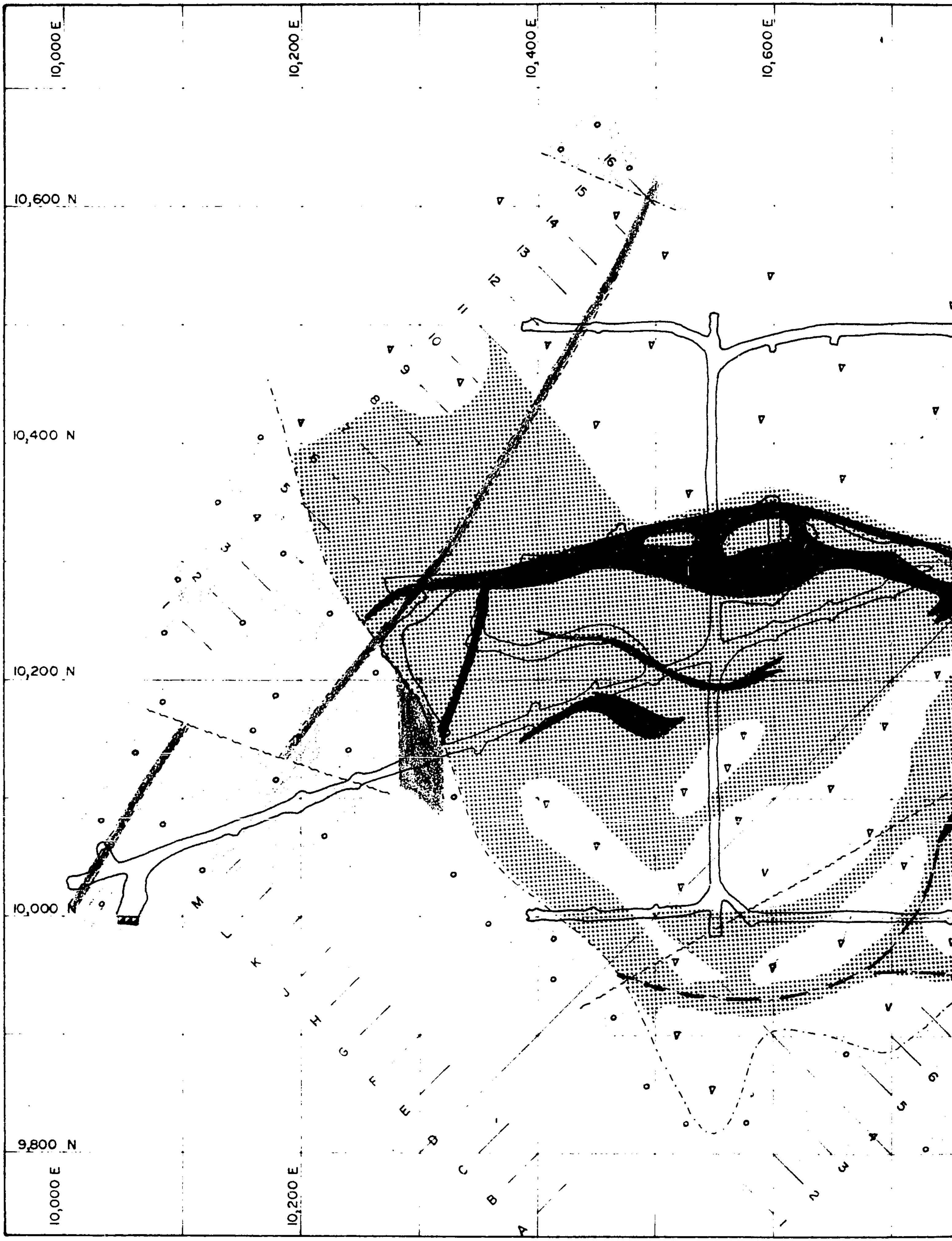

LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
PORPHYRY DYKE
DIABASE
GRANITE
BASIC VOLCANICS
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
M
L
K
J
H
G
F
E
D
C
B
A
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TRIBAG MINING CO. LTD.
225 SUB LEVEL
SCALE 1" : 100'
PLATE 14

