A SPECTROCHEMICAL STUDY OF ROCKS ASSOCIATED WITH THE SULPHIDE ORE DEPOSITS OF CHIBOUGAMAU DISTRICT, QUEBEC

by

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Chapter 1

INTRODUCTION

Purpose of the Investigation

It is well known that halos of altered rocks surround many deposits of sulphide and other ores. These halos are characterized by a mineralogical and, or, chemical composition which is different from that of the rocks farther away from the deposits. The mineralogical and chemical changes in such zones of alteration are often best expressed near the deposit, and gradually fade away with distance from the ore. It is generally conceded that these changes in the wall rocks are the result of processes which accompanied the introduction of the ore. Most geologists consider alteration halos as useful guides to ore.

This thesis is a study of the chemical changes in the wall rocks of some ore zones in the Chibougamau district of Quebec. The purpose of this investigation is to detect such chemical changes in these rocks as may be useful in narrowing the target area in searching for new ore deposits in the same district.

The Chibougamau district is well suited for an investigation of this sort. Most of the deposits are in what appears to be a single intrusive mass of anorthosite. The composition of this intrusive mass was, before the introduction of the ore, more uniform than are the host rocks in most mining districts. It should therefore be easier to detect and classify chemical changes superimposed on it. Another advantage is that numerous diamond drill holes have been bored in many parts of the anorthosite and most of the drill core is available for study. Drill cores provide excellent continuous samples of the rocks selected for analysis and the mining companies have been very cooperative in permitting the cores to be used for this purpose.

Method of Investigation

The following steps were included in the investigation:

1) Systematic sampling of fresh and altered rocks of all types near, and away from, the known ore deposits.
2) Qualitative scanning for 20 elements, using an x-ray spectrometer and an optical spectrograph.
3) Quantitative determinations on 575 samples using an optical spectrograph and an x-ray spectrometer for 13 elements which showed measureable variations in distribution that may be related to ore or structures that controlled ore emplacement.
4) Microscopic examination of 85 thin sections to identify the minerals containing any elements linked to ore, or to mineralogical assemblages peculiar to ore-bearing localities.

During two months of the summer of 1958 the writer systematically collected some 600 samples of wall rock, representing over 16,000 feet of drill core, from the Chibougamau district. The core samples were selected from massive anorthosite, sheared anorthosite, sheared and mineralized anorthosite, fresh dykes within shears, and mineralized parts of the same dykes within mineralized shears. The details of the sampling procedure and the locations of the samples are described in Chapter 4.

While at Chibougamau the writer also collected information and geological data on properties other than those sampled, and visited some of the underground workings, in order to get a general geological picture of the district.

In the spectrographic laboratory in the Department of Geological Sciences at McGill University, the writer made qualitative scans on 60 samples for 20 common elements, using an x-ray spectrometer and an optical spectrograph. The results indicated that 13 elements showed detectable variations in their distribution, using more or less standard techniques on these instruments.

The elements chosen for quantitative analysis were Si, Al, Fe, Mg, Ca, Na, K, Mn, Co, Sr, Ni, Cu, and V. The other elements, Ti, Cr, Ba, Zn, Pb, Rb, and Cs, either showed too little variation in distribution to be useful, or would have required for their analysis special and time-consuming spectrographic techniques, considering the large number of samples to be treated.

For the purpose of the present study the quantitative determination of the 13 more common elements in these rocks was considered adequate. The analytical work was carried out during the summer and autumn of 1959. The analytical techniques are described in Chapter 5.

The analytical results were plotted in histogram form to show the quantitative changes in these elements in the rock along each sampled drill hole, or a particular section of a drill hole. The plotted results are described and interpreted in Chapter 6.

For each sample length of drill core the writer collected a hand specimen considered typical of that length. From these hand specimens a total of 85 thin sections were prepared, which the writer considers representative of the different zones studied. The results of the studies on thin sections are given in Chapter 3.

Location and Access

Chibougamau is located just south of the 50th parallel, about 300 miles due north of Montreal, and 150 miles northwest of St. Felicien on Lake St. John. The present mines of the district are located along the shores of Doré Lake which lies 3 miles south of the town of Chibougamau.

Access to the Chibougamau district has improved greatly in the past decade. Prior to 1949 the area could be reached only by float, or ski-equipped aircraft, depending on the season, and by canoe routes from the Lake St. John area to the southeast, or from Senneterre to the southwest.

At present Chibougamau is linked to both Senneterre and St. Felicien by branch lines of Canadian National Railways, and by an all-weather road to St. Felicien. Work is in progress on extending the Senneterre-Bachelor Lake road to Opemiska and Chibougamau, thus providing motor access from the Noranda area of Western Quebec. Nordair, Limited, provides scheduled airline service from Montreal to Chibougamau.

History and Previous Work

Mineral occurrences in the Chibougamau district were observed in 1870 and reported by Richardson, (1872), an officer of the Geological Survey of Canada. Other early geological reports on the district are those by Low, (1885), (1892), (1895), (1906), Obalski, (1905), (1906), Dulieux, (1909), and Barlow, (1911).

Increasing interest in the mineral potential of the district resulted in the establishment of the Chibougamau Mining Commission headed by Barlow, (1911). The commission was to evaluate the economic mineral possibilities of the area and to decide whether a railroad into the district was justified. The report of the commission Barlow, (1911), suggested that building a railroad to facilitate exploration and development of the mineral resources of the area was not warranted at the time.

In the absence of rail and, or, road transportation to the district, exploration continued intermittently chiefly on the gold prospects in the vicinity of Doré Lake. Parts of the area were mapped by Mawdsley, (1927), Retty, (1930), and Mawdsley and Norman, (1935).

Between 1934 and 1936, Consolidated Chibougamau Goldfields, Limited, a subsidiary of Consolidated Mining and Smelting Company of Canada, Limited, did considerable drilling and other work on the copper-gold showings of Merrill Island and on the gold-quartz veins at Cedar Bay on Doré Lake (see Map 2). At Cedar Bay the work included a 522 foot shaft, nearly 5,000 feet of drifts and crosscuts, and about 34,000 feet of diamond drilling. Work was discontinued in late 1936 because the grade of the prospect was too low at the existing copper price, and because of transportation difficulties.

With the completion of a gravel-surfaced road from St. Felicien in 1949, exploration activity in the district accelerated. The renewed exploration and development efforts, and higher copper prices, resulted in the definition of several ore bodies in the district.

The Opemiska Copper Mine, 25 miles west of Chibougamau, came into production in December 1953. Campbell Chibougamau Mines, Limited, began production in May, 1955, from its ore body under Doré Lake, just north of Merrill Island. Merrill Island Mining Corporation, Limited, brought into production its ore body on Merrill Island in February, 1958.

Other prospects were not so fortunate at the time. Underground exploration was carried out, with different degrees of success, by New Royran Copper Mines, Limited, Copper Cliff Consolidated Mining Corporation, Quebec Chibougamau Goldfields Limited, Chibougamau Jaculet Mines Limited, and Bateman Bay Mining Company, Limited.

Ground formerly held by New Royran Copper Mines, Limited, and Copper Cliff Consolidated Mining Corporation is now held by Copper Rand Chibougamau Mines, Limited, which started production from its Eaton Bay zone on Gouin Peninsula early in 1960. Ore from the Chibougamau Jaculet Mines, Limited, shaft will be trucked to the Copper Rand mill for treatment.

Bateman Bay Mining Company, Limited, is planning production from its ore body on Gouin Peninsula in 1961. Campbell Chibougamau Mines, Limited, brought into production, early in 1958, the Cedar Bay mine, and is preparing the Henderson ore body, just offshore from Portage Island in Lake Chibougamau, for production in 1961. Campbell is also scheduling the Kokko Creek ore body for production early in 1961. Portage Island Chibougamau Mines, Limited, is carrying out an intensive exploration program on Portage Island.

Since 1950 the results of several geological investigations of the Chibougamau district have been published. Graham, et al (1953a) described mining properties and development in the area, as did Graham (1953b) and Assad (1957). Graham (1953c) described mining properties to the east of those reported in the 1953b publication.

Mapping of certain parts of the district has been carried out by Allard (1956a, 1956b), Graham (1956, 1957), Smith and Allard (1957), Smith (1953), Longley (1951), and Horscroft (1957, 1958).

Field and laboratory investigations, described in theses submitted to various universities, have been carried out in recent years by Allard (1956a), Horscroft (1957), Miller (1957), Jeffery (1959), Sutton (1959), Vollo (1959), and Raychaudhuri (1959).

From the foregoing it is evident that much geological work has been done in the district in the last decade. Undoubtedly more geological investigations of this comparatively young mining camp will be made in the future.

Acknowledgements

The writer wishes to acknowledge the kind assistance and advice, given by many persons, which made possible the completion of this study.

To Professor J.E. Gill, Chairman of the Department of Geological Sciences, at McGill University, and co-director of this thesis, is given special acknowledgement for first suggesting the project to the writer, and for enlisting the financial, physical and other cooperation of some of the mining companies of the Chibougamau district in the carrying out of the program.

The companies who participated in this project are:

Copper Rand Chibougamau Mines, Limited
Campbell Chibougamau Mines, Limited
Chibougamau Mining and Smelting Company, Incorporated
Quebec Chibougamau Goldfields, Limited

The staffs of these companies helped the writer in many ways to collect the required samples of drill core, and permitted free access to their drill logs, maps, and other data. Their financial contributions paid for the cost of supplies and some equipment used in the analytical work, as well as the cost of map drafting and printing, and the typing of the manuscript.

The writer owes a specific debt of gratitude to the following persons in the Chibougamau district:

Dr. S.E. Malouf, chief geologist of Campbell Chibougamau Mines, Limited, who took a great interest in the writers's work. Dr. Malouf kindly arranged several months accommodation and transportation for the writer at Chibougamau during the summer of 1958. He also permitted the use of crushing and grinding equipment at the assay laboratory of the mine to prepare the samples of drill core.

Dr. G.O. Allard, formerly chief geologist of Chibougamau Mining and Smelting Company, Limited, and Mr. C. Krause, geologist of this company, supplied useful information on the general geology of the area, and provided other assistance.

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Mr. G.E. Lacaille, resident engineer for Quebec Chibougamau Goldfields, Limited, helped the writer select samples of drill core from this property, and contributed useful ideas. Mr. Jean Drouin, watchman on this property, split over 4,600 feet of drill core in his spare time for the writer.

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At McGill University, Professor G.R. Webber of the Department of Geological Sciences, and also co-director of this thesis, freely offered advice and assistance that guided the writer through several crises in optical spectrographic work. Other staff members and fellow students gave advice which is duly appreciated.

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To all the people who contributed suggestions and ideas during this investigation the writer wishes again to express gratitude. However the writer alone should be held responsible for the opinions expressed in this thesis, and for any errors of omission and commission that may have entered this study.

Chapter 2

REGIONAL GEOLOGY

THE SUPERIOR GEOLOGICAL PROVINCE

The Chibougamau district lies near the eastern edge of the Superior geological province near the boundary of the Grenville geological province.

The Superior geological province is featured by a distinct east-west structural trend in the rocks (Gill, 1948). Its area includes most of the province of Ontario west and north of Lake Huron. Its eastern margin, irregular in places, trends to the northeast from Georgian Bay, passing southeast of Sudbury, Cobalt, Val d'Or, and Lake Chibougamau, to Lake Mistassini and probably farther. Along this boundary, the east-west structural trends defining the Superior province are truncated by northeast structural trends which are characteristic of the Grenville geological province.

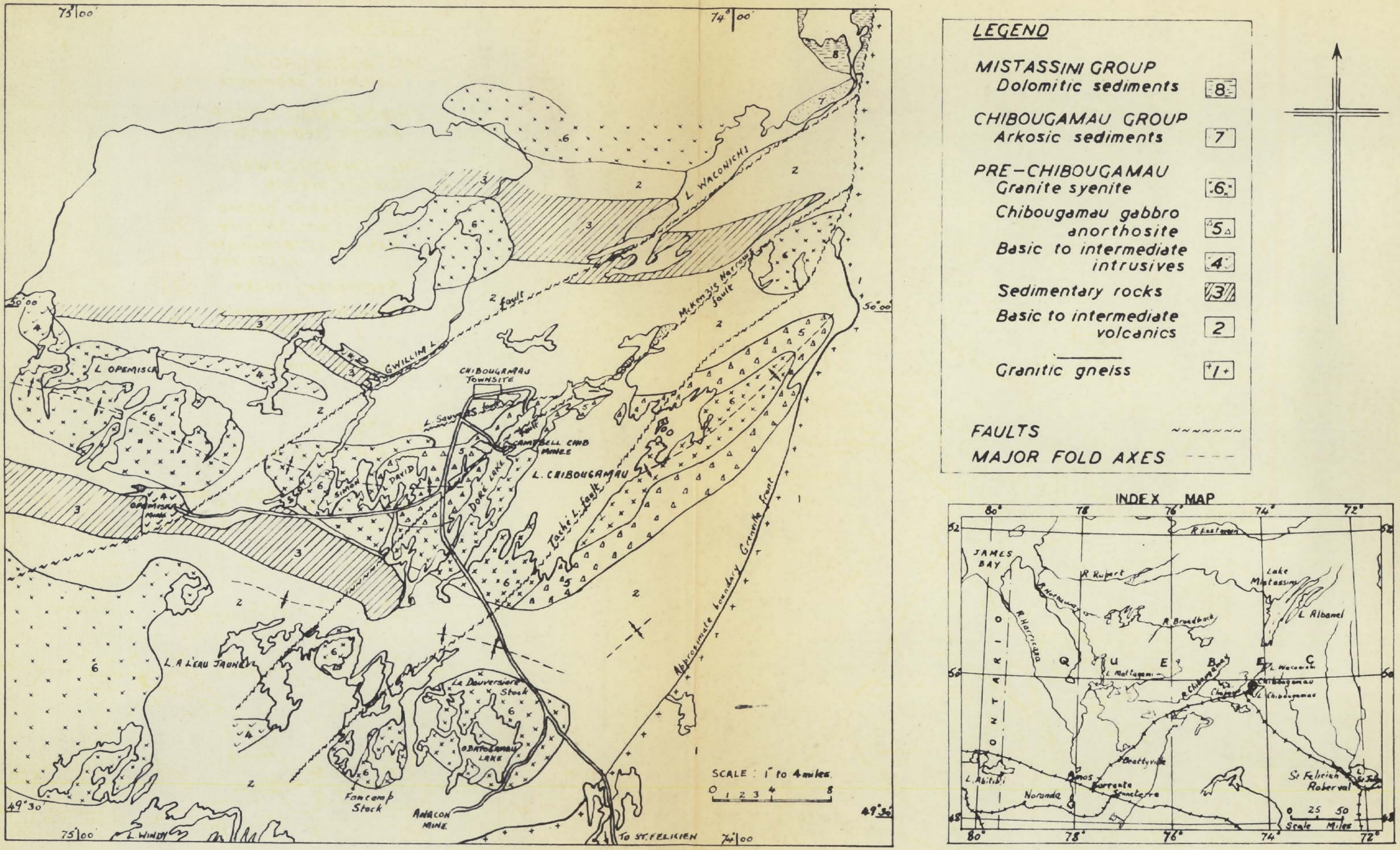
The rocks of the Superior province include an assemblage of metamorphosed and deformed sedimentary and volcanic rocks commonly called "greenstone" belts. These east-west trending belts are often separated by areas of granite or granitized rocks, and younger intrusives. Many ore deposits and mineralized areas are found at or near the contacts of these "greenstone" belts and younger intrusives.

A number of large sulphide, gold, and other deposits are found near the termination of the easterly structural trends against the Grenville province. Examples of these deposits are the Sudbury nickel-copper sulphides, Cobalt silver-cobalt ores, Malartic-Val d'Or copper and gold ores, and the Chibougamau copper-gold ores.

The Geology of the Chibougamau Area

The earliest definitive work on the geology of the Chibougamau district was done by Mawdsley and Norman (1935). Since then, mapping of parts of the area by Allard (1956a, 1956b), Horscroft (1957), Graham (1956, 1957), and Smith and Allard (1957), and detailed mine geological mapping has furnished much new information, although not changing the basic interpretation of Mawdsley and Norman. In discussing the general geology of the area, the writer has drawn freely upon these and other related reports.

The oldest rocks in the Chibougamau district are an early Precambrian assemblage of metamorphosed and deformed sediments and volcanics, which have, in general, an easterly strike (see Table I, page 12). Intrusive into these are masses of anorthosite, serpentine, pyroxenite, gabbro, diorite, granite, and related rocks. Dykes having a composition ranging from pyroxenite to quartz porphyry cut all older rocks. Relatively undisturbed sedimentary rocks - conglomerate, arkose, quartzite, dolomitic limestone, and shale locally cover the older rocks, but not necessarily in the order given. Strong northeast regional faulting is prevalent in the area.



MAP I, GENERAL GEOLOGY, CHIBOUGAMAU DISTRICT

TABLE I

TABLE OF FORMATIONS

(adapted from Graham, 1957, p.425)

Cenozoic	Recent and Pleistocene	clay, sand, gravel, morainic material, peat
Precambrian		Diabase dykes
	Mistassini Group	Dolomitic limestone, sandstone and shale.
	Chibougamau Group	Conglomerate, arkose, greywacke, quartzite.
		Dykes of grandiorite, gabbro, feldspar and quartz-feldspar porphyry; granite; diorite and related rocks; anorthosite and associated gabbro and serpentine; serpentine, pyroxenite, gabbro and diorite.
		Greywacke, arkose, conglomerate, quartzite and chert.
		Feldspathic sediments, minor slate and argillite, tuff, agglomerate, acid to basic lavas; related diorite and gabbro.

The term Mistassini group and Chibougamau group are preferred to Mistassini series and Chibougamau series, (Bergeron, 1957, p.126).

Volcanic Rocks

Rocks of volcanic origin are present in an east-west belt passing through McKenzie and Roy townships north of Doré Lake. This volcanic assemblage includes metamorphosed lavas and pyroclastics. In general the primary structures and textures are well preserved although the original minerals have undergone almost complete alteration.

The volcanic rocks are either vertical or dip steeply to the north as part of the south limb of a syncline. Along the suspected axis of this syncline, two miles north of Chibougamau, there occurs an east-west belt of serpentine and peridotite intrusives. The thickness of the volcanic rocks in McKenzie township has been estimated by Allard (1956a, p. 18) at between 14,000 and 16,000 feet.

The lavas were originally chiefly basalt and andesite. These are interlayered with thin lenticular beds of agglomerate and tuff. Layers of well-preserved pillows, present in both the andesite and the basalt, are often separated by thin layers of massive, fine-grained lava. Flow structures, amygdules, and fragmental and scoriaceous flow tops are well preserved.

The Doré Lake Complex

The Doré Lake Complex consists of metamorphosed anorthosite, gabbroic anorthosite, anorthositic gabbro, gabbro, and minor occurrences of amphibole schist, pyroxenite-magnetite-ilmenite rock, and chlorite-serpentine-talc rock.

The northern margin of the Dore Lake Complex is, in some places, in fault contact with the volcanics, in other places, in intrusive contact. In the Doré Lake area the complex forms a belt two to four miles wide, extending east across the north end of Lake Chibougamau. Allard (1956a, p. 117) describes it as a stratiform sheet, over 10,000 feet thick, arched up by the intrusion of granite which underlies Lake Chibougamau.

The rocks comprising this basic assemblage were named the Doré Lake group by Graham (1956, p.4) and were called the Doré Lake Complex by Allard (1956a, and 1956b). It is well described by Allard who compares it with the Bushveldt Complex, the Stillwater Complex and the Duluth gabbro. The Chibougamau occurrence has many features in common with these well-described stratiform rocks so that the term Doré Lake Complex is more applicable than Doré Lake group.

According to Allard (1956a, p.117) the sequence of rocks from the top to the base of the Doré Lake Complex is:

Acid Rock	Granophyre Hornblende diorite
Upper Zone	Diorite Magnetite-rich diorite Meta-gabbro Porphyritic meta-gabbro
Central Zone	Titaniferous ilmenite-magnetite Meta-pyroxenite and magnetite Meta-pyroxenite Anorthositic meta-gabbro
Lower Zone	Meta-pyroxenite Gabbroic meta-anorthosite Meta-anorthosite Anorthosite

The rocks of the Lower Zone in general, and the meta-anorthosite in particular, are host to all the copper-gold deposits so far discovered in the area. They will be described and discussed in detail in Chapter 3.

In the Doré Lake area, the rocks of the Doré Lake Complex dip steeply to the north, or are vertical. Southeast of Lake Chibougamau the strata of the complex dip steeply to the southeast. Thus the Doré Lake Complex has the structure of an anticline, the central part of which is occupied by granite.

Granite

A large body of grey granite intrudes the Doré Lake Complex in and near the centre of Lake Chibougamau. Smaller bodies of similar granite are found near the north shore of Lake David (4 miles west of Doré Lake) and in areas south and west of Lake Chibougamau. These granites, dykes, and associated masses were termed the Lake David group by Graham (1956, p.3).

The granite observed by the writer on Gouin Peninsula south of Merrill Island and also near the southwest end of Doré Lake is generally grey but in places has pink or greenish tinges. It is fine to medium grained. The feldspar is commonly albite or albite-oligoclase. No orthoclase is visible.

A spectrochemical analysis of this granite by the writer from Gouin Peninsula, south of Merrill Island, gave the following results:

TABLE II

SiO_2	69.5 %
Al_2O_3	14.40
Fe_2O_3	0.86
MgO	0.22
CaO	2.70
MnO	0.055
Na_2O	8.30
K_2O	1.80
Sr	25 ppm
V	under 15 ppm
Cu	under 10 ppm
Co	not detected
Ni	not detected

It is evident that in this area the granite is soda-rich. It is significant that here, soda-rich granite is in such close proximity to ore deposits in this area, as it is in other localities in northwestern Quebec and Ontario.

Dykes

Dykes of diorite, quartz porphyry, feldspar porphyry, quartz-feldspar porphyry, granodiorite, and gabbro are found intrusive into both the Doré Lake Complex and the granite. They are commonly reported in fault and shear zones but this is because more detailed attention is given to these zones as potential ore-bearing localities, than to the massive rock.

The thicknesses of these dykes usually range from a few inches to 20 feet, rarely to 100 feet. Some of the dykes within shear zones are themselves sheared and altered, especially in and near sulphide bodies. Local geologists apply the term "grey" dykes to light coloured dykes, and "black" dykes to the dark coloured. The term "black" schist is also locally applied to sheared dark coloured dykes. Where the writer uses local terminology the words "grey" and "black" appear within quotation marks.

Most geologists familiar with the area hold the opinion that at least some of the "grey" dykes found in the shears are genetically related to the granite. The genetic relation is inferred from a spatial continuity of the dykes from the shears to the granite, and by similarities in bulk chemical composition.

Structure

Folding

The assemblage of volcanic rocks north of Doré Lake is folded into an east-west syncline. The Doré Lake Complex forms an anticlinal structure, the axis of which trends about N. 55° E. Westward, toward Opemiska, the succession, from north to south, of volcanics, basic monomineralic rocks of the Doré Lake Complex type, and granite is evident. Locally the strike of the volcanics has been changed by stock-like intrusions of granite, but regionally the east-west trend is prevalent.

Farther to the east, in McCorkill and Dollier townships, the easterly trend of the volcanics swings to the northeast as the Grenville front is approached. The anticlinal axis followed by the Dore Lake Complex and the granite also swings to the northeast in the northern part of Lake Chibougamau.

The bending of these east-west folds into general conformity with the northeast trend of the Grenville front suggests a regional movement of this part of the Grenville province to the northeast with respect to the Superior province. This suggestion is supported by the presence of several northeast-striking regional faults west of the Grenville front.

Faulting

There are three major fault sets in the district whose directions are:

1) Approximately northeast
2) Northwest to west
3) West

There are also minor faults trending north-south, and in other directions. These may be branches of the major faults.

In order of occurrence from east to west, the northeast trending faults are the Taché Lake fault, McKenzie Narrows fault, and the Gwillim Lake fault.

Taché Lake Fault

This fault is found at Taché Lake in the eastern part of Roy township, and extends southwest through Bag Bay into Lake Chibougamau. A large fault in the south end of Lake Chibougamau is aligned with the Taché Lake fault and may be part of it. The Taché Lake fault is reported to dip 45° to 65° to the southeast (Mawdsley and Norman, 1935, p.56).

On the east side of the fault, the northern contact between the meta-anorthosite and the volcanics is offset 6,000 to 7,000 feet to the north, with respect to the west side. Mawdsley and Norman (1935, p.56) state that upthrusting from the southeast occurred along the fault plane.

McKenzie Narrows Fault

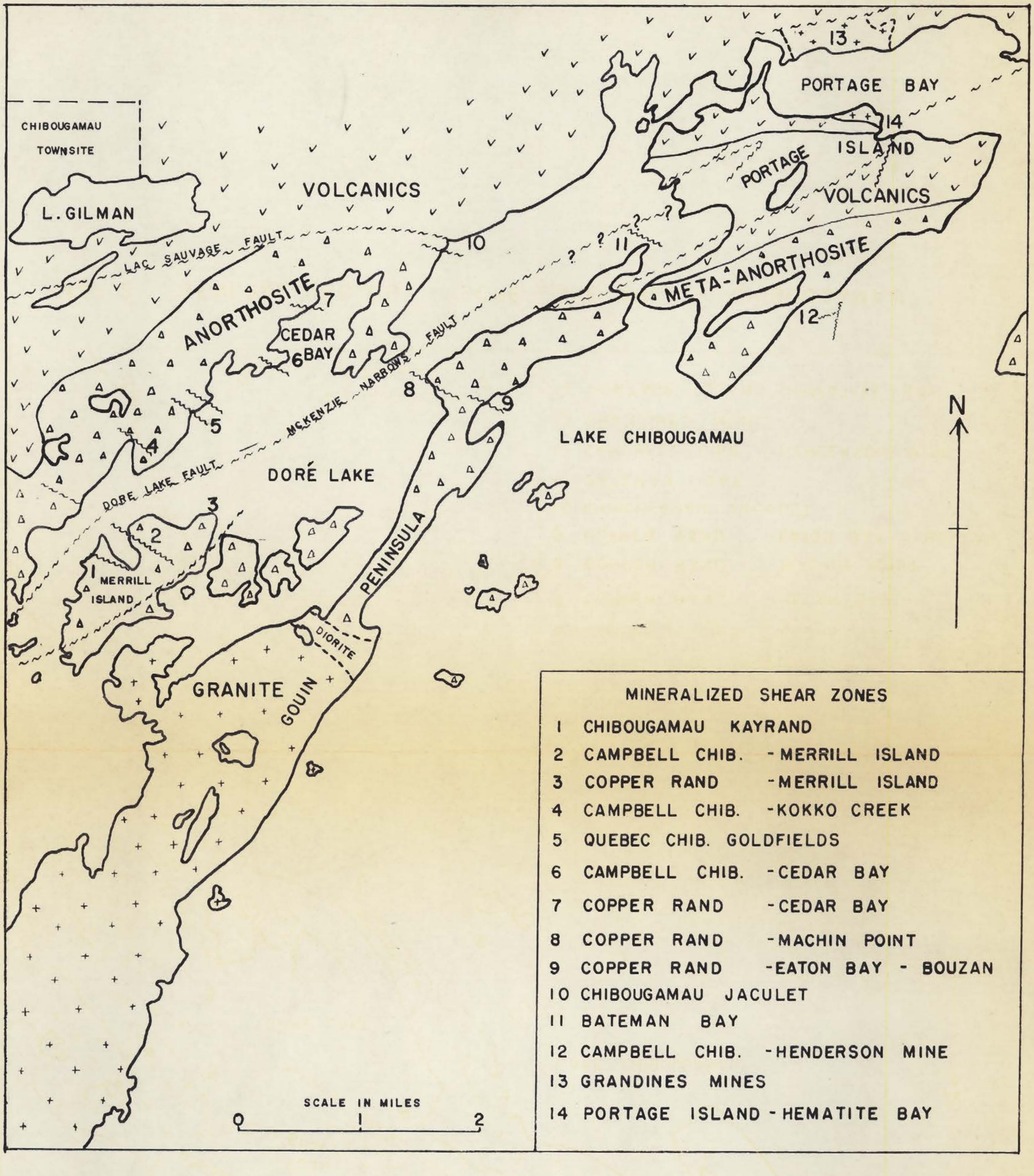
This fault is found at McKenzie Narrows, the extreme north arm of Lake Chibougamau. It cuts all the rocks, including those of the nearly horizontal Chibougamau group. The fault strikes N. 45° E. and dips steeply to the southeast. At McKenzie Narrows there is an offset of about 3,500 feet, the east side displaced to the south with respect to the west side. The direction of offset is opposite to that of the Taché Lake fault, four miles to the east.

Most geologists working in the area assume that the McKenzie Narrows fault passes southwest through Portage Island into Doré Lake. Deep drift conceals evidence of it on Portage Island. Geophysical work on Doré Lake shows the presence of a strong fault extending to the southwest, passing close to the north shore of Merrill Island and following Caché Creek to Caché Lake.

An exploration drift on the 550 foot level of the Campbell Chibougamau property north of Merrill Island (Jeffery, 1959, p.54) has intersected a shear zone from 250 to 300 feet wide, striking about N. 55° E. and dipping vertically. It is interpreted as the southwest extension of the McKenzie Narrows fault.

At Caché Creek, which drains Caché Lake into Doré Lake, Graham (1956, p.17) has mapped a fault zone 50 feet wide, striking N. 60° E. and dipping vertically. He reports a horizontal displacement of the transition zone between the meta-anorthosite and the meta-gabbro of about 3,700 feet, with the east side offset to the southwest. The amount and direction of offset here appears to be of the same order as at McKenzie Narrows. Hence it is probable that the observed segments are part of the same fault, although more information on Portage Island would be desirable.

The part of the fault passing through Doré Lake is called the Doré Lake fault by geologists in the area. Mawdsley and Norman first used the name McKenzie Narrows fault after its location. Whether a fault actually extends all the way from McKenzie Narrows to Caché Lake is uncertain. Because the writer is concerned chiefly with the Doré Lake area, the strong northeast fault passing through



MINERALIZED SHEAR ZONES

1 CHIBOUGAMAU KAYRAND
2 CAMPBELL CHIB. - MERRILL ISLAND
3 COPPER RAND - MERRILL ISLAND
4 CAMPBELL CHIB. - KOKKO CREEK
5 QUEBEC CHIB. GOLDFIELDS
6 CAMPBELL CHIB. - CEDAR BAY
7 COPPER RAND - CEDAR BAY
8 COPPER RAND - MACHIN POINT
9 COPPER RAND - EATON BAY - BOUZAN
10 CHIBOUGAMAU JACULET
11 BATEMAN BAY
12 CAMPBELL CHIB. - HENDERSON MINE
13 GRANDINES MINES
14 PORTAGE ISLAND - HEMATITE BAY

MAP 2 GENERAL GEOLOGY - DORÉ LAKE AREA - CHIBOUGAMAU.

this lake will be called the Doré Lake fault in this thesis, in conformity with local terminology.

Gwillim Lake Fault

This fault has been in part geologically, in part geophysically traced for nearly 150 miles from the east end of Lake Waconichi where it appears to merge with the Grenville front, southwest through Gwillim Lake and Bachelor Lake, and disappears beneath the sand plains near the Bell River north of Senneterre. At different places along its length it is called different names, Bachelor Lake fault, Campbell Lake fault, and so on. In this thesis it is called the Gwillim Lake fault. At Lake Waconichi it dips 75° to the southeast (Gilbert, 1951, p.9).

Other northeast trending faults of smaller magnitude are found locally. These may be branches of the larger northeast faults.

Northwest to West Shears

In the Doré Lake area there are a number of faults and shear zones whose trends range from northwest to nearly west (see Map 2). They are important economically because most of the sulphide deposits found to date in the area occur within them. Map 2 shows the distribution of the more important northwest to west shears.

The strikes of these shears range from about N. 40° W. to N. 80° W. Some dip steeply either to the southwest, or to the northeast, others are vertical. They cut across the layering in the Doré Lake Complex, but do not appear to cut the granite underlying Lake Chibougamau. The widths of these shears range from a few feet to hundreds of feet. Intense shearing is a characteristic feature of these zones. Very little brecciation is evident.

Some northwest-trending shears appear to be offset by the Doré Lake fault. Graham (1956, p.19) notes that a northwest sulphide-bearing shear on the east tip of Merrill Island has been offset by a northeast fault (parallel to the Doré Lake fault) in the channel between Merrill Island and Lefebvre Island. Except for minor pyrite, no sulphide mineralization has been found in the Doré Lake fault.

East-West Faults

The Lac Sauvage shear zone is the most important fault in the area having this direction. North of Cedar Bay it separates the Doré Lake Complex from the volcanics for a distance of about two miles and then continues in the volcanics west through Lac Sauvage into Barlow township. At its eastern end, it enters Doré Lake at the Chibougamau Jaculet property. Its re-appearance on Portage Island has not been confirmed by mapping due to heavy drift cover.

Where the Lac Sauvage fault separates the Doré Lake Complex from the volcanics, it is marked by the presence of carbonates, chiefly siderite-ankerite, with minor chlorite-sericite schist. The carbonate contains some chloritoid, also minor pyrite and chalcopyrite. This mineralogical assemblage is also common in the Chibougamau Jaculet sulphide deposit which lies in a southern branch of the Lac Sauvage fault. Within the volcanics to the west, it is essentially a strike fault marked by chlorite and sericite schists.

Minor east-west strike faults are present in the volcanics north of Portage Island and north of Lake Chibougamau. Some east-west faulting is found in meta-anorthosite at the Henderson property of Campbell Chibougamau Mines, Limited, and also on other properties.

Age Relations of the Faults

The age relations between the northeast-trending faults in the area have not been definitely established. Many northwest and some east-west faults and shears contain sulphide deposits. The northeast faults, except for minor pyrite, do not contain sulphide deposits. From this it may be inferred, but not proved, that the barren northeast faults are younger than the sulphide-bearing northwest to west faults. However the absence of ore-bearing sulphides in the northeast-trending faults could be interpreted to mean that these structures were too tight, or otherwise unfavourable, for the deposition of ore.

There are three cases found to date in the Doré Lake area of ore-bearing northwest shears displaced by northeast faults:

1) On the northeast tip of Merrill Island an ore-bearing northwest shear is offset by a northeast fault in the channel between Merrill Island and Lefebvre Island (Graham, 1956, p. 19).

2) Miller (1957, p. 79) reports a strong northeast fault cutting the northwest ore-bearing faults at the Cedar Bay mine.

3) The east end of the No. 2 ore zone at the Chibougamau Jaculet mine has been displaced about 250 feet to the south by a northeast fault, according to staff geologists.

The relations between these northeast-trending post-ore faults and the Doré Lake fault zone, except for approximate parallelism of strikes, are not known.

The distribution and proximity of the northwest to west-trending faults and shear zones to the Doré Lake fault zone suggest that they could have formed subsidiary to the Doré Lake fault. They intersect, or would intersect upon projection, the Doré Lake fault zone at angles ranging from 40° to 80°.

The Campbell-Merrill Island shear zone and the Bouzan-Royran shear zone intersect the Doré Lake fault at about 80°. This angular relation suggests that both the Campbell-Merrill Island shear zone and the Bouzan-Royran shear zone could have formed in response to a shearing couple along the Doré Lake fault. The faults whose projections would intersect the Doré Lake fault zone at angles ranging from 40° to 65° could have formed originally as tension fractures in response to the same shearing couple along the Dore Lake fault. Later movements along the Doré Lake fault zone, in a different sense and probably direction, could have imparted to the faults of tensional origin the shearing characteristics now observed.

Displacements along the Doré Lake-McKenzie Narrows fault and along the Taché Lake fault, discussed earlier, suggest that movement along these faults occurred as a response to regional stresses from the southeast. Both the Taché Lake fault and the Bachelor Lake-Gwillim Lake fault appear to merge with the Grenville front in the vicinity of Lake Waconichi. It is possible that these three faults owe their origin to movements along the western margin of the Grenville geological province.

Age determinations on granites and pegmatites in the southwestern part of the Grenville province show a range from 850 to 1,350 million years (Shillibeer and Cumming, 1956, p.56). However the age of the rocks cut by these granites and pegmatites is unknown. In addition, no age determinations are available, as far as is known, on the Grenville rocks in the Chibougamau district. Wilson et al (1956) reports an age of 2,000 ± 200 million years for a sample of galena from the Campbell Chibougamau mine. However many more age determinations should be made in the district in order to set up some framework of the relative ages between the sulphide mineralization, the Chibougamau granite, and the rocks presently included in the Grenville province in the area.

The origin of the ore-bearing northwest shears is a problem. They are found chiefly in the rocks of the Doré Lake Complex. Many are older than the granite because granitic dykes may be traced into some of the shears from the Chibougamau granite. Acid-type dykes are present in most of the northwest shears. Several possibilities arise as to the age of the northwest-trending shears:

1) Shearing occurred during the folding of the Doré Lake Complex
    - a) without the emplacement of granite
    - or
    - b) with the emplacement of granite.
2) Shearing occurred after the folding of the Doré Lake Complex
    - a) without the emplacement of granite
    - or
    - b) with the emplacement of granite.

The northwest-trending shears have strikes which range from N. 40° W. to N. 80° W. and dip either vertically, or steeply to the southwest. From the field evidence available, steep dips to the southwest are more common than vertical dips. The anticlinal axis of the Doré Lake Complex trends approximately N. 55° E. The amount of plunge to the northeast is unknown. The northwest-trending shears on the northwest limb of the anticline, if projected to the southeast, would make angles of intersection with the axis ranging from 55° to 90°. This angular relation suggests a form of cross-faulting during folding.

During the folding about the N. 55° E. axis, tension fractures could develop on the limbs of the fold nearly normal to the axis. Such zones of failure, although no longer showing tensional features, may be represented by the Campbell-Merrill Island shear, and the Bouzan-Royran shear. The tensional features of these fractures could later have been modified by shearing movements along the fault. Shear-faults making acute angles from 50° to 60° with the axis of the anticline could be produced by stretching along the axis during folding. These shear-faults may be represented by the N. 70° W. to west-trending shear zones.

Insufficient detailed work has been done to date to determine the presence or absence of cross-faulting and shearing on the southeast limb of the anticline in Lemoine and Rinfret townships.

The lack of suitable marker horizons in the meta-anorthosite makes it very difficult to determine the direction and amount of displacement in the northwest to west-trending faults and shears.

The northwest to west-trending faults and shears in the Doré Lake area may have formed then in one of two ways:

1) As tension and shear fractures subsidiary to movements along the Doré Lake fault zone later than the folding of the Doré Lake Complex.
2) As tension and shear fractures during the folding of the Doré Lake Complex into an anticline.

In either case it seems that later movement is necessary to impart shearing characteristics to the faults of tensional origin.

Chapter III

GEOLOGY OF THE ORE ZONES

The ore deposits found in the Chibougamau district occur in northwest to west-trending shear zones in the meta-anorthosite of the Doré Lake Complex. Dykes ranging in composition from quartz porphyry to gabbro occur within the shears and frequently lie adjacent to the ore. The dykes often exercise a structural control on the loci of ore deposition. The meta-anorthosite, because of its many unique features and its role as host to the shears containing ore deposits, is discussed first.

Massive Meta-Anorthosite

The meta-anorthosite in the Doré Lake area lies between the Chibougamau granite to the south and the more gabbroic facies to the north. It is found near the base of the stratiform Doré Lake Complex depicted by Allard (1956a, p.117). The meta-anorthosite grades through a transition zone, which ranges in width from a few feet to hundreds of feet, to meta-gabbro. The transition zone is also reported present on the southeast limb of the Doré Lake Complex.

The meta-anorthosite is the product of regional alteration of the anorthositic part of the Doré Lake Complex. The rock, now highly saussuritized, is composed of remnants of albite-oligoclase feldspar, abundant zoisite, clinozoisite, and epidote, with interstitial chlorite and sericite. Some magnetite and leucoxene are present locally. An isolated occurrence of fresh anorthosite has been reported by Mawdsley and Norman (1935, p.28) from Last Island in the northern part of Lake Chibougamau. Here the feldspar is labradorite (An 65-68). Allard (1956a) reported anorthosite from this vicinity having plagioclase An 78.

The feldspar grains, originally up to 2 inches in size, are almost completely replaced by zoisite and clinozoisite with only a remnant core of sodic plagioclase. The zoisite-clinozoisite units themselves are seamed with chlorite and sericite, sometimes with a little calcite.

Jeffery (1959, p.37) notes the presence of layers of coarse-grained meta-anorthosite alternating with fine-grained layers on the 550-foot level of the Campbell Mine. This layering is in general conformity with the strike and dip of the different members of the Doré Lake Complex. This suggests a segregation within the meta-anorthosite as well as between the meta-anorthosite and the other stratiform members of the Doré Lake Complex.

Several textures have been ascribed to the meta-anorthosite by geologists working in the area. "Tombstone" or "Polka-dot" meta-anorthosite is used to describe the coarse-grained rock where the zoisite-clinozoisite units are large and isolated. The term "coalescent" meta-anorthosite is applied to the rock where the zoisitized feldspar grains appear to have merged.

The meta-anorthosite has a coarse, porphyritic appearance. Large feldspar grains, partly or wholly replaced by zoisite-clinosoisite are generally white to creamy white against a green chloritic background. The zoisitized feldspar grains may be either whole or separated into smaller units by the chloritic matrix.

Whether this separation is due to cataclasis or to division by hydrothermal alteration is difficult to determine for lack of clear evidence. In the separated grains there is frequently insufficient feldspar remaining to establish the presence or absence of optical continuity between the grains. Optical continuity would suggest a division by hydrothermal solutions and replacement rather than by cataclasis.

Many feldspar grains are sub-rounded to sub-angular, suggesting attrition during crystal settling from a magma. However, hydrothermal alteration could produce a similar rounding effect on the grains.

The terms "porphyritic", "pseudo-porphyritic", "porphyroblastic", and "pseudoporphyroblastic" have been used by geologists in the area to describe the massive meta-anorthosite. The writer feels that such terminology with genetic implication is more confusing than useful and should be deleted from the description of the meta- anorthosite. For descriptive purposes the terms coarse, medium, or fine-grained, and spotted meta-anorthosite are adequate.

In thin section the multiple twinning of the plagioclase grains is often visible through the zoisite-clinozoisite in less severely altered samples. Frequently in highly altered sections the zoisite-clinozoisite shows vague extinction lamellae resembling those of plagioclase feldspar. Several instances were noted in the massive meta-anorthosite where chlorite had partly replaced zoisite-clinozoisite which had not yet completely replaced albite feldspar.

It is possible that the formation of zoisite-clinzoisite from feldspar is an intermediate step to the formation of chlorite.

The mafic minerals formerly present in the anorthosite have been replaced by chlorite. In thin sections of massive meta-anorthosite there are areas of chlorite the outlines of which resemble euhedral grains of pyroxene or amphibole. However no pyroxene or amphibole were seen in the massive rock, either megascopically or microscopically.

Small, euhedral grains of magnetite are present in chloritic areas that have replaced pyroxene or amphibole. Near such chloritic patches are also areas of leucoxene, probably a product of the breakdown of ilmenite. Very small cube-shaped grains of pyrite are infrequently seen in the chlorite matrix of the spotted meta-anorthosite.

The composition of the chlorite in the meta-anorthosite ranges from iron-rich to magnesium-rich. These two types may be distinguished optically by using the following criteria:

	Mg-rich	Fe-rich
Optic sign	positive	negative
Elongation	length fast	length slow
Pleochroism	very faint	strong
Interference colours	buff to brown	pale blue to blue

For the Chibougamau district Miller (1957) and Jeffery (1957) use the term Chlorite I for the Mg-rich variety, and Chlorite II for the Fe-rich variety.

Hey (1954) shows the relation between the iron-magnesium content of chlorites and the corresponding changes in birefringence. In the transition from magnesian chlorite to ferrian chlorite the birefringence passes through zero, as does the optic sign. A reasonably accurate measure of the birefringence is necessary to use Hey's table for the identification of the different types of chlorite. A sufficient distinction between the ferrian and magnesian varieties can be made on the basis of the optical characteristics given above.

Magnesian chlorites are more abundant than ferrian chlorites in the massive meta-anorthosite. This suggests that either the original mafics, which were completely altered to chlorite, were Mg-rich, or that magnesium was introduced during regional alteration. The writer presents evidence in Chapter VI to show that little or no magnesium was introduced during the regional alteration of the anorthosite.

Sheared Meta-Anorthosite

The sheared meta-anorthosite shows a higher degree of alteration than the massive meta-anorthosite. In general, little or no plagioclase is present in the shear zones. The zoisite-clinozoisite has been extensively altered to dark green chlorite. The common alteration products in the shears are ferrian chlorites, epidote, sericite, quartz, and carbonates. In some shears quartz is present as veins, veinlets, lenses and pods usually parallel to the schistosity.

The changes in the chemical constituents in the shears, as reflected in the mineralogy, are demonstrated and discussed in Chapter VI.

Problem of the Meta-Anorthosite

The meta-anorthosite of the Doré Lake Complex poses the following problems:

1) origin of the anorthosite.

2) processes which altered the anorthosite.

The origin of anorthosite bodies has been discussed by Daly (1933), Bowen (1917, 1928), Balk (1930), Buddington (1939), Goldschmidt (1954), Rankama and Sahama (1950), and others. Anorthosite masses in different parts of the world have many features in common, such as protoclastic textures, layering within the mass, gradations to other basic monomineralic rocks, and inclusions, or segregations, of magnetite-ilmenite. No clear-cut conclusion has been reached by authorities on anorthosite on the origin of these rock bodies and their mode of emplacement. There is some agreement of opinion that anorthosite masses are formed by differentiation from a gabbroic magma. However the mechanism of differentiation is still subject to debate.

The Chibougamau anorthosite has been steeply folded, and regionally altered to the greenschist-epidote facies. The feldspar, where present, is now albite-oligoclase. In places the feldspar has been completely replaced by zoisite-clinozoisite. Zoisite and clinozoisite-epidote minerals are abundant, and some sericite is present in the feldspars. The original mafics such as pyroxene and olivine have been completely converted to chlorite. Ilmenite has been altered to leucoxene.

During the alteration of calcic plagioclase to albite-oligoclase, the excess calcium and aluminum was taken up by the zoisite-clinozoisite minerals. The potash necessary for the formation of sericite was probably derived from the calcic feldspars. Little or no introduction of cations is necessary to explain the formation of the new minerals. However the water required for the zoisite-clinozoisite minerals and for the chlorites is another problem.

According to Daly (1933, p.18) anorthosite contains 0.75% water. On the average, the meta-anorthosite at Doré Lake contains about 75% zoisite-clinozoisite, and 20% chlorite. According to Ford (1932, pp. 621, 623), the zoisite-clinozoisite group of minerals contains about 2% water, and (p. 671) clinochlore (chlorite) contains 13% water. Assuming that the chlorite in the meta-anorthosite contains 10% water, the chlorite alone contributes 2% to the present water content of the rock; the zoisite-clinozoisite contributes another 1.5%. These rough calculations indicate that the water content of the meta-anorthosite is in the order of 3.5%. It is evident that the initial water content of 0.75% (Daly's figure) is insufficient to meet the requirements of the chlorites and zoisite-clinozoisite, and as a consequence water must have been introduced into the rock.

The source of this water is unknown, but possibilities should include a magma younger than the anorthosite. The Chibougamau granite may represent such a source, whether its origin is magmatic or by granitization. Certainly the granite is intrusive into the anorthosite.

Dr. R.W. Boyle* of the Geological Survey of Canada has

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* Personal communication.

offered the suggestion that the Chibougamau granite represents granitized and mobilized sediments that underlay the original anorthosite. This is an interesting theory but one that remains to be tested. Nevertheless the granite, of whatever origin it may be, should not be overlooked as a source of volatiles to assist the alteration of the anorthosite, or indeed, a source of the ores in the meta-anorthosite.

COPPER RAND, EATON BAY ZONE

The ore deposits now being developed by Copper Rand Chibougamau Mines, Limited, occur in the Bouzan-Royran shear (see Maps 8, 10, 11). This shear transects Gouin Peninsula from Machin Point on Doré Lake to Eaton Bay on Lake Chibougamau, a distance of about 3,600 feet. The north end of the shear terminates against the Doré Lake fault (on geophysical and drilling evidence). To the south-east, under Lake Chibougamau, extensions or branches of the shear have been located by geophysical surveys and diamond drilling.

Four sulphide-bearing zones have been located within the shear to date: Machin No. 1 zone, Machin Hangingwall zone, Main Eaton Bay zone, and the Eaton Bay Hangingwall zone.

Structure

The Bouzan-Royran shear is about 1,200 feet wide at Machin Point and 800 feet wide at Eaton Bay. It strikes N. 70° W. and dips about 65° to the southwest. The sheared rock is meta-anorthosite. Relative movement along the shear is unknown. Dykes of a composition ranging from quartz-porphyry to gabbro occur within the sheared zone, roughly parallel to the schistosity. Little shearing is noted in the dykes.

The sulphide deposits occur as lenses up to 50 feet thick and 400 feet long mainly on the concave side of flexures in the dykes. The Main Eaton Bay zone is essentially a series of such lenses lying between the footwall gabbroic dyke and the hangingwall quartz-porphyry dyke.

Comparative lack of shearing in these dykes suggests that they were emplaced later than the main shearing, or concurrent with late stages of weak shearing. Subsequent movement along the shear planes, preceding, or concurrent with, the introduction of the ore was resisted by the dykes which behaved as struts under shear stress. As a result, some flexuring rather than shearing occurred locally along the dykes, creating openings and zones of dilation favored as channelways and loci of deposition by the ore-bearing fluids.

Mineralogy

The primary sulphides in the Main Eaton Bay zone are, in the order of abundance, pyrite, chalcopyrite, pyrrhotite, sphalerite, and galena. Chalcopyrite is the chief copper mineral although traces of native copper occur erratically in leached zones between the surface and about the 400-foot level. The gold and silver content is reportedly small, according to the staff geologists. The paragenesis of the sulphides is not clear although Sutton (1959, p.24) reports pyrite replacing pyrrhotite and suggests that most of the early iron sulphide was pyrrhotite.

The gangue minerals in the order of abundance in the Main

Eaton Bay zone are chlorite, quartz, carbonates, sericite, and talc. This assemblage is a marked contrast to the Machin Point zones where carbonates are more abundant than the other gangue minerals. Within, and adjacent to, both ore zones some actinolite and chloritoid are present.

Wall Rock Alteration

A series of holes, R-52, R-52-W, R-45, R-53, R-70, and R-72 form a section across the Bouzan-Royran shear at Eaton Bay (see Map 10), and cut the southeast end of the Main Eaton Bay ore zone. The availability of core from these holes afforded a good opportunity for study of the alteration minerals present on both sides of the ore zone, as well as of the chemical changes in these rocks. The chemical changes are described and discussed in Chapter VI.

The sequence of alteration minerals occurring in the shear outwards from the ore, according to microscopic identification is:

1) Actinolite, ferrian chlorites, quartz, siderite and very little chloritoid and epidote.

2) Ferrian chlorites, quartz, siderite, sericite; minor magnesian chlorites, and epidote.

3) Sericite, quartz, magnesian chlorites; minor siderite, ferrian chlorites, zoisite, clinozoisite and epidote.

4) Magnesian chlorites, zoisite, clinozoisite; minor quartz, ferrian chlorites, sericite, and very fine-grained clay-like mineral (or minerals). This clay mineral, or minerals, needs more positive identification than that afforded by the microscope.

It must be pointed out that this sequence is gradational and as the abundance of one mineral decreases, the abundance of another increases. The sequence of alteration minerals is in fair agreement with the chemical variation diagrams shown and discussed in Chapter VI.

QUEBEC CHIBOUGAMAU GOLDFIELDS, LIMITED

The main property of Quebec Chibougamau Goldfields, Limited is located on the north shore of Doré Lake, due north of Merrill Island, (see Map 2). Several sulphide-bearing shear zones occur near the shore, three of which have been designated the "A", "B", and "H" zones (see Map 3).

Mine development has been limited to the "A" zone on which an 858-foot shaft has been sunk and lateral work carried out on the 200, 350, 500, 650, and 800-foot levels. According to a staff report, about 800,000 tons of ore material grading 1.4% copper has been outlined between the 200 and 650-foot levels. About half this tonnage is reported to grade about 2.2% copper. The mine has been dormant since December 1957.

Structure

The sulphide-bearing shears occur in the meta-anorthosite. They strike about N.75°W. and dip either vertically, or steeply to the south. Their widths range up to 200 feet. Fewer "grey" dykes or "black" dykes have been observed in these shears than on other properties in the district. This is probably because less detailed geological work has been done on the property than elsewhere.

In the "A" zone, where all the mine development was done, the ore occurs as an eastward-plunging lens between slightly sheared meta-anorthosite on the north, and what is called "Black Schist" on the south. Small pockets of massive and disseminated sulphides occur on the concave side of flexures in the "Black Schist" both east and west of the main body of sulphides.

"Black Schist" is the name given by the mine staff to the occurrence of black, dense, fine-grained, highly schistose rock. It serves as a descriptive term only. The "Black Schist" occupies the greater part of the "A" shear zone; slightly sheared meta-anorthosite occupies the remainder. The width of the "Black Schist" ranges from a few feet up to 200 feet and follows a sinuous course from west to east. The ore body pinches out between the "Black Schist" and the meta-anorthosite between the 650 and 800-foot levels.

The close structural association between the "Black Schist" and the more massive sulphide lenses merits more detailed attention than has, in the writer's opinion, been given to it.

According to the writer's spectrochemical analyses of different rocks on the property, the unmineralized parts of the "Black Schist" have almost the same composition as the massive unsheared meta-anorthosite, with the exception of Fe_2O_3, Na_2O, K_2O, and MnO, (Table III).

Table III

	Q-118	Q-171
SiO_2	46.25%	47.80%
Al_2O_3	18.45	18.75
Fe_2O_3	7.30	10.15
MgO	3.90	3.60
CaO	10.55	11.20
MnO	0.08	0.23
Na_2O	3.65	2.40
K_2O	0.28	1.30
Ni	145 ppm	95 ppm
Co	95	75
Cu	115	100
V	45	20
Sr	40	25

Q-118 - sample of massive meta-anorthosite from D.D.H. Q-190.

Q-171 - sample of unmineralized "Black Schist" on the 800-foot level.

A comparison of composition of unmineralized "Black Schist" and massive meta-anorthosite shows almost the same silica, alumina, magnesia, and lime content. The schistose material is higher in iron, manganese, potash than the massive meta-anorthosite, and slightly lower in soda, nickel, cobalt, copper, vanadium, and strontium. It is probable that some metasomatic effects occurred during, or later than, the shearing. These changes also could have been caused by slight hydrothermal effects preceding or accompanying the introduction of ore nearby.

The writer found no evidence, either megascopic or microscopic, to suggest that the "Black Schist" is a separate rock unit, such as a highly sheared dyke. On the contrary, the compositional and structural relations between the "Black Schist" and the meta-anorthosite indicate a common origin for the two. The writer concludes that the "Black Schist" is a highly schistose part of the meta-anorthosite, and represents a major shear which trends N.75°W. The dark color of the schist is due chiefly to the chlorite which has been enriched in iron and probably manganese.

Mineralogy

The primary sulphides in the sulphide deposits are, in the order of abundance, pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. Some magnetite is also present. The gold and silver content is unknown.

The gangue minerals, in disseminated sulphides and adjacent to massive sulphides, in the order of abundance are quartz, carbonates, chlorite, and sericite. Within the massive sulphides some actinolite and chloritoid are found closely associated with the carbonates. The carbonates are generally rich in iron and manganese.

Wall Rock Alteration

The assemblage of alteration minerals near the "A" zone is similar to that of other sulphide deposits in the area.

A roughly tabular body of coarse-grained siderite, ranging in thickness from a few inches to 10 feet, lies between the main body of massive sulphide and the "Black Schist". The siderite contains some ferrian chlorite, sericite, chloritoid, quartz, and calcite, as well as about 5% of sulphides, chiefly pyrite with traces of sphalerite and chalcopyrite.

The siderite-chlorite-sericite assemblage shows good schistosity. Some quartz occurs as lenticular, fine-grained aggregates parallel to the schistosity. Coarser-grained quartz and calcite form veinlets that cut the schistosity. Chloritoid occurs as stubby blades and rosettes, many of which cut across the schistosity of the siderite, chlorite and sericite. Some of the chloritoid grains have fractures which are filled with fresh quartz and calcite. Frequently a few small grains of pyrite and sphalerite occur along the boundary between the chloritoid and the quartz-calcite fracture filling.

The siderite, with increasing chlorite content, grades rapidly into the "Black Schist". The schist consists of about 75% dark green to black chlorite, 10% fine-grained quartz, 10% fine-grained carbonates and about 5% sericite and talc. A few grains of pyrite are also present. The "Black Schist" grades to the south into slightly sheared meta-anorthosite containing less black chlorite and more pale green chlorite, clinozoisite, zoisite, epidote, and sericite.

On the north, or footwall side of the massive sulphides, there is a thin zone, up to 5 feet wide, of dark chlorite in slightly sheared meta-anorthosite. Very little carbonate is present in this chlorite-rich band. The chlorite zone grades rapidly into a sericitic zone within the shear. Foliation diminishes rapidly to the north and the accompanying sericitic alteration grades into the more or less normal assemblage of zoisitized feldspar, clinozoisite, and chlorite, - characteristic of the massive meta-anorthosite.

The sequence of events associated with the alteration of the wall rock appear to have been:

1) Intense shearing along a zone now marked by the "Black Schist", siderite, and sulphides.

2) Introduction of iron, potash, lime, water, and carbon dioxide to form the chlorite, sericite, and siderite zones within the shear.

3) Formation of chloritoid and actinolite in the siderite. Recurrent movements of small magnitude which fractured the chloritoid and actinolite.

4) Introduction of the sulphide minerals, probably preceded or accompanied by quartz and calcite formation in the fractured chloritoid. The sulphides replaced some of the siderite and chlorite zones.

Events 2 to 4 inclusive may have been part of a continuous process which culminated in the emplacement of the sulphide minerals.

CAMPBELL CHIBOUGAMAU MINES, LIMITED

The main ore body is located within the Campbell Chibougamau-Merrill Island shear which trends about N. 70° W. from Merrill Island beneath Dore Lake. The main Campbell ore body occurs beneath the lake. Jeffery (1959) and Raychaudhuri (1959) have done detailed work on the structure, lithology, mineralogy, paragenesis, and wall rock alteration of the Campbell ore bodies. Therefore the writer does not propose to treat in detail these features of the ore body.

Structure

The ore-bearing Campbell Chibougamau-Merrill Island shear occurs in meta-anorthosite, strikes about N. 70° W. and dips steeply to the south. The shear is about 900 feet thick at the surface and narrows gradually with depth. It pinches and swells with depth and locally steep dips to the northeast may be observed in the schistosity. Narrower shears occur subparallel to both the hanging wall and footwall of the main shear.

Dykes are a common feature of the ore-bearing shear zone. They are generally acidic types - granite, feldspar porphyry, quartz-feldspar porphyry, and diorite, locally termed "grey" dykes. Their attitudes are parallel to subparallel with the schistosity of the shear. Between the 400-foot level and the 850-foot level, the main ore zone lies on the footwall side of a quartz-feldspar porphyry dyke. On other levels dykes of the "grey" type also occur, near the ore, or at the boundaries of the ore.

Mineralogy

The sulphides present in the order of decreasing abundance are pyrrhotite, chalcopyrite, pyrite, sphalerite. Some gold, silver, nickel, and cobalt are present in the sulphides. The paragenetic sequence of the ore minerals as suggested by Jeffery (1959, p. 155) is pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, cubanite, valleriite, gold, and tetradymite.

Hawley and Nichol (1959) in a study of the distribution of selenium in sulphides, found that the selenium content of pyrrhotite increased from 40 ppm on the 448-foot level to 66 ppm on the 1,000-foot and 1,150-foot levels.

Malouf and Hinse (1957, p. 448), Jeffery (1959, p. 155) and Raychaudhuri (1959) are of the opinion that the ore body is of a replacement type, emplaced by hydrothermal solutions. The presence of actinolite at the boundaries of the ore suggests an upper limit of 500°C for the temperature of the ore bearing solutions. This is the highest temperature generally accepted for the amphibolite facies.

Wall Rock Alteration

Jeffery (1959), Raychaudhuri (1959), and the staff geologists at the Campbell Mine agree that there is more alteration of the wall rocks along the strike of the shear beyond the ends of the ore body than across the shear into the massive meta- anorthosite. This may be explained by greater permeability to fluids parallel to the schistosity than across.

According to Jeffery (1959) the ore body is enveloped by a zone rich in ferrian chlorite which extends for several hundred feet beyond the ends of the ore body within the shear. Some actinolite and chloritoid are present in the chloritic gangue material in the ore. Fine-grained quartz, sericite, and calcite are present in the chloritized wall rock. In addition, quartz and calcite stringers cut the schistosity of the wall rocks near the ore. There is a tendency for ferrian chlorite to decrease in abundance relative to sericite and magnesian chlorite across the schistose wall rocks into the massive meta-anorthosite.

CEDAR BAY MINE

The ore bodies occur in northwest to west trending shears in meta-anorthosite on the west side of Cedar Bay on Doré Lake (see Map 2).

Miller (1957) gives a detailed account of the geology and mineralogy of the sulphide deposits. Therefore it is not necessary for the writer to discuss these features in detail.

Structure

Three fault directions, all steeply dipping, or vertical, are recognized at the Cedar Bay Mine:

1) N. 55°W. (Cedar Bay Shear)

2) N.70°W. to east-west faults.

3) N.55°E. fault zone, also called a cross fault.

Miller (1957, p. 71) states that,

> "Two large lenses of sulphide mineralization are seen to occur within the main northwest shear (Cedar Bay Shear). The surface indications confirmed by observations underground are that the lenses occur at the intersection of east-west faults (strike faults) and the northwest shear (Cedar Bay Shear)."

Another feature of the Cedar Bay deposit is the presence of two dykes, one "grey" and one "black" within the northwest shear system close to the ore. The "grey" dyke (see Map 12), lies mainly on the south side of the ore occurrences, and is displaced slightly in places by east-west faulting. The displacement is right-handed.

Mineralogy

The primary sulphide minerals are pyrite, pyrrhotite, chalcopyrite, and sphalerite. Other minerals present in the sulphides are arsenopyrite and magnetite. Pyrite exceeds pyrrhotite in abundance and appears to be the earliest sulphide formed.

Miller (1957, p.93) gives the following paragenetic sequence of minerals in the Cedar Bay deposit:

Magnetite-ilmenite
Magnetite
Apatite (anomalous)
Pyrite
Arsenopyrite
Pyrrhotite
Chalcopyrite
Sphalerite.

On the basis of paragenetic sequence, and wall rock alteration, the ore deposits at Cedar Bay appear to be a hydrothermal replacement type.

Wall Rock Alteration

The minerals actinolite, sericite, ziosite, carbonates, apatite, epidote, chlorite, and feldspar represent alteration products in the wall rocks. According to Miller (1957, Table I) the following mineralogical changes occur in the wall rocks with increasing distance from the ore:

1) Fe-rich chlorite zone gives way to Mg-rich chlorite zone.
2) Decrease in sericite.
3) Decrease in actinolite.
4) Decrease in carbonates.
5) Increase in sodic feldspar.

6) Decrease in apatite.

7) Decrease in epidote.

8) Fe-rich zoisite gives way to Fe-low zoisite.

The quantitative changes in this mineralogical assemblage, except for actinolite and epidote, are gradational. Actinolite and apatite are present in the ore zone and as such are of little value as mineralogical ore indicators.

The writer was interested mainly in the chemical changes along both the "grey" and "black" dykes as the massive sulphide lenses were approached. These changes are described and discussed in Chapter VI.

CHIBOUGAMAU JACULET MINES, LIMITED

The sulphide deposits of Chibougamau Jaculet Mines, Limited occur in 3 subparallel, nearly east-west shear zones in the meta-anorthosite. From south to north these are known as the No. 1, No. 2, and No. 3 zones. The No. 2 and No. 3 are closely related, structurally and mineralcgically, to the Lac Sauvage fault zone which in this area separates the meta-anorthosite from the volcanic rocks to the north and is marked by sideritic to ankeritic carbonates.

No. 1 Zone

The shear containing the No. 1 zone strikes N.70°W. and dips 77° to the north. On the 600-foot level it has been explored along strike for 1,000 feet. In the vicinity of the sulphide deposit its width ranges from 25 feet to 50 feet. The northward dip of the shear zone is unique amongst schist zones in the Doré Lake area.

The sulphide minerals are pyrite, chalcopyrite, and traces of pyrrhotite, sphalerite, and galena. Dark chlorite constitutes over 80 per cent of the sheared wall rock. Fine-grained quartz, sericite, and carbonate, in about equal proportions, constitute the remainder.

No. 2 Zone

The No. 2 zone, about 900 feet northeast of the No. 1 zone, occurs in a carbonatized, east-west striking shear zone which separates gabbroic meta-anorthosite on the north from the ordinary meta-anorthosite on the south. It has been traced for 3,000 feet on the surface and for 1,500 feet on the 600-foot level. Its width ranges from 50 feet to 150 feet. The foliation dips 80° to the south. Thus the No. 1 and No. 2 zones dip, at 77° and 80° respectively towards each other, at least as far as the 600-foot level. Insufficient deep drilling has been done to determine whether the two merge at depth.

The rocks in the shear zone have been altered to chlorite-sericite-carbonate schist. At least two basic dykes, probably gabbroic originally, occur parallel to the schistosity. The dykes show increasing alteration from west to east. Irregularly-shaped lenses of siderite containing some pyrite and chalcopyrite are present in the shear, mainly near the basic dyke which lies along the footwall of the shear. Sulphides increase in abundance towards the east to about section 5900E where the shear appears to be displaced to the northeast by a fault. Chalcopyrite and pyrite are disseminated throughout most of the sheared zone but their abundance increases in the siderite-rich sections.

Core intersections of the basic dyke along the footwall of the shear zone were sampled for spectrochemical analysis on both the 300-foot and 600-foot levels for a distance of 1,000 feet (Maps 15 and 16).

Thin sections of this dyke show increasing alteration from west to east, that is, towards the sulphide-rich sections of siderite (Maps 15 and 16).

The fresher part of the dyke is composed of about 80% dark chlorite, 10% fine-grained quartz, and about 10% sericite and carbonate. This assemblage shows good schistosity indicating that some shearing occurred within the dyke. The alteration towards the sulphide-bearing siderite lenses is expressed by an increase in carbonate and a decrease in chlorite. At the contact with the lenses of siderite, the dyke consists of about 60% carbonate, 25% chlorite, and 15% quartz and sericite. The carbonatized sections of the dyke are also very schistose.

Chloritoid is present as blades and rosettes in the carbonatized sections of the dyke, as well as in the adjacent siderite. The blades and rosettes of chloritoid in the dyke transgress the schistosity. This indicates that the chloritoid formed later than the schistosity. However a few chloritoid blades and rosettes are fractured, generally parallel to the schistosity. These cracks are filled with clear, fine-grained quartz and calcite. Between the quartz-calcite filling and the chloritoid there are frequently a few blebs of pyrite and chalcopyrite.

From the structural and mineralogical relations between the foliation and the dykes and from the characteristics, abundance, and distribution of the wall rock alteration minerals, the following succession of events may be deduced for the No. 2 zone:

1) Formation of the shear.

2) Introduction of basic dykes parallel to the schistosity.

3) Recurrent movement along the shear. Shearing in the dykes probably preceded, and, in part accompanied the introduction of siderite. However, much of the siderite shows a preferred orientation that could have been inherited from the schistosity.

4) Formation of chloritoid in the siderite-rich lenses as well as in the carbonatized parts of the basic dykes.

5) Slight recurrent movement along existing shear planes that fractured the chloritoid. This movement was accompanied, or succeeded, by the introduction of the quartz-calcite gangue as well as some pyrite and chalcopyrite.

Some overlapping of these postulated events no doubt has occurred.

The results of the spectrochemical analyses are discussed in Chapter VI, but it may be noted here that the carbonate zones at Jaculet are abnormally high in manganese. Sideritized parts of the basic dyke contain 4% to 5% MnO. The ore-bearing siderite lenses, although not analysed, may be expected to have a similar, or higher, manganese content. This raises the interesting possibility of producing a manganese concentrate as a by-product if sufficient copper ore is found in this zone to warrant mining. The origin of the siderite and the high manganese content will be discussed later.

No. 3 Zone

This zone, consisting of areas of disseminated chalcopyrite and pyrite, lies in a carbonatized shear about 2,000 feet northeast of the No. 2 zone. It strikes east-west and is believed by local geologists to be part of the Lac Sauvage fault. Little exploration has been done on this zone to date.

CHIBOUGAMAU MINING AND SMELTING COMPANY, INCORPORATED

The drill holes from which core samples were selected by the writer for analysis are located in the T group of claims, held by this company, in Lake Chibougamau, about 1/2 mile southeast of Eaton Bay (see Map 8).

Winter drilling in this area intersected several northwest trending shears which had previously been located by geophysical techniques. Some of these shears are considered by the company geologists to be a continuation of the mineralized Bouzan-Royran shear system on Gouin Peninsula. The core intersections of these shears do not contain sulphides. Hence they are well-suited for chemical comparison with the Bouzan-Royran shear further to the northwest.

The massive rock in this area is meta-anorthosite composed mainly of saussuritized sodic feldpsar in a chloritic matrix. The meta-anorthosite in this area appears very similar to the massive meta-anorthosite elsewhere in the Doré Lake area.

The color of the meta-anorthosite ranges from grey to creamy white and has a mottled appearance in general. Zoisitized feldspar grains up to one inch across are a characteristic of the meta-anorthosite. These grains are often seamed and, or, separated, by pale green chlorite.

In thin sections the penetration of the zoisitized feldspar grains by chlorite is clearly evident. Less zoisitized plagioclase ranges from An 5 to An 15. Frequently the zoisite-clinozoisite and sericite are more abundant along cleavage planes and composition planes of the twins. Optically, the chlorite shows the characteristics associated with the Mg-rich varities of chlorite. Within this chlorite there are often minute grains of magnetite. Small, irregular patches of leucoxene are present also.