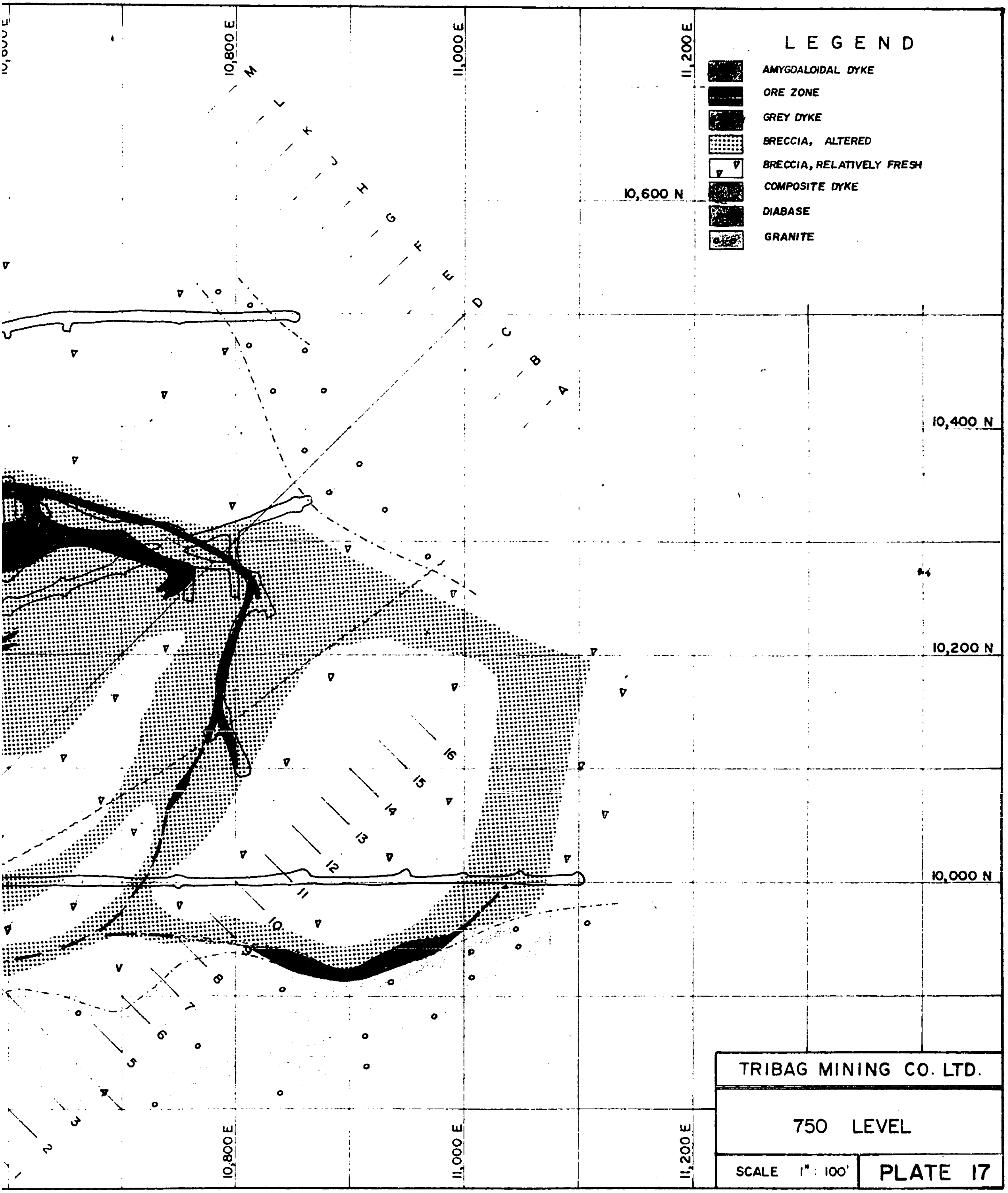

10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E

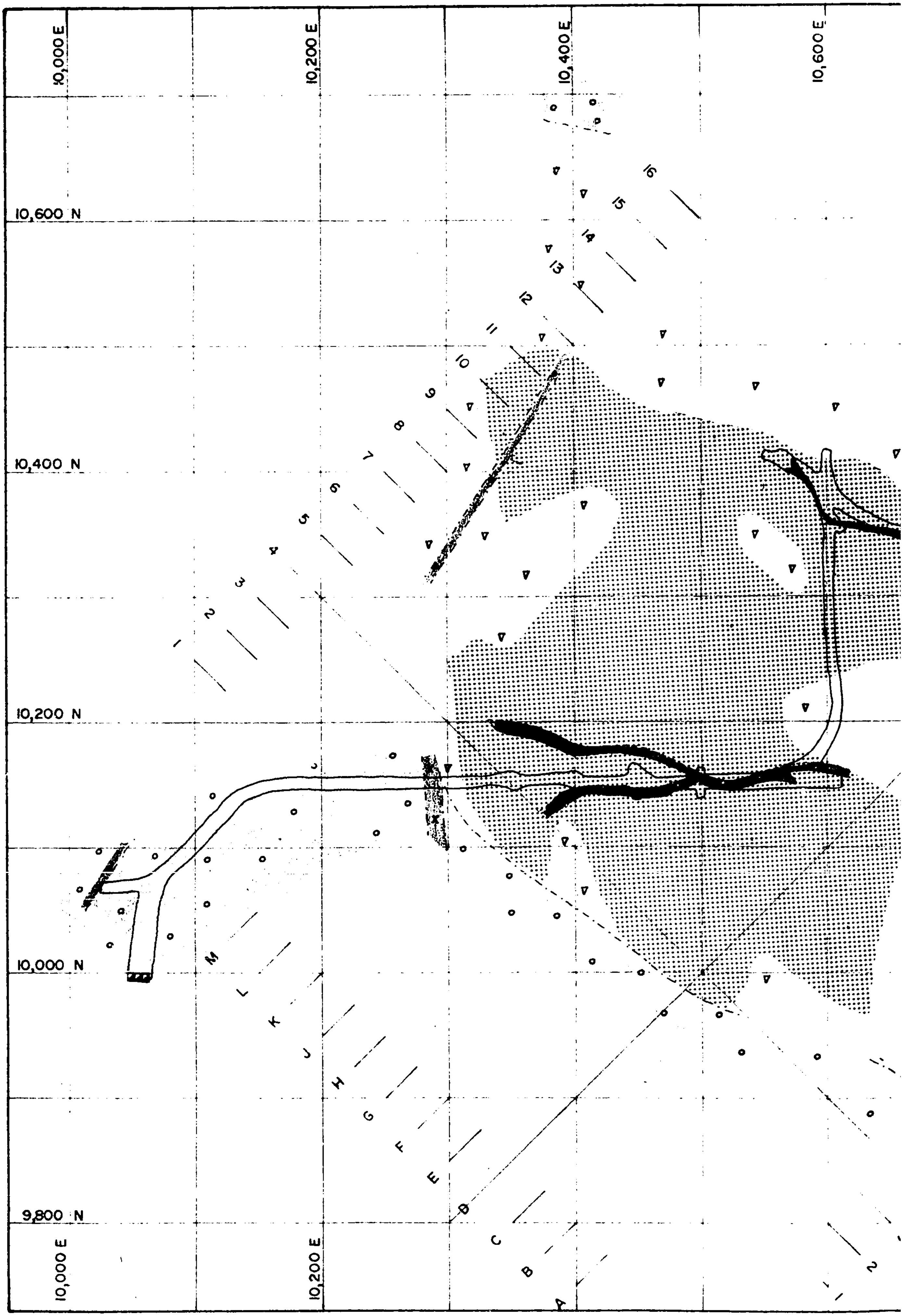

LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
PORPHYRY DYKE
DIABASE
GRANITE
BASIC VOLCANICS
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
M
L
K
J
H
G
F
E
D
C
B
A
4
5
6
7
8
9
10
11
12
13
14
15
16
TRIBAG MINING CO. LTD.
375 LEVEL PLAN
SCALE 1" 100'
PLATE 15

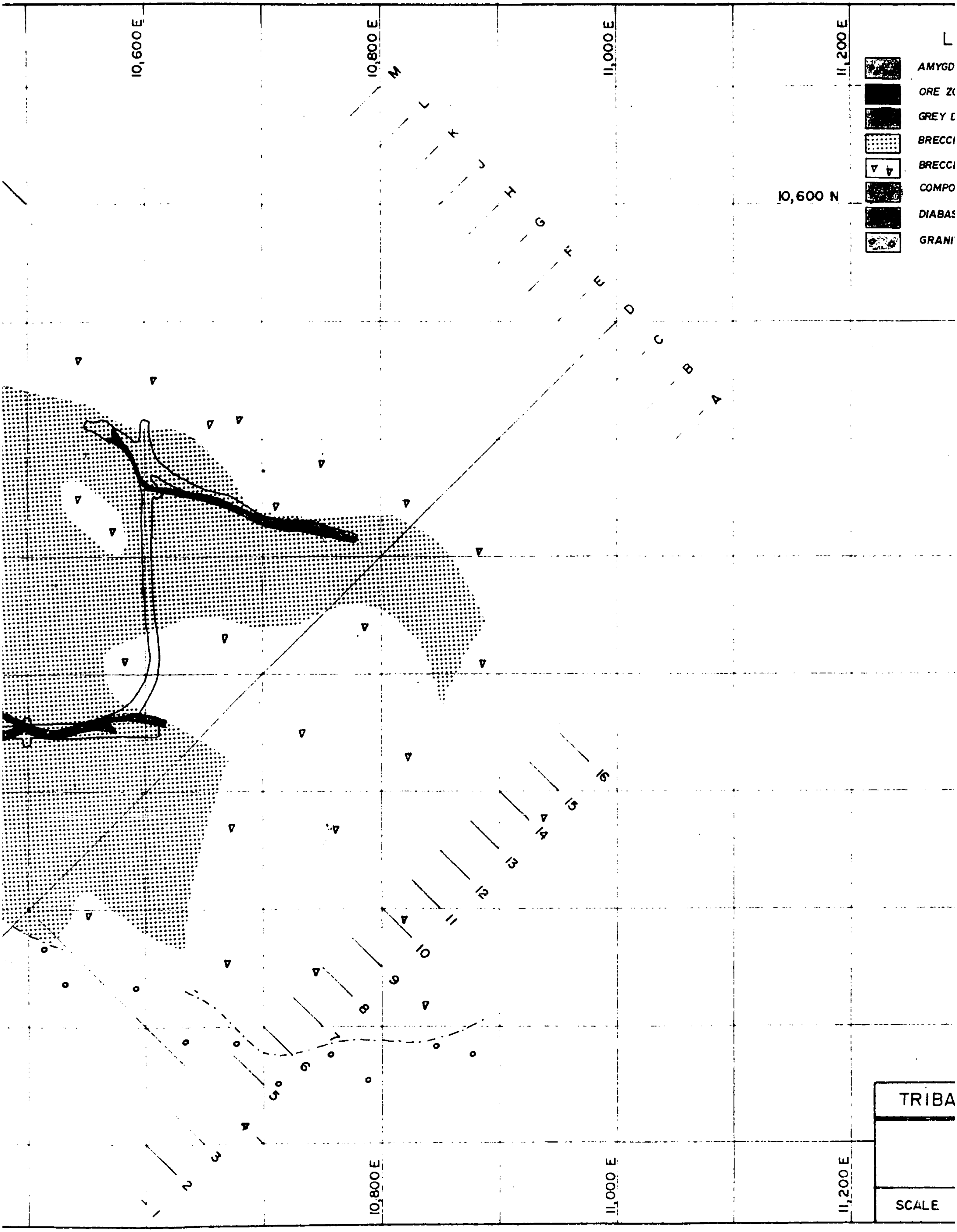

10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E


LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
DIABASE
GRANITE
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
TRIBAG MINING CO. LTD.
625 LEVEL
SCALE 1" : 100'
PLATE 16