Within the shears the color of the meta-anorthosite has been homogenized to pale grey or pale green. Thin sections of the sheared material show, in general, about 30% sheared zoisite-clinozoisite, 40% to 50% chlorite, 10% sericite, the remainder is usually fine-grained quartz. Talc may be present in amounts ranging up to 10%. Traces of magnetite, leucoxene, and pyrite may be present also.

Summary of the Geology of the Sulphide Deposits

The sulphide deposits in the Doré Lake area have the following features in common:

1) They are found in shear zones in meta-anorthosite.

2) The ore-bearing shear zones have strikes that range from N.40°W. to due west.

3) The ore-bearing shears contain dykes mainly parallel to the schistosity, which are commonly quartz-feldspar porphyry, quartz porphyry, diorite, granite, and gabbro.

4) With few exceptions the dykes are post-shearing and pre-ore, although some overlapping between dyke intrusion and shearing has occurred locally.

5) Most of the economic sulphide deposits occur adjacent to one or more dykes.

6) The sulphide minerals are mainly pyrite, pyrrhotite, chalcopyrite, and traces of sphalerite and galena. The pyrite-pyrrhotite ratio varies from deposit to deposit.

7) The alteration minerals in the wall rocks, with variations in abundance, are similar from one deposit to another. The common alteration mineral assemblage is dark chlorite, quartz, sericite, carbonates (calcite-siderite-ankerite), with minor occurrences of chloritoid, actinolite, and talc.

Chapter 4

SAMPLING

Selection of Samples

In order to select drill core samples from a particular property, the writer first examined the geological maps, sections, drill logs, assay maps, and other data on the drilling done to that time. This was the critical part of the sampling program, the purpose of which was to collect successive samples from a rock unit that ranged from massive to sheared, and from massive to sheared and mineralized.

The core samples selected were not always accessible, but with some effort most of them could be found. The core was then thoroughly examined, and in effect re-logged. Lithological, mineralogical, structural, and other features were noted, and the core was then marked off for sampling. Each sample length of core was then split; one half was placed back in the box, the other half into a labelled sample bag or box.

The sample lengths ranged from 12 inches in highly altered and, or, mineralized rock, up to 100 feet in massive meta-anorthosite showing no hydrothermal effects. Dyke intersections were taken from contact to contact as one sample in the case of fresh dykes, or were divided into two or more samples in the case of unusually wide and mineralized dykes. Thus the entire length of core from a drill hole was sampled at intervals determined by the observed changes in the mineralogy, lithology, or structure.

Location, Distribution and Footage of Samples

I. Quebec Chibougamau Goldfields, Limited

A. Surface hole numbers: Q-118, Q-119, Q-121, Q-146, Q-190 (see Map 3)

Total footage	4,665
No. of samples	145

B. Underground hole numbers: U-3-11, U-3-13, U-3-17, U-5-5, U-5-13, U-5-16, U-5-18, U-5-24, U-6-5, U-6-12, U-6-8, U-8-4, U-8-5.

Total footage	614
No. of samples	30

II. Copper Rand Chibougamau Mines, Limited, (Eaton Bay zone)

A. Surface drill hole numbers: R-45, R-52, R-52-W, R-53, R-70, R-72. (see Maps 8, 10)

Total footage	4,349
No. of samples	157

B. Underground hole numbers: 5-R-66, 5-R-69, 5-R-87, 5-R-89, 5-R-138, 5-R-139, 5-R-140. (see Map 11)

Total footage	192
No. of samples	12

III. Chibougamau Mining and Smelting Company, Limited

Surface drill hole numbers: T-7, T-8, T-10, T-16 (see Maps 8, 9)

Total footage	3,467
No. of samples	67

IV. Cedar Bay Mine

A. Surface drill hole numbers: CS-69, CS-75, CS-82, CS-88. (see Map 17)

Total footage	856
No. of samples	21

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IV. Cedar Bay Mine (contd.)

B. Underground drill hole numbers: CU-321, CU-411, CU-243, CU-399, CU-331, CU-319, CU-358, CU-228, CU-194, CU-383.
(see Map 12)

Total footage	1,128
No. of samples	23

V. Campbell Chibougamau Mines, Limited

Underground drill hole numbers: U-510, U-371, U-379, U-698, U-950, U-575, U-715.
(see Map 14)

Total footage	656
No. of samples	10

VI. Chibougamau Jaculet Mines, Limited

Underground drill hole numbers: 3-J-1, 3-J-2, 3-J-3, 3-J-5, 3-J-7, 3-J-8, 3-J-9, 3-J-10, 3-J-11, 3-J-17, 3-J-19, 3-J-21, 3-J-22, 3-J-24, 3-J-26, 6-J-2, 6-J-4, 6-J-5, 6-J-6, 6-J-7, 6-J-9, 6-J-10, 6-J-14, 6-J-49, 6-J-50, 6-J-51, 6-J-52, 6-J-53.
(see Maps 15, 16)

Total footage	977
No. of samples	70

Crushing

The samples of split core were transferred from each of the properties to the assay laboratory of Campbell Chibougamau Mines, Limited. The manager of this company kindly permitted the writer to use the crushing and other equipment in this laboratory, when not needed for routine assay work. The equipment included a small jaw crusher, a roll crusher, and a riffle splitter for reducing the bulk of the sample.

In crushing the core samples, necessary precautions were taken to reduce contamination from the equipment which was normally used to crush sulphide samples. Before crushing a group of core samples, the equipment was cleaned with a jet of compressed air.. Then about 50 lbs. of barren drill core, available from a dump near the laboratory, was run through to remove all possible traces of sulphides from the equipment. The equipment was then again cleaned with compressed air.

The drill core was first passed through the jaw crusher set at ½ inch, then through the roll crusher set at 1/8 inch. The bulk of the sample was reduced to 4 or 5 lbs. by passing it through a riffle splitter. After crushing and splitting a sample, the equipment was cleaned with compressed air.

It is admitted that a certain amount of Fe, Mn, Ni, Co, Cr, and probably other metals, was introduced into the samples from this equipment, particularly the jaw crusher. This is practically unavoidable and it is assumed that the amount of contamination was uniform for each sample. The writer is interested, not so much in the absolute concentration of the elements sought, as in the differences in the concentration of these elements from sample to sample. Uniform contamination of the samples at this stage of comminution would, in the writer's opinion, not seriously affect the differences in concentration. Contamination may be very slight in coarse crushing where the metal parts of the equipment do not abrade against one another. In the next step, that of fine pulverization, contamination from the metal grinding plates is considered more serious.

Grinding

The final grinding of the samples was done at McGill University using a Braun-type pulverizer fitted with ceramic plates, thus avoiding contamination by alloy steel constituents. The composition of the ceramic plates is unknown but presumably they are rich in silica and alumina, and so contamination from these constituents would not seriously affect the high concentration of silica and alumina in the samples.

In order to reduce the time required for fine grinding, the 4 or 5 lb. bulk sample was passed through a riffle splitter several times to obtain a final lb. sample. This sample was then passed through the pulverizer, the plates of which were set as close as possible. Screen analysis of the product on samples selected at random showed that 80% of the material was minus 150 mesh. This size is suitable for both optical and x-ray spectrometry.

The finely-ground sample was mixed on a clean sheet of paper, coned and quartered. About 100 grams of this material was then placed in a labelled, tightly capped, plastic container and stored for spectroscopic analysis.

Between grinds, the plates were cleaned thoroughly with a brush. In addition, a handful of the next sample was run through to decontaminate the plates, which were then brushed clean. When the plates became contaminated with sulphide-bearing sample, several handfuls of clean quartz sand was run through, cleaning the ceramic plates satisfactorily.

Chapter 5

SPECTROSCOPY

Section A: Optical Emission Spectrography

Principles

In quantitative spectrochemical analysis it is assumed that the intensity of an emitted line within the source of excitation is directly proportional to the concentration of the emitting atoms. This assumption, while not strictly true, may be expressed by the relation

$$I_o = K.C.,$$

$$\text{or} \quad \log I_o = \log K + \log C,$$

where I_o is the intensity of line emission, K is a constant, and C is the concentration.

Some absorption of I_o often occurs at the outer fringes of the excitation source so that what is measured is not I_o but I. If background and self-absorption are negligible, then I_o is about equal to I. Theoretically then, a plot of log I versus log C should produce a curve of unit slope which is called the working curve. In general practice the slope of the working curve approaches unity over a considerable length but flattens out near the base due to background and also near the top due to self-absorption at higher concentrations.

Many excition sources are used for spectral line emission. Different sources are used for specific purposes such as to increase line sensitivity, atomic selectivity, and wavelength selectivity. The most common excitation source used in optical spectrography for silicate analysis is the carbon d.c. arc.

Geological Application

It is often important to have some knowledge of the abundance and distribution of major and minor constituents in rocks and ores. In addition, such knowledge may help to furnish support, or objections to theories of petrogenesis and ore-genesis. Descriptive and interpretative petrology and ore mineralogy rest on a firmer foundation if supported by a statement of the chemical composition of the material concerned.

It is generally recognized that chemical analysis of rocks is very slow and costly. Many steps are required, each tailored for a specific element. The time and cost involved, using this method, is often prohibitive for the analysis of many samples.

Spectrochemical analysis on the other hand provides a rapid and less expensive method of determining the constituents of rocks, ores, and related materials. With careful sample preparation, many elements can be determined quantitatively with reasonable accuracy. Ahrens (1954, p. 223) defines "reasonable accuracy" as ± 4-5%, or less, of the amount present. This is probably optimistically stated because most spectrographers report accuracies for the major constituents in rocks and ores in the order of 5% to 10% or more of the amount present.

In recent years many advances have been made in spectrochemical methods for the rapid quantitative analysis of rocks, ores, and related materials (Ahrens, 1954, pp. 223-232). Current papers on the subject appear in the periodicals Applied Spectroscopy, Journal of the Optical Society of America, Analytical Chemistry, Spectrochimica Acta, and others.

The methods developed by Kvalheim (1947, p. 585); Jaycox (1947, p. 162; 1957, p. 358), and Oshry, Ballard, and Schrenk (1942, p. 672) offer good starting points for evolving a procedure for determining quantitatively the major constituents Si, Al, Mg, Fe, Ca, Ti, K, Na, and Mn present in rocks. While probably no single method is satisfactory for detecting all these elements, the procedure reported by Jaycox (1947, p. 162; 1957, p. 358) was found suitable for the purpose of this investigation.

The Jaycox Method for Major Constituents

The method developed by Jaycox (1957, p. 358) was tried and adopted by the writer for the analysis of the following major constituents: Si, Al, Fe, Mg, Ca, Mn, Na, Ti, and K. For reasons given later, analysis for Ti was discontinued, and K was analysed by another method.

In the Jaycox method, the rock powder is mixed with a large amount of copper oxide (CuO), and graphite. The common ratios of sample: CuO:C used in this method are 1:9:20; 1:19:40; and 1:39:80. The writer used the 1:9:20 ratio after some preliminary runs using other ratios. The CuO serves as a buffer, diluent, and internal standard, while the graphite serves as a further diluent and increases the electrical conductivity of the silicate sample.

High concentrations of the major constituents in rock samples produce self-absorption in sensitive lines, and very high intensities in others. To reduce line intensity to measurable levels, extreme dilution is necessary. High dilution reduces selective volatilization and results in a more uniform burn, since there is only 1 part sample to 29 parts of mix.

Preparation of Samples

A large amount of CuO-graphite mix was prepared by weighing 9 parts CuO (Fisher Scientific Co. product) and 20 parts spectrographic grade graphite (United Carbon Products Co., size UCP-2-100). These constituents were mixed by grinding for 45 minutes in a mechanical agate mortar. The mix was then stored in a clean bottle.

The rock samples were previously ground to 80% minus 150 mesh in a Braun-type pulverizer equipped with ceramic plates. Ten milligrams of sample and 290 mg. of CuO-graphite mix were weighed and thoroughly mixed in a small mullite mortar. A "Wiggl-Bug" sample mixer was tried for this step but its use was discontinued when cleaning it became too time-consuming. The mullite mortar and pestle were easily cleaned in about one minute with a soft, gum eraser. The prepared samples were then stored in small plastic bottles.

Preparation of Standards

The following certified samples from the National Bureau of Standards were used in preparing the standards:

1a Argillaceous limestone

97 Flint clay

98 Plastic clay

99 Soda feldspar

69a Bauxite

88 Dolomite

102 Silica brick

104 Burned magnesite

In addition, two samples, A-53, an intrusive rock, and A-69, a meta-peridotite were used. These showed good agreement with the working curves established from the N.B.S. samples. Only a few grams of each of the standard rocks G-1 and W-1 are available at McGill University and are reserved for non-destructive analytical work. Therefore G-1 and W-1 were not used as standards in optical spectrography.

The upper limit of concentration of the major constituents in the standard samples was sufficient for the rock samples analysed, except for Fe and Mn. Only 27 samples contained more Fe or Mn than present in the standard samples. The writer extended the working curves for Fe and Mn by the addition method. This was achieved by adding manganiferous iron formation material, analysed chemically for Fe and Mn by Mr. H. Dehn at the McGill Geochemistry Laboratory, to rock samples containing 0.05% Fe_2O_3 and 0.018% MnO respectively. This method increased the concentration of Fe_2O_3 and MnO in the standards to 23.6% and 12.86% respectively (see working curves, Appendix 2). The extended working curves derived by this method showed good agreement with those made from the N.B.S. samples.

The standard samples were prepared by weighing and mixing 1 part sample and 29 parts CuO graphite mix respectively. The procedure followed was identical to that in preparing the analysis samples.

Apparatus and Operating Conditions

Spectrograph	Jarrell-Ash 3.4 metre plane grating, Ebert mount, 15,000 lines per inch, first order dispersion 5 Å per mm.
Electrodes	National Carbon Co. ST-45 3/16" graphite rod as anode, cavity 5mm deep, 3.7 mm wide. ST-40 1/8" graphite rod as cathode, mixed sample firmly packed into cavity with a glass rod.
Arc gap	5mm
Voltage	230 volts d.c. on open circuit.
Current	12 amperes
Pre-burn time	2 seconds
Total burn time	90 ± 3 seconds
Slit width	15 microns
Slit length	3mm, fishtail adjustment.
Filter	Seven step filter at slit, 4th and 5th steps used for intensity calibration at 25% and 16% transmission respectively.

Photographic Plate	Eastman-Kodak Spectrum Analysis No. 2 plate, range 2100 Å – 4800 Å. Only one plate used in plate holder, covering range from 2200 Å to 3550 Å.
Processing	3½ minutes in D-19 developer at 68° ± 3°F, 10 seconds rinse in water, 8 minutes in acid fixer with hardener, 45 minutes wash in running water.
Exposure Sequence	Samples analysed in duplicate, each on a separate plate. Samples R-5An exposed on each plate to check calibration curves, and for reproducibility.
Photometry	Jarrell-Ash Non-Recording Microphotometer. Transmission readings between 3% and 95% were used, slit width 5 microns, slit length 0.5mm. Readings taken on 4th and 5th steps for initial calibration and subsequent checks; on the 4th step only for routine samples.
Calculations	A Keuffel and Esser calculating board fitted with Seidel function paper was used to establish preliminary and final emulsion calibration curves for each element, and for converting transmission readings to intensity ratios. Concentration of an element in a sample is the

average of the concentrations in the duplicates.

Analytical Line Pairs

Element	Analytical Line Å	Internal Standard Line Å
Si	2435.159	Cu 2768.88
Al	2576.100	Cu 2768.88
Fe	2599.40	Cu 2768.88
	2756.3	Cu 2768.88
Mg	2779.30	Cu 2768.88
Mn	2575.10	Cu 2768.88
Ca	3180.516	Cu 3128.701
Na	3302.32	Cu 3128.701
Ti	3361.26	Cu 3128.701

(discontinued after 80 samples were run).

Sr	4607	none
K	4044.140	none
	4047.201	none

Heavy cyanogen band interference made it impossible to obtain satisfactory readings on these K and Sr lines. Analysis for K and Sr was done using an x-ray fluorescence technique described later.

Analysis for the Minor Elements

Analysis for the minor elements Ni, Co, Cu and V were also carried out on the JACO spectrograph.

Sample preparation.

1 part finely ground sample mixed in a mullite mortar with 3 parts United Carbon Co. UCP-2-100 graphite containing 0.1% MoO_2 as the internal standard. MoO_2 was prepared by reducing MoO_3 in a hydrogen atmosphere at 600°C.

Standards preparation.

Addition method used. To a rock sample containing only traces (less than 10ppm) of Ni, Co, V, and Cu, also no detectable Mo, there was added 0.5% Ni, 0.5% Co, 0.1% V, and 1% Cu all as "Spex Mix" oxides. This was diluted in steps by the addition of original rock sample to produce a series of decreasing concentrations for each element, from which working curves were constructed.

Apparatus	Same JACO spectrograph with the following settings:
Voltage	230 volts d.c. on open circuit
Current	10 amperes
Pre-burn time	2 seconds
Total burn time	110 ± 5 seconds
Electrodes	same type and cavity size as used for analysis of major constituents
Arc gap	5mm

Slit width	15 microns
Slit length	3mm, fishtail adjustment
Filter	seven step filter, 4th and 5th used for intensity calibration at 25% and 16% respectively.
Photographic Plate	Eastman-Kodak Spectrum Analysis No. 2 plate, range 2100 Å to 4800 Å. Only 1 plate exposed in plate holder covering range from 2300 Å to 3550 Å.
Exposure Sequence	samples analysed in duplicate, each on a separate plate. Standard sample run every 5th plate; analysis sample R-116 was run on each plate and served as a check on reproducibility.

Processing, Photometry, and Calculations same as for the major constituent runs.

Analytical Line Pairs

Element	Analytical Line Å	Internal Standard Line Å
Ni	3050.819	Mo 2816.154
Co	3044.005	Mo 2816.154
V	3185.396	Mo 2816.154
Cu (under 100ppm)	3273.962	Mo 2816.154
Cu (over 100ppm)	2824.369	Mo 2816.154

Limits of detectability with this procedure:

Ni	30 ppm
Co	30 ppm
V	15 ppm
Cu	10 ppm

<u>Cyanogen Interference</u>

In addition to line spectra emitted by atoms and ions at excitation level, some band spectra or molecular spectra are also emitted. The most common band spectra, using the carbon arc, are those of CN molecules. In a carbon arc, nitrogen from the air combines with incandescent carbon of the electrode tips, and graphite in the mixed sample, to form CN molecules which emit molecular spectra. These spectra are also called cyanogen bands.

Cyanogen bands have three main sequences in the ultra violet region of the spectrum. Each band sequence shows an increasing darkening of the photographic plate with increasing wavelength, and terminates abruptly at what is called a band head. These band heads are at 3590 Å, 3883 Å, and 4216 Å. Weaker CN bands occur in the longer wavelength regions of the spectrum.

Spectral lines of elements lying in these regions are obscured by the CN bands so that measuring the intensities of these lines is impractical. Of the elements sought by the writer, the sensitive lines K 4044, K 4047, Sr 4077, Sr 4607, Ba 4554, Cr 4254, Cr 4274, and Cr 4289 all suffered severe interference from the cyanogen bands. Heavier cyanogen interference was probably introduced by the large amount of graphite required by the Jaycox method.

The spectral range of the S.A. No.2 plates extends from 2100 Å to about 4900 Å. In practice, the writer preferred to work in the ultra violet region of the spectrum, from 2200 Å to about 3400 Å, covered adequately by one photographic plate in the plate holder. To determine the potassium content spectrographically in a spectral region free from cyanogen interference would have necessitated the use of lines K 7664 Å or K 7698 Å, both in the infra red region. This would have required the use of infra red sensitive photographic plates as well as preparing and running all the samples separately from the main sequence of determinations of the major constituents. It was then decided to determine the potassium content by x-ray fluorescence as an alternative method.

Strontium lines 4607 Å and 4077 Å also suffered CN interference to the extent where they could not be used. As a result, strontium was also determined quantitatively by x-ray fluorescence.

Cyanogen bands also interfered seriously with Ba 4554. As it was impractical to determine the Ba content by x-ray fluorescence with the equipment available, or to use a chemical method on the large number of samples, it was deleted as one of the elements sought.

The three most sensitive chromium lines in the ultra violet region, Cr 4254 Å, Cr 4274 Å, and Cr 4289 Å also suffered cyanogen interference. Cr 2835 Å would have been suitable to use in this region but it was too weak for many samples with a low Cr content. Using a higher sample to graphite ratio would have probably strengthened this line. However this would have necessitated the preparation of a mix suitable for these samples. Chromium, after some preliminary runs, was deleted from the list of elements sought.

Titanium, because it is nearly always present in anorthositic rocks, was also sought. The lines Ti 3341 Å, Ti 3349 Å, and Ti 3361 Å were tried. These lines occur in a region of background, increasing with wavelength, due to cyanogen interference. These lines gave low transmission readings in the order of 3% to 5% and hence were not too reliable. In addition the TiO_2 content on some 80 samples run at random was generally low, ranging from 0.5% to 1.5%. It is quite probable that cyanogen interference tended to equalize the transmission readings and therefore also the calculated concentrations. If the cyanogen interference could be cleared, the determinations on the TiO_2 content would be more significant. Because of the cyanogen problem, titanium was also deleted from the list of elements sought.

Methods of Eliminating Cyanogen Interference

Ahrens (1954, p. 148) points out several methods which are used to reduce or eliminate interference from cyanogen bands when the carbon arc is employed.

One method is to introduce alkali metal salt into the sample. The alkali metal reportedly gives a uniform burn, and lowers the temperature of the arc whereby the intensity of CN emission is also reduced. The disadvantages of this method are:

1) It is impossible to determine the content of that alkali metal in the sample itself.

2) Rapid volatilization of the alkali metal occurs before the other metals are burned. Unless the internal standard compensates for the unburned part of the sample, the result is apt to be erroneous.

Another method of suppressing cyanogen band interference is to arc the sample in a nitrogen-free atmosphere. This approach seems the most promising at present. Success with this method has been reported by Johnson and Norman (1943, p.119), Marks and Gardner (1947, p.370), and Smith and Wiggins (1948, p.325).

More recently, Hawley and MacDonald (1956, pp.197-223), reported satisfactory suppression of cyanogen bands using a Stallwood air-jet. With this device a concentric jet of air encloses the arc column. The air-jet lowers the arc temperature and also excludes nitrogen from the arc.

Shaw, et al, (1958, pp.197-201) used a modification of the Stallwood air-jet. The arc was enclosed by a pyrex cylinder through which a 1:1 mixture of argon:oxygen was passed at 5 litres a minute. This technique eliminated nitrogen completely from the arc.

The JACO spectrograph in the Department of Geological Sciences at McGill University was not equipped with a Stallwood air-jet when the writer was analyzing the samples.

After some preliminary runs on the samples in the 2200 Å to 4800 Å range, the writer did not use any spectral lines of wavelength greater than Na 3302.32. The spectrum in the 2200 Å - 3300 Å is relatively free of molecular spectra interference. This part of the ultra violet spectrum is satisfactory for the determination of the major, and some minor, constituents in the rocks, - Si, Al, Fe, Ca, Mg, Na, Mn, Ni, Go, V, and Gu.

Sample Loss During Arcing

There was some loss of sample during the early period of arcing, generally less than 5 seconds. The spattering was more noticeable with samples rich in hydrous and carbonate minerals, probably due to the escape of gases from these minerals at high temperatures. The writer attempted to drive off some of these volatiles by keeping loaded electrodes at red heat in a Bunsen burner for 5 minutes. This pre-heating resulted in no noticeable reduction in spattering.

The reproducibility of the analyses, as shown in Tables V and VI, indicate that the internal standard satisfactorily compensated for the sample loss.

Section B: X-Ray Emission Spectrometry

General Principles

In x-ray emission spectrometry a sample, which may be in powder, solid, or liquid form, is exposed to primary radiation from an x-ray tube. The primary radiation on the sample produces secondary radiation from the sample. The secondary x-rays, having wavelengths characteristics of the elements in the sample, are dispersed by an analyzing crystal so that the different wavelengths can be distinguished and measured. A detection unit, commonly a type of Geiger tube, is used to measure the pulse rate of the secondary X-rays. The pulse rate at the detection unit is then translated to intensity readings on a chart recorder, or expressed as counts per second on a scaling unit. In general, an increase in the concentration of an element produces an increase, not necessarily proportional, in the pulse rate of radiation from that element.

X-ray spectrometry is in many ways analogous to optical spectrography. Both techniques require an excitation source, collimation, dispersion, and recording of the intensity of the secondary radiation.

The spectral ranges covered by each method are different however. The wavelengths of x-rays used in emission spectrometry range from about 0.25 angstroms to 10 angstroms; the range most commonly used is from 0.5 Å to 2.5 Å. The spectral range used in optical spectrometry, with proper equipment, extends from about 1,000 Å to 16,000 Å, but more commonly from 2,000 Å to 8,000 Å. By comparison, visible light has a wavelength range from 4,000 Å to 7,000 Å.

Under x-ray excitation, heavy elements, with some exceptions, emit stronger radiations than do light elements, therefore their detection is easier. Elements with atomic number less than 22 (titanium) emit comparatively weak secondary radiations so that it becomes necessary to prevent their absorption by air when they pass from the sample to the detection unit. Helium, having a low absorption because of low density, is normally used to flush the x-ray path in order to increase the intensity of the detected radiations. In some laboratories (Kelly, 1959, p.693), hydrogen is used instead of helium to flush the x-ray path.

Applications in the Analysis of Rocks and Ores

X-ray emission spectrometry is now commonly used in many laboratories for the rapid quantitative analysis of rocks, ores, and related materials. The method is non-destructive to the sample, and is less costly and more rapid than ordinary chemical techniques. With careful preparation of the sample, the accuracy and precision obtained compare favorably with that of chemical methods. Current articles and references describing these applications are found in the periodicals Applied Spectroscopy, Analytical Chemistry, and the Norelco Reporter.

Determination of Potassium and Strontium

Potassium Analysis

The potassium analyses were made on a General Electric XRD-3 spectrometer with a Machlett AEG-50S tungsten target tube and a G.E. flow counter using a mixture of 90% argon and 10% methane. Flowing helium was used to flush the x-ray path at the rate of 2.5 litres per minute. The operating conditions were:

X-ray tube	50KV, 35Ma
Scaler	fixed time (10 seconds)
Geiger tube.	2200 volts

Soller slit . . . . .0.010"
Analyzing crystal . . . . . . .lithium fluoride, 200 plane
K wavelength. . . . . .K_{ka} = 3.741 Å
2θ = 136.74°

The samples ground to 80% minus 150 mesh were placed in plastic holders 1 inch in diameter and one-quarter inch deep which were then placed in the sample holder in the x-ray machine. Direct counts per second were taken on the samples without internal standardization. Background ranged from 30 to 50 counts per second.

The working curve was constructed from direct counts on the potassium content of G-1, W-1, and N.B.S. samples 98, 102, and 88. The working curve (Fig.8, Appendix 2) is considered satisfactory for the purpose of this study, that is to detect the variations rather than the absolute potassium content of the samples.

For this study, the potassium determinations were made more rapidly than would have been possible with a flame photometer. Emerson (1959) reports that potassium analyses in feldspars by x-ray fluorescence are as accurate as by flame photometry. Where a high degree of accuracy is not required but rapidity of analyses is important, the determination of potassium by x-ray fluorescence is more advantageous than by flame photometry.

Strontium Analysis

The strontium analyses were made using the x-ray spectrometer. The operating conditions for strontium differed from those for potassium in the following respects:

X-ray tube 50KV, 50Ma

Scaler . . . . fixed time (100 seconds)

No helium flow used.

Sr wavelength . . . . Sr_{ka} = 0.875 Å

2θ = 25.16°

As for potassium, direct counts were taken on the samples without internal standardization. Due to the low strontium content of the samples, a counting time of 100 seconds was used to smooth out irregularities in intensity. Background level for strontium was generally about 80 counts per second.

The working curve (Fig.12, Appendix 2) was constructed from direct counts on the known strontium content of standard samples prepared by the addition method. A finely ground sample which showed no detectable strontium by x-ray fluorescence was selected as a base. To a known weight of this sample there was added strontium chloride ($Sr\,Cl_2 \cdot 6H_2O$), dissolved in alcohol, to give it a Sr concentration of 500 ppm. This was mixed in a mechanical mortar for 30 minutes. A portion of this base was then successively diluted with the strontium-free material to give samples containing 250, 100, 50, 25 and 10 ppm Sr. Direct counts per second on these samples gave points from which the working curve was constructed.

Statistics

Accuracy

The unavailability of G-1 and W-1 for destructive analysis made it impossible to check the accuracy of Jaycox's method using these standard rock samples. However the writer obtained four samples of meta-anorthosite from the 550 level of Campbell Chibougamau Mines, Limited, Merrill Island, which had been chemically analysed in the laboratory of the Quebec Department of Mines for Jefferry (1959). The writer made eleven replicate spectrochemical runs of each of these samples. A comparison of the results of the two methods of analysis are given in Tables IV and V.

It is evident from the tabulation that the spectrochemical analyses show consistently higher SiO_2 and lower Al_2O_3 content than the chemical analyses. The spectrochemical analyses on Fe_2O_3, MgO, CaO, and K_2O, are all higher than the chemical analyses. It is interesting that in sample Z.d. 3875, no K_2O is reported by chemical analysis, whereas the writer detected 0.06% K_2O by x-ray fluorescence. On MnO and Na_2O there is no consistent difference between the results of the two analytical methods.

The certainty of the accuracy of the chemical method used at the Quebec Department of Mines laboratory is not known. In view of this, the tabulation is more of a comparison with the chemical results than a check on the accuracy of the spectrochemical results.

TABLE IV

Comparison of Analyses of 2 samples of
Meta-Anorthosite from the 550-foot Level,
Campbell Chibougamau Mines Ltd.

	Z.d. 3875			Z.d. 3876		
	I	II	III	I	II	III
SiO_2	46.69	49.80	3.11	44.74	47.08	2.24
Al_2O_3	24.29	22.48	1.81	26.60	24.39	2.21
FeO	2.86			3.60		
Fe_2O_3	2.80			2.40		
*Fe_2O_3	5.97	6.25	0.28	5.81	6.16	0.35
MgO	1.93	2.08	0.15	2.17	2.25	0.08
CaO	15.23	16.20	0.97	12.50	13.14	0.64
MnO	0.100	0.090	0.010	0.070	0.077	0.007
Na_2O	2.17	2.35	0.18	2.30	2.13	0.17
K_2O	0.00	0.06	0.06	0.46	0.49	0.03

Sample Z.d. 3875 is from D.D.H. U-66, from 175' to 198'

Sample Z.d. 3876 is from D.D.H. U-66, from 902' to 911'

Column I - Chemical Analysis by the Quebec Department of Mines Laboratory.

Column II - Spectrochemical Analysis (mean of eleven runs) by the writer at the Department of Geological Sciences, McGill University.

Column III - Difference between Col. 1 and Col. 2.

* Total iron expressed as Fe_2O_3

TABLE V

Comparison of Analyses of 2 Samples of Meta-Anorthosite from the 550 foot Level of Campbell Chibougamau Mines, Limited.

	Z.d. 3877			Z.d. 3880		
	I	II	III	I	II	III
SiO_2	42.29	45.92	3.65	44.34	48.15	3.81
Al_2O_3	25.00	22.65	2.35	24.49	22.15	2.34
FeO	3.22			4.34		
Fe_2O_3	1.96			1.37		
*Fe_2O_3	5.53	5.88	0.35	6.18	6.64	0.46
MgO	2.07	2.15	0.08	2.41	2.55	0.14
CaO	8.71	9.15	0.44	13.20	13.92	0.72
MnO	0.07	0.075	0.005	0.10	0.095	0.005
Na_2O	3.51	3.72	0.21	1.32	1.25	0.07
K_2O	1.15	1.22	0.07	0.64	0.68	0.04

Sample Z.d. 3877 is from D.D.H. U-66, from 1175' to 1180'

Sample Z.d. 3880 is from D.D.H. U-698, from 143' to 149'

Column I - Chemical analysis by Quebec Department of Mines Laboratory

Column II - Spectrochemical Analysis (mean of eleven runs) by writer at the Department of Geological Sciences, McGill University.

Column III- Difference between Col. 1 and Col. II.

* Total iron expressed as Fe_2O_3.

Precision

To check the precision of the spectrochemical technique employed for the major constituents, the writer made 30 replicate runs, on separate plates, on sample R-5An. The K_2O determinations were made by x-ray fluorescence. The results are given in Table VI. The precision appears to be of a reasonable order. The relative deviation (C) for MgO (10.80%) is higher than for most of the other constituents. The relative deviation (C) ranges from 4.58% for Al_2O_3 to 10.80% for MgO.

The precision of the spectrographic analyses for Ni, Co, V, and Cu was determined by making 37 runs on sample R-116, chiefly on separate plates, (Table VII). The precision for these minor constituents appears to be not as good as for the major constituents. The relative deviation (C) for the minor elements ranges from 8.40% for nickel to 12.40% for vanadium.

TABLE VI

Precision Data on Sample R-5An for Major Constituents

Oxide of Element	u	Sd	$S\bar{x}$	C%	E%
SiO_2	51.59	2.62	0.48	5.05	0.93
Al_2O_3	4.14	0.19	0.035	4.58	0.84
Fe_2O_3	12.20	0.65	0.12	5.33	0.98
MgO	11.05	1.19	0.22	10.80	1.97
CaO	17.35	1.12	0.20	6.45	1.15
MnO	0.252	0.022	0.004	8.74	1.58
Na_2O	1.04	0.09	0.016	8.65	1.54
K_2O	0.040	0.003	0.0005	7.50	1.37

u = arithmetic mean

n = number of determinations (30 in this case)

d = deviation from the mean, of single measurements

Sd = $\sqrt{\frac{\sum d^2}{n-1}}$ = standard deviation) for single

C = $\frac{Sd}{u}$ x 100 = % relative deviation) determinations

$S\bar{x}$ = $\frac{Sd}{\sqrt{n}}$ = standard error) for the mean

E = $\frac{S\bar{x}}{u}$ x 100 = % relative error)

TABLE VII

Precision Data on Sample R-116
for Minor Constituents

Element	u	Sd	$S\bar{x}$	C	E
Ni	75	6.3	1.03	8.40	1.37
Co	68	7.8	1.27	11.45	1.87
V	42	5.2	0.86	12.40	2.05
Cu	50	5.4	0.89	10.80	1.96

n = number of determinations (37 in this case)

u = arithmetic mean

d = deviation from the mean, of a single measurement.

Sd = $\sqrt{\frac{\sum d^2}{n-1}}$ = standard deviation) for single

C = $\frac{Sd}{u}$ x 100 = % relative deviation) determinations

$S\bar{x}$ = $\frac{Sd}{\sqrt{n}}$ = standard error) for the mean

E = $\frac{S\bar{x}}{u}$ x100 = % relative error)

Presentation of Analyses

The analytical results of the samples analyzed for both major and minor constituents are given in Appendix 1. The concentrations of the major constituents are expressed as per cent of oxides, - SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, MnO, Na_2O, and K_2O. The minor constituents Ni, Co, Cu, V, and Sr are expressed in parts per million (ppm).

It is not possible to distinguish between ferrous and ferric iron in spectrographic analysis. All the iron detected in the sample is expressed as Fe_2O_3. All the manganese detected in the samples is expressed as MnO, although some manganiferous carbonate is present in carbonate-rich shear zones.

Where there is more than one sample from a drill hole, the analyses are presented in succession from the collar to the end of the hole. Further explanations are given at the beginning of Appendix 1.

Controversy Over Ca-V Line Interference at 3185.4Å

For determining low vanadium concentrations the line at 3185.4Å has been widely used. Recently there has been an exchange of opinions on vanadium-calcium line interference at 3185.4Å between Shaw (1958b, 1959) and Scott and Swaine (1959). These investigators seem to agree that V 3185.4 coincides with a weak Ca line, and that V 3185.4 should not be used for vanadium determinations in calcium-rich samples.

The presence of a weak Ca line at 3185.4Å has been suspected for some years, (Kvalheim 1942, Harvey 1947, and others). Yet V 3185.4 has commonly been used for the determination of vanadium in rocks and ores. Ca 3185.4 is not listed in the M.I.T. Wavelength Tables.

Hawley and MacDonald (1956, p.220) have used V 3185.4 for the determination of the vanadium content of iron ores from Mesabi, Minnesota, and Steep Rock, Ontario. The vanadium content of these ores ranged from 0.003% to 0.2%, and the CaO content was 0.22%. In view of the low calcium content there was probably little if any interference from Ca 3185.4Å.

The writer used V 3185.4 in determining the vanadium content of the Chibougamau wall rocks, which often have a high CaO content. From the variation diagrams (Chapter VI) showing the changes in concentration of 13 elements in these rocks, there is little evidence to show that a high calcium content enhances the intensity of V 3185.4.

In some calcite-rich sections the vanadium content is apparently higher. In other sections where the CaO content increases to 20%, or more, the vanadium content remains at levels comparable with those samples where the CaO is in the order of 1% or so. For example, sample R-92C (Appendix 1, p. 14) contains 0.20% CaO and 30 ppm V; sample Y-25 (Appendix 1, p. 4) contains 25.0% CaO and 15 ppm V. This does not suggest enhancement of V 3185.4 by calcium. It may be that the sensitivity of Ca 3185.4 is very low and therefore does not seriously interfere with the intensity of V 3185.4.

Chapter VI

RESULTS AND INTERPRETATION

Section A: Chemical Variations in Schist Zones

General Statement

The results of the spectrochemical analyses are presented in variation diagrams and interpreted in this chapter. In these diagrams the writer has attempted to show the range of difference in the concentration of a constituent rather than the amount detected. The base of the histogram for each constituent is drawn usually just below the lowest concentration detected in a drill hole. The reader is advised to refer to the range of the scale given on the left side of each histogram when examining the diagrams.

The chemical variations detected across the Bouzan-Royran shear zone are given first and will serve as the basis of comparison with variations detected in other schist zones in the area.

Chemical Variations Across The Bouzan-Royran Shear Zone

Of the schist-zones investigated in the area, the Bouzan-Royran shear zone offers perhaps the best example of chemical variations from massive to sheared and mineralized meta-anorthosite in a single section. This section is formed by drill holes R-52, R-52-W, R-45, R-53, R-72, and R-70, shown on Maps 8 and 10. The corresponding analyses of cores from these drill holes are shown on Figures 4, 5, 6, 7, 8, and 9, and also in Appendix 1.

Chemical variations along drill holes R-52, and R-52-W through the shear zone into the massive rock are shown in Figure 5 and are discussed constituent by constituent. Drill hole R-52, shown in Figure 5, was collared in slightly sheared and brecciated meta-anorthosite, pemetrated highly schistose meta-anorthosite a section of which contains sulphides, was wedged at 450 feet and completed as R-52-W in massive meta-anorthosite.

Silica

The silica content shows first a progressive decrease in the schists, then increases to a maximum of nearly 70% in the hanging wall, about 100 feet from the sulphide zone. The silica content remains at about 48% across the sulphide zone, then decreases to about 45% in the massive meta-anorthosite.

The significant feature of the silica content in this section is that its concentration in the hanging wall of the sulphide zone is about 25% greater than in the massive meta-anorthosite.

The increased abundance of silica in the hanging wall of the sulphide zone is expressed mineralogically chiefly as fine-grained quartz dispersed through the chloritic schists. Some quartz is also found as veinlets, stringers and pods parallel to the schistosity.

Alumina

The alumina content along the drill hole remains fairly uniform at nearly 20%, decreases to about 12% at around 100 feet from the sulphides, then regains its former level of about 20% in the immediate hanging wall of the sulphide zone. Across the mineralized section it decreases to a minimum of about 8% and then regains the level of nearly 20% in the massive meta-anorthosite.

There are no significant trends in the alumina content on either side of the sulphide zone which would indicate a proximity to ore. The sharp decrease in alumina coincides with a richer sulphide section of the mineralized zone.

Lime

On the hanging wall side of the sulphide zone the distribution of the lime content is somewhat erratic and shows no conclusive trend. Local highs are probably caused by calcitic pods and stringers. However for a distance of 100 feet in the hanging wall and continuing through the sulphide zone for 50 feet into the footwall, the lime content is almost negligible and then levels off at between 12% and 15% in the massive rock. There is no significant build-up of lime on either side of the sulphide zone.

The chief feature about the distribution of the lime content is its virtual depletion throughout, and on both sides of the sulphide-bearing section. This variation of the lime content is more widespread than for any of the other constituents studied.

Magnesia

The magnesia content shows little significant change in the hanging wall except at about 100 feet from the sulphide zone where it decreases to less than 1%. Within the mineralized section the magnesia content is nearly 5%, about the same as in most of the hanging wall and the footwall. On the footwall side of the sulphide zone the magnesia content reaches a maximum of 7% in a gabbroic dyke.

The magnesia content may be related chiefly to the chlorite which is widespread throughout the schist zone as well as the massive rock.

The only distinct variation shown by magnesia is a decrease to less than 1% at a distance of 100 feet from the sulphides, in the hanging wall.

Iron

The iron content on the hanging wall side of the sulphide zone shows little variation except at about 25 feet from the sulphides where it shows a slight increase. Within the sulphide zone the equivalent Fe_2O_3 content increases to nearly 30%, and in the footwall gabbroic dyke decreases to 15%. In the massive rock, the iron content shows little variation.

In the hanging wall near the sulphides the iron content is related chiefly to the abundant dark chlorite with traces of pyrite. The mineralized section contains about 15% of sulphides, most of which is pyrite with minor chalcopyrite. Dark, ferrian chlorite is also abundant in the mineralized zone. The iron content of the gabbroic dyke is attributed to ferrian chlorite, and also traces of pyrite.

The chief feature of the distribution of the iron content is the high concentration within the mineralized section and for about 100 feet into both the hanging wall and footwall.

Soda

The main feature of the distribution of the soda content in this section is a noted depletion across most of the mineralized zone and for a distance of 25 feet into the footwall, and an increase in both the hanging wall and the footwall of the sulphides. In the hanging wall, the soda content is highest at about 75 feet from the sulphides. In the footwall, 50 feet from the sulphides, the soda content is about 5% and decreases to about 1 1/2% in the massive rock.

The minerals which may contain the increased soda content on both sides of the sulphide zone have not been identified. Paragonite, a sodic mica, may be present but it cannot be distinguished microscopically from sericite with much certainty. No albite or other sodic minerals were identified in thin sections.

Potash

The potash content of this section, while generally under 1%, shows some distinct variations. On the hanging wall it shows a decrease at about 150 feet from the sulphides, then increases again to nearly 1% for the remaining 100 feet to the sulphide zone. Across the mineralized section potash is nearly absent. In the footwall and in the massive meta-anorthosite it remains at a fairly uniform level of about 0.3%.

In thin sections an increase of sericite is noted which correlates well with the increase of potash on the hanging wall side of the sulphides.

The chief feature of the potash variation in this section is a distinct increase in the immediate hanging wall compared to a near-absence across the sulphide zone.

Manganese

The manganese content of this section shows little variation except in the hanging wall about 100 feet from the sulphides, where it increases to 4800 ppm MnO. Across the sulphide zone, little change is evident. In the footwall, for a distance of about 100 feet, the Mn content shows a slight increase, then decreases to about 300 ppm MnO in the massive rock.

The writer is unable to correlate the manganese increase in the hanging wall with any minerals, but it might be associated with some iron in the chlorite.

Strontium

Strontium is absent across most of the sulphide zone as well as for about 30 feet into the footwall. Throughout most of the hanging wall and the footwall the strontium content is fairly uniform at about 35 ppm. A slight decrease in Sr is noted across 25 feet in the hanging wall adjacent to the sulphide zone.

The depletion of strontium across most of the sulphide zone is an important feature in the variation of constituents in this section.

Vanadium

Vanadium shows few variations which may be significant in relation to the sulphide zone. Its distribution is somewhat erratic in the hanging wall, and also for 150 feet into the footwall. The gabbroic dyke in the footwall of the sulphide zone may be responsible for some increase in the vanadium content in comparison with the meta-anorthosite.

Copper

The distribution of copper across the section forms an interesting pattern. From a low of about 50 ppm in the hanging wall, the copper content increases progressively toward the sulphide zone where it reaches a maximum of 2650 ppm, and then decreases to about 50 ppm in the massive meta-anorthosite in the footwall.

The copper in the mineralized zone is present as chalcopyrite associated with pyrite. Adjacent to the mineralized section, a few blebs of chalcopyrite are scattered throughout the schists.

Cobalt

In most of the hanging wall and the footwall sections the cobalt content ranges between 75 and 100 ppm. In the hanging wall, beginning at about 200 feet from the sulphides, the cobalt values are erratic, but they increase to a maximum of 1000 ppm in the sulphide zone.

The cobalt maximum coincides with the pyrite high. This relation suggests that the cobalt may be associated with the pyrite, either as a separate mineral, or by isomorphous substitution in the pyrite.

Nickel

The nickel content ranges from 100 ppm in the hanging wall, 600 feet from the sulphides, to a maximum of 675 ppm within the sulphides, to about 150 ppm near the bottom of the drill hole. The high nickel content in the sulphides suggests an association with pyrite.

The most interesting feature of the nickel distribution is a decrease of about 25 ppm across a distance of 75 feet on both the hanging wall and the footwall sides of the sulphide zone.

Chemical Variations Across Other Schist Zones in the Area

Copper Rand Chibougamau Mines, Limited

On the northeast side of, and subparallel to, the Bouzan-Royran shear zone, there are several schist zones in which sulphides have not been found. The chemical variations across these zones are shown in Figures 8 and 9.

In the moderately-sheared meta-anorthosite shown in Figure 8 there is a general increase of lime, magnesia, soda, potash, and manganese. These increases are spatially associated with a zone of carbonate stringers within the schist. Above the zone of carbonate stringers there is a quartz-rich vein, and below, there are numerous, thin, quartz stringers parallel to the schistosity.

The meta-gabbro (Figure 9) shows slight, local shearing from 250 feet to 600 feet, and more intense shearing from 600 feet to 700 feet along the drill hole. The well-sheared section shows an increase of iron, magnesia, and copper and a decrease of alumina, soda, potash, and strontium. The variations shown by these constituents are similar to the variations shown in the Bouzan-Royran shear zone.

In the moderately-sheared part of the meta-gabbro (Figure 9) there is an increase of potash and soda, and a decrease in manganese, with little significant variation in the other constituents.

It is noted in Figure 9 that in the transition from the moderately to the well-sheared rock there is a gradational increase in iron, manganese, and magnesia, and gradational decrease in strontium, lime, alumina, and silica, and a rapid decrease in soda and potash.

Chibougamau Mining and Smelting Co., Inc.

A number of northwest-trending shear zones have been explored by diamond drilling on this property in Lake Chibougamau. Some of these shear zones and the locations of the drill cores sampled are shown on Maps 8 and 9 (in pocket). The drill holes from which the core samples were taken are T-7, T-8, T-10, and T-16, and the analyses of these cores are shown in Figures 1, 2, 3, and 4.

Well-sheared sections in the meta-anorthosite (Figure 3) show an increase of magnesia, iron, silica, soda, potash, copper, cobalt, and nickel, and a decrease of lime, alumina, and vanadium.

A slightly-sheared section shown in Figure 1 at the 200-foot mark of the drill hole, shows an increase of silica, iron, magnesia, soda, potash, nickel, and cobalt, with a very slight decrease in alumina only.

Another slightly-sheared section shown in Figure 2 near the 400-foot mark of the drill hole shows an increase of magnesia, iron, manganese, vanadium, copper, and cobalt, and a decrease of lime, alumina, soda, potash, strontium, and nickel.

Another well-sheared section (Figure 4, centred at the 700-foot mark of the drill hole) shows an increase of magnesia, iron, manganese, copper, cobalt, and nickel, with a decrease of alumina, silica, lime, soda, potash, and strontium.

In these schist zones as in the Bouzan-Royran shear zone the increase in magnesia and iron corresponds to an increase in chlorite. A few traces of pyrite in the schists may account for some of the increase in the iron content as well. The breakdown of the zoisite and clinozoisite with an accompanying decrease in the alumina and lime content is compensated by the increase in the chlorite content.

Quebec Chibougamau Goldfields, Limited.

The surface drill holes sampled - Q-190, Q-146, Q-118, Q-119, and Q-121, shown on Map 3 (in pocket) form a general section from southwest to northeast across the property. Each drill-hole intersects at least one northwest to west-trending schist zone, either poorly or moderately mineralized. Westward extensions of the "A" zone and the "B" zone are intersected at depth by drill holes Q-190, and Q-146 respectively (Map 3).

The well-sheared and/or mineralized sections of the meta-anorthosite shown at the right side of Figures 12 and 13 have the following chemical variations compared with the massive rock:

Increase of magnesia, iron, manganese, copper, cobalt, and nickel.

Decrease of silica, alumina, potash, strontium and vanadium.

The moderately-mineralized section shown in Figure 12 has a slightly higher soda and lime content than the barren part of the schist zone. The silica and potash content is higher on the hanging wall side of the mineralized section. This distribution of silica and potash is similar to that in the Bouzan-Royran shear zone.

Slightly-sheared but barren meta-anorthosite shown in Figure 12, at the 900-foot mark in Figure 13, and at the 300-foot mark in Figure 16 show the following chemical variations with respect to the massive rock:

A general increase of silica, potash, soda, iron, magnesia, and manganese.

A general decrease of strontium, vanadium, cobalt, and nickel.

In Figures 14, 15, and 16, the sheared sections in the meta-anorthosite show a characteristic increase in potash, copper, and commonly in silica, iron, and manganese with respect to the massive rock.

Summary of the Chemical Variations in Schist Zones

An attempt is made at classifying the schist zones in Table VIII on the basis of the relative variations of the constituents with increasing alteration and mineralization. This classification is inferred from the observed variations in the schist zones which have undergone different degrees of alteration, and which sometimes contain sulphide bodies. The 3-fold classification is simply a convenience and it is realized that rather than this sharp division, a gradation from slight alteration to sulphide mineralization exists. The increases or decreases of constituents in the schist zones are noted with reference to the massive rock. Further explanations are given in Appendix IV.

The writer is of the opinion that different stages of alteration in schistose meta-anorthosite may be generally identified with the following chemical and mineralogical changes:

1) Early stages of alteration in shear zones are marked chiefly by an increase of silica (silicification), potash (sericitization), iron and manganese (chloritization), and soda. There may also be a minor increase of copper, cobalt, and nickel, but these increases are not consistent.

2) More advanced stages of alteration are marked chiefly by an increase of iron and magnesia as more intense

TABLE VIII

Chemical Variations In Different Schist Zones

	Class 1	Class 2	Class 3
SiO_2	+	-?	-
Al_2O_3	-	-	-
CaO	-	-	-
MgO	-	+ ?	+ ?
Fe_2O_3	+	+	+
Na_2O	-	-	-
K_2O	+	+ ?	-
MnO	+	+	+
Sr	- ?	- ?	-
V	+ ?	+ ?	+ ?
Cu	+ ?	+	+
Co	+ ?	+	+
Ni	+ ?	+	+

Class I Shear Zone - Moderately schistose, little alteration, no mineralization.

Class 2 Shear Zone - Moderately to high schistose, increasing alteration, ± sparse sulphides.

Class 3 Shear Zone - Well-sheared and altered, contains sulphides.

+ - increase with respect to massive rock.

- - decrease with respect to massive rock.

chloritization. However the Fe-rich chlorite is frequently more abundant than the Mg-rich variety. The zones of earlier silicification and sericitization show a tendency to migrate into the walls of the shear zone. These changes are frequently accompanied by a further increase of Ni, Co, Cu, and Mn. Decreases are frequently noted in the alumina, lime, soda, and strontium content.

3) Where sulphides are present in a schist zone, there is a further increase in the Fe, Mg, Mn, Cu, Co, and Ni content. Some of the increase of iron is accounted for by the sulphides, the rest by the chlorites. Within the mineralized zone there is also a further decrease of silica, potash, alumina, soda, and lime. An increase of silica and potash is frequently noted in the hanging wall of the mineralized zone, marked by an increase of quartz and sericite. The quartz-sericite zone is overlapped by the chlorite zone which extends outward from the mineralized section. The strontium content of the mineralized section frequently decreases to nearly zero.

Where the sampling was more closely spaced, the distribution pattern of Cu, Co, and Ni is interesting. Copper shows a progressive build-up toward the mineralized section. The nickel and, to a lesser extent, cobalt content shows a slight decrease before increasing again in the mineralized section.

Section B: Chemical Variations Along Dykes

I Acidic Dykes

General Statement

The quartz-feldspar porphyry dyke at the Campbell mine (Map 14, and Figure 26); the "grey" dyke at the Cedar Bay mine (Map 12, and Figure 24); and the quartz-porphyry dyke at the Copper Rand mine (Map 11, and Figure 10) are termed acidic dykes in this section of the chapter. Parts of these dykes lie adjacent to, or approach, known ore deposits within schist zones in meta-anorthosite.

The chemical variations along the quartz-feldspar porphyry dyke on the 550-foot level of the Campbell mine, shown in Figure 26, are discussed first, and the chemical variations along the other acidic dykes are compared with it.

Quartz-Feldspar Porphyry Dyke at Campbell

The constituents which show an increase along this dyke toward the ore (Figure 26) are magnesia, copper, nickel; those showing a decrease are silica, alumina, potash, and strontium. The variations shown by cobalt, lime, iron, soda, manganese, and vanadium are inconclusive.

The potash content decreases eastward from D.D.H. U-715, reaches a minimum at U-698 and U-379, then increases in D.D.H. U-371 which is 100 feet from the ore zone. Another sample across the dyke between D.D.H. U-371 and the ore body would probably have given more conclusive trends in some of the constituents. However such a sample was unavailable.

The mineralogical changes with proximity to the ore involve chiefly a partial breakdown of the feldspars and the removal of some silica with an increase of chlorite and thin carbonate stringers. With the removal of some alumina and lime, the feldspars have become slightly more sodic. Some calcium from the plagioclase has probably gone into the formation of the carbonate stringers now present. Very little sericite is present.

"Grey" Dyke at Cedar Bay

Part of the "grey" dyke at the Cedar Bay mine (Map 12, and Figure 24) lies parallel to, and on the south side of, a series of sulphide deposits.

In the section of the dyke parallel to the sulphides (east of section 450 E., Figure 24) the nickel, cobalt, copper, manganese, potash, iron, magnesia, and lime content is, in general, higher than to the west and away from the ore. The variations in vanadium, soda, alumina, and silica are inconclusive.

The increase in iron, magnesia, and probably manganese may be accounted for by an increase of chlorite in the dyke. Some manganese may be present in the small stringers of carbonate which appear more numerous near the sulphides than further away.

At section 835 E. there is a sharp decrease in silica and soda which may be due to a small lens of massive sulphide adjacent to the dyke (see Map 14). However, at section 960 E., a larger lens of massive and disseminated sulphide lies adjacent to the dyke without an accompanying decrease in silica and soda.

The more significant indications of a sulphide body, or bodies, near the "grey" dyke are increasing magnesia, iron, potash, manganese, copper, cobalt, and nickel. Except potash, these constituents are not normally present in great abundance in acidic dykes so it is probable that they were introduced from the ore-bearing fluids.

Quartz-Porphyry Dyke at Copper Rand

The quartz-porphyry dyke at Copper Rand, the location of which is shown on Map 11, and the chemical variations in Figure 10, forms the hanging wall of the Main Eaton Bay ore body. Unfortunately, no samples of this dyke were available west of section 7800 E. to determine the chemical variations along strike further away from the ore.

At section 7800 E., 20 feet beyond the end of the ore zone the concentration of lime, magnesia, iron, vanadium, copper, cobalt, and nickel is considerably higher than in the section of the dyke parallel to the ore. The distribution of these constituents with respect to the ore is unusual.

This unusual relation may stem from a weakly-mineralized, carbonate-filled fracture, 6 inches thick, which was cut by the drill hole at section 7800 E. The carbonate filling contains about 5% of sulphides, mostly pyrite and a few traces of chalcopyrite. The sulphides may account for the high iron, vanadium, copper, cobalt, and nickel content at this section of the dyke. Chlorite is present in the dyke near the fracture. The high carbonate and chlorite content accounts for the high concentration of lime, magnesia, and some of the iron, with a decrease of silica.

The variations in this dyke indicate the mineralized fracture rather than the main sulphide zone, and as such are not significant.

Conclusions on Variations in the Acidic Dykes

The chemical variations in the acidic dykes sampled and analysed at the Campbell, Cedar Bay, and Copper Rand mines do not show many trends which may indicate the presence of sulphides. The trends in the acidic dyke at Copper Rand appear inconclusive. Increases are noted in magnesia, nickel, and copper in the acidic dykes at both the Cedar Bay and Campbell mines, and in cobalt, manganese, potash, iron, and lime at the Cedar Bay mine alone. At these two mines the constituents which show an increase in abundance, except potash, are those which are not normally abundant in acidic dykes. This suggests that these constituents were introduced into the dykes, possibly from the ore-bearing fluids.

II Basic Dykes

General Statement

The basic dykes, the chemical variations of which are discussed in this section, include true dykes and geologic units called "black" dyke and "Black Schist." Included in this section are the gabbroic dyke at Copper Rand, shown on Map 11; an altered basic dyke at Chibougamau Jaculet, shown on Maps 15 and 16; the "black" dyke at Cedar Bay, shown on Maps 13 and 17, and the "Black Schist" at Quebec Chibougamau Goldfields, shown on Maps 4, 5, 6, and 7. The chemical variations along the gabbroic dyke at Copper Rand are discussed first and the variations in the others are compared with it.

Gabbroic Dyke at Copper Rand

The chemical variations along this dyke in relation to the ore zone are shown in Figure 11. The dyke forms part of the footwall of the ore body which begins 20 feet to the east of section 7800 E.

Silica

The silica content of the dyke increases from about 40% at section 7500 E. to nearly 60% at section 7800 E., then decreases irregularly alongside the sulphide zone. The increase in the silica content is expressed mineralogically chiefly by an increase of fine-grained quartz dispersed through the dyke, and also by thin stringers and veinlets of quartz.

Alumina

The alumina content of the dyke increases slightly from nearly 11% at section 7500 E. to nearly 12% at section 8150 E. The total increase of about 1% may not be very significant because an analytical error of about 10% could well account for this difference.

The minor increase in alumina is difficult to explain mineralogically.

Lime

The lime content, from west to east, ranges from a high of 17% at section 7600 E. to a low of 8% at section 7800 E., then progressively increases to about 13% at section 8150 E.

The low lime content at section 7800 E. is partly accounted for by an increase of quartz, chiefly as thin veinlets and fine grains dispersed through the rock.

Magnesia

The magnesia content is relatively uniform at nearly 8% except at section 7800 E. where it decreases to about 2%. The magnesia is present chiefly in the chlorite. The low magnesia and low chlorite content at section 7800 E. is partly compensated for by the increase in quartz as noted previously.

Iron

The Fe_2O_3 content ranges from 12% to 14% along the dyke except at section 7800 E. where it decreases to about 9% and at section 8150E. where it also decreases to about 10%. Most of the iron is present in the chlorite, although a few traces of pyrite are also present in the dyke.

Soda

Soda, which is present chiefly in the plagioclase feldspar, shows an irregular distribution along the dyke. The soda content increases toward and overlaps the beginning of the sulphide zone and then decreases further to the east.

Potash

The chief feature of the potash distribution is the high value (2.60%) at section 7800 E., near the beginning of the ore zone. Further to the east, parallel to the ore, the potash content is higher than from section 7500 E. to 7700 E. The potash is present chiefly in sericite which is abundant at section 7800 E.

Manganese

The manganese content is lowest at section 7600 E. and highest at section 8050 E. adjacent to the ore. No significant trend can be interpreted from the distribution of manganese. Some manganese is probably present in the chlorite as well as in the carbonates.

Strontium

The strontium content is fairly uniform at about 16 ppm along the dyke except at section 7800 E. where it increases to about 25 ppm. The increase in strontium near the end of the sulphide body may be significant.

Vanadium

The vanadium content of the dyke adjacent to the sulphides is nearly 80 ppm as compared with about 60 ppm between sections 7500 E. to 7700 E. The V content at section 7800 E. is only about 20 ppm.

Copper

The copper content is fairly uniform at about 100 ppm along most of the dyke except at section 8050 E., adjacent to the ore, where it is about 450 ppm. The copper values do not show a significant trend toward the ore.

Cobalt

Little trend is indicated in the cobalt distribution. At section 7800 E. the cobalt content decreases to about 30 ppm from values of about 80 ppm further west. Adjacent to the ore, the cobalt content again increases to nearly 80 ppm.

Nickel

The nickel values also show little trend except for an abrupt decrease from 90 ppm to about 40 ppm at section 7800 E.

The single feature of the distribution shown by the constituent of the dyke is that at section 7800 E., 20 feet from the end of the ore zone, there is a sharp decrease in nickel, cobalt, vanadium, iron, magnesia, and lime, and an increase in silica, potash, and strontium.

Altered Basic Dyke at Chibougamau Jaculet

The No. 2 ore zone at Chibougamau Jaculet lies on the south side of an altered basic dyke shown in Maps 15 and 16. The massive sulphide occurrences are generally east of section 5400 E. The basic dyke is altered throughout the sampled length, the alteration being most severe adjacent to the ore. Figures 22 and 23 show the chemical variations along the dyke on both the 300-foot and 600-foot levels.

Figure 22 shows the chemical variations along the dyke on the 600-foot level. The variations of note are decreasing silica, alumina, lime, magnesia, and vanadium, and increasing iron, potash, soda, manganese, copper, and cobalt as the sulphide zone is approached. Nickel shows little variation, and strontium was not detected.

Figure 23 shows the variations of these constituents on the 300-foot level. In general, on this level the variations are not as clear as on the 600-foot level. Figure 23 shows a general decrease of silica, lime, magnesia, and vanadium, and an increase of iron, manganese, soda, potash, copper, and cobalt as the sulphide zone is approached. Nickel and alumina show little variation, and strontium was not detected.

The mineralogical changes that are noted in the dyke toward the ore zone are chiefly an increase of carbonate and a decrease in chlorite. The carbonate is low in calcium but high in iron and manganese and may be called manganosiderite. Increasing Mn and Fe in the basic dyke may be particularly good indicators of sulphides at the No. 2 zone at Chibougamau Jaculet because the ore is closely associated with sideritic masses.

"Black" Dyke at Cedar Bay

The rock known as a "black" dyke at the Cedar Bay mine is very schistose and irregular in outline. It has not been established whether it is a well-sheared and altered dyke, or well-sheared and altered meta-anorthosite. The "black" dyke is an important geological feature at the Cedar Bay mine because sulphide bodies are frequently found along its boundaries. The location of the "black" dyke on the 125-foot level, from where the core samples were taken, is shown on Map 13.

The chemical variations from section 100 W. to section 250 E. along the "black" dyke, shown in Figure 25, are somewhat irregular, probably due to the irregular distribution of sulphides along its boundaries. However it is apparent that with an increasing abundance of massive sulphides to the east, there is a decrease in silica, iron and manganese, and an increase in alumina, lime, magnesia, soda, potash, strontium, vanadium, copper, nickel and cobalt.

The mineralogical increases are carbonate (chiefly calcite stringers), chlorite, sericite, and albitic feldspar. This is the only observed occurrence of an increase in albite near an ore zone in the area.

"Black Schist" at Quebec Chibougamau Goldfields

At Quebec Chibougamau Goldfields, the ore zone lies between the "Black Schist" to the south and sheared meta-anorthosite to the north. Some carbonate, chiefly siderite, occurs locally between the sulphide body and the "Black Schist". The sulphide body appears to pinch out between the 650-foot and the 800-foot levels.

The drill holes from which the core samples of the "Black Schist" were taken are shown on Maps 4, 5, 6 and 7. The chemical variations in the "Black Schist" on the different levels are shown in Figures 17, 18, 19, 20, and 21. Insufficient drill core was available along the strike of the "Black Schist" on the 350, 650, and 800-foot levels for analysis beyond the ends of the sulphide body. Hence the variation diagrams (Figures 18, 19, and 20) of the "Black Schist" on these levels have insufficient extent to permit very definite conclusions.

Figure 21 shows the chemical variations in the "Black Schist" on the 500-foot level, adjacent to and beyond the ends of the sulphide body. Adjacent to the sulphide body (Map 5) the "Black Schist" has a higher content of silica, lime, potash, and strontium than beyond the ends of the sulphides.

The observed mineralogical increases accompanying these chemical increases are quartz, carbonate, and sericite, formed mostly at the expense of dark chlorite.

Figure 17 shows the chemical variations in the "Black Schist" in a vertical section at 4400 E. between the 350-foot and 800-foot levels. The alumina, lime, soda, strontium, vanadium, and copper content decreases with depth, while the silica, magnesia, iron, manganese, and nickel contents increase. The potash content reaches a maximum of 1.9% at the 500-foot level and then decreases with depth.

The ore zone contains more massive sulphide on the 500-foot level at section 4400 E. than either above or below (see Maps 4, 5, 6, and 7). This may account for the higher potash, iron, and silica content on this level than on either the 350-foot on the 650-foot levels.

The writer pointed out in Chapter III the lack of evidence that the "Black Schist" is a sheared and altered dyke. On the contrary, analyses of the unmineralized "Black Schist" indicate that it may be altered, schistose meta-anorthosite.

Summary of Variations in Basic Dykes

In Table IX, increases, or decreases of constituents are noted in the basic dykes adjacent to the ore on different mining properties. These changes are relative to the unmineralized parts of these dykes further away from the ore.

There appears to be more similarity in the behaviour of the constituents in the basic dykes at Copper Rand and Chibougamau Jaculet, than in the "Black Schist" at Quebec Chibougamau Goldfields, and the "black" dyke at Cedar Bay. (See Table IX on following page).

Note on the Strontium Content of Basic Dykes

There is an increase of the strontium content in the "Black Schist" adjacent to the ore on the 500-foot level at Quebec

TABLE IX

Chemical Variations In The Basic Dykes

	Copper Rand 525 Level	Chibougamau Jaculet		Cedar Bay 125 Level	Quebec Chibougamau Goldfields 500 Level
		300 Level	600 Level		
SiO_2	-	-	-	+	+
Al_2O_3	+	- ?	- ?	+	+
CaO	+ ?	-	-	+	+
MgO	+ ?	-	-	+	+ ?
Fe_2O_3	+ ?	+ ?	+	-	+
Na_2O	-	+ ?	+	+	-
K_2O	-	+	+	+	+
MnO	+ ?	+	+	-	+ ?
Sr	-	none	none	+	+
V	+	-	-	+	-
Cu	+	+	+	-	+ ?
Co	+	- ?	+	+ ?	+ ?
Ni	+	- ?	+	+ ?	+ ?

\+ - An increase with respect to an unmineralized part of the dyke

\- - A decrease with respect to an unmineralized part of the dyke

Chibougamau Goldfields (Figure 21) and in the "black" dyke on the 125-foot level at the Cedar Bay mine (Figure 25). The increase, in the order of 5 ppm from a level of 25 ppm, is too high to be attributed to analytical error. The amount of increase is in itself not as important as the fact that strontium is present in sheared and highly altered rock adjacent to deposits of massive sulphides.

In other mining properties investigated, it was found that the strontium content of the rocks decreased with intensified shearing and sulphide mineralization. At the Chibougama Jaculet No. 2 zone, for example, no strontium was detected along a well-sheared and highly altered basic dyke for a distance of over 1,000 feet adjacent to zones of sulphide mineralization. It is unlikely that there was no strontium in the dyke originally. In acidic dykes in the area, the strontium content decreased toward the sulphide zones. In the schistose and mineralized meta-anorthosite the strontium content is lower than in the massive rock.

The increase of strontium in the "black" dyke at Cedar Bay and in the "Black Schist" at Quebec Chibougamau Goldfields adjacent to massive sulphides is an unresolved problem.