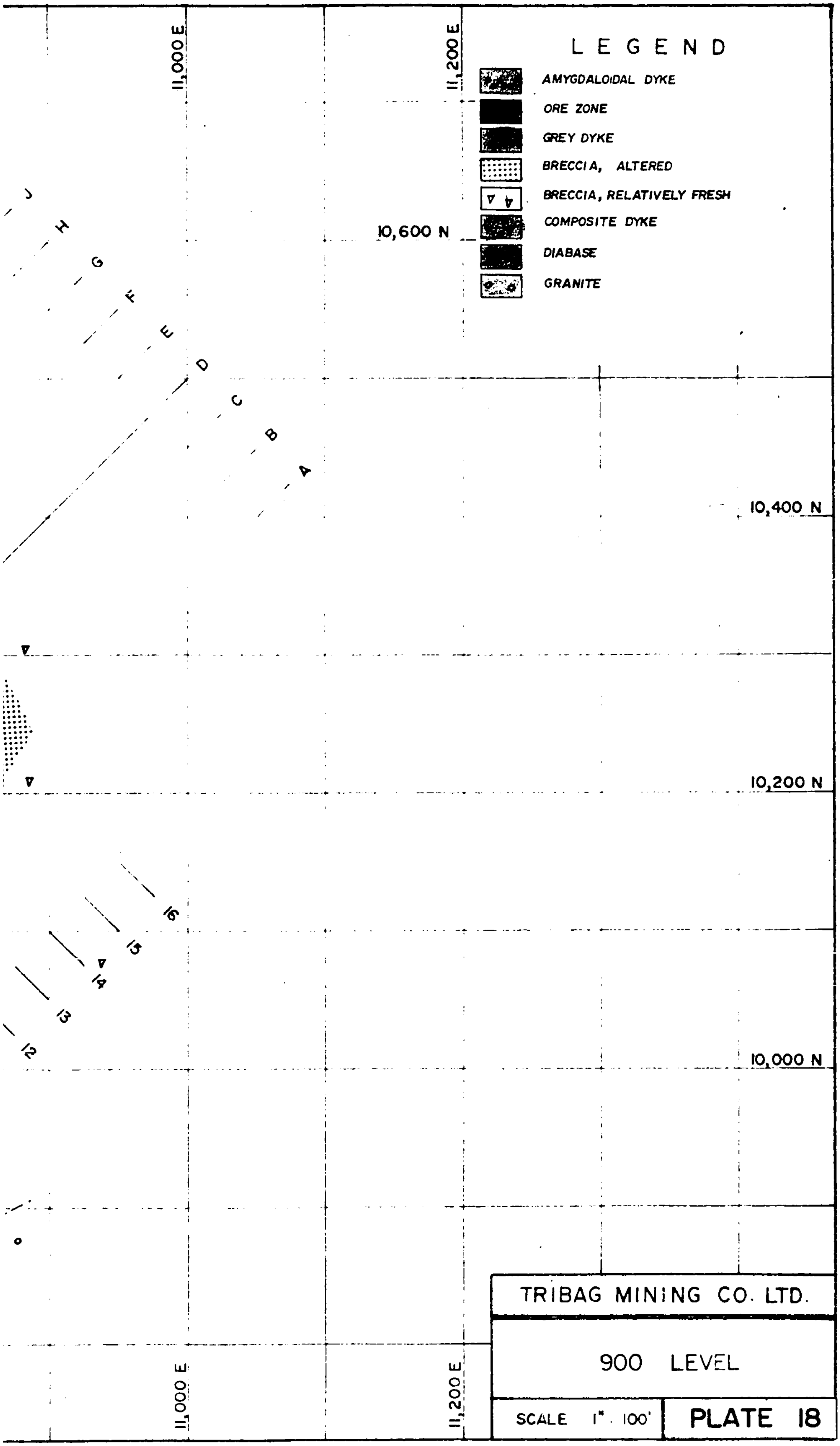

10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E

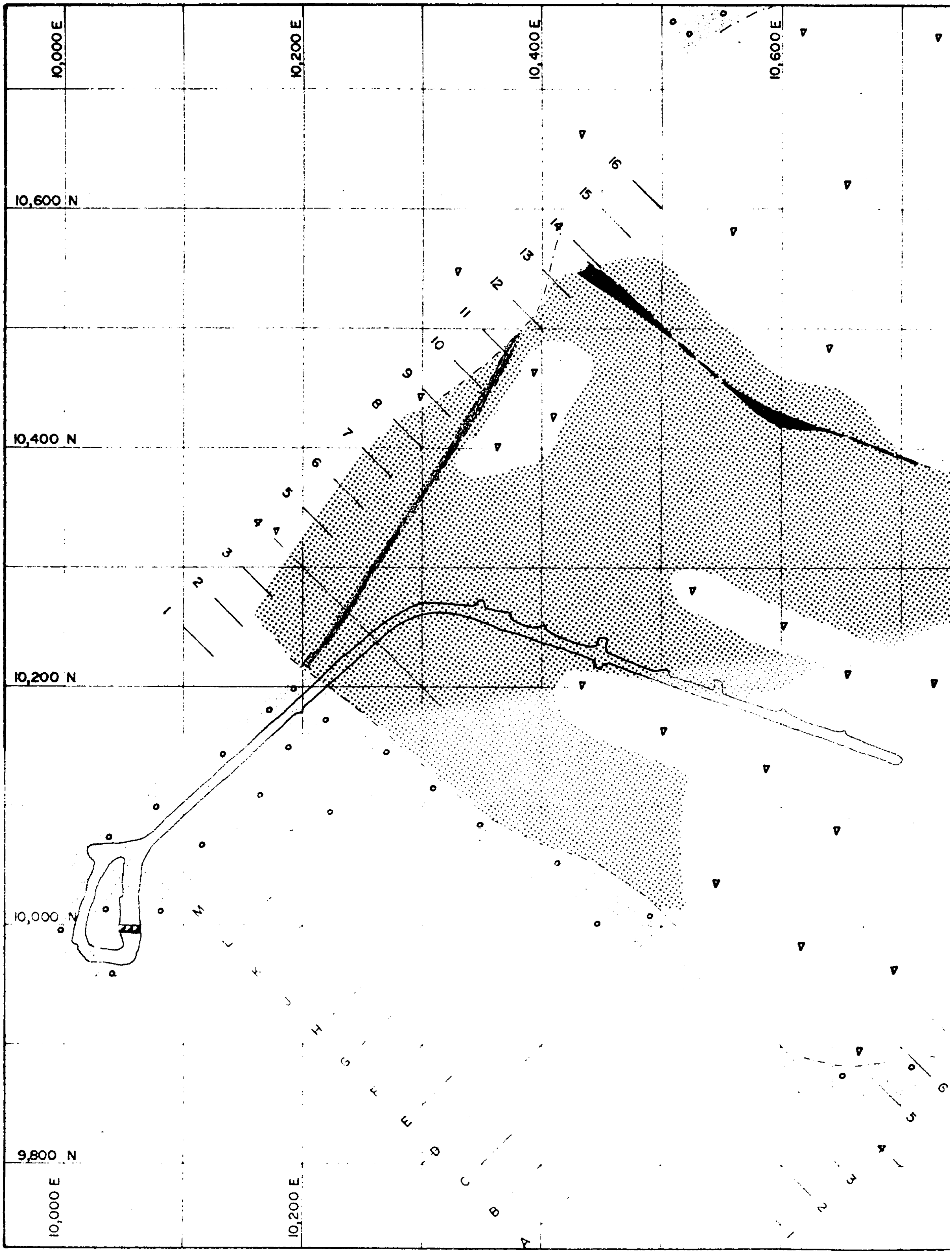

LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
DIABASE
GRANITE
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
M
L
K
J
H
G
F
E
D
C
B
A
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
TRIBAG MINING CO. LTD.
750 LEVEL
SCALE 1" : 100'
PLATE 17

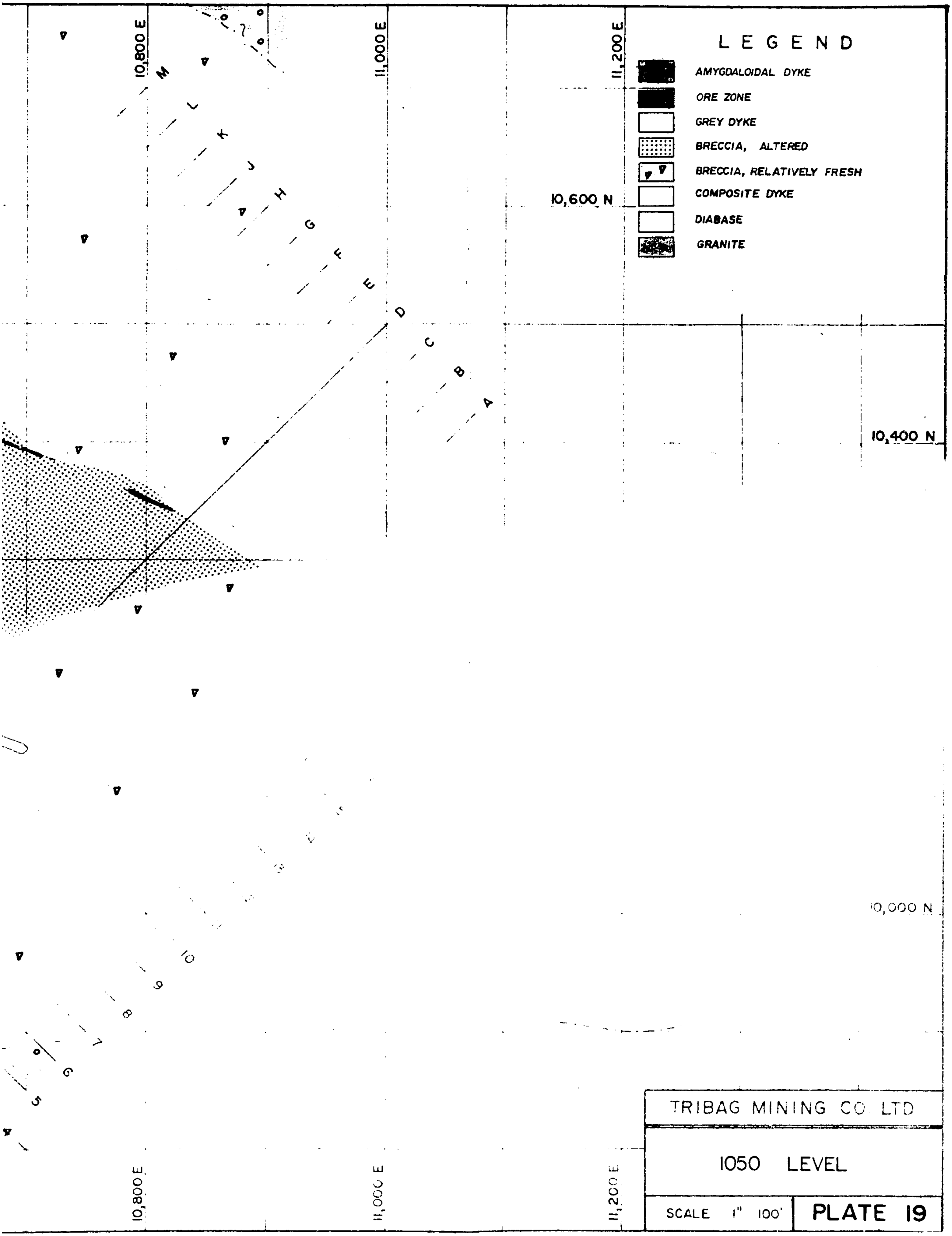

10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E



10,600 E
10,800 E
11,000 E
11,200 E
10,600 N
AMYGD
ORE ZO
GREY D
BRECCI
BRECCI
COMPO
DIABAS
GRANI
TRIBA
SCALE


LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
DIABASE
GRANITE
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
J
H
G
F
E
D
C
B
A
16
15
14
13
12
TRIBAG MINING CO. LTD.
900 LEVEL
SCALE 1" . 100'
PLATE 18