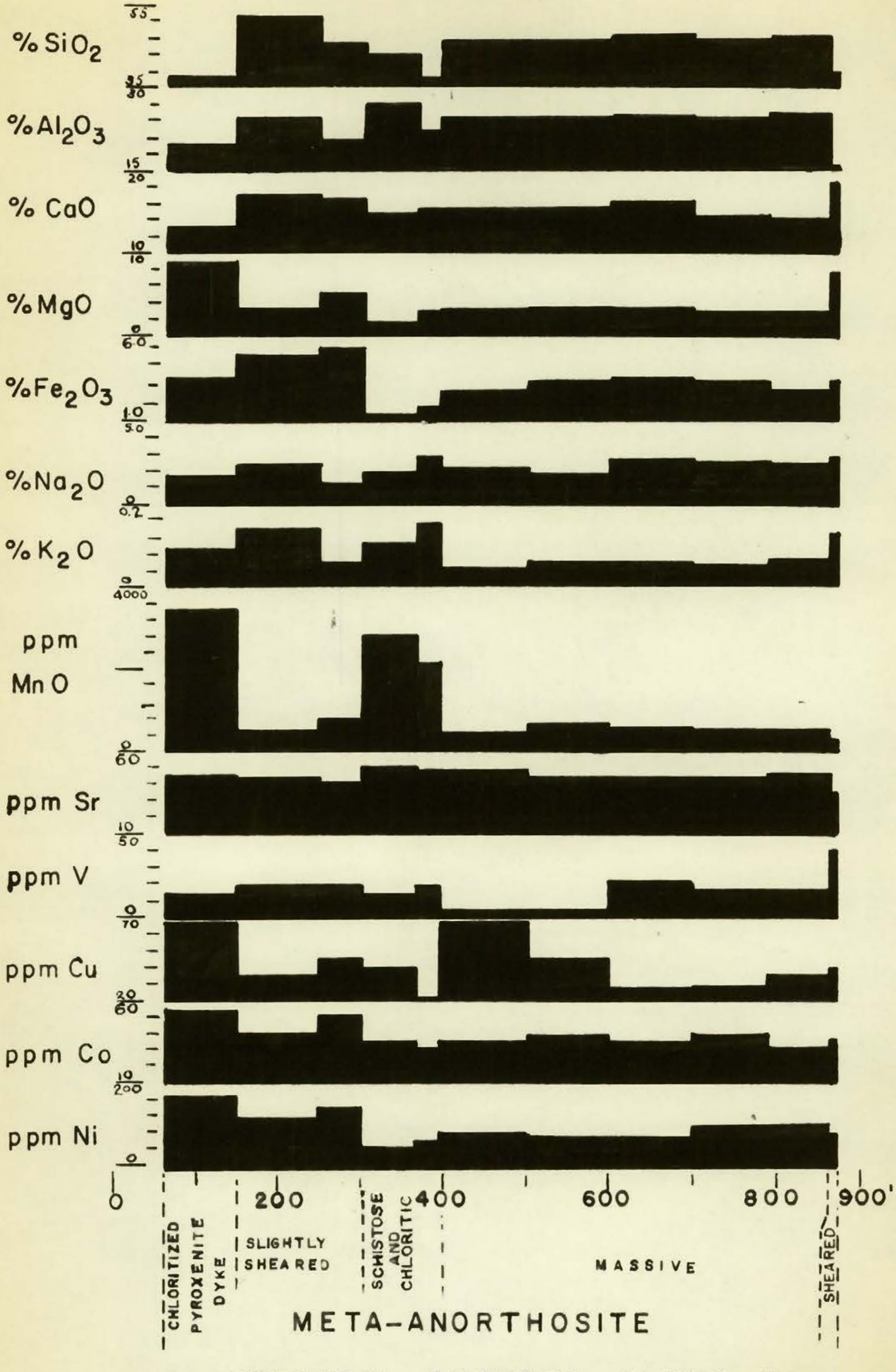


Fig. I   CHEMICAL CHANGES ALONG D.D.H. T-7

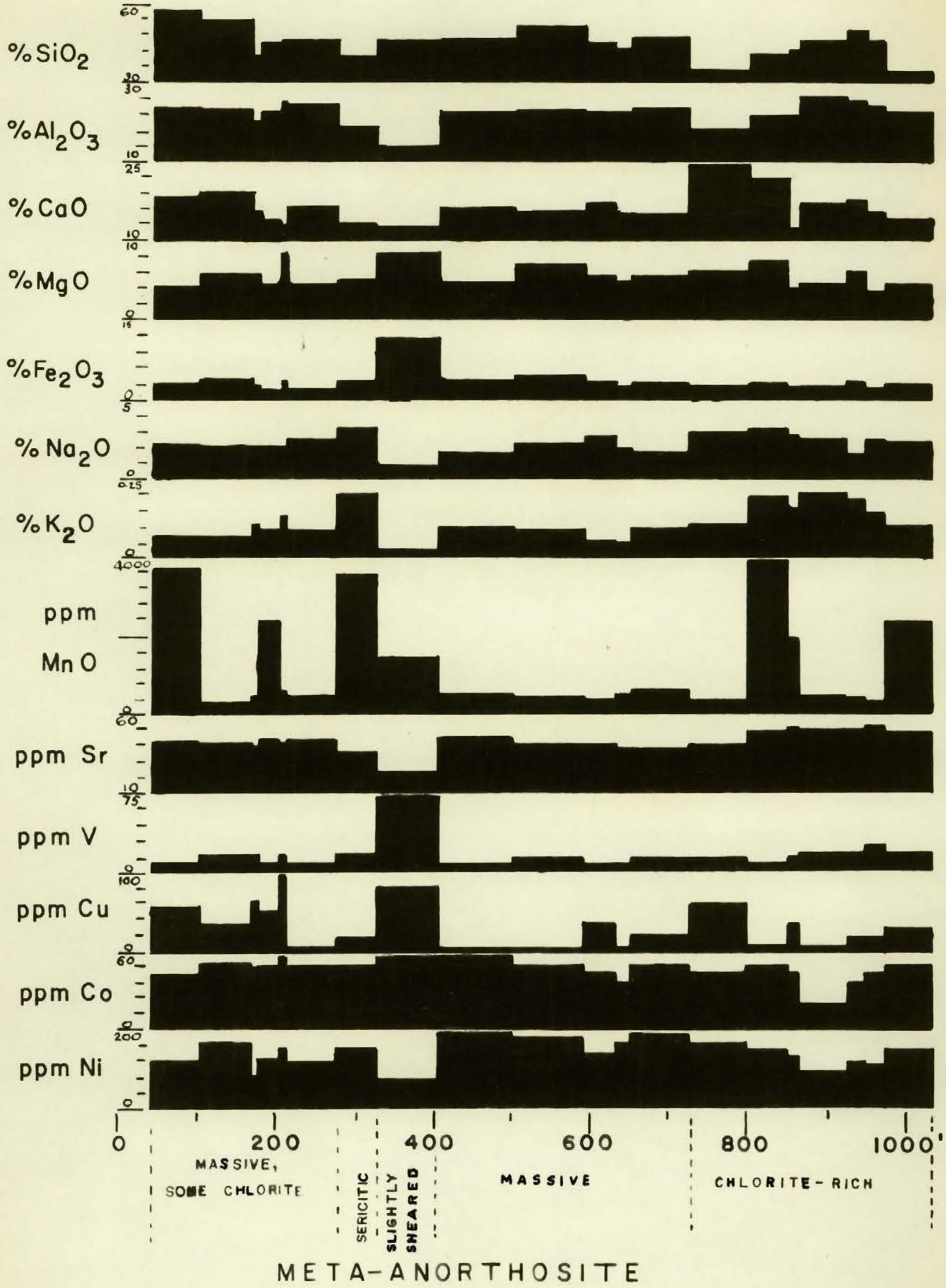


Fig. 2 CHEMICAL CHANGES ALONG D.D.H. T-8

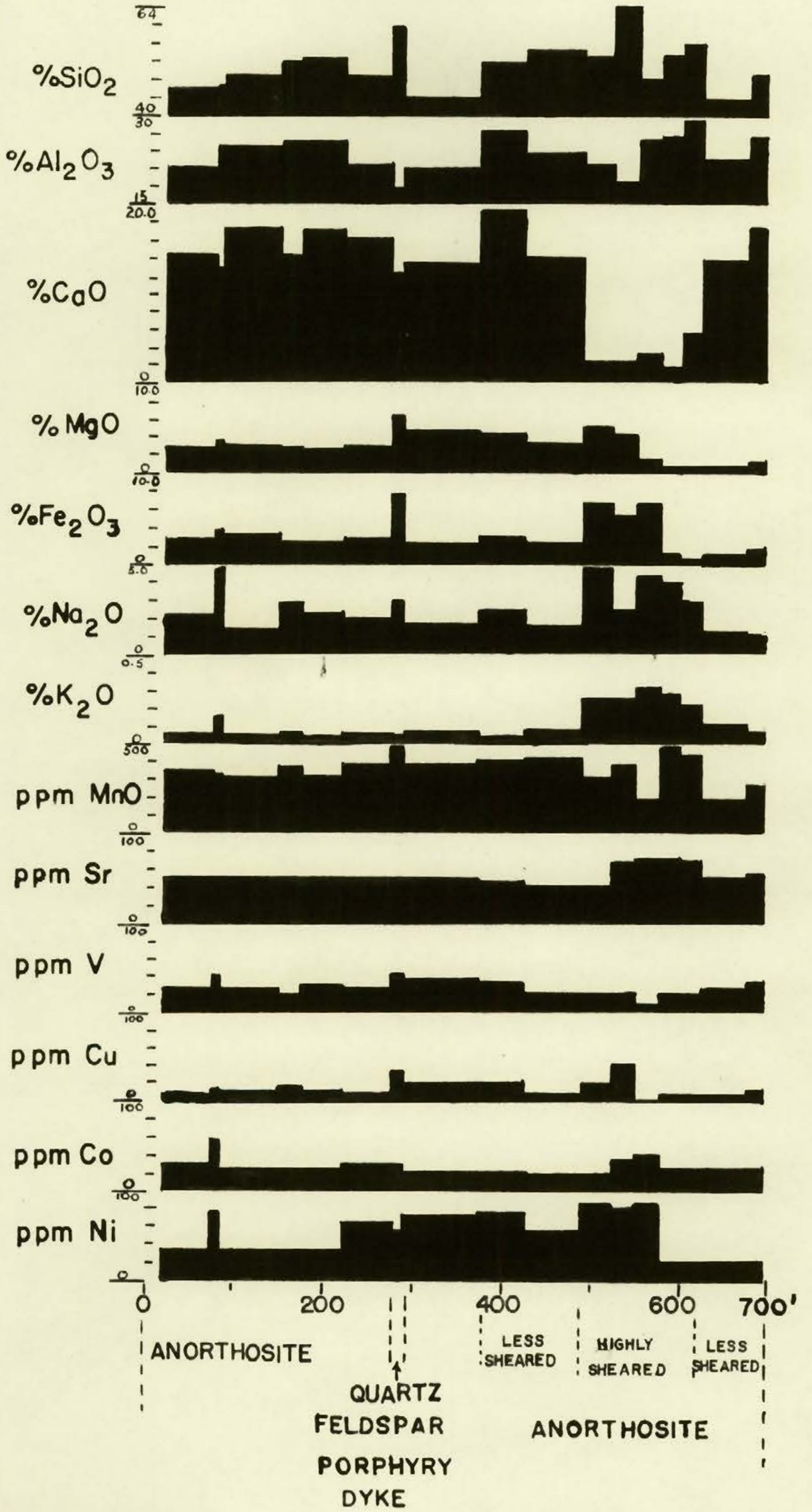


Fig. 3 CHEMICAL CHANGES ALONG D.D.H. T-10

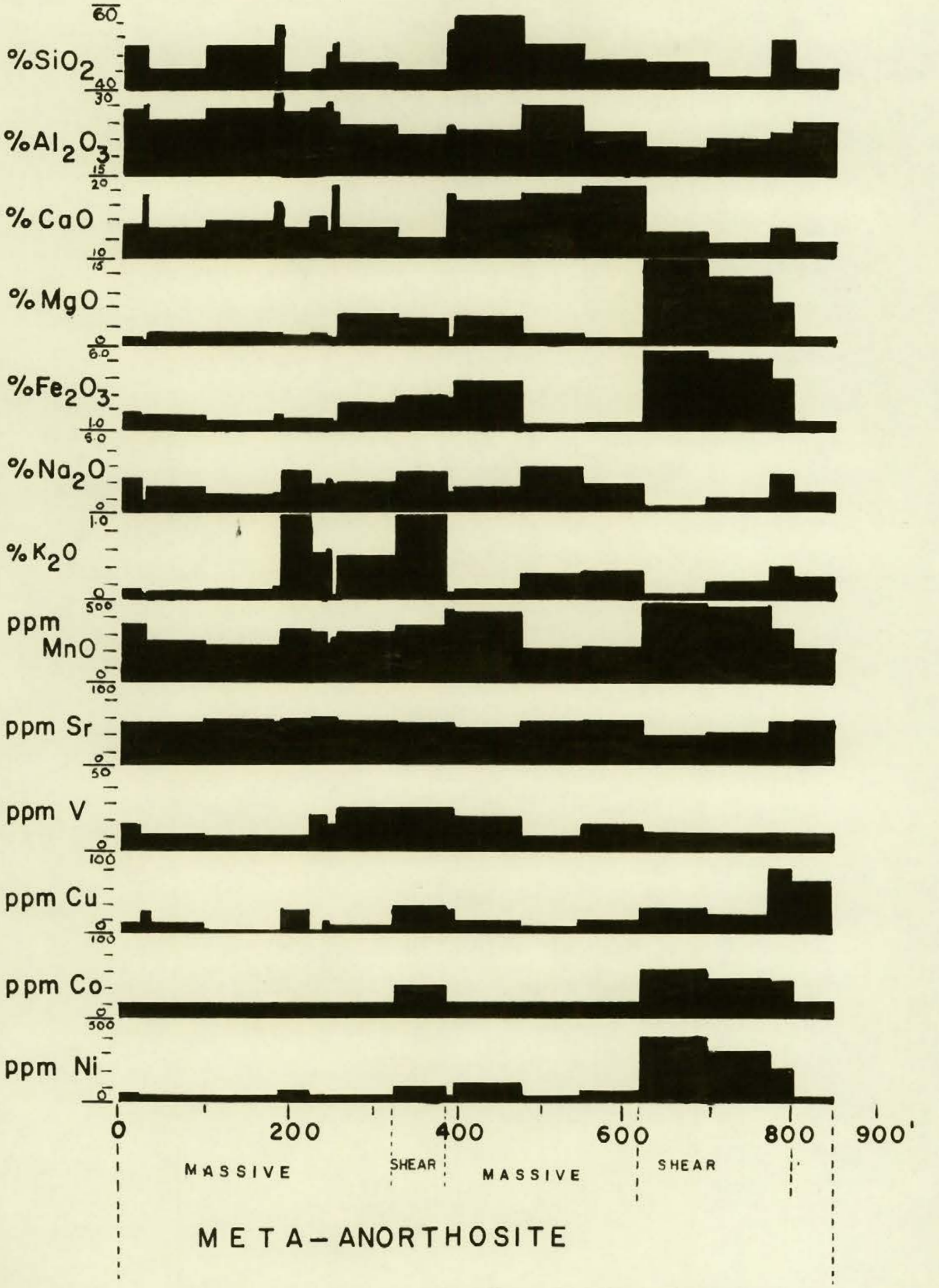


Fig. 4 CHEMICAL CHANGES ALONG D.D.H. T-16

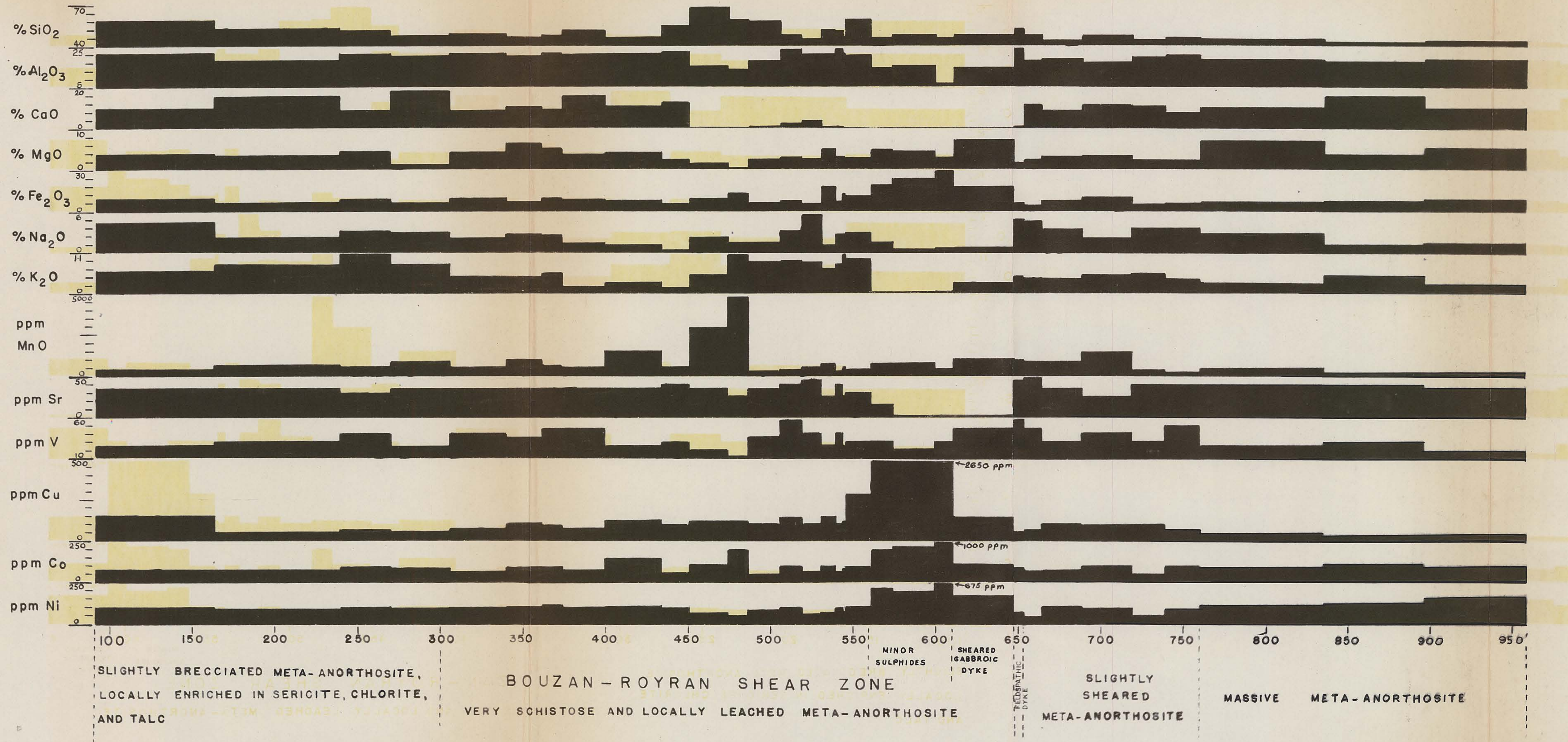
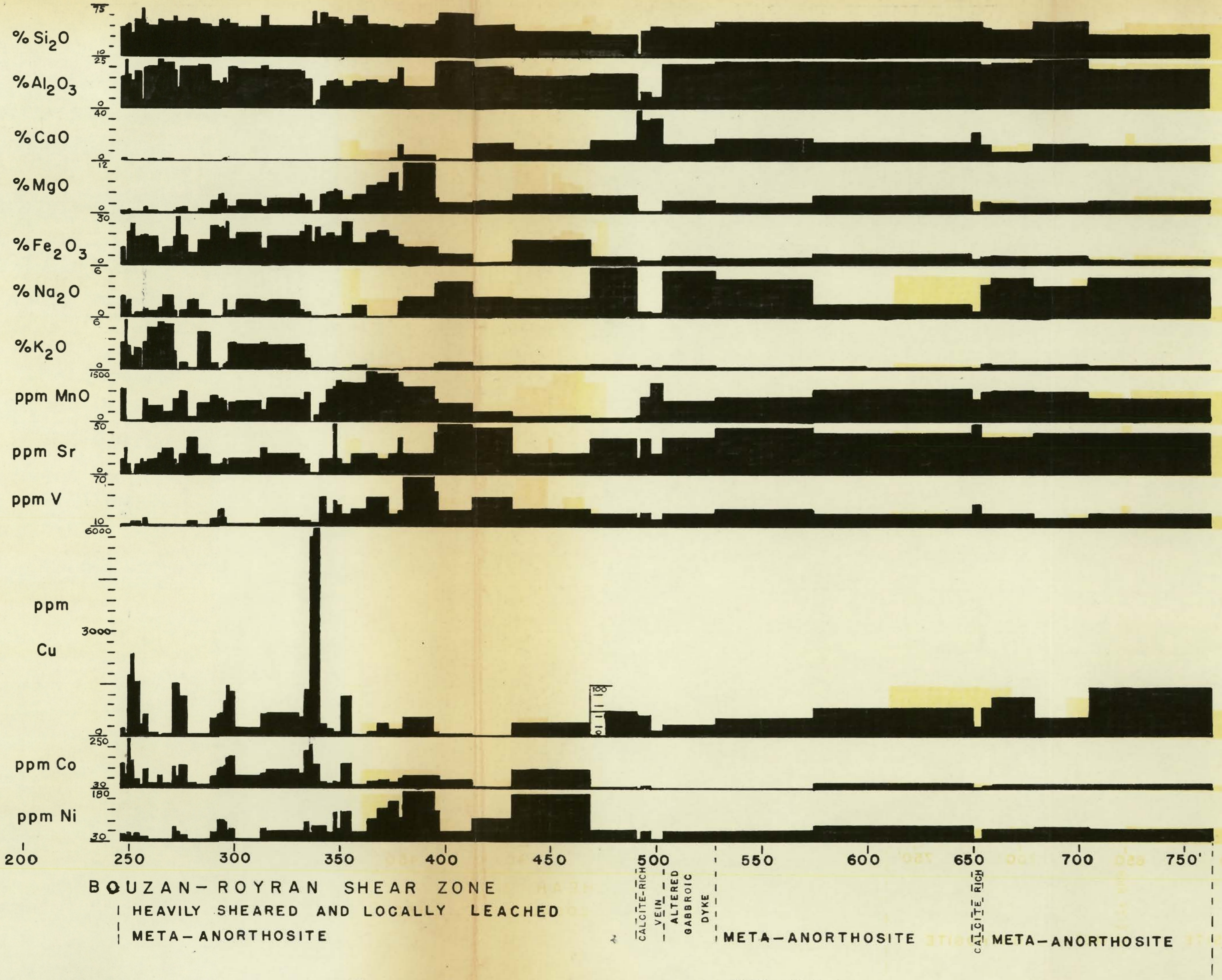


Fig. 5 CHEMICAL CHANGES ALONG D.D.H. R-52 and R-52W



NOTE CHANGE OF SCALE FOR Cu VALUES FROM 470' ON

Fig. 6 CHEMICAL CHANGES ALONG D.D.H. R-45

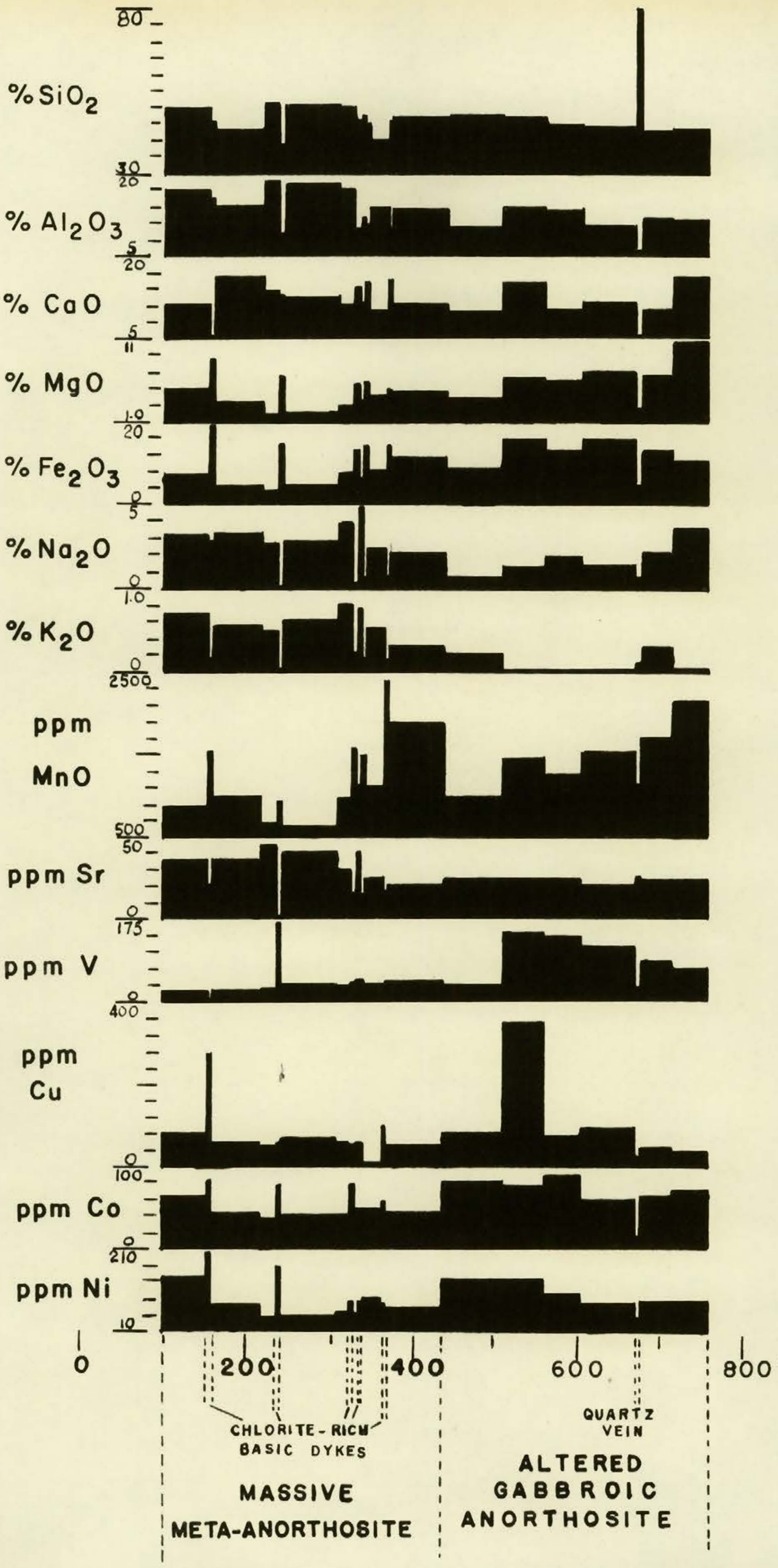


Fig. 7 CHEMICAL CHANGES ALONG D.D.H. R-53

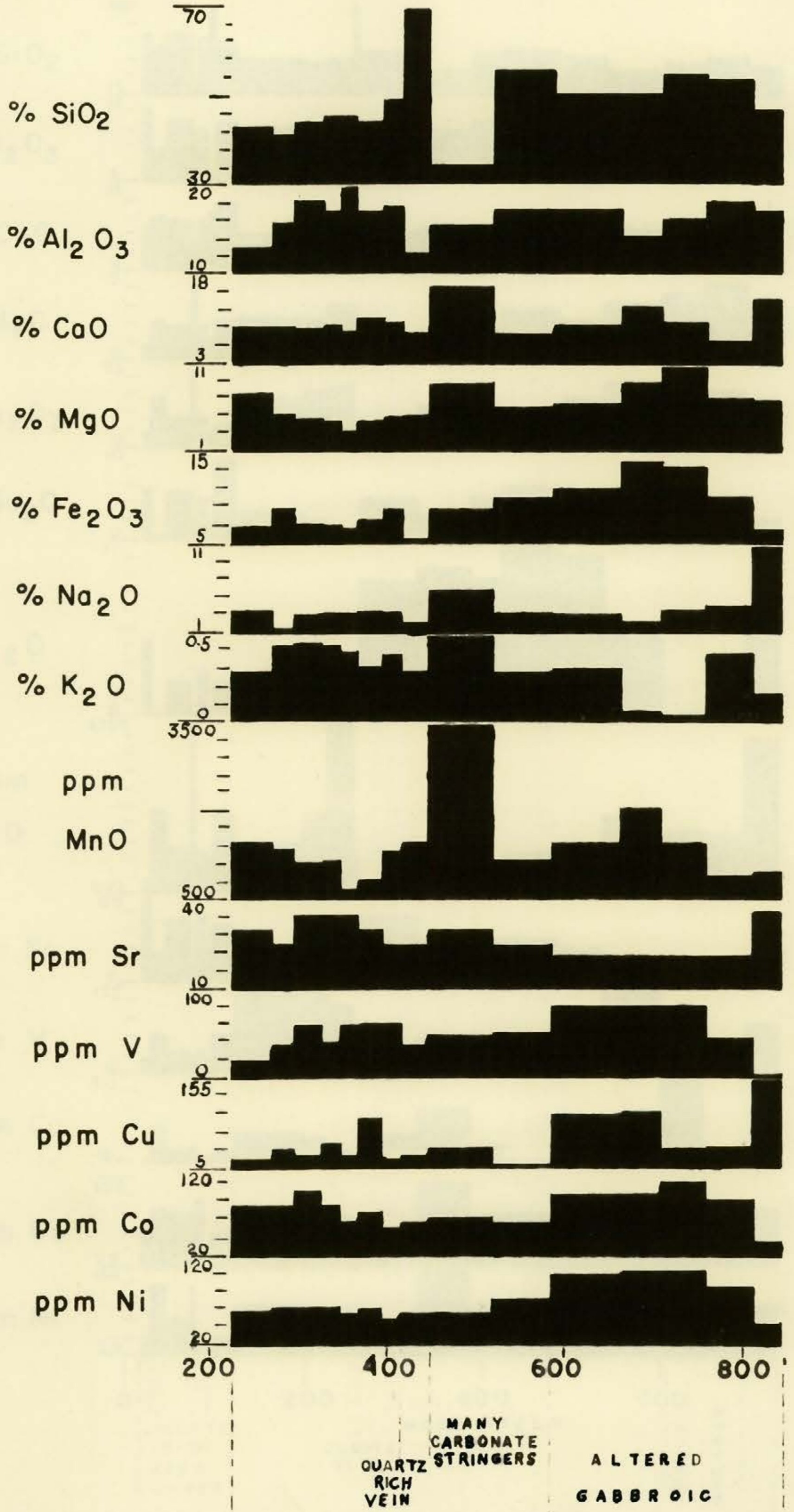


Fig. 8 CHEMICAL CHANGES ALONG D.D.H. R-70

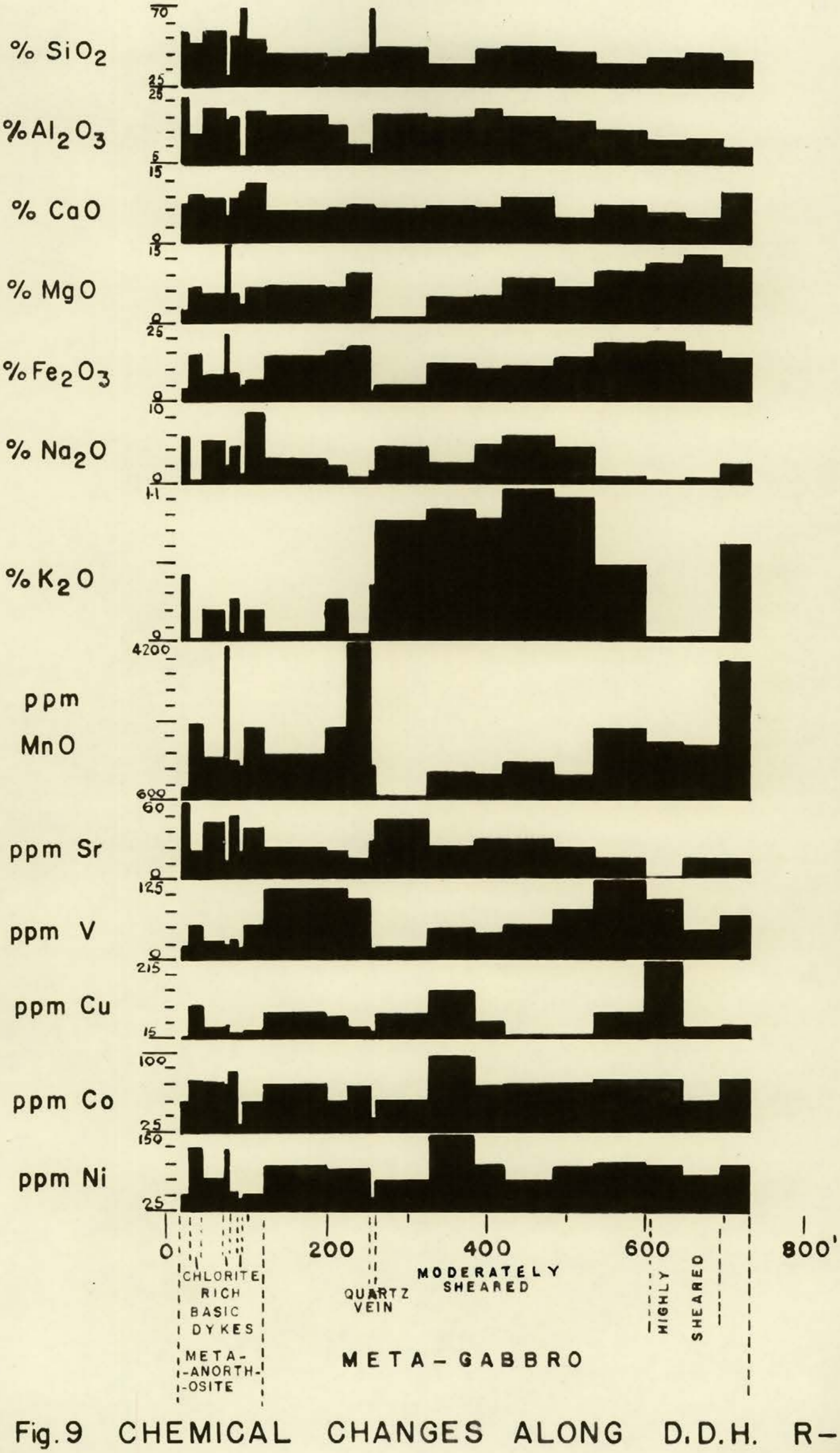


Fig. 9 CHEMICAL CHANGES ALONG D.D.H. R-72

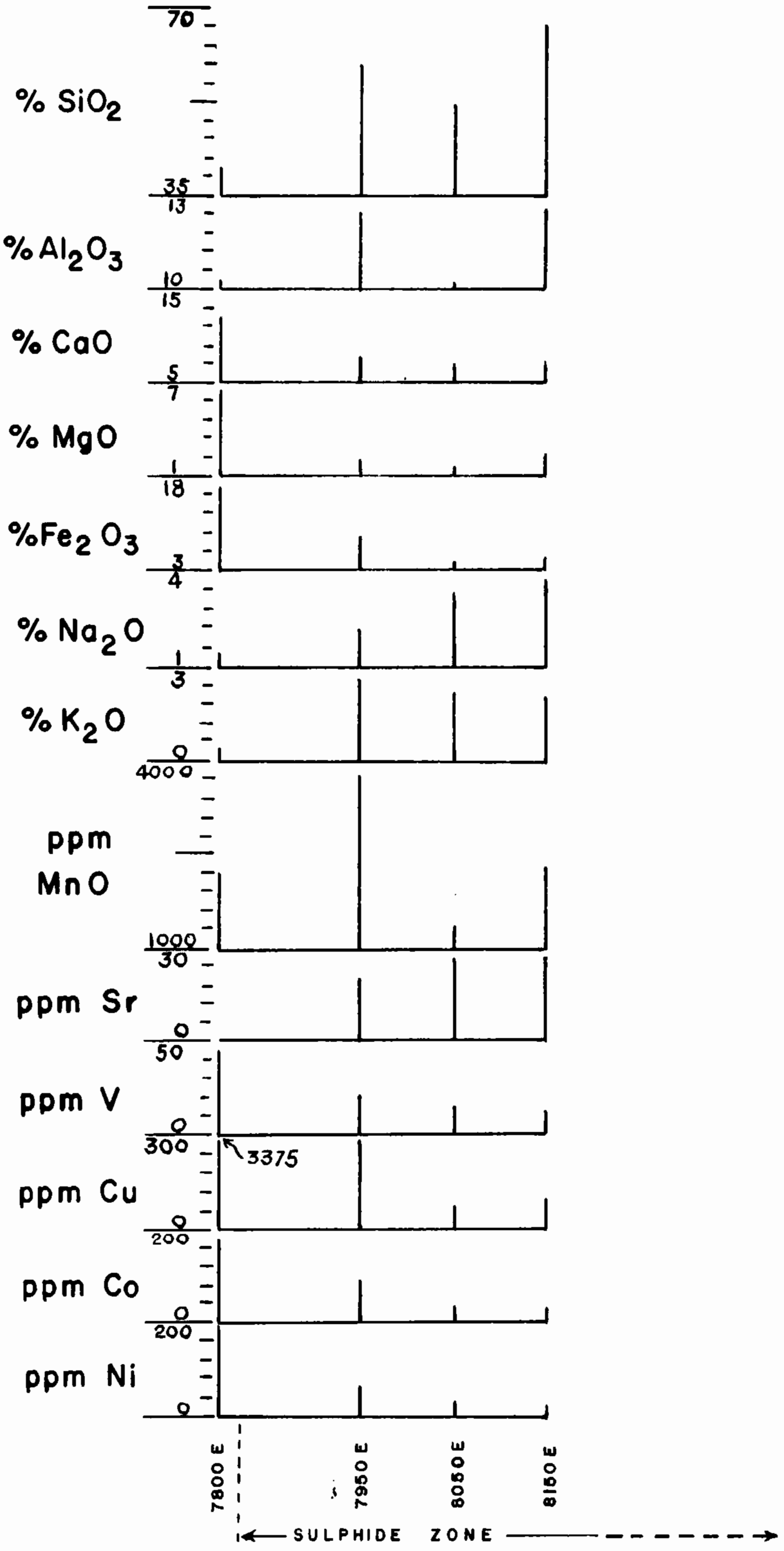


Fig. 10 CHEMICAL CHANGES ALONG PART OF THE HANGINGWALL QUARTZ PORPHYRY DYKE, 525 LEVEL, NO. 4 SHAFT, COPPER RAND CHIBOUGAMAU MINES LTD.

NOTE HIGH COPPER VALUE ON SECTION 7800 E.

SCALE: 1" = 200'

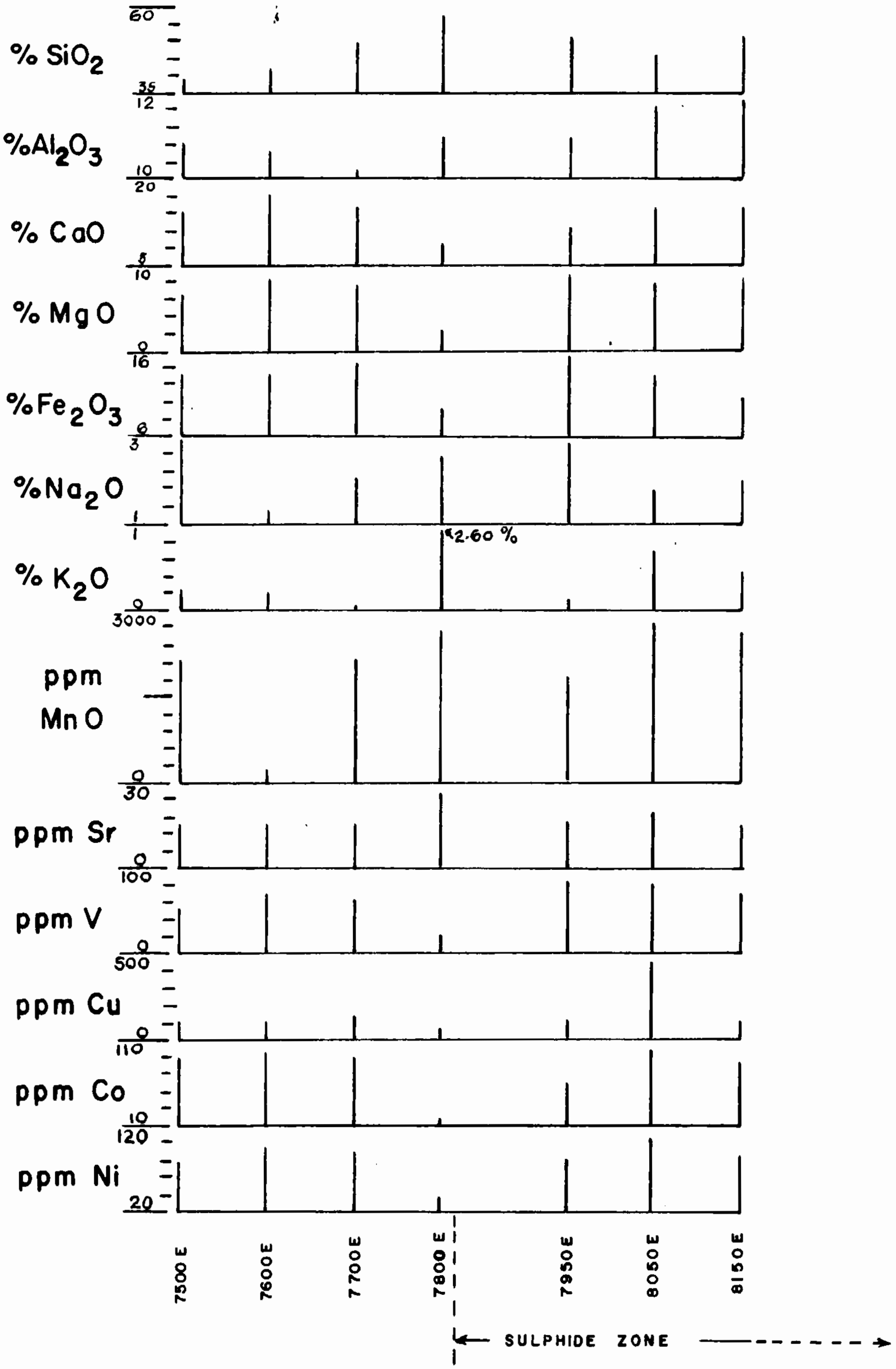
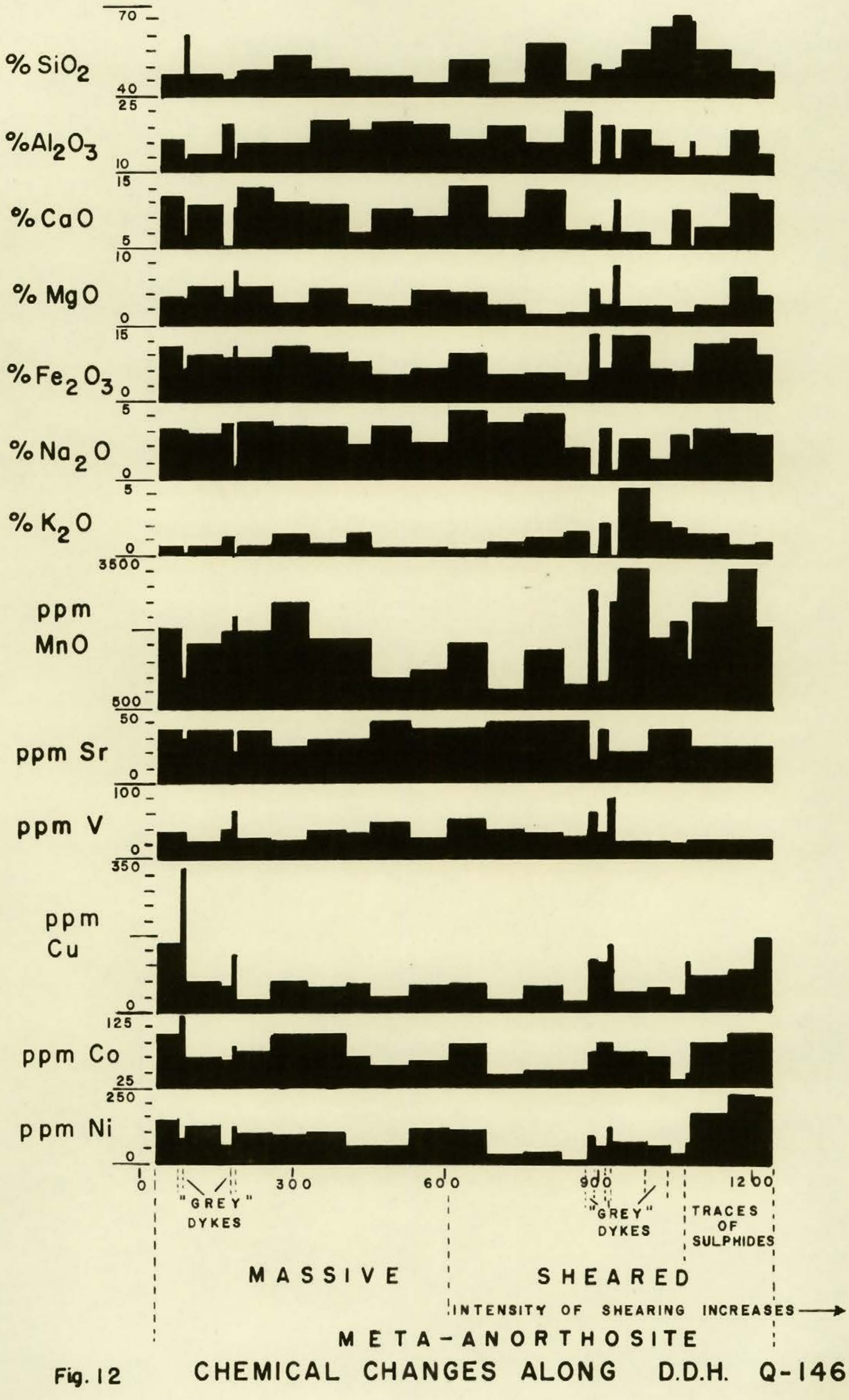


Fig.11 CHEMICAL CHANGES ALONG PART OF THE FOOTWALL GABBROIC DYKE 525 LEVEL, NO. 4 SHAFT, COPPER RAND CHIBOUGAMAU MINES LTD.

NOTE: ON SECTION 7800E THE K_2O VALUE IS HIGHER THAN THE LIMIT OF THE SCALE.

SCALE: 1" = 200'



META-ANORTHOSITE

Fig. 12 CHEMICAL CHANGES ALONG D.D.H. Q-146

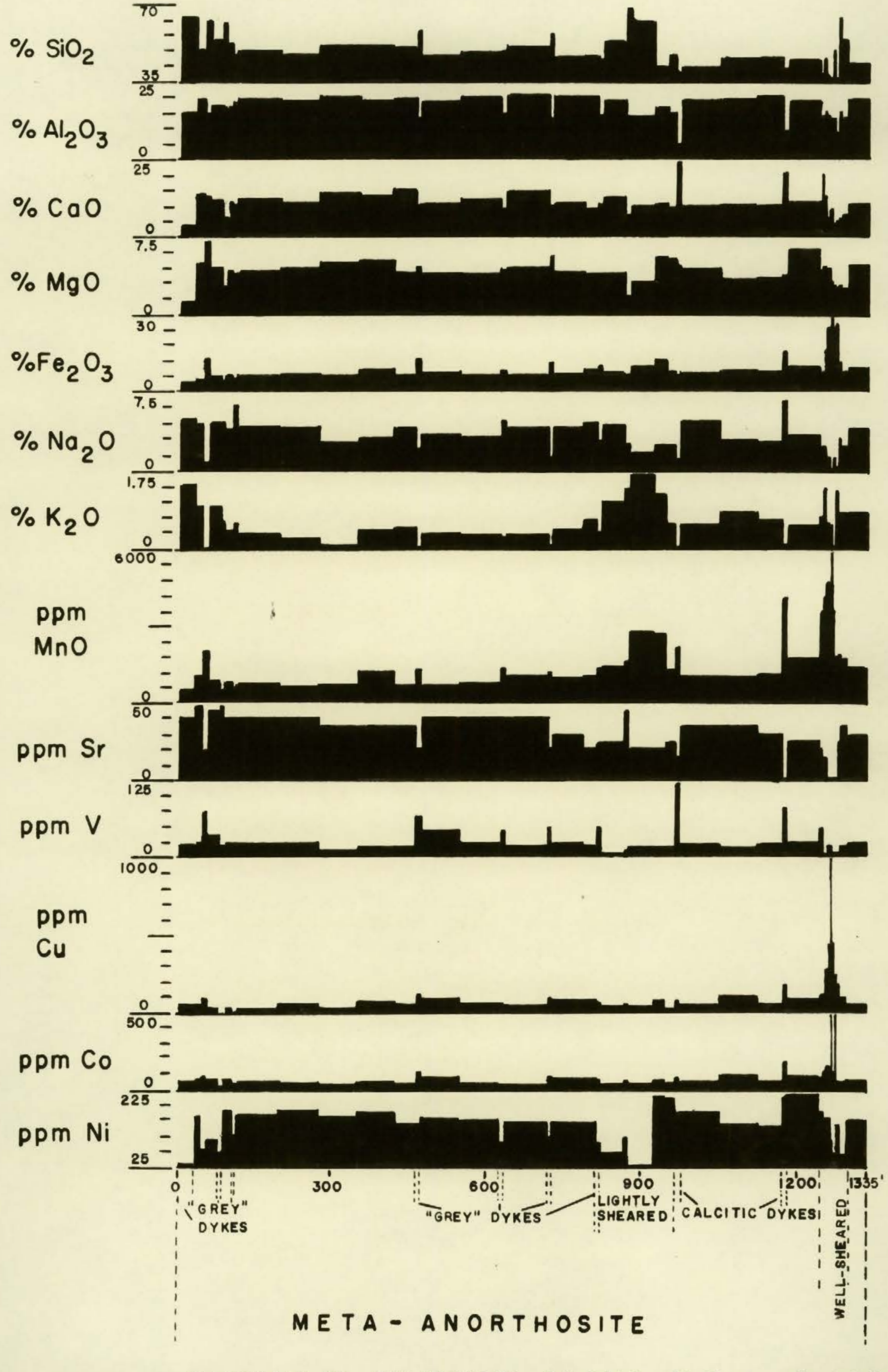


Fig. 13 CHEMICAL CHANGES ALONG D.D.H. Q-190

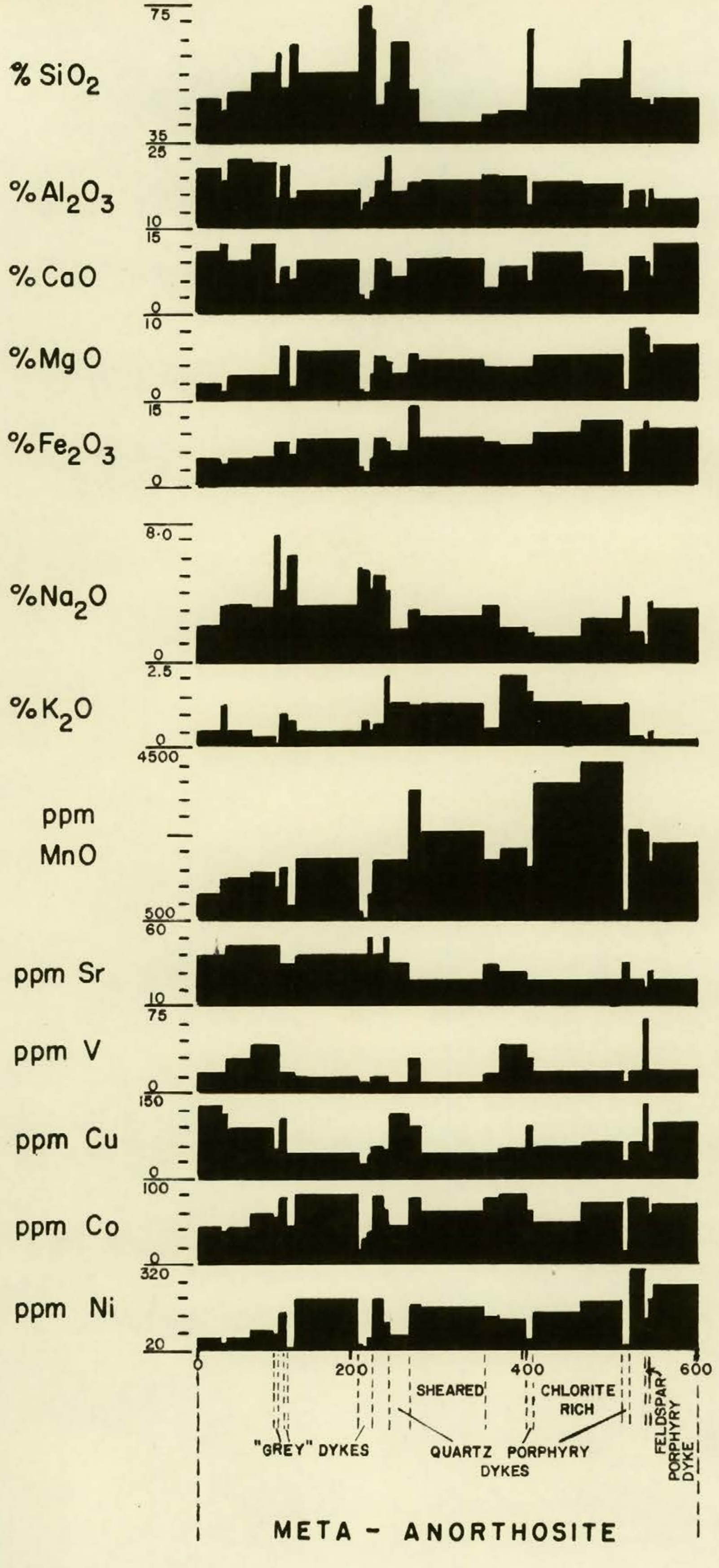


Fig. 14 CHEMICAL CHANGES ALONG D.D.H. Q-118

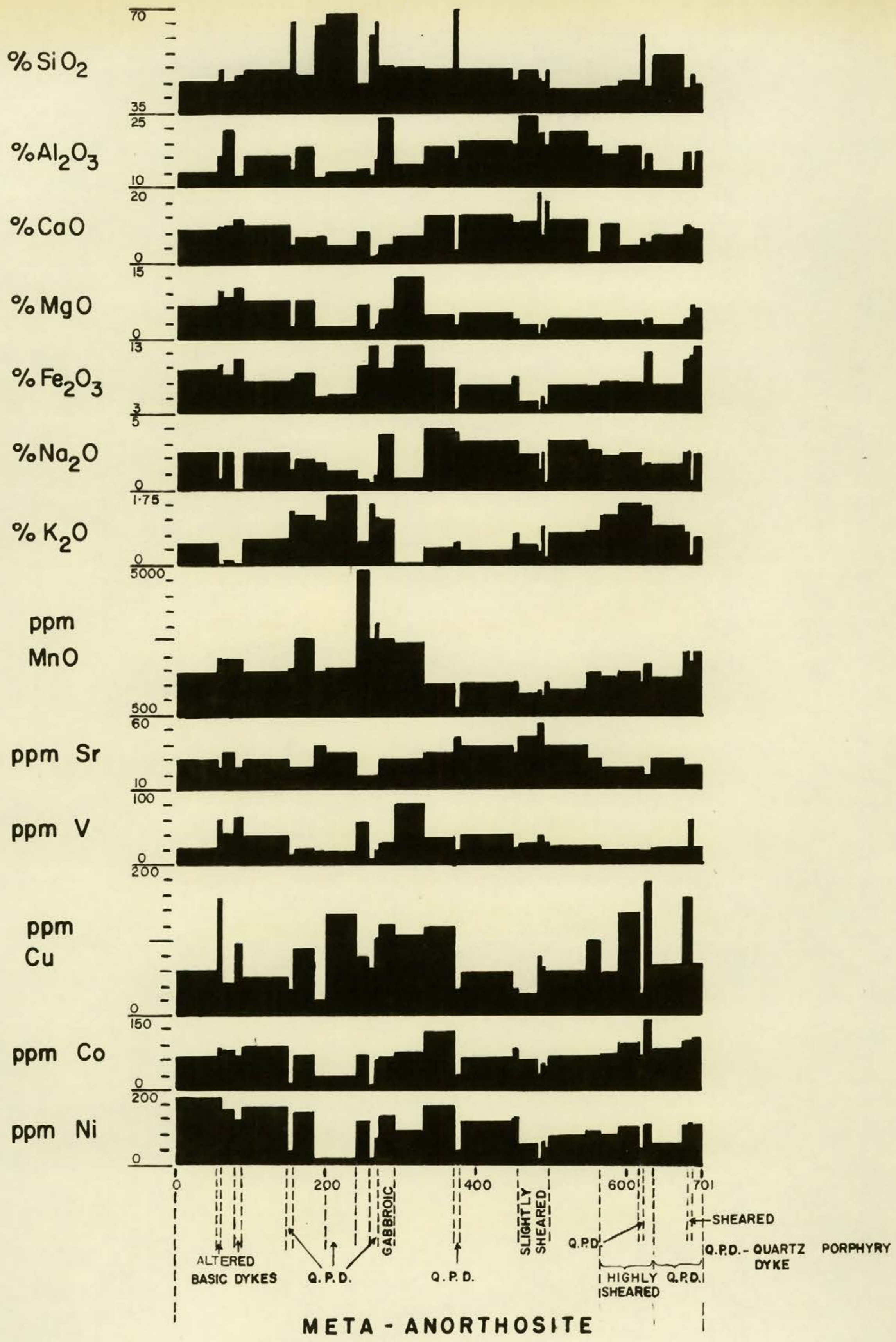


Fig. 15 CHEMICAL CHANGES ALONG D.D.H. Q-121

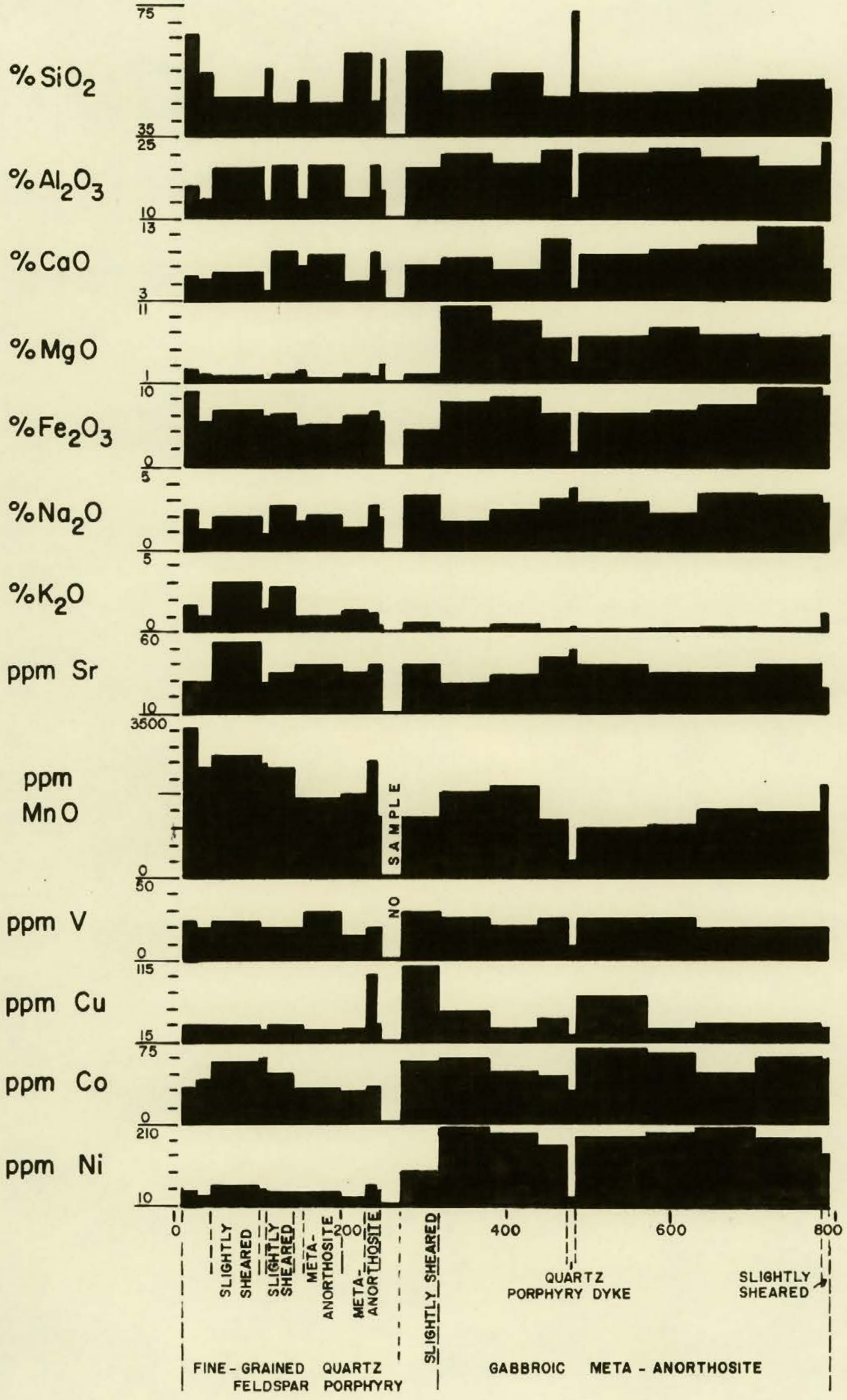


Fig. 16 CHEMICAL CHANGES ALONG D.D.H. Q-119

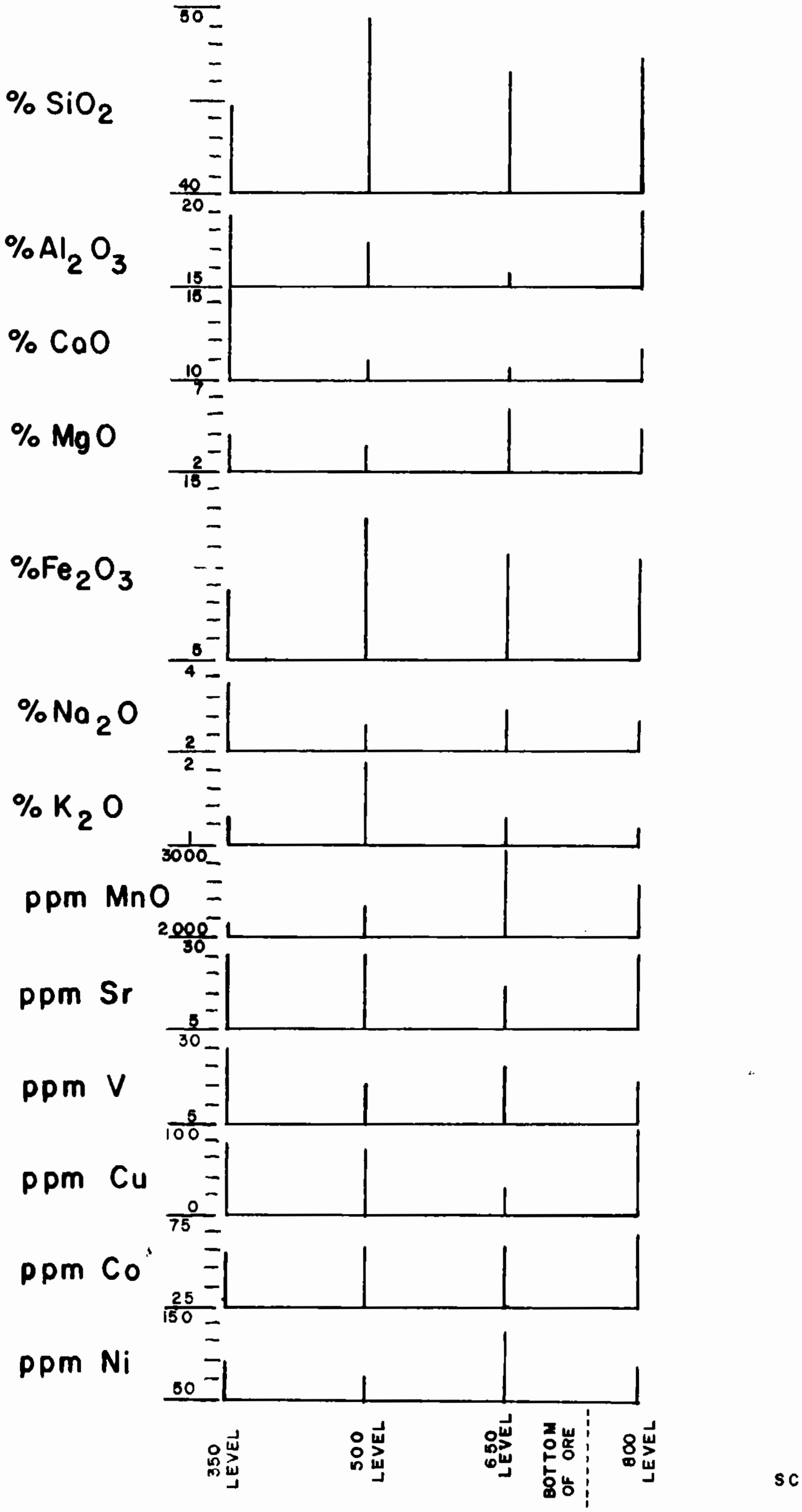


Fig. 17 CHEMICAL CHANGES IN "BLACK SCHIST", SOUTH OF THE MAIN SULPHIDE BODY, IN A VERTICAL SECTION AT 4400 E BETWEEN THE 350-FOOT AND 800-FOOT LEVELS, QUEBEC CHIBOUGAMAU GOLDFIELDS, LIMITED.

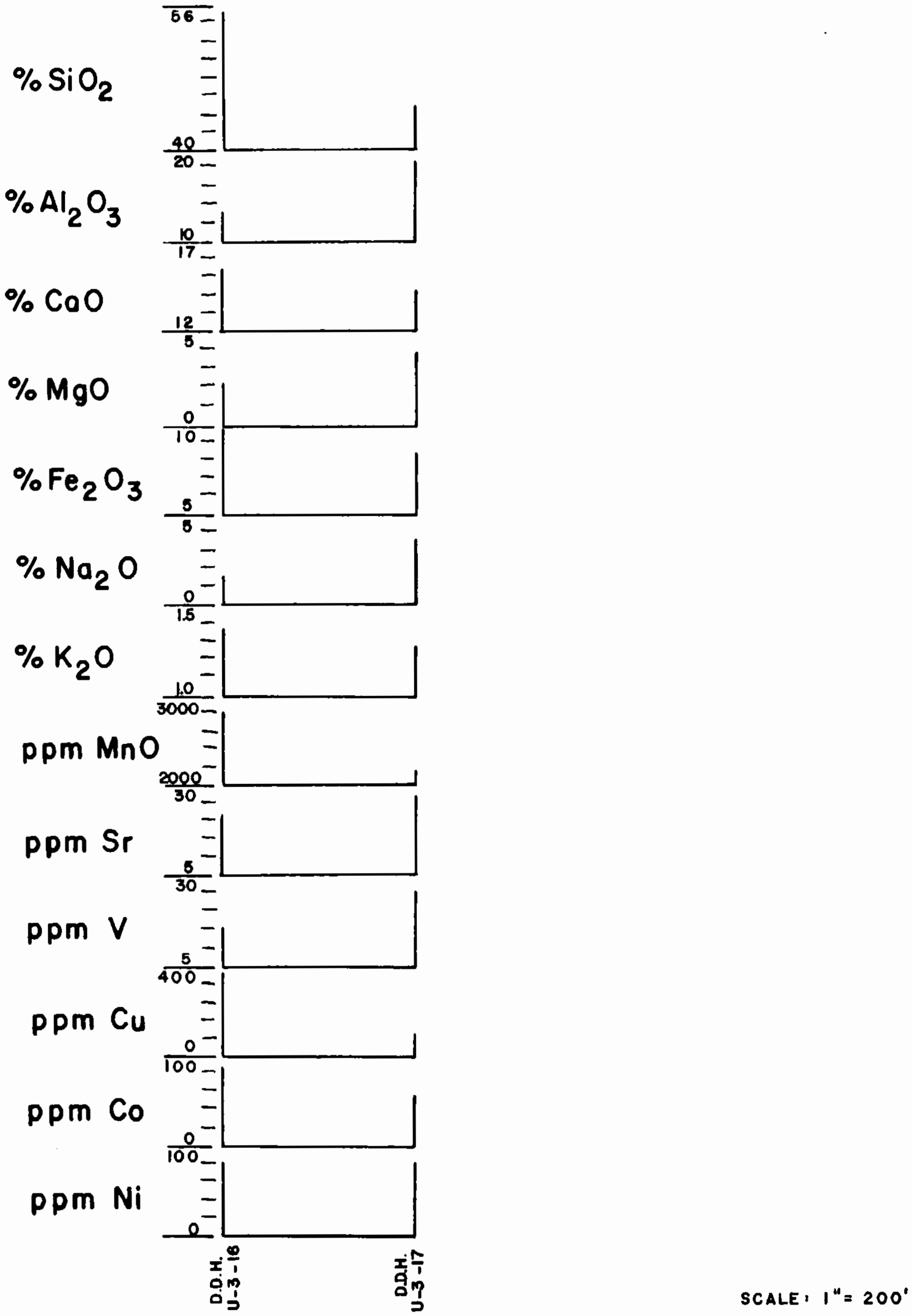
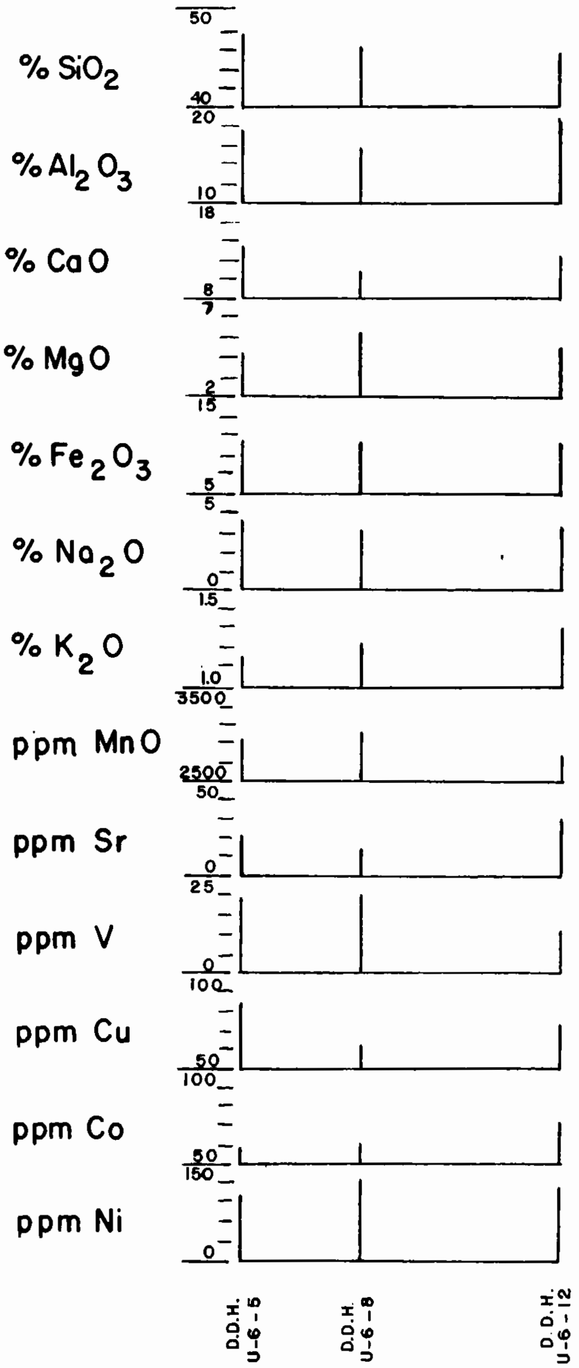
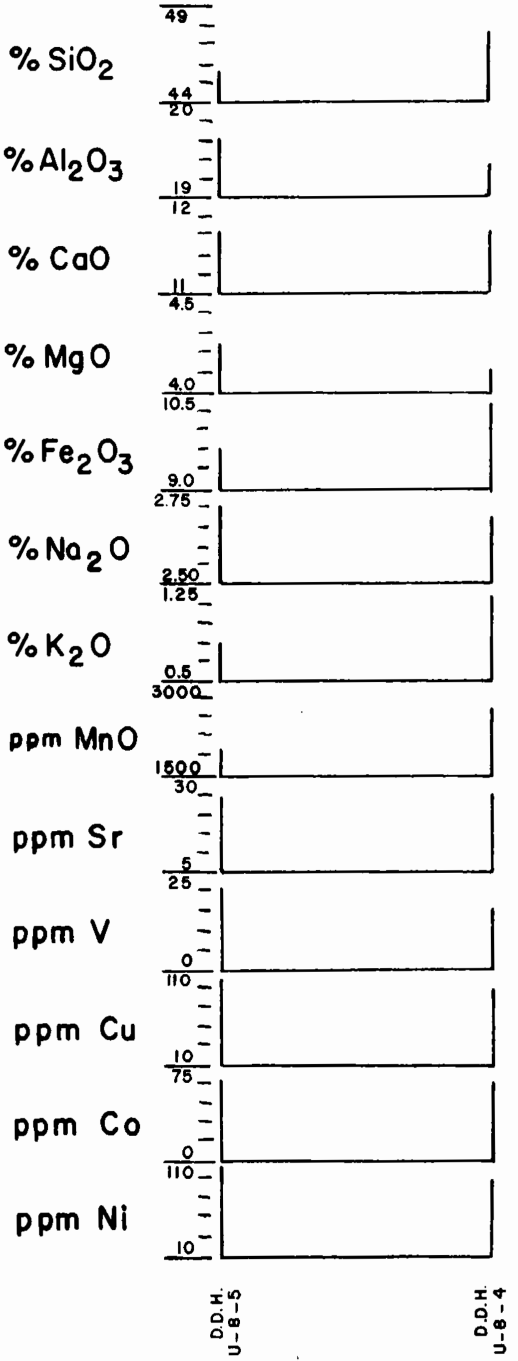


Fig. 18 CHEMICAL COMPOSITION OF "BLACK SCHIST" SOUTH OF, AND ADJACENT TO, A MINERALIZED ZONE ON THE 350-FOOT LEVEL, QUEBEC CHIBOUGAMAU GOLDFIELDS, LIMITED.