10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
10,000 E
10,200 E

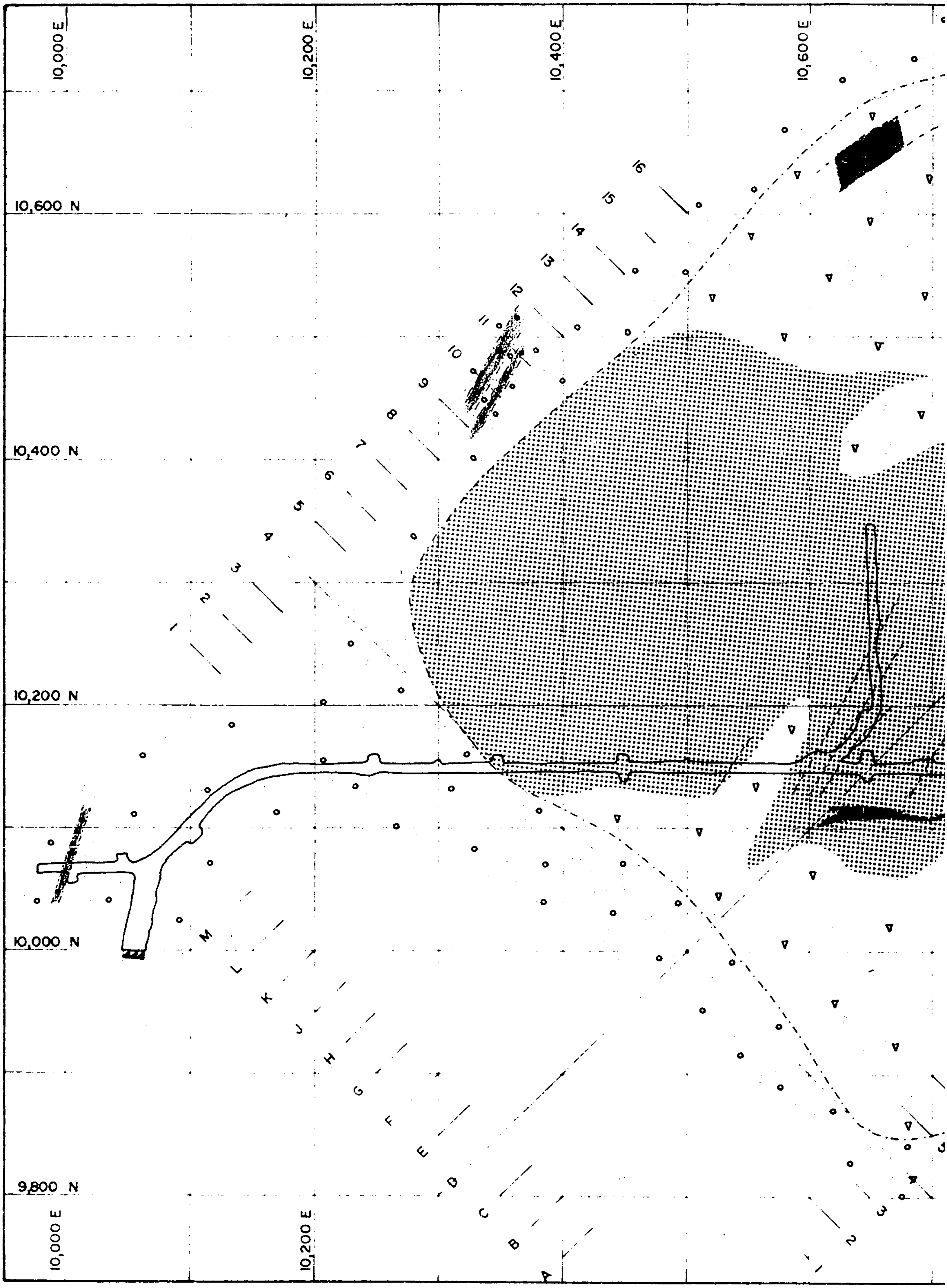


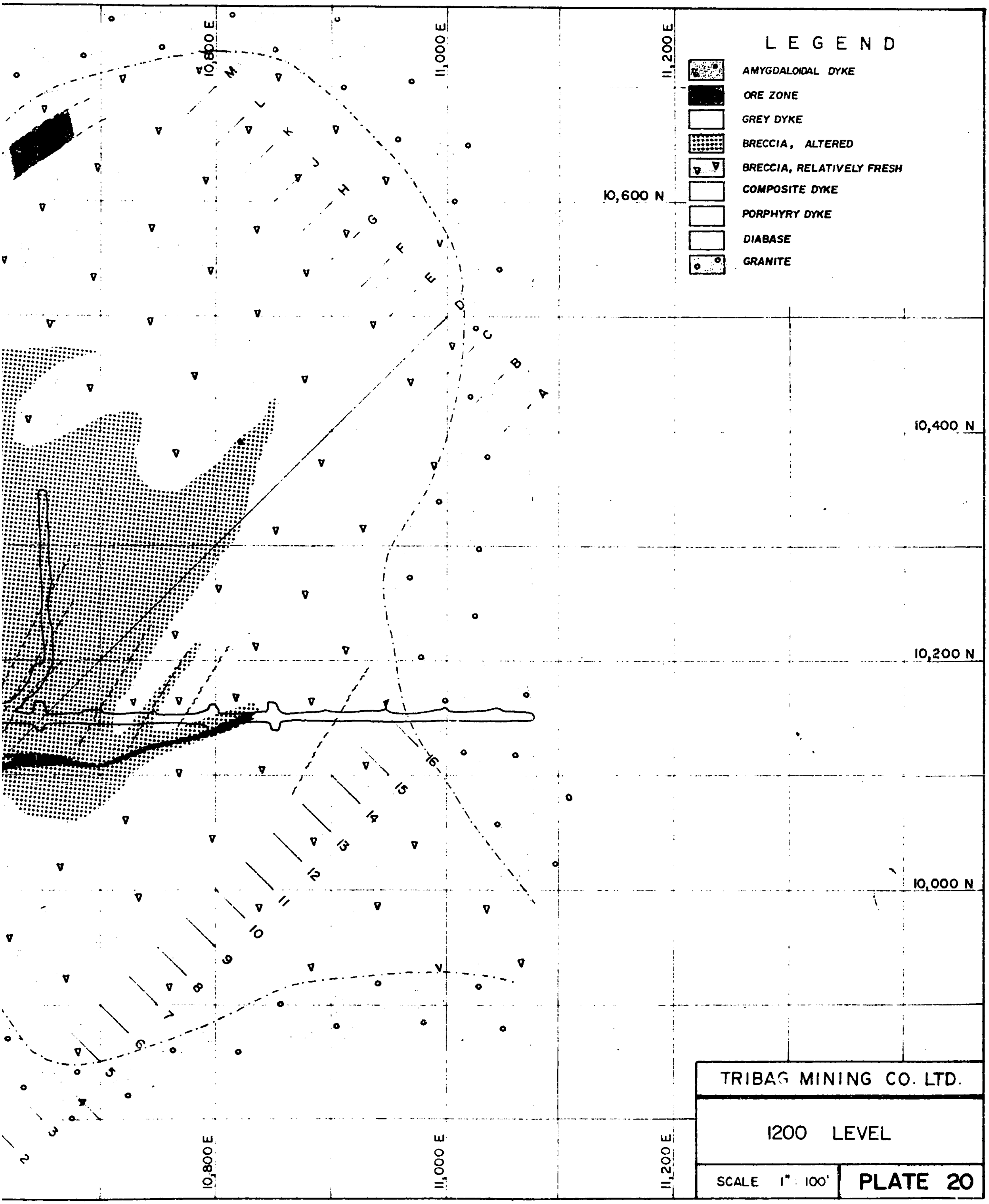
TRIBAG MINING CO LTD

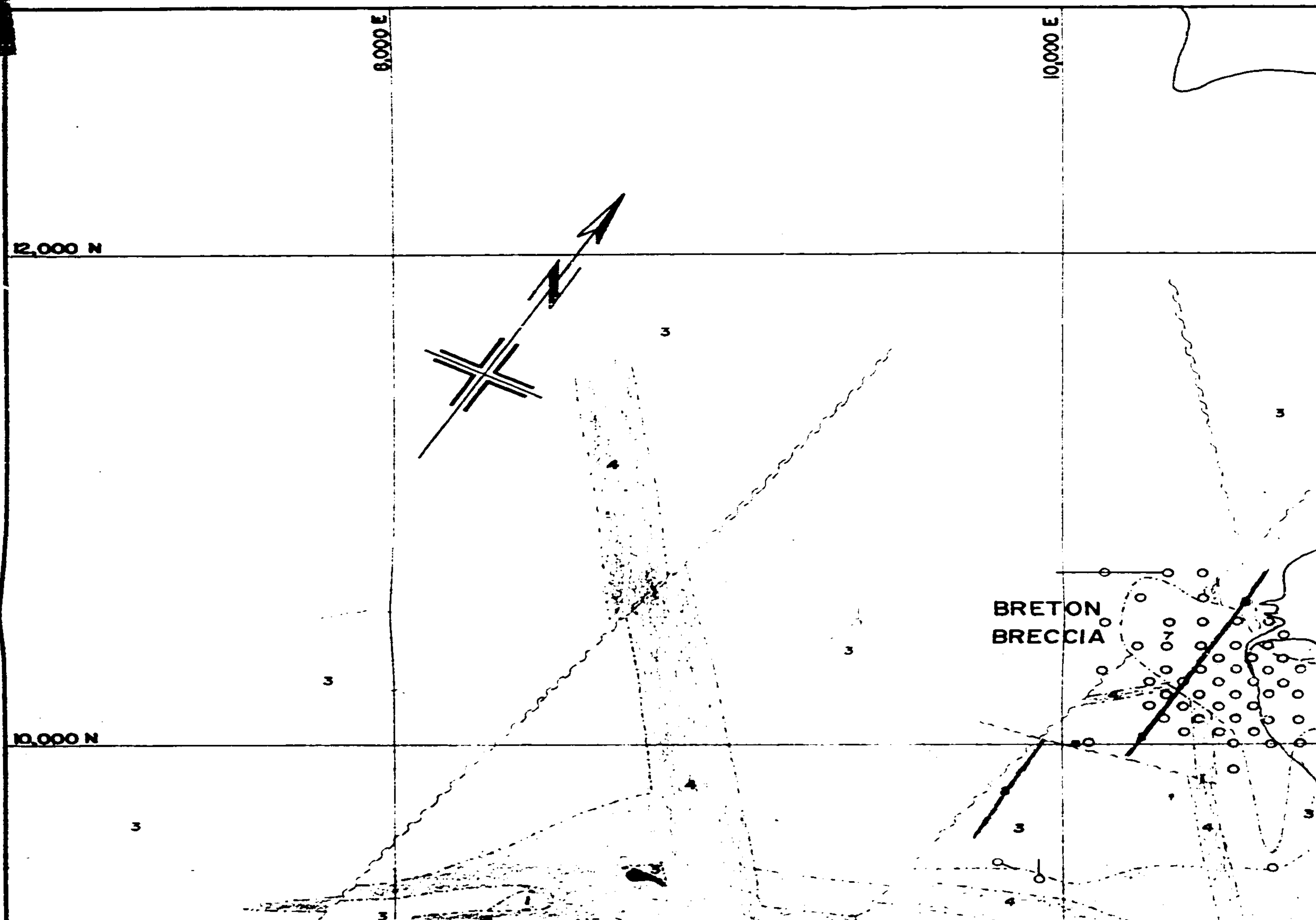
1050 LEVEL

SCALE 1" 100'