SCALE: 1" = 100'

Fig. 19 CHEMICAL COMPOSITION OF "BLACK SCHIST" IMMEDIATELY SOUTH OF MAIN ORE ZONE ON THE 650-FOOT LEVEL, QUEBEC CHIBOUGAMAU GOLDFIELDS, LIMITED.



SCALE: 1" = 100'

Fig. 20 CHEMICAL COMPOSITION OF "BLACK SCHIST" ON 800 FOOT LEVEL DIRECTLY BELOW ORE ZONE ON THE 650 FOOT LEVEL,

QUEBEC CHIBOUGAMAU GOLDFIELDS, LIMITED.

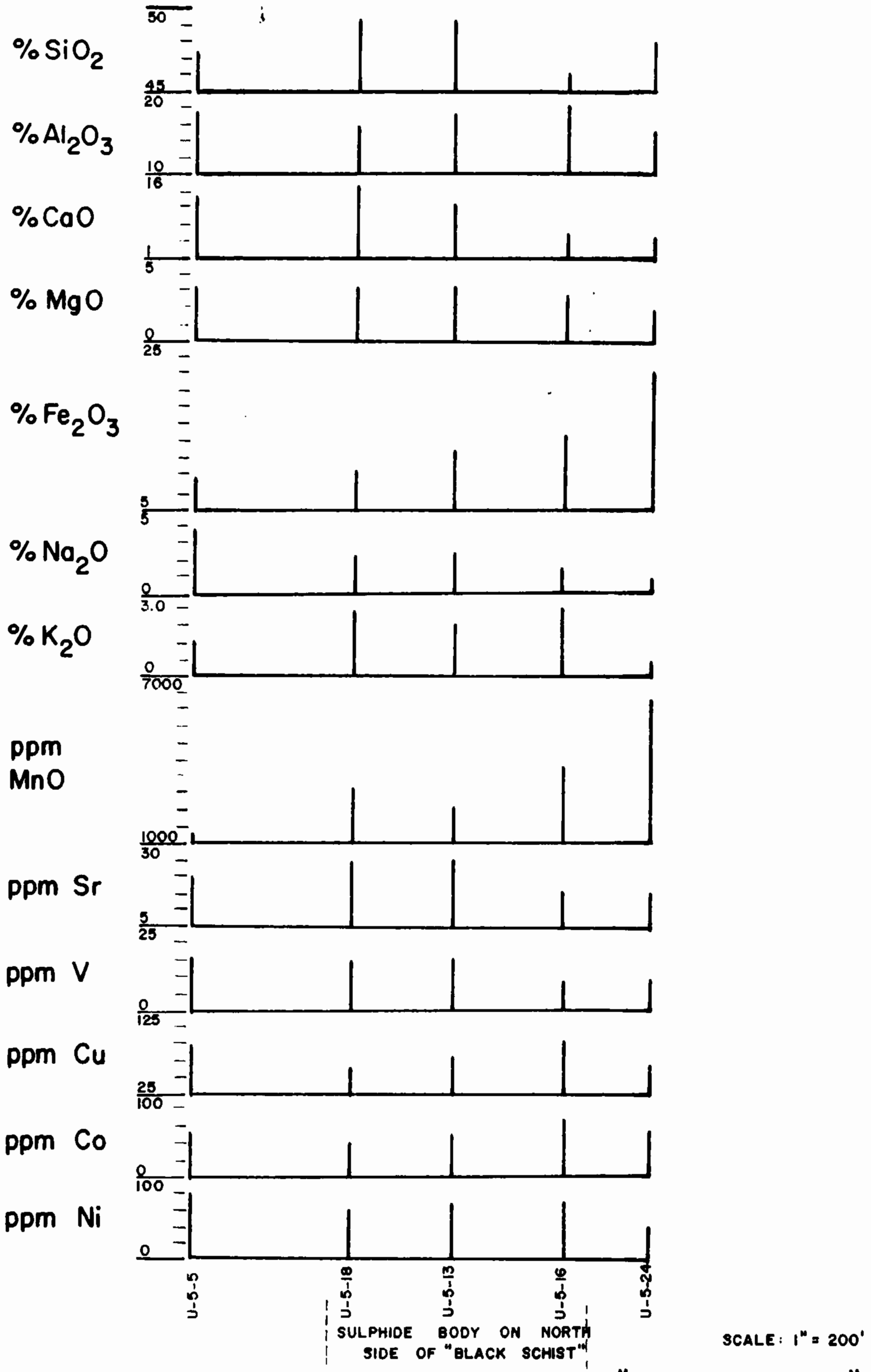


Fig. 21 CHEMICAL COMPOSITION OF "BLACK SCHIST" ADJACENT TO A SULPHIDE BODY - 500 LEVEL. QUEBEC CHIBOUGAMAU GOLDFIELDS, LTD.

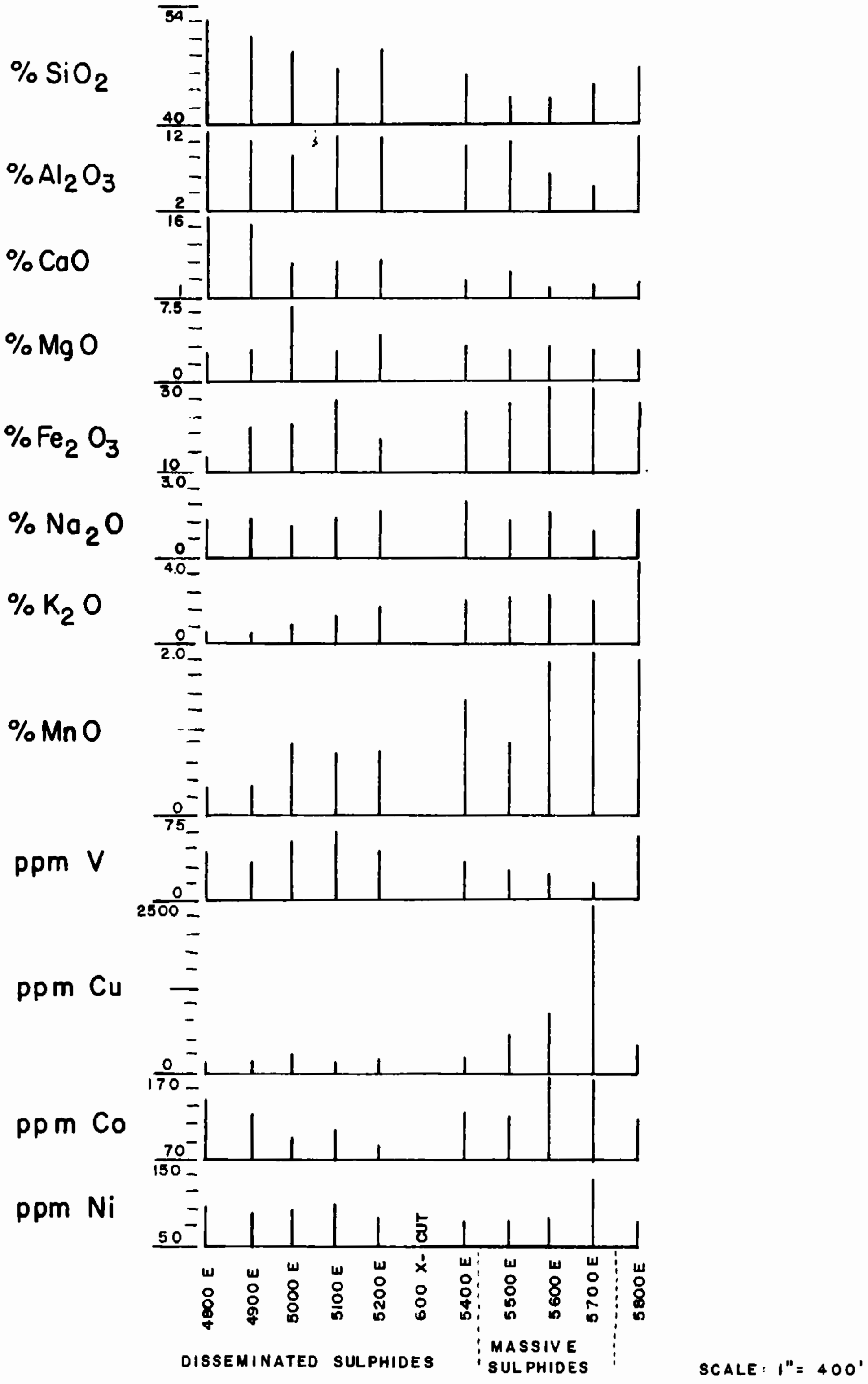


Fig. 22 CHEMICAL CHANGES ALONG ALTERED BASIC DYKE ON THE NORTH SIDE OF THE MAIN SULPHIDE BODY, No. 2 ZONE, 600-FOOT LEVEL, CHIBOUGAMAU JACULET MINES, LIMITED.

NOTE: NO STRONTIUM WAS DETECTED

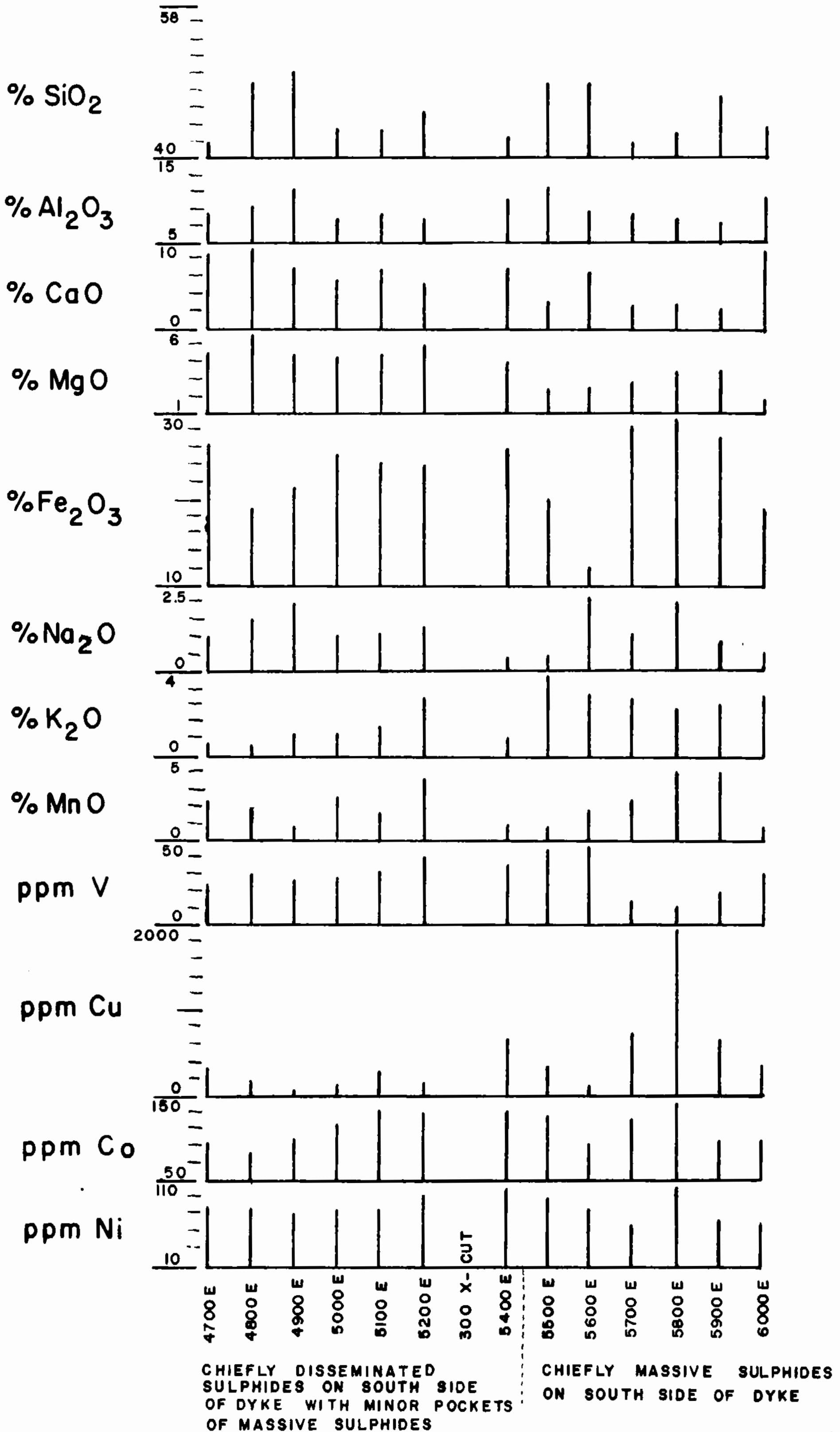


Fig.23 CHEMICAL CHANGES ALONG ALTERED BASIC DYKE ON THE NORTH SIDE OF THE MAIN SULPHIDE BODY, No.2 ZONE, 300—FOOT LEVEL, CHIBOUGAMAU JACULET MINES, LIMITED.

NOTE: NO STRONTIUM WAS DETECTED

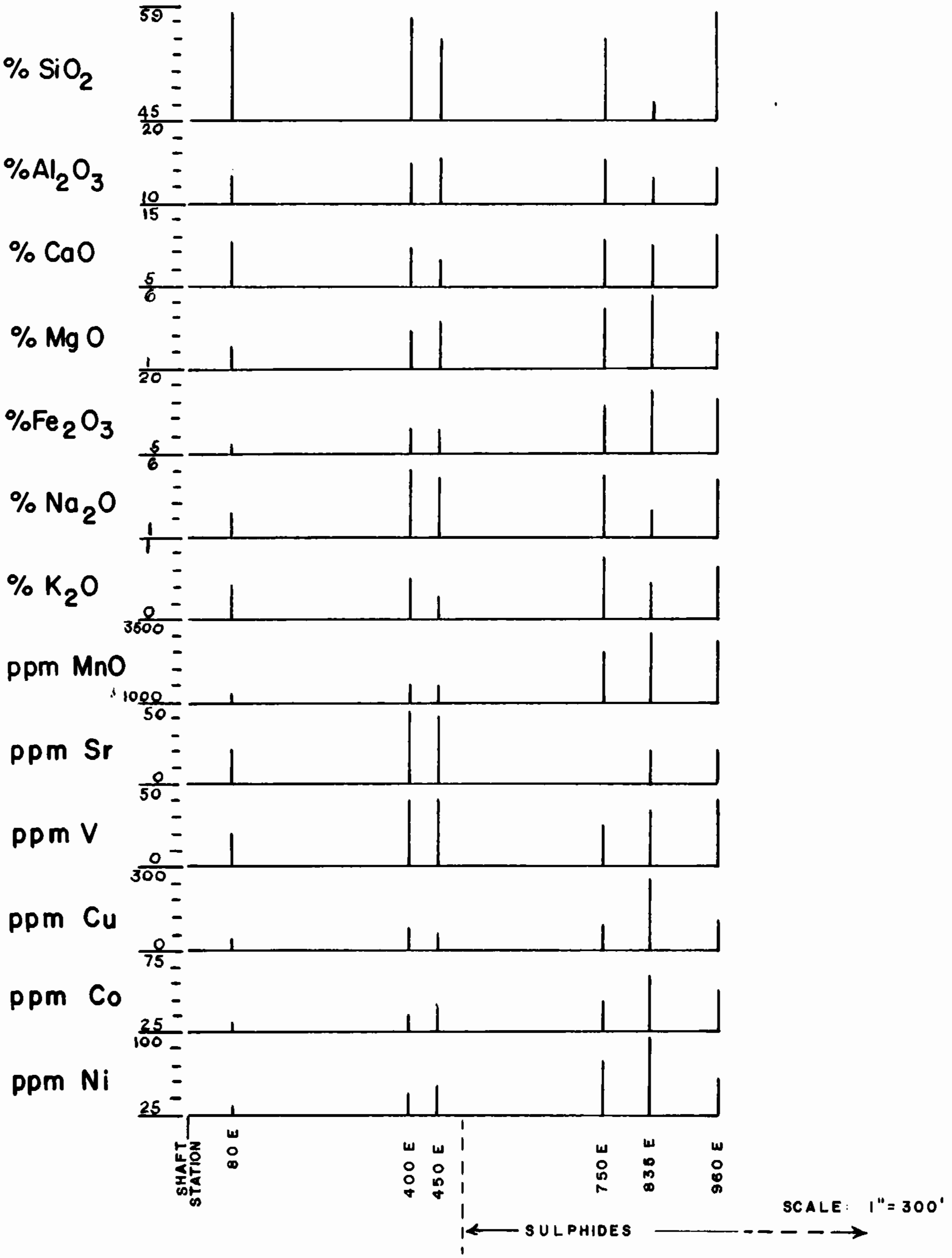


Fig. 2 4 CHEMICAL CHANGES ALONG PART OF THE "GREY" DYKE SOUTH OF A SULPHIDE ZONE, 500 LEVEL, CEDAR BAY MINE.

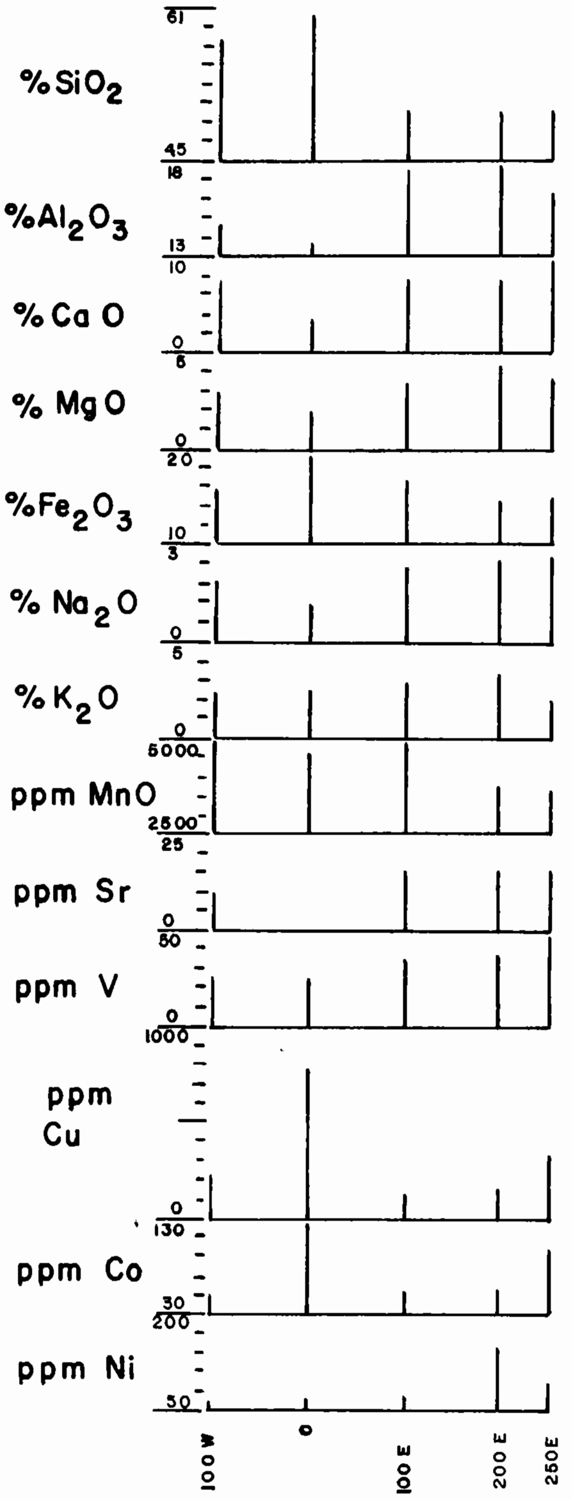


Fig. 25 CHEMICAL CHANGES ALONG PART OF THE "BLACK" DYKE AT THE 125-FOOT LEVEL OF THE CEDAR BAY MINE. THE DYKE IS FLANKED ON BOTH SIDES BY SULPHIDES WHICH, WITH IRREGULARITIES, BECOME MORE MASSIVE TO THE EAST.

SCALE: 1" = 200'

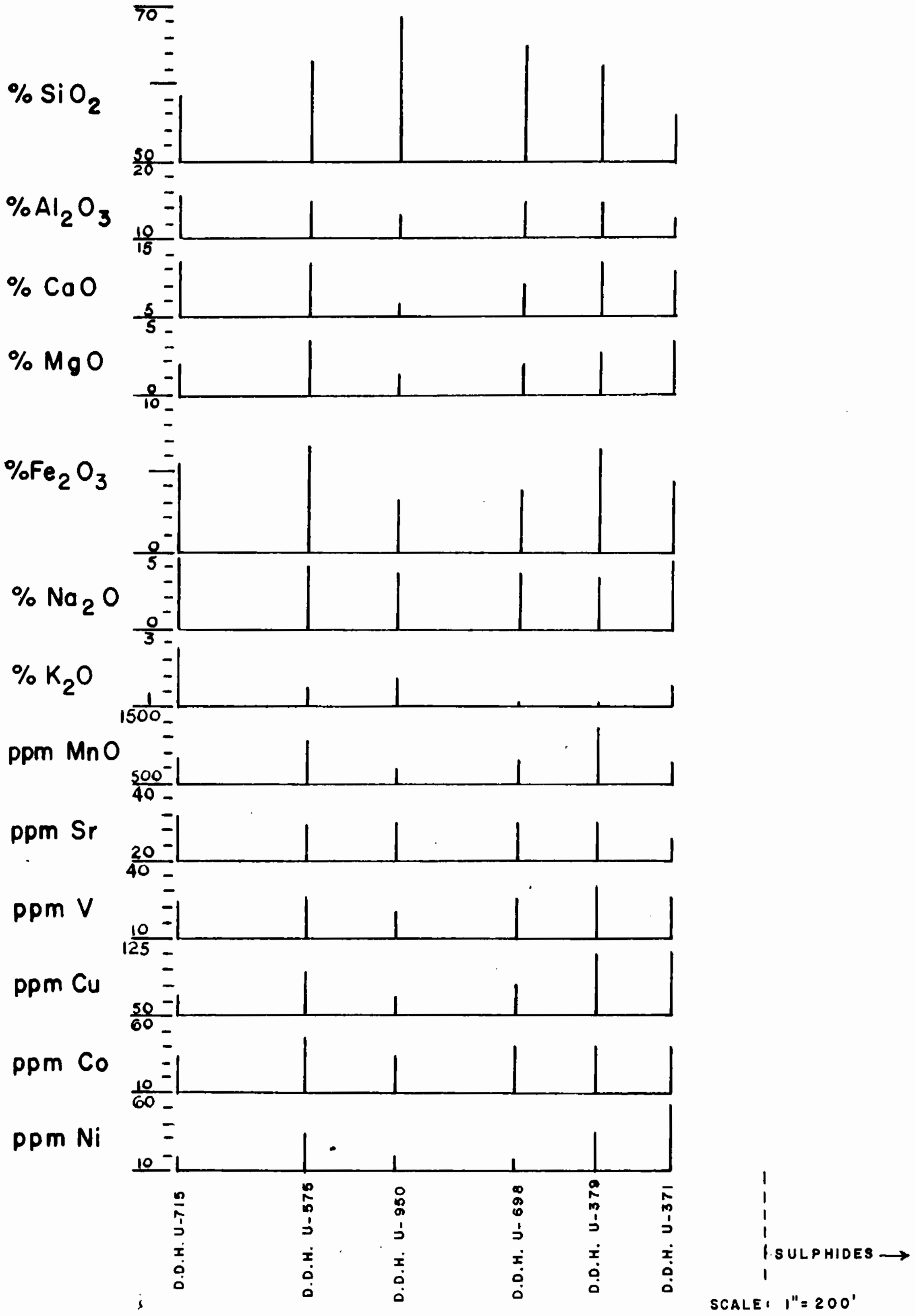


Fig. 26 CHEMICAL CHANGES ALONG PART OF A QUARTZ-FELDSPAR PORPHYRY DYKE TO THE WEST OF AN ORE ZONE, 550 LEVEL, WEST ZONE,

CAMPBELL CHIBOUGAMAU MINES LTD.

Chapter VII

DISCUSSION

General Statement

In the Doré Lake area, the alteration minerals present in the massive meta-anorthosite are also found in the altered wall-rocks of the sulphide bodies. Included in this suite of minerals are chlorite, zoisite, clinozoisite, quartz, sericite, and minor carbonates and pyrite. The occurrence of this mineralogical assemblage in both the massive rock and in the schist zones adjacent to sulphide ores raises the important question whether the alteration of the massive anorthosite resulted in the formation of local sulphide deposits, or, the formation of local sulphide deposits resulted in the widespread alteration of the anorthosite, or whether these were separate processes.

In this chapter, the writer reviews the chief features of the alteration products, and associated problems, occurring in both the massive rock and in the schistose rock near the ore zones, and discusses the different mechanisms that could have been instrumental in causing these chemical changes, particularly those indicated by the distribution patterns of the element shown in the previous chapter.

Section A: Alteration of the Anorthosite

The anorthosite at Chibougamau appears unique compared with anorthosites elsewhere. Anorthositic masses in Labrador, the Grenville province north of the St. Lawrence River, the Adirondack area of New York state, Fennoscandia, and in layered intrusives such as the

Stillwater Complex, Duluth gabbro, and the Bushveldt Complex are all relatively fresh. The anorthosite at Chibougamau is well altered, as described in an earlier chapter, and for this reason is unique among anorthosites.

The writer has attempted to compare the composition of some of the least-altered, massive rock with the average compositions given for anorthosite (Table X). It is important in making such comparisons to note that the writer's spectrochemical analyses are accurate only to about ± 10% of the amount of each element present.

Some 450 feet of drill core, comprising 5 samples, from drill hole T-7 (Map 8), and 800 feet of core (except dyke intersections), comprising 13 samples, from drill hole Q-190 (Map 3) were taken as representative of least altered meta-anorthosite in the area. The mean, maximum, and minimum concentrations are given for each of the constituents analysed. The mean compositions, except for Ni, Co, Cu, V, and Sr, are compared in Table X with average compositions of anorthosites given by Nockolds (1954, p. 1020).

Except for Al_2O_3 and MgO, the two average samples T-7 and Q-190 correlate better with the localized anorthosite of Nockolds than with anorthosite from massifs. They differ from both groups mainly in having 4 to 5 times the MgO content, lower alumina (1 to 9%) and much higher water.

The iron, magnesia, soda, nickel, cobalt, copper, and vanadium contents of sample Q-190 are substantially higher, and the alumina and strontium contents lower than in sample T-7. These differences are greater than a 10% analytical error, and may indicate that sample Q-190 was either a more gabbroic anorthosite or that these changes are due to metasomatism. On the basis of the analyses alone

TABLE X

Some Comparisons Of Compositions of Anorthosites

	T - 7			A.M.	A.L.	Q - 190		
	Mean	Max.	Min.			Mean	Max.	Min.
SiO_2	46.34	47.40	46.00	54.54	49.98	49.64	53.50	46.15
Al_2O_3	24.58	25.00	24.40	25.72	28.94	19.53	21.05	17.00
Fe_2O_3	2.95	3.33	2.48	*2.45	*2.39	7.27	9.65	6.25
MgO	3.42	3.78	3.18	0.83	0.84	4.37	4.95	3.85
CaO	15.11	16.25	13.90	9.62	14.01	12.41	14.90	9.75
MnO	0.060	0.071	0.050	0.02	0.07	0.096	0.145	0.082
Na_2O	2.51	2.58	1.70	4.66	2.73	3.84	4.65	2.65
K_2O	0.06	0.07	0.05	1.06	0.42	0.45	0.98	0.24
Ni	81	90	70			145	175	130
Co	36	40	30			73	85	55
Cu	33	45	25			58	120	35
V	15	10	15			25	45	20
Sr	49	50	45			36	40	20

T-7 - Average composition of 5 samples from 400' to 850'

Q-190 - " " " 13 " " 0' " 800'

A.M. - " " " 9 " of anorthosite
from massifs (Nockolds, 1954, p. 1020)

A.L. - Average composition of 8 samples of localized
anorthosite (Nockolds, 1954, p. 1020)

* Total iron expressed as Fe_2O_3

it is a reasonable assumption that both T-7 and Q-190 samples were originally closer to a gabbroic anorthosite than anorthosite.

Sections of massive meta-anorthosite whose compositions correspond reasonably well with sample Q-190 are shown in:

Figure 5 - beginning about 150 feet from the mineralized zone to the end of the drill hole.

Figure 6 - beginning at about 525 feet and continuing to the end of the drill hole.

Figure 7 - from the surface to about the 400-foot mark of the drill hole.

Figure 12 - from the surface to about the 600-foot mark of the drill hole.

Figure 13 - from the 500-foot mark to about the 800-foot mark of the drill hole.

No sheared, barren meta-anorthosite was found to have a composition similar to either T-7 or Q-190.

In general, the analyses of massive meta-anorthosite from Lake Chibougamau (Figures 1, 2, 3, and 4) show a closer correspondence with the average analysis of composite sample T-7 than with sample Q-190. This indicates that although anorthosite from Lake Chibougamau was slightly more gabbroic than normal anorthosite (Nockolds, 1954, p. 1020; Daly, 1933, p. 18), it was less gabbroic than the anorthosite on the north shore of Doré Lake at Quebec Chibougamau Goldfields.

Assignment of the regional alteration of the anorthosite to a particular process, or a combination of processes is admittedly a difficult task. However the examination of several possible processes is in order at the present time.

Deuteric Alteration

The writer uses the term deuteric alteration to mean the alteration of an almost completely crystallized magma by its own volatiles. In the Chibougamau anorthosite, it is conceivable that the aqueous or gaseous fraction of the basic magma did not escape after the crystallization of the feldspars and mafics was essentially completed. These fluids could have attacked and altered the newly-formed minerals at reduced temperatures to the mineralogical assemblages associated with the greenschist facies.

Deuteric alteration in anorthosites, even in mild forms, has not been proved, so far as the writer is aware. This does not however preclude the possibility that the Chibougamau anorthosite did indeed undergo deuteric alteration.

It is generally conceded that anorthositic magmas are lacking in water and other volatiles which are the active agencies in deuteric alteration. If the Chibougamau anorthosite was indeed a "dry" melt originally, then deuteric alteration must be ruled out. On this basis the writer finds it difficult to accept deuteric alteration as a possible mechanism for the regional alteration of the anorthosite.

Propylitization

The writer uses the term propylitization as defined in the A.G.I. Glossary* (p. 232): "The introduction of, or replacement by,

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*A.G.I. - American Geological Institute Glossary of Geology and Related Science.

an assemblage of minerals including carbonates, epidote, secondary quartz, and chlorites." This definition implies the addition of constituents, chiefly carbon dioxide, water, and other volatiles to the rock. In effect, propylitization can be considered a form of hydrothermal alteration.

If the Chibougamau anorthosite crystallized from a "dry" melt, as most anorthosites are believed to have done, then the later addition of carbon dioxide, water and other volatiles was necessary in order to alter the rock to the mineral assemblages of the greenschist facies now observed. The addition of these constituents to the anorthosite is a more likely possibility than their occurrence in an anorthositic magma.

In the process of altering the anorthosite, the water, carbon dioxide, and other volatiles must have moved through the rock. The rock must have had some permeability to allow the fluids to migrate through it. Anorthosites are usually coarse-grained rocks and, as such, would have spaces, admittedly small, between the grains. Other discontinuities around and across mineral grains would also permit the migration of fluids.

These fluids could have attacked and partly altered the calcic feldspars of the anorthosite to zoisite and clinozoisite. The pyroxenes and olivine could have been completely altered to chlorites. Excess calcium and silicon from the breakdown of the primary minerals could have formed the small amounts of calcite and quartz now present in the rocks. A small amount of potassium which is usually present in plagioclase feldspars could have contributed to the formation of sericite during the breakdown of the feldspars.

A source of these fluids is required. The underlying granite, or other source at depth, could have supplied the fluids which altered the anorthosite. Although there is little direct evidence that these fluids originated in the granite, or at greater depth, these sources are nonetheless the most logical. During the crystallization of the granite from a magma, or the formation of the granite by granitization of sediments, a sufficient amount of volatiles could have been introduced into the overlying anorthosite to bring about the observed changes in this rock.

Contamination of Anorthositic Magma

Another possibility for the alteration of the anorthosite is contamination of the anorthositic magma with constituents of rocks which it intruded. If the magma had invaded some sedimentary rocks, or other rocks containing water, and other fluids, these constituents could conceivably be incorporated in the magma and become available for deuteric alteration at a later stage.

This theory is, however, stretching the possibility of such an event taking place. In other areas in Canada and elsewhere there is little evidence of an anorthositic magma becoming contaminated with wall rock constituents. The large anorthositic bodies north of the St. Lawrence River have invaded sediments of the Grenville province with little evidence of contamination therefrom. Hence the writer is of the opinion that the anorthositic magma was not likely to have been contaminated by constituents of the rocks which it intruded.

It appears to the writer that hydrothermal alteration, from sources at depth, is the most feasible process by which the anorthosite was changed to the greenschist facies. The following theory is proposed to account for this alteration: A sill-like mass of anorthosite was intruded between volcanics above and sediments below. The presence of sediments is assumed rather than known; however the assumption is based on the common association of sediments and volcanics in the Superior province. During an orogeny, the sediments were granitized, releasing vast volumes of water and other gases which permeated the overlying anorthosite and altered it to the greenschist facies. The granitized sediments became mobilized and behaved as an intrusive into the anorthosite during regional folding.