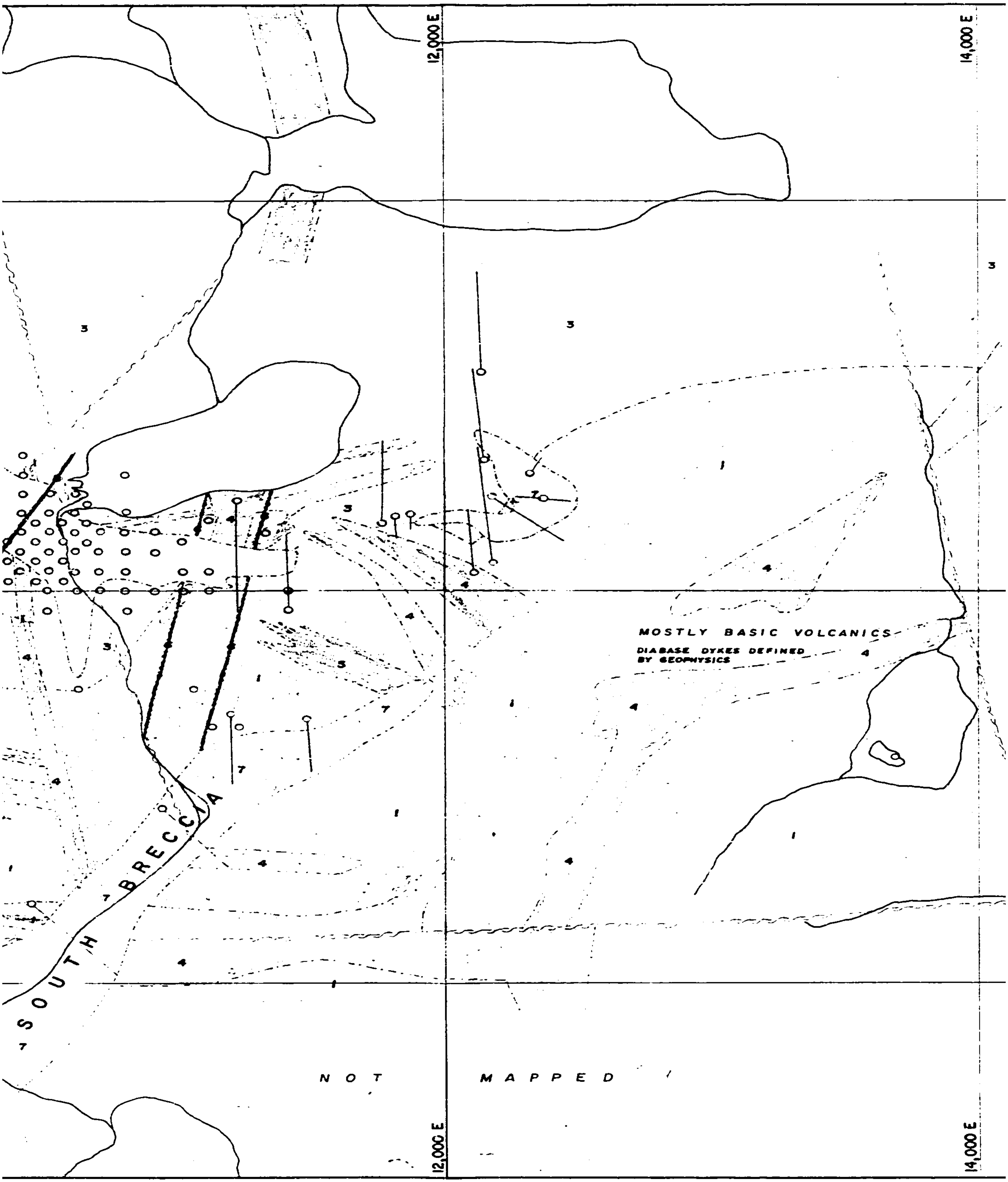
PLATE 19


10,000 E
10,200 E
10,400 E
10,600 E
10,600 N
10,400 N
10,200 N
10,000 N
9,800 N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
M
L
K
J
H
G
F
E
D
C
B
A
10,000 E
10,200 E

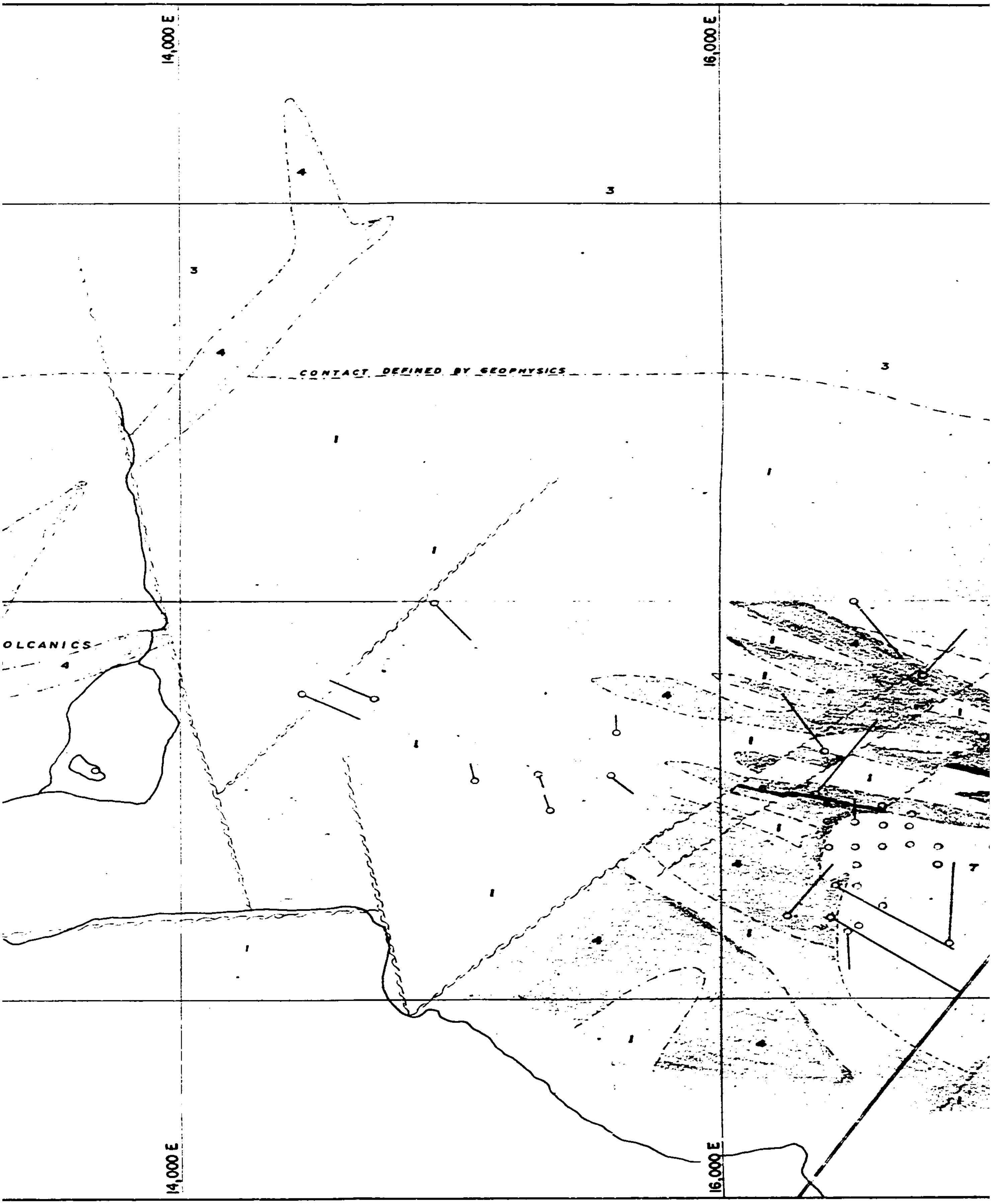

LEGEND
AMYGDALOIDAL DYKE
ORE ZONE
GREY DYKE
BRECCIA, ALTERED
BRECCIA, RELATIVELY FRESH
COMPOSITE DYKE
PORPHYRY DYKE
DIABASE
GRANITE
10,800 E
11,000 E
11,200 E
10,600 N
10,400 N
10,200 N
10,000 N
TRIBAG MINING CO. LTD.
1200 LEVEL
SCALE 1" : 100'
PLATE 20

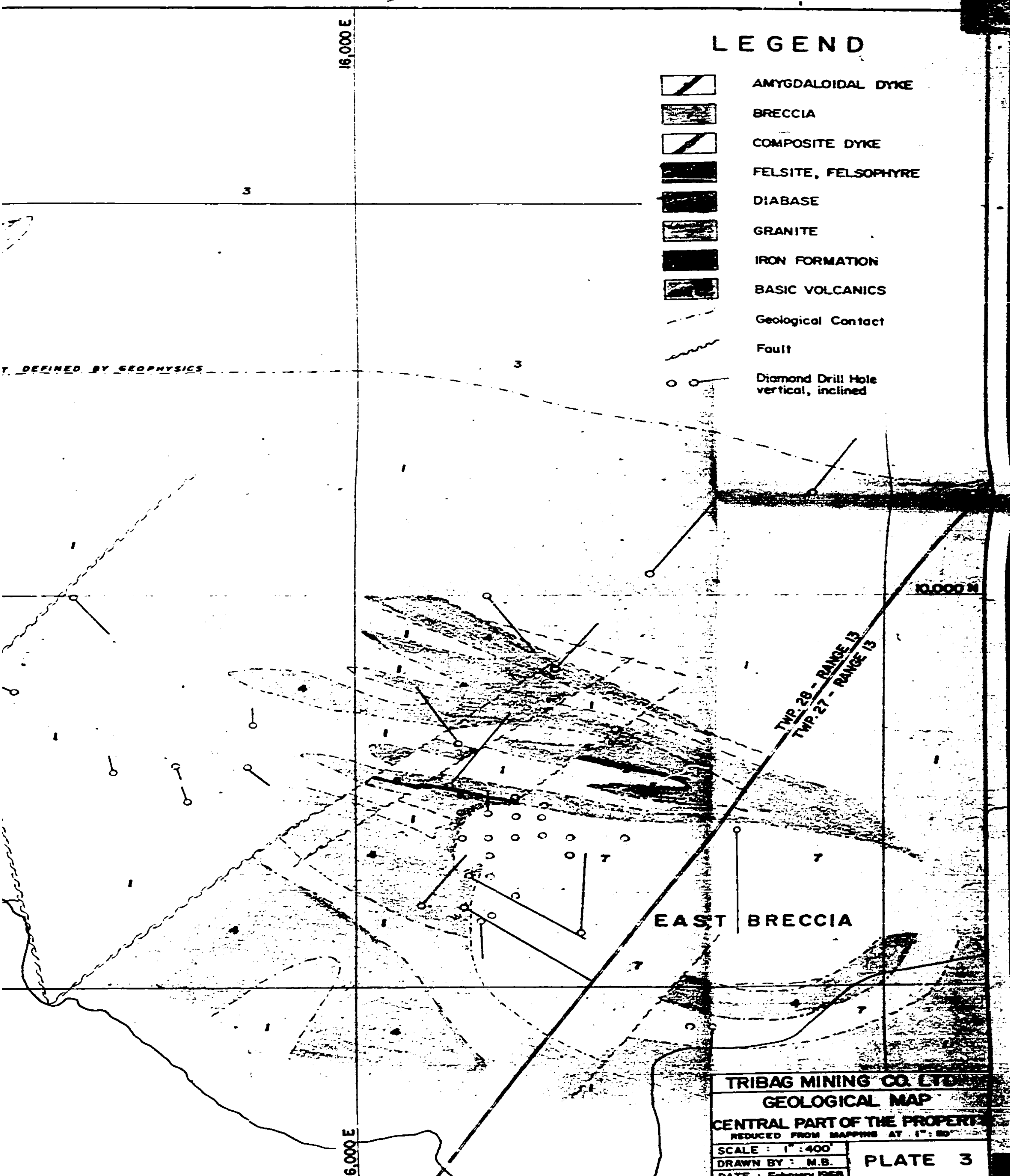


8,000 E
10,000 E
12,000 N
10,000 N
8,000 N
N
BRETON
BRECCIA
WEST BRECCIA
NOT MAPPED
SOUTH

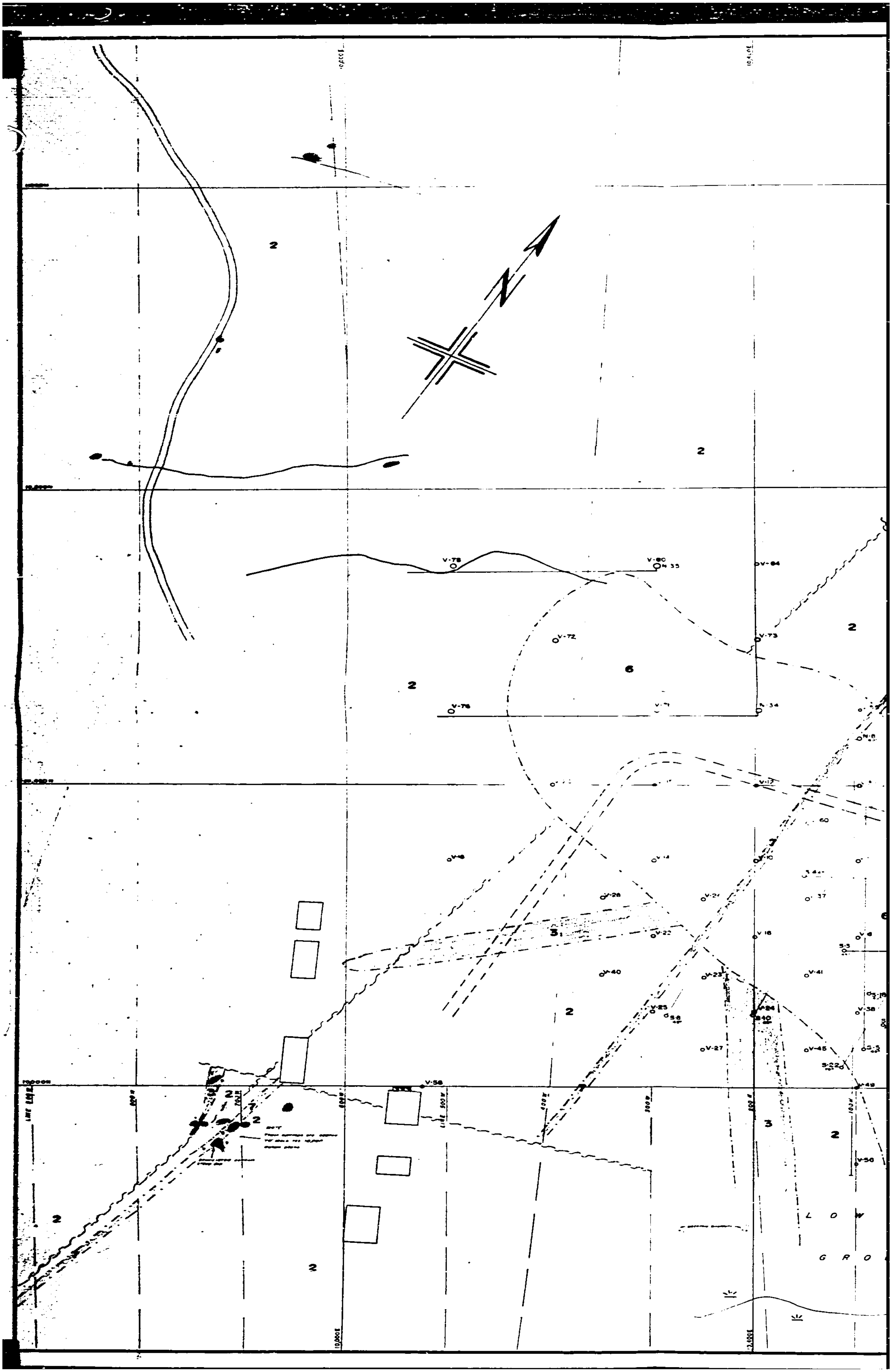


12,000 E
14,000 E
MOSTLY BASIC VOLCANICS
DIABASE DYKES DEFINED BY GEOPHYSICS
SOUTH BRECCIA
NOT MAPPED
12,000 E
14,000 E

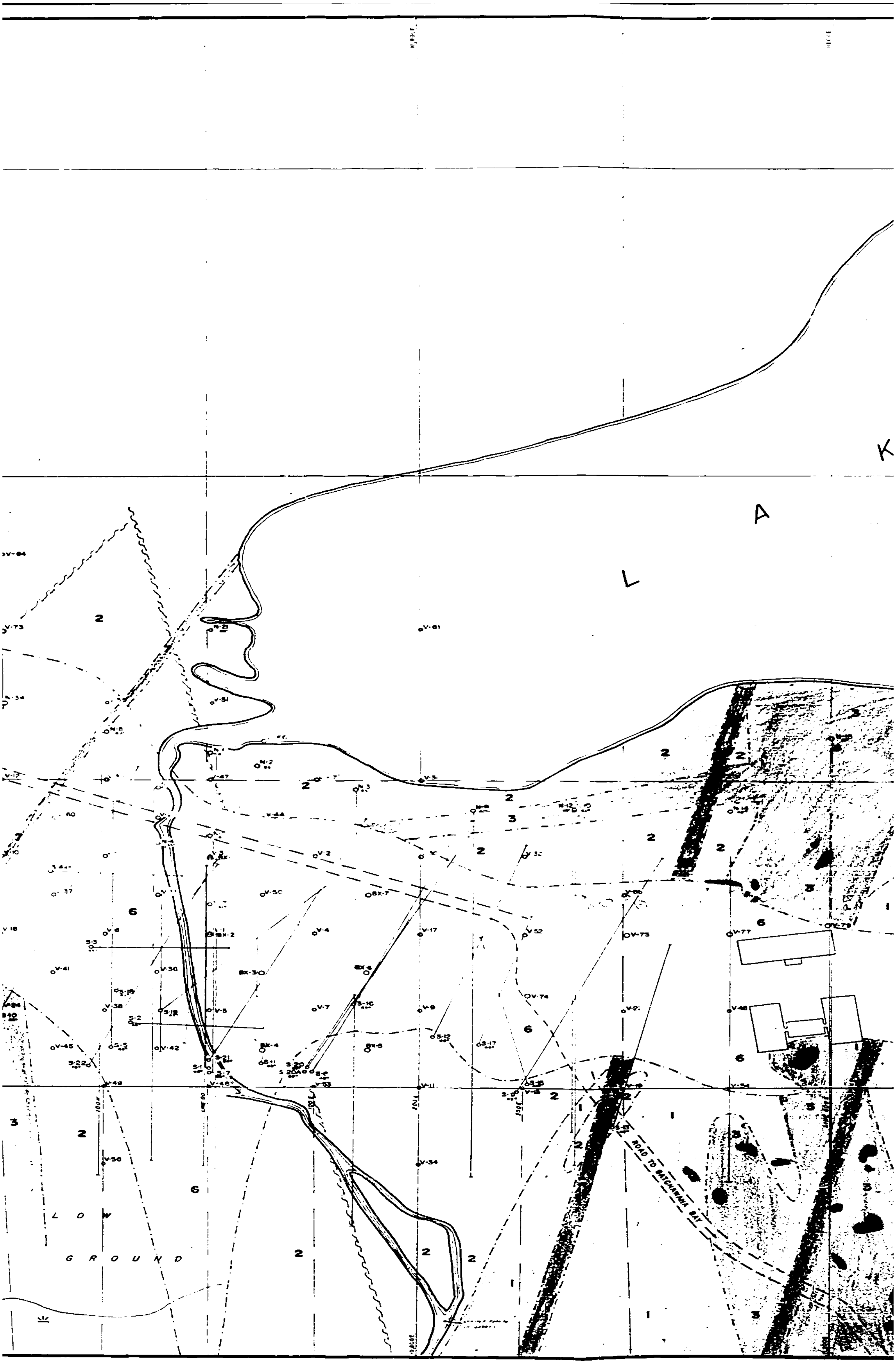

14,000 E
16,000 E
CONTACT DEFINED BY GEOPHYSICS
OLCANICS
3
4
1
7
14,000 E
16,000 E



LEGEND
AMYGDALOIDAL DYKE
BRECCIA
COMPOSITE DYKE
FELSITE, FELSOPHYRE
DIABASE
GRANITE
IRON FORMATION
BASIC VOLCANICS
Geological Contact
Fault
Diamond Drill Hole vertical, inclined
16,000 E
10,000 N
T DEFINED BY GEOPHYSICS
TWP. 28 - RANGE 13
TWP. 27 - RANGE 13
EAST BRECCIA
TRIBAG MINING CO. LTD.
GEOLOGICAL MAP
CENTRAL PART OF THE PROPERTY
REDUCED FROM MAPPING AT 1" : 80'
SCALE : 1" : 400'
DRAWN BY : M.B.
DATE : February, 1968
PLATE 3

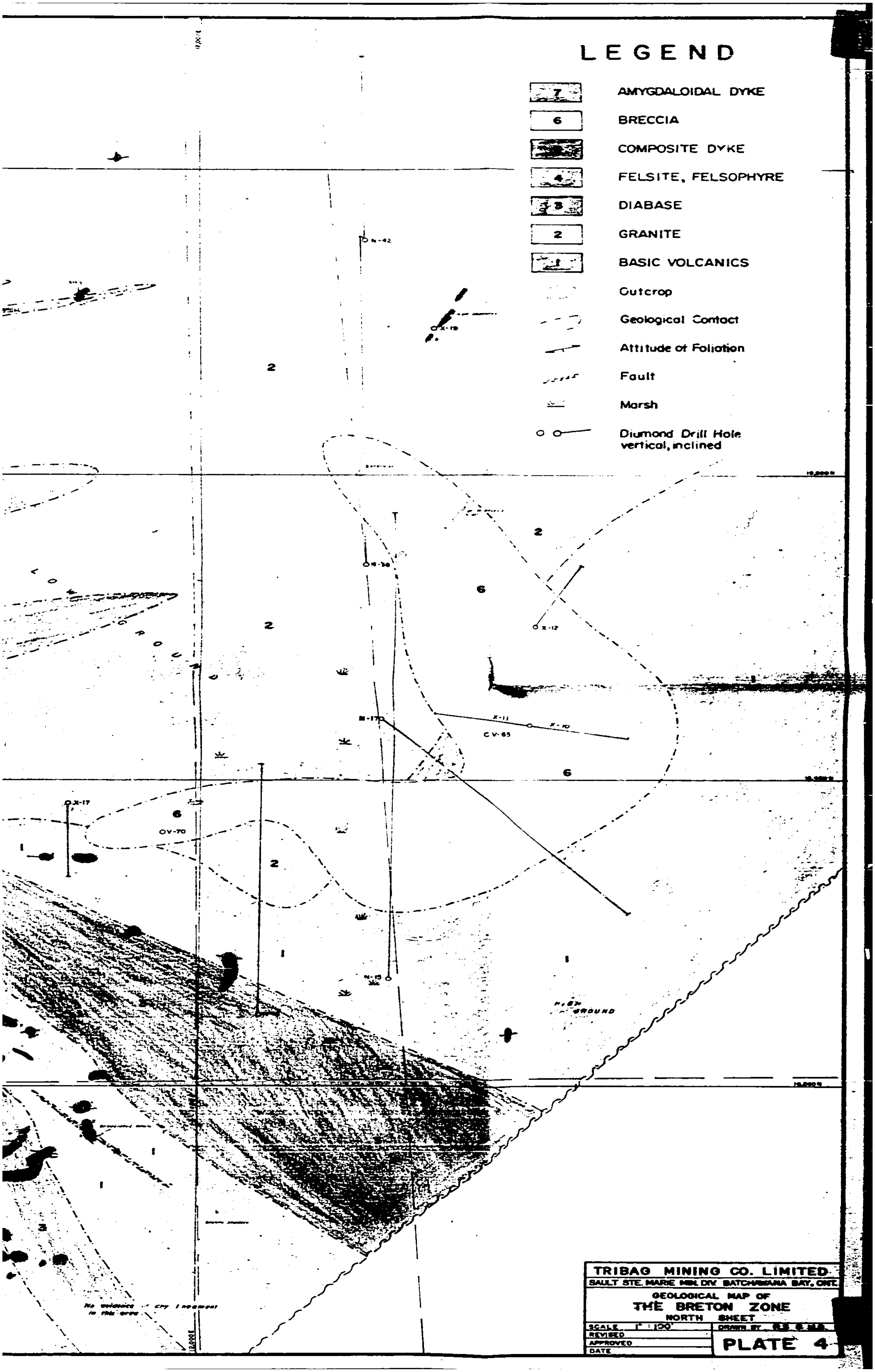


V-78
V-80
N 35
V-84
V-73
V-72
6
V-76
N 34
V-17
V-14
V-10
V-26
V-22
V-18
V-40
V-23
V-25
V-27
V-45
V-41
V-49
V-50
V-56
L O W
G R O

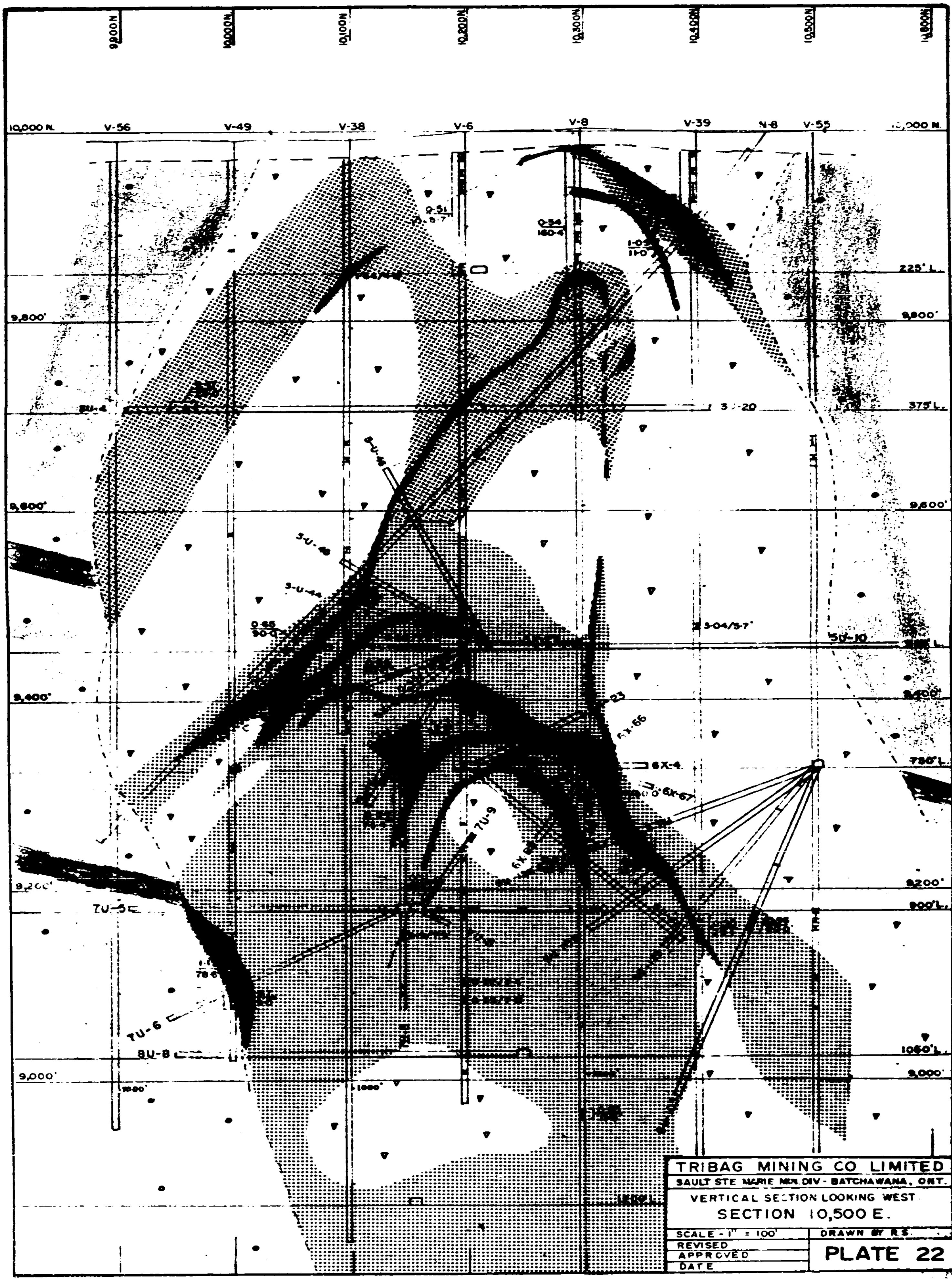


L A K
L O W
G R O U N D
ROAD TO BATCHAWANA BAY
V-61
V-34
V-11


A K E
LOW GROUND
DRIFT COVERED
HIGH GROUND
OX-17
OV-70
ON-30

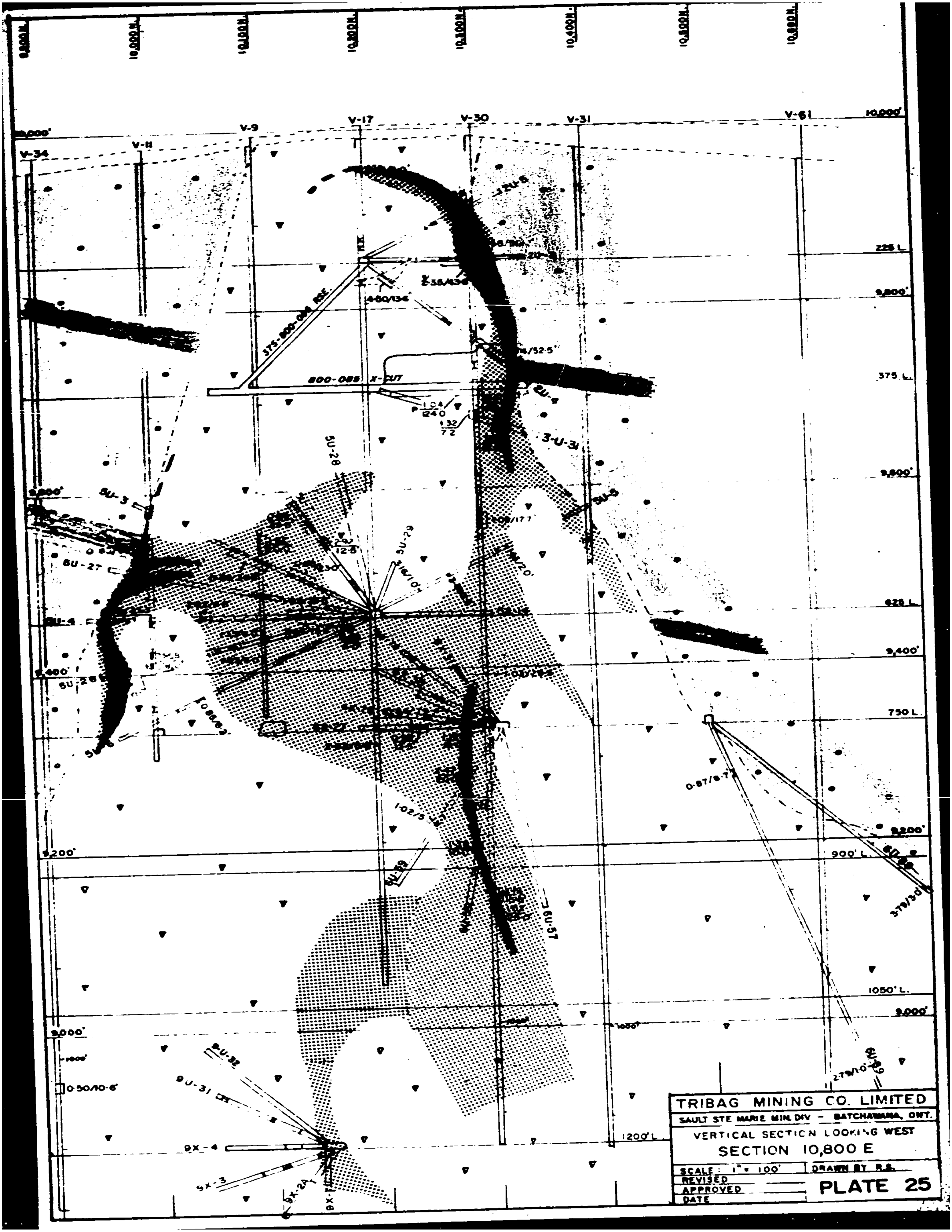

LEGEND
7 AMYGDALOIDAL DYKE
6 BRECCIA
COMPOSITE DYKE
4 FELSITE, FELSOPHYRE
3 DIABASE
2 GRANITE
1 BASIC VOLCANICS
Outcrop
Geological Contact
Attitude of Foliation
Fault
Marsh
Diamond Drill Hole vertical, inclined
TRIBAG MINING CO. LIMITED
SAULT STE. MARIE MIN. DIV. BATCHAWANA BAY, ONT.
GEOLOGICAL MAP OF
THE BRETON ZONE
NORTH SHEET
SCALE 1" : 100'
REVISED
APPROVED
DATE
DRAWN BY
PLATE 4

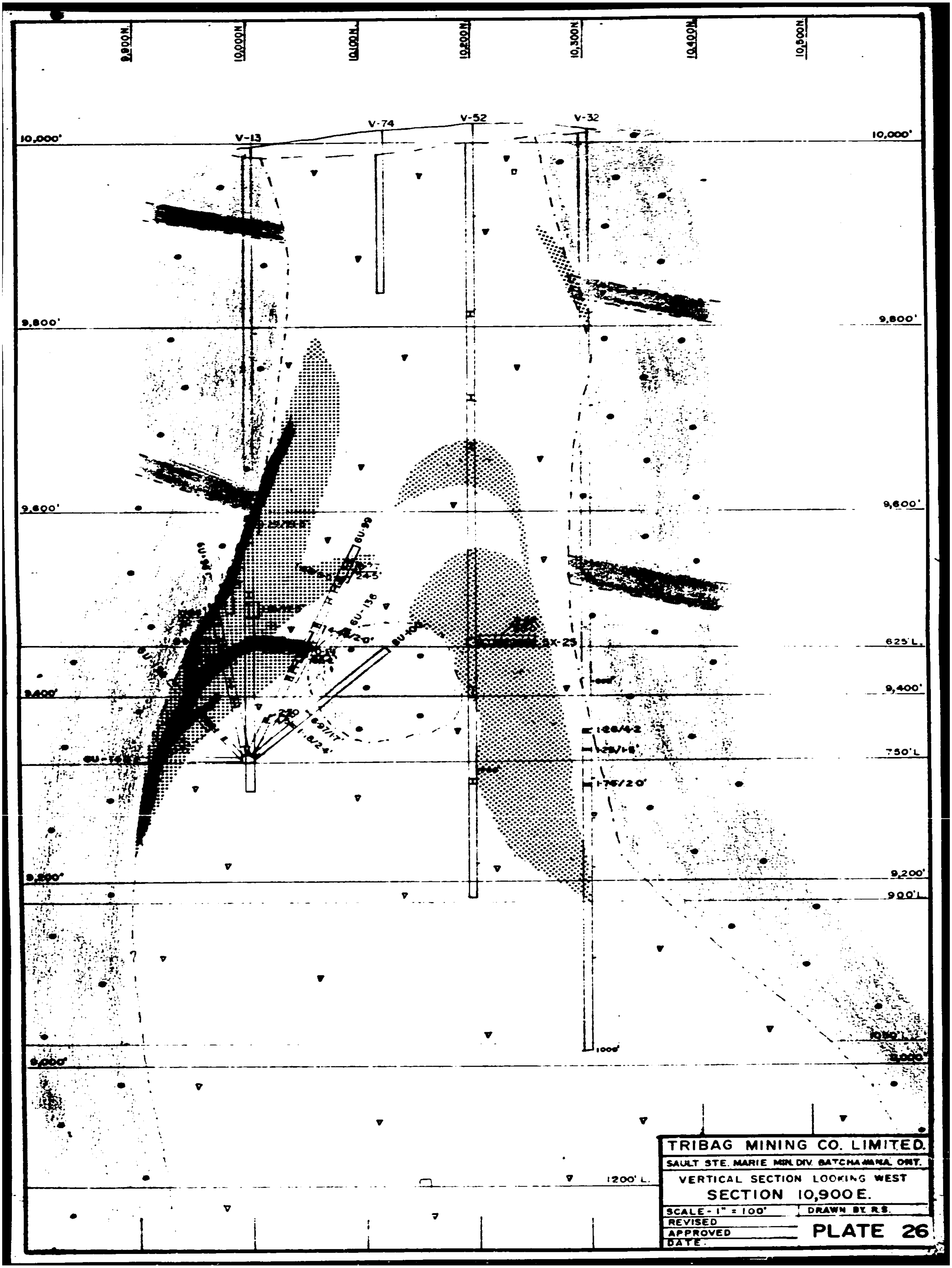

10,000N
10,100N
10,200N
10,300N
10,400N
10,500N
10,600N
10,700N
V-24
V-16
V-10
V-12
V-73
V-64
10,000'
9,800'
9,600'
9,400'
9,200'
9,000'
225 L.
375 L.
625 L.
750 L.
900 L.
1050 L.
5U-11
6U-109
6U-108
6U-122
6U-6
7X-2
8U-16
8U-18
8U-19
6X-18
TRIBAG MINING CO. LIMITED
SAULT STE. MARIE MIN. DIV. BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,400 E.
SCALE - 1" = 100'
REVISED
APPROVED
DATE
PLATE 21


9,900 N.
10,000 N.
10,100 N.
10,200 N.
10,300 N.
10,400 N.
10,500 N.
10,600 N.
10,000 N.
V-56
V-49
V-38
V-6
V-8
V-39
N-8
V-55
10,000 N.
225' L.
9,800'
9,800'
8U-4
375' L.
9,600'
9,600'
5-U-46
5-U-44
0.65
90.0
3-04/5-7'
5U-10
9,400'
9,400'
6X-66
6X-4
6X-67
780' L.
7U-9
9,200'
9,200'
7U-5
900' L.
7U-6
8U-8
1050' L.
9,000'
9,000'
TRIBAG MINING CO LIMITED
SAULT STE MARIE MIN. DIV - BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,500 E.
SCALE - 1" = 100'
DRAWN BY R.S.
REVISED
APPROVED
DATE
PLATE 22


9,900 N.
10,000 N.
10,100 N.
10,200 N.
10,300 N.
10,400 N.
10,500 N.
10,600 N.
10,000'
V-46
V-5
8X-2V-1
N-7
8X-1,V-3
N-1
V-47
N-6
V-51
N-21
225'L
9,800'
3U-27
3U-5
375'L
9,600'
625'L
9,400'
6X-37
6X-24
6X-7B
750'L
9,200'
900'L
1060'L
9,000'
9X-8
9X-10
1.75
33.8'
4.95/1.0'
0.72/12.4'
1.16
24.5'
0.80
13.0'
0.98
10.0'
0.84
40.0'
3U-22
3U-28
3U-25
1.18/8.5'
TRIBAG MINING CO. LIMITED
SAULT STE. MARIE MIN. DIV - BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,600 E
SCALE - 1" = 100'
DRAWN BY R.S.
REVISED
APPROVED
DATE
PLATE 23


9,900 N.
10,000 N.
10,100 N.
10,200 N.
10,300 N.
10,400 N.
10,500 N.
10,600 N.
10,000'
9,800'
9,600'
9,400'
9,200'
9,000'
225 L.
375 L.
625 L.
780 L.
V-53
V-7
V-4
V-2
V-67
3U-13
3U-14
3U-11
3U-15
3U-2
3U-7
3U-10
6U-11
6X-39
6U-13
6U-14
6X-11
6U-73
9U-16
9X-6
TRIBAG MINING CO. LIMITED
SAULT STE. MARIE MIN. DIV. - BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,700 E
SCALE: 1" = 100'
DRAWN BY
REVISED
APPROVED
DATE
PLATE 24


TRIBAG MINING CO. LIMITED
SAULT STE MARIE MIN. DIV - BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,800 E
SCALE: 1" = 100'
DRAWN BY R.S.
REVISED
APPROVED
DATE
PLATE 25
V-34
V-11
V-9
V-17
V-30
V-31
V-61
225 L.
375 L.
625 L.
750 L.
900' L.
1050' L.
1200' L.
800-088 X-CUT
375-800-088 RSE.
9X-4
9X-3


9,900N.
10,000N.
10,100N.
10,200N.
10,300N.
10,400N.
10,500N.
V-13
V-74
V-52
V-32
10,000'
9,800'
9,600'
9,400'
9,200'
9,000'
625'L.
750'L.
900'L.
1050'L.
1200'L.
SX-25
1000'
TRIBAG MINING CO. LIMITED.
SAULT STE. MARIE MIN. DIV. BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 10,900 E.
SCALE - 1" = 100'
DRAWN BY R.S.
REVISED
APPROVED
DATE
PLATE 26


9,900N.
10,000N.
10,100N.
10,200N.
10,300N.
10,400N.
10,500N.
V-19
V-21
V-75
V-68
10,000'
9,800'
9,600'
9,400'
9,200'
9,000'
750'L.
900'L.
1050'L.
1200'L
1.42/5.0'
2.93/5.0'
1.00/5.0'
0.55
40.0
0.66
15.0
0.66
20.0
0.64
10.0'
1.01/9.0'
0.51/10.0'
6U-90
6U-92
6U-93
0.73
14.4
0.98
42.0
0.87
13.6
6X-14
6X-13
TRIBAG MINING CO. LIMITED
SAULT STE MARIE MIN DN BATCHAWANA, ONT.
VERTICAL SECTION LOOKING WEST
SECTION 11,000E.
SCALE- 1" = 100'
DRAWN BY. R.S.
REVISED
APPROVED
DATE
PLATE 27