The writer holds the opinion that the location of the Chibougamau anorthosite has an important bearing on the extent and intensity of its alteration. It is located near the boundary between the Superior and Grenville geological provinces. The fact that it is invaded by granite suggests that at least a mild orogeny occurred along this boundary.

It is unfortunate that so little work has been done on the Chibougamau granite to date. The writer feels that more structural, petrological, and chemical data on this granite should be acquired to provide evidence of its origin, not only to support or reject the above theory, but also to build up a fund of information on this important rock.

Section B: Alteration Associated with the Sulphide Deposits

The alteration minerals associated with the sulphide deposits are the same as those found in the massive meta-anorthosite. The degree of alteration is generally higher near the sulphide bodies than in the massive rock, but a higher degree of alteration is not always indicative of sulphide bodies in this area.

Problem of Silicification

In the variation diagrams in Chapter VI it is noted that there is a general increase in silica within barren schist zones, and an increase of silica in the walls, particularly the hanging walls of mineralized schist zones in the meta-anorthosite. Microscopic examination of rocks from these zones shows fine-grained quartz dispersed through the schists, and also occurring as veinlets, pods, and stringers in the schist. Little or no quartz occurs in the altered, massive meta-anorthosite. The silica content of the massive meta-anorthosite is in the order of 45% to 50%; in the barren schist zones and in the walls of mineralized schist zones it often approaches 60%.

This raises the problem of the source and mode of migration of the extra silica. It could have been removed from rocks through which the hydrothermal fluids passed, or it could have been derived from magmatic or other deep-seated sources. Either, or both sources, could have contributed this silica.

The silica content is lower in the mineralized schist zones and higher in the adjacent rocks. Hence the migration of some silica from the zone of mineralization into the wall rocks is strongly indicated. In the variation diagrams it is also noted that the increase of silica in the hanging wall of mineralized schist zones is frequently higher than in the footwall side. This indicates upward movement of silica, probably in solution, along the schist zone into the hanging wall.

In other areas in northwestern Quebec, silicification, to a greater or lesser degree, of wall rocks associated with ore deposits has been reported at the Noranda mine by Price (1953, p. 1464) and Riddell (1952, p. 205); the Normetal mine by Riddell (1952, p. 205); the Waite-Amulet mine - Waite section by Price and Bancroft (1948, p. 752), and the East Sullivan mine by Assad (1958, p. 95).

Problem of Chloritization

Chlorite is widely distributed throughout the meta-anorthosite but is frequently more abundant within, and adjacent to, schist zones containing sulphide deposits. Both magnesian and ferrian chlorites are found in the massive meta-anorthosite but ferrian chlorites appear more abundant in the schistose meta-anorthosite. However, Fe-rich chlorite is found in local concentrations in the massive rock as well. Segregations of iron-rich pyroxenes and/or olivines occurring within the anorthosite could have been converted to iron-rich chlorites. Hence the presence of ferrian chlorites in the meta-anorthosite need not be associated with sulphides.

The sulphide deposits at Copper Rand, Cedar Bay, Quebec Chibougamau Goldfields, and Campbell Chibougamau, all occur within, or adjacent to, chloritized sections of schistose meta-anorthosite. Jeffery (1959, p. 164) reports that Fe-rich chlorite may be found in the massive meta-anorthosite away from foliated and mineralized meta-anorthosite, and states,

> "Thus with respect to the wall rocks the writer concludes that chlorite is of little use as an ore-indicator."

Miller (1957, p. 126) concludes that,

> "Chlorite is the best ore-indicator alteration mineral

found at Cedar Bay. It should not be used alone; however it does form the main basis of the zone classification of alteration minerals."

The present writer, although not having studied microscopically the wall rocks as intensively as Jeffery and Miller did on the Campbell and Cedar Bay mines respectively, tends to share their view that chlorite alone has limited use as an ore-indicator, chiefly because it is widely distributed and therefore not an exclusive characteristic of the schist zones in which ore-bodies occur.

The chlorite in the schist zones appears to have formed chiefly by the replacement of zoisite and clinozoisite with the addition of iron, magnesia, and water. On a less intense scale, chlorite similarly replaces zoisite-clinozoisite in the massive rocks.

Other ore deposits in northwestern Quebec closely associated with distinctively chloritized wall rocks are Noranda (Price, 1948, p. 769; 1953, p. 1464); Normetal (Riddell, 1952, p. 96; Brown, 1948, p. 687); Aldermac (Hawley, 1948, p. 725); Quemont (Riddell, 1952, p. 116; Taylor, 1957, p. 413); Waite-Amulet mine - Waite section (Price and Bancroft, 1948, p. 752), and the East Sullivan mine (Cornwall, 1953, p. 23; Assad, 1958, p. 101).

Problem of Pyritization

Traces of pyrite are found associated with chlorite in the massive meta-anorthosite. Slightly greater amounts of pyrite occur within the schist zones, also closely associated with chlorite. The ore-bearing sulphides also contain varying amounts of pyrite.

Rankama and Sahama (1950, p. 746) give the sulphur content of anorthosite as 1000 gm./ton, i.e. - 0.1%. This amount of sulphur is equivalent to 0.18% pyrite, which may be interpreted as a trace amount. It is not known if the pyrite was originally present in the anorthosite or if it formed during the regional alteration of the anorthosite.

The slight increase of pyrite noted in the schistose meta-anorthosite could be attributed to the introduction of iron and sulphur either from the wall rocks or from underlying sources tapped by the shear zone. Sulphur, if introduced alone, could combine with iron in the chlorite to form pyrite.

The presence of pyrite is not a good indicator of ore in the area. Its distribution in the massive meta-anorthosite is too sparse to be of value. Within the schist zones the pyrite is distributed chiefly in the chloritic zones as individual grains and as small aggregates. The pyrite abundance shows a definite increase usually only a few feet from the ore itself.

Problem of Sericitization

In the Dore Lake area, sericite is a common constituent occurring in minor amounts in the massive meta-anorthosite. This sericite probably formed during the regional alteration of the anorthosite. The potash required for the formation of the sericite could have been derived in part from the small potassium content usually present in plagioclase feldspars, and in part from outside sources. Around the sulphide deposits there is usually some enrichment in sericite, found generally amongst the chlorite.

Frequently the sericite content is higher in the hanging wall of a mineralized zone than in the footwall.

The main problem of sericitization near the ore deposits is the source of potash. It could have been driven out of the zone now occupied by sulphides, into the wall rocks, or it could have been brought in by fluids preceding or accompanying the emplacement of ore. Another possible source of potash is the meta-anorthosite adjacent to the schist zones. A loss of a few ppm of potassium from a sufficient volume of meta-anorthosite nearby could account for the higher potash concentration around the ore-zones.

Within mineralized sections of schist zones the potash content is very low, frequently zero, while the walls, chiefly the hanging walls, are enriched in potash. This relation implies removal of potash from the mineralized section and redeposition chiefly in the hanging wall. The amount of sericite concentrated in the hanging wall is usually small, in the order of 5%. Sericitization, although present near the ore, is not a characteristic feature of wall rock alteration in the area. Sericite is generally a less characteristic mineral formed during the alteration of basic rocks such as anorthosite.

Problem of Carbonatization

Some enrichment in carbonates, particularly calcite and siderite, is noted near the ore deposits at Campbell Chibougamau, Quebec Chibougamau Goldfields, Cedar Bay, and Copper Rand. The carbonates are closely associated with chlorite and frequently show a schistosity which may be original, or inherited from the chlorite they replace.

At the Chibougamau Jaculet No. 2 deposit, siderite bodies contain most of the sulphides. Carbonatization, or more specifically, sideritization is more evident in the Jaculet deposit than in the others investigated. The carbonates in the Jaculet deposit are manganese-rich also, so it may be inferred that at the time of rock alteration and ore deposition the constituents introduced included iron, manganese, and carbon dioxide.

In the variation diagrams it is evident that the lime content of the mineralized sections within schist zones is usually very low. It is conceivable that carbon dioxide from the ore-bearing fluids, or other sources, could have removed calcium from such zones and redeposited it as carbonate in the wall rocks.

Near the ore, the carbonates occur as replacement veinlets, pods, and larger bodies in the chlorite. In the massive rock, calcite occurs as individual grains and small aggregates in the chlorite and clinozoisite.

Carbonatization of the rocks is not a good indicator of ore because its effects are limited to short distances, often a few feet from the ore. In places such as Chibougamau Jaculet, the Machin Point Zone of Copper Rand, and the Copper Rand No. 1 shaft area, the sulphides are present within sideritic masses.

The Soda Problem

In some variation diagrams in the previous chapter it is evident that an increase of soda occurs in some schistose sections, and near the sulphides in others. However, the minerals in which this soda may be contained are unknown. Some paragonite, a sodic mica, may be present amongst the sericite, but it is difficult to distinguish microscopically from sericite which itself is dispersed through the chlorite. One occurrence of fresh albite was found in the altered wall rocks, in the "black" dyke at Cedar Bay.

Problem of Mineralogical Identification

Specific alteration minerals are a characteristic feature of many different ore deposits the world over as has been well summarized recently by Schwartz (1955, 1959). The detection of mineralogical changes in the wall rocks of a given ore deposit is frequently a long study in itself. The separation of these minerals on a quantitative basis in order to establish some sequence of geological events and/or zones of alteration is often a difficult task when the petrographic microscope is the only tool used. A combination of techniques is a better approach.

The work of Sales and Meyer (1948) on the Butte deposits is an example of the use of a combination of techniques in the studies of mineralogical changes in the wall rocks, - x-ray diffraction studies, differential thermal analysis, and specific gravity determinations, in addition to microscope work.

Another technique which can be used is infrared spectroscopy. Lyon, et al, (1959) report the successful quantitative determination of some minerals commonly found in altered wall rocks using an infrared spectrophotometer and concluded (p. 1053) that,

> "In particular the alteration minerals - kaolinite, alunite, sericite, jarosite, albite feldspar and chlorite - are very sensitive to infrared analysis."

Some such technique, or preferably a combination of techniques, is needed to assist in distinguishing more clearly between the fine-grained alteration minerals, and to avoid the subjective element frequently present in microscope work.

With respect to the Dore Lake area, the writer is forced to the conclusion that microscopic distinctions between the minerals formed during the regional alteration of the anorthosite, and those formed by alteration accompanying ore deposition are insufficient to deduce mineralogical trends toward the ore deposits. Although some minerals such as actinolite, chloritoid, and apatite are often present in the gangue, their distribution is too limited to be used as ore-indicators. The apparent increases of chlorite, sericite, and quartz near the ore deposits have more significance when supplemented by spectrochemical, or other, analyses of the rock.

As pointed out in the previous chapter, the distribution patterns of Si, Na, K, Ca, Sr, Mg, Mn, Fe, Co, and Ni can be used as indicators of sulphide deposits. The distribution patterns for these constituents were established horizontally toward known sulphide zones. In view of the fact that alteration halos are frequently three-dimensional features, it would be interesting to test these distribution patterns vertically along a shear zone toward a known sulphide deposit at depth.

SECTION C: Migration of Constituents

In this section an attempt is made to deduce some of the conditions which existed during the alteration of the massive anorthosite, the schistose anorthosite, and during the formation of the sulphide deposits. From postulated conditions during these events, some inferences are drawn as to the mechanisms which could have been operative in the migration of some constituents.

Conditions During the Alteration of the Massive Anorthosite

The anorthosite of the area has been altered to the mineralogical assemblage commonly associated with the greenschist facies. This implies a lower temperature limit of about 300° C. (Fyfe, et al, 1958, p. 218) for the formation of these alteration minerals. There is little evidence that the alteration of the anorthosite extended into the amphibolite facies, the temperature of which Ramberg (1952, p. 156) concluded rarely exceeds 400° - 500° C. Hence it appears probable that the anorthosite was altered in a temperature range from 300° C. to about 400° C. Most of the heat required for this alteration is thought to have been added from the same source as the fluids, that is, the granite.

The pressure conditions at which the alteration of the anorthosite occurred are somewhat more difficult to estimate. According to Fyfe, et al (1958, p. 183, Fig. 77), a minimum depth of 10 kilometers, corresponding to pressures in the order of 4 kilobars is postulated for the formation of the greenschist facies.

As noted earlier, the present water content of the meta-anorthosite is in the order of 3.5%. This indicates that at least this amount of water was present during the alteration processes.

Conditions During the Alteration of the Schistose Anorthosite

As noted previously, the alteration minerals in the schist zones, with the exception of actinolite and chloritoid, are the same as in the massive rock. However the alteration in the schist zones is usually more intense, and more hydrous minerals such as chlorite are present.

An upper temperature limit for the stability of actinolite is generally accepted at about 500°, although the temperature of formation of this mineral may be considerably lower. Hence it is a reasonable assumption that the temperature during the alteration of the shear zones also did not exceed 500° C., indeed, it could have been somewhat lower.

Within a shear zone, or other physical discontinuity in the rock, the pressure would normally be less than in the massive rock. This difference in pressure is an important condition which will be discussed more fully later.

The abundance of hydrous minerals present in the shear zones is one of the striking features of these zones in the Doré Lake area. The abundance of hydrous minerals proves that water and other fluids were present in large volumes at the time of alteration of the shear zones.

Conditions During the Formation of the Sulphide Deposits

The close association between the sulphide minerals in the schist zones and the hydrous mineral assemblages present in the gangue and wall rocks suggests that similar pressure-temperature conditions prevailed during the formation of the sulphides and the alteration minerals. Admittedly the formation of the sulphides could have been in part contemporaneous with, and in part later than, the formation of the associated alteration minerals. However this does not preclude the possibility that the physical conditions during the formation of the sulphides and the alteration minerals were similar. In addition to similar pressure and temperature conditions, there was in all probability a large volume of water and other fluids moving along the schist zones during the formation of the sulphides.

Possible Mechanisms Involved in the Migration of Elements

I In Massive Anorthosite

Recent studies on the migration of elements in the metamorphic rocks in the northwest Adirondack mountains by Engel and Engel (1958) show that little mobilization occurs at temperatures below 550° C., but that mobilization and migration is well defined at temperatures of 600° C. and higher. The high temperatures are associated with high-grade metamorphism.

Shaw (1954, p. 1161), in a study of the migration of constituents of pelitic rocks in New Hampshire, found that, except for lithium, there is no significant difference in composition between rocks of low- and medium-grade metamorphism. In high-grade metamorphic rocks (containing sillimanite) he found that some migration of the elements, particularly of lithium and lead, did occur. However, the increase in lithium may be attributed to potash metasomatism from a nearby intrusive of monzonite.

The results found by these investigators suggest that high temperatures in the order of 500° C., and greater, are needed for the mobilization and migration of many elements under metamorphic conditions. This may be the case if water, or other fluid, was absent from the rocks, and other factors did not promote migration.

In the Chibougamau anorthosite there is no evidence that temperatures exceeding 500° C. existed at the time of alteration. On the contrary, the hydrous mineralogical assemblage of the greenschist facies indicates temperatures between 300° C. and 400° C. at the time of alteration. It is doubtful if migration of elements in the alteration of the anorthosite occurred as a response to these low temperatures alone, that is, by solid diffusion under a temperature gradient. This does not however mean that solid diffusion is not an operative process, but distances over which it would work in this case would probably be very short. It is not likely that the entire anorthositic mass at Chibougamau was altered by solid diffusion.

It appears that hydrothermal alteration is the only tenable explanation for the alteration of the anorthosite. Although the transportation of large amounts of material could be accomplished efficiently by hydrothermal solutions, it is difficult to visualize large volumes of aqueous solutions percolating through massive rock.

A more tenable explanation for the migration of constituents during the alteration of the massive rock is the movement of ions in a fluid medium under a moderate temperature gradient. The fluids themselves would also tend to migrate under a temperature gradient, and towards zones of lesser pressure. One may picture the intergranular spaces, and other discontinuities (cleavage planes, microfractures, and twin planes of crystals) filled with hot fluids, chiefly water and other volatiles. This fluid need not be actively mobile, but may simply serve as a medium in which ions may move. In such a medium,ionic replacements in minerals may be readily accomplished without recourse to actively moving fluids. This process is ionic diffusion through a fluid medium filling the spaces in the rock.

Experimental work by Gillingham (1948), Kennedy (1950), and Morey (1957) has demonstrated that silica, potash, and soda are readily soluble in steam at supercritical temperatures and pressures, and may be transported in this medium. Gillingham (1948) also concluded that the rate of transfer of silica from quartz is lower than the rate of transfer from a silica gel.

The present writer holds the opinion that the alteration of the anorthosite at Chibougamau was accomplished chiefly by ionic diffusion through a gaseous medium which filled all the available spaces in the rock and its minerals.

II <u>In Sheared Anorthosite</u>

The abundance of hydrous minerals in the schist zones is strongly indicative of hydrothermal alteration in these places. The alteration minerals in the shear zones are similar to those in the massive rock. Some actinolite and chloritoid, absent in the massive rock, occur within gangue material in sulphide zones in parts of schist zones.

It is quite probable that the chemical changes observed in the schist zones were the result of migration of elements under hydrothermal conditions. Bodily transport of elements in solution along channelways of the shear zones is a more efficient mechanism than ionic diffusion through a fluid. However, mechanical transport of elements in solution does not preclude the movement of ions through that solution also.

On the basis of similar alteration mineral assemblages in both the massive rock and in the sheared zones, the writer makes the assumption that these changes occurred at about the same time and were created by similar factors.

Earlier the writer stated the argument that ionic diffusion through a fluid medium was instrumental in altering the massive rock. One may picture what would happen if these fluids, under high pressure in the massive rock, suddenly entered the comparatively open spaces of a shear zone. Under reduced pressure of such zones the fluids would tend to become supersaturated and then might precipitate some material which would result in the formation of new minerals such as quartz, sericite, chlorite, and carbonates. This appears to be a logical explanation for the formation of the increased abundance of these minerals in barren schist zones.

While some secondary minerals were forming in a schist zone, there no doubt was an upward movement of fluids along the schist zone. Such an upward movement of fluids could carry in solution (gaseous or liquid) some of the constituents which had not gone into the formation of new minerals. These constituents could be precipitated as new minerals higher up in the shear zone. Such appears to be the case for silica, potash, and to some extent soda, more particularly in the hanging wall than the footwall of a well-mineralized shear zone.

These remarks should not carry the implication that all the fluids migrating up a shear zone were derived from the fluid content of the massive rock. In part these may have been derived from a source at depth, tapped by the shear zone, possibly the same source from which the fluids permeated the massive rock.

The information supplied from analyses permits a few deductions to be made on the nature of the hot fluids that apparently transported materials along the shear zones. Well-altered and mineralized shear zones are low in lime, potash, and soda. This indicates the removal of these constituents and implies that the resulting fluids were alkalic. Removal of Si from a mineralized part of a shear zone is more readily accomplished by alkalic solutions than acidic. The fact that silica was precipitated in the walls suggests that the pH of the solution may have been reduced. Reduction of the pH of this solution may have been accomplished by reaction with the wall rocks, or by local mingling with neutral or acid solutions. From the abundant chlorite present in the well-altered shear zones it may be inferred that the fluids were rich in ferrous iron and magnesium. To account for the pyrite present in some well-altered shear zones, some sulphur was undoubtedly present in the fluids. In summation it appears that the hot fluids which altered the schist zones were alkalic, rich in ferrous iron and magnesium, and contained sulphur. The concentrations of these constituents could have varied with time in the migratory processes. Changes in pressure, temperature, and chemical composition along the paths travelled by these alkalic fluids were probably effective in either the dissolution of old minerals or in the precipitation of new ones.

The close association between the sulphides and the hydrous alteration minerals in the schist zones carries the implication of a close time relation for the origin of the two. Many sulphide bodies the world over are also closely associated with abundant hydrous alteration minerals as has been well summarized by Schwartz (1955, 1959). It is difficult to separate the processes that formed the hydrous mineral assemblages from those that formed the sulphide minerals.

Source of Sulphides

A source is required for both the sulphur and the metals Fe, Cu, Ni, Co, Zn, V, Pb, and others found in trace amounts in the mineralized zones. A possible source of these constituents may have been the anorthosite, or the underlying granite or other intrusive mass, or a combination of these.

As pointed out earlier, the sulphur content of anorthosite is given by Rankama and Sahama (1950, p. 746) as 100 gm/ton, i.e. - 0.1%. Removal of some of this sulphur from a large enough volume of the anorthosite at Chibougamau by ionic diffusion and/or bodily transport could conceivably satisfy the requirements of the sulphide minerals present. Similarly Cu, Fe, Ni, Co, Zn, Pb, and V, if concentrated from a large enough volume of rock, could account for the higher content of these metals in the ore zones. Successful appeal to the wall rocks as a source of metals commonly depends on the volume of rock chosen to supply these metals - the larger the volume of rock, the more adequate the supply.

Boyle (1959, p. 1519, Table 4) gives calculations to show that relatively small concentration factors were needed to supply the metals and sulphur from the Giant-Campbell shear system into the orebodies contained therein. However he assumes that the ore constituents moved up from a depth of 3 miles along the shear system, whereas the ore bodies have been proved to comparatively shallow depths (less than 2,000 feet).

If the metals now present in the ores originated in the wall rocks, these rocks should now show a deficiency of these metals in the vicinity of the ore zone. This in fact is the case for nickel and to a certain extent for cobalt in the Bouzan-Royran shear zone (Figure 5, Chapter VI).

In the Bouzan-Royran shear zone the nickel content decreases by about 25 ppm on both sides of the sulphide zone for a distance of 75 feet (Figure 5). The cobalt decrease is about 15 ppm across the same distance. The decreases noted are relative to the present nickel-cobalt content of the meta-anorthosite hundreds of feet from the ore zone. The original nickel-cobalt content of the fresh anorthosite in the same place is unknown.

In the section shown in Figure 5, the removal of 25 ppm Ni across a distance of 75 feet in both the hanging wall and footwall accounts for about one-half of the nickel increase in the mineralized section above the 100 ppm Ni background level in the meta-anorthosite. The removal of 15 ppm Co across the same distance as Ni accounts for about one-eighth of the Co increase in the mineralized section above the 100 ppm Co background level in the meta-anorthosite.

On the other hand, the copper content of the Bouzan-Royran shear zone increases toward the mineralized section therein. This suggests migration of copper from the zone of deposition outward into the wall rocks.

The underlying granite might well have supplied all of the metals except those parts that have obviously been removed from the wall rocks of the shear zones. During the emplacement of this granite there undoubtedly were large volumes of fluids, and probably some metals given off into the overlying anorthosite. These volatiles and their content of metals would have sought zones of easy passage such as shear zones and other fractures in the anorthosite. These events are postulated according to the hydrothermal theory of a magmatic source of ores. However the formation of granite by granitization could also produce such an escape of fluids and metals into the overlying rock. The granitic source for most of the metals and sulphur in the ores, in the writer's opinion, is the most logical.

It is difficult to determine how much metal was contributed to the ores by the wall rocks, and how much by a magmatic source. As Hawley (1956, p. 15) expressed it:

> "There are also indications that either metamorphic processes or metamorphic products may contribute to or contaminate primary magmatic ore fluids rising from great depths, but it is not clear how a distinction may be drawn between them."

Migration and Deposition of the Sulphide Ores

The mechanisms by which ore constituents migrate from their source, or sources, and their mode of deposition have been subjects of much debate over the decades. The literature on these matters is so voluminous that only skeletal ideas can be mentioned here.

With respect to the sulphides in the Dore Lake area, the field of debate is narrowed considerably by the fact that the ores are hypogene, and in the writer's view, the reasonable assumption that their source was in part the anorthositic wall rock, and in part magmatic, probably mostly magmatic.

From the fact that some sulphides, particularly pyrite, are found replacing secondary minerals such as chlorite and carbonates, it is suggested that the formation of the sulphides was a continuation of the hydrothermal replacement process. Early-formed minerals were replaced by later minerals.

It was deduced earlier that the fluids active in altering the schist zones were rich in alkalies, iron, magnesia, and probably contained some sulphur. The formation of the sulphides was in part contemporaneous with, and in part later than, the hydration of the wall rocks. From this association one may infer that the ore-forming fluids were also alkaline, rich in iron, magnesia, and probably contained sulphur.

How do ore-forming fluids arrive at the sites of deposition? Fenner (1940) expresses the view that transfer of ore constituents in the gaseous state is an important mechanism. Graton (1940) supports the traditional hydrothermal theory whereby ore constituents are transferred in solution. Garrels (1944) in a critical review of possible mechanisms concluded that:

1) Dilute and weakly dilute acid solutions are not capable of carrying metals.

2) Transport as alkali sulphide solutions is feasible but such solutions cannot carry iron.

3) Metal sulphides are probably transported in a dispersed solid state.

Boyle (1959) attempts to explain the origin and migration of gold and sulphide minerals at Yellowknife by gaseous transfer from the wall rocks into dilatant zones such as the Giant-Campbell shear zone.

The distribution patterns of Cu, Ni, Fe, and Co, shown in Chapter VI in this thesis do not show many clues as to the mode of transfer from source to site of deposition. Earlier it was inferred that the ore-forming fluids were alkaline, rich in iron, magnesium, and contained sulphur. It is probable that the fluids which altered the schist zones became ore-forming fluids by the addition of sulphur and some ore metals. The ore-forming fluid phase may be thought of as a continuation of the hydrothermal alteration phase.

By further inference, the metals and sulphur could have been mechanically transported with the fluids (gaseous or liquid) and they could also have moved to a degree through the fluids by ionic diffusion. Another possibility is that the metals were transported into the shear zones early, in the alkaline fluid phase, and the sulphur could have been introduced later and then combined with the metals to form sulphides. Yet another possibility is that the sulphides were transported as finely divided solids dispersed through the ore-bearing fluid and later coagulated and recrystallized, leaving no clue as to their mode of transport.

Deposition of the sulphides appears to have been favored by dilatant zones such as flexures along dykes within shear zones. From this relation it is inferred that reduced pressure, and probably temperature were important factors in the formation of the sulphide zones.

A Note on Possible Ca-Sr Separation

An interesting point has arisen from the spectrochemical analyses of the meta-anorthosite with respect to the distribution of calcium and strontium. The variation diagrams in Chapter VI frequently show that strontium does not follow calcium as closely as might be expected in view of the chemical similarity of these elements.

In Figure 5 it is noted that calcium is depleted across a greater section of the schist zone than is strontium. In other sections, a similar, or reverse, discrepancy is noted. This implies a partial separation of strontium from calcium under hydrothermal conditions. The differences are too consistent across mineralized sections to be attributed to analytical error.

The writer checked the accuracy of the addition method of preparing the Sr standards against the Sr content of G-1 (236 ppm) and W-1 (180 ppm). The x-ray technique used by the writer gave the Sr content of these standard rocks as 195 ppm for G-1, and 165 ppm for W-1.

The addition method gave results from 10% to 15% too low. However this analytical error cannot account for the apparent independent behaviour of strontium, nor for the consistently low Sr values in the massive meta-anorthosite.

The strontium content of the massive meta-anorthosite ranges from 50 to 80 ppm, rarely to 100 ppm. This is considerably lower than the strontium content of anorthosites elsewhere. Turekian and Kulp (1956) give a figure of about 1000 ppm Sr for Adirondack anorthosite (p. 252) and 481 ppm Sr for anorthosite from the Duluth gabbro (p. 253).

If in the Doré Lake meta-anorthosite the observed separation of Sr from Ca is real, then it may have an interesting bearing on the behaviour of these two elements under hydrothermal conditions. Turekian and Kulp (1956, p. 290) found that strontium in schists is independent of calcium and state that,

> "There is no correlation of Sr with Ca, as in the case of the granites; evidently the metasomatism and metamorphism was not adequate to allow mass migration and consequent attainment of equilibrium ratios of Sr/Ca."

In granites, Turekian and Kulp (1956, p. 276) found that the strontium content increases as the calcium content increases. They found the reverse relation in basic rocks such as the Stillwater Complex, Montana (p. 270). Wager and Mitchell (1951, p. 194) found that the strontium content of plagioclase in the Skaergaard intrusion increases from labradorite An60 to andesine An37.

The conclusion seems to be that in basic and metamorphic rocks the strontium content varies independently of the calcium content. In the Chibougamau meta-anorthosite, strontium varies also independently of calcium. Perhaps a closer investigation of the Sr/Ca divergence in schistose meta-anorthosite at Chibougamau will yield results which may be useful in searches for ore.

Chapter VIII

SUMMARY

The copper-gold ore deposits in the Chibougamau district are found chiefly in the meta-anorthosite member of the Dore Lake complex which was a sill-like mass intrusive into volcanic rocks. The basic magma of this intrusive formed, by differentiation, an anorthositic base grading toward a gabbroic top. Structurally and lithologically this intrusive is similar to other stratiform, igneous masses such as the Duluth gabbro and the Stillwater Complex. The Doré Lake Complex has been anticlinally folded about a northeast axis. The central part of the fold is now occupied by intrusive, soda-rich granite which is similar to sodic intrusives closely associated with ore deposits elsewhere in northwestern Quebec and northern Ontario. The time relations between the folding and the faulting of the anorthosite have not yet been established but these events may in part have been contemporaneous.

The rocks of the Doré Lake Complex have been extensively altered so that the terms meta-anorthosite and meta-gabbro are more appropriate. The process by which these rocks have been altered appears to be ionic diffusion through a fluid medium which filled all spaces in the rock and minerals. The anorthosite now consists chiefly of zoisite, clinozoisite, epidote, chlorite, and a few remnants of sodic feldspars.

Two sets of faults are dominant in the area, one set trending northeast, the other to the west-northwest. The northeast-trending set of faults, to which the Dore Lake-McKenzie Narrows fault belongs, are of a regional nature (Norman, 1948), have displacements measured in thousands of feet, and appear to be related to movements along the so-called Grenville front. Numerous northwest to west-trending faults occur mainly in the meta-anorthosite, and contain most of the sulphide deposits found to date in the area. The age relations between these two sets of faults have not yet been definitely established.

The ore deposits frequently occur adjacent to pre-ore dykes, the compositions of which range from acidic to basic. These dykes appear to have been emplaced roughly parallel to the schistosity of the shear zones after most of the movements along the shear zones had ceased. Concave flexures along these dykes seemed particularly favored as sites for ore deposition.

The sulphide minerals of the ore deposits are pyrite, pyrrhotite, chalcopyrite and minor sphalerite and galena. Associated with the sulphide minerals are minor magnetite, arsenopyrite, gold, silver, and locally valerite. The gangue minerals are chiefly chlorite, quartz, calcite and other carbonates, epidote, and locally actinolite and chloritoid. The close association of the ore minerals with the hydrous gangue minerals and the wall rock alteration minerals suggests a hydrothermal origin for all three.

From the facts available on the rocks and sulphide deposits in the Dore Lake area the following sequence of geological events seems tenable:

1) Intrusion, into volcanic rocks, of a basic magma which differentiated into a sill-like, layered complex, anorthositic near the base, and gabbroic toward the top.

2) Folding of the sill-like complex into an anticline about a northeast axis as part of the regional folding. Folding of the complex may have been accompanied by:

   a) cross-faulting in a northwest to west direction.

   b) intrusion of the granite.

3) Possible hydrothermal alteration of the anorthosite by fluids from the granite.

4) Formation of northwest to west-trending shear zones subsidiary to the formation of the Doré Lake fault, the direction of which is northeast.

5) Possible intrusion of the granite accompanied by alteration of the shear zones.

6) Intrusion of dykes, ranging in composition from acidic to basic, along many shear zones. The acidic dykes may be genetically related to the granite.

7) Renewed movements along the shear zones accompanied by, and succeeded by, further hydrothermal alteration and the formation of sulphides and gangue minerals. Flexures along dykes and other dilatant zones were favored loci of ore deposition.

8) Strong movement along the Doré Lake fault zone, probably in connection with regional movements along the Grenville front.

It should be noted that the granite could have been emplaced during either event 2, or event 5.

Spectrochemical analyses of what is considered least-altered meta-anorthosite from Lake Chibougamau show that this rock was probably either slightly gabbroic originally or that magnesia and lime were introduced into it later. Least-altered rock from the north shore of Doré Lake at Quebec Chibougamau Goldfields is higher in iron and magnesia and lower in alumina than normal anorthosite, thus indicating that this rock was originally a gabbroic anorthosite. On the basis of present compositions the rock on the north shore of Doré Lake is closer to a gabbroic anorthosite than the rock in Lake Chibougamau.

Spectrochemical analyses of meta-anorthosite show that in the early stages of alteration within a northwest to west-trending shear zone there was frequently an increase of silica, potash, soda, lime, iron, and manganese. Increasing alteration accompanied by sulphide mineralization in a shear zone is characterized by an increase of iron, magnesium, nickel, cobalt, copper, and frequently vanadium, and a decrease of lime, soda, potash, strontium, and silica. These increases and decreases are relative to the massive rock. Across a well-mineralized section, lime, soda, potash, and strontium are nearly absent. Frequently, lime is depleted across a greater section than strontium, although in some cases the reverse is true. Potassium and silicon show a well-defined tendency to migrate into the hanging wall of a mineralized shear zone.

The mineralogical changes which express the chemical changes in the early stages of alteration in a shear zone and in walls of mineralized zones are the formation of quartz, sericite, carbonates, chlorite, pyrite, traces of albite and probably paragonite.

Chlorite is the most abundant mineral in these places. Quartz occurs as individual grains, and as pods, veinlets, and lenses in the chlorite. Sericite is fine grained, intimately associated with chlorite, and is commonly difficult to identify microscopically. Carbonates (calcite, siderite, and manganosiderite) occur as grains, aggregates of grains, veinlets, lenses, and larger bodies replacing chlorite. In some localities, particularly Chibougamau Jaculet, and Quebec Chibougamau Goldfields, sideritic masses (often Mn-rich) are closely associated with sulphide bodies.

In the acidic and basic dykes associated with sulphide bodies, the chemical and mineralogical changes are similar to those in the schistose meta-anorthosite. Adjacent to sulphide bodies, the dykes have commonly become enriched in Fe, Mg, Mn, Ni, Co, and Cu, and deficient in Si, K, Ca, Na, and Sr.

From the alteration mineral assemblage it is inferred that silicification, chloritization, sericitization, carbonatization, and pyritization were active processes preceding and accompanying the emplacement of the main mass of sulphides. These processes imply the migration of Si, K, Ca, Na, Fe, Sr, Mg, Mn, Ni, Cu, Co, and S.

The writer holds the opinion that within the shear zones the migration of these elements was accomplished by transport in moving fluids as well as ionic diffusion through the fluid medium. If some of these elements were derived from the wall rocks, ionic diffusion through fluids which saturated the rock appears to be a tenable explanation for their migration. The ore-forming fluids were probably alkaline, rich in Fe, Mg, Cu, and S. The formation of the sulphide ores occurred in dilatant zones where conditions of reduced pressure and probably temperature were important factors in the precipitation of the ores.

Iron-rich chlorite is commonly found as a gangue mineral and also in the wall rocks of mineralized schist zones. However, iron-rich chlorite is also found locally in the massive meta-anorthosite, so that it alone is not a reliable guide to ore. Taken as a group, chlorite, sericite, and secondary quartz are better mineralogical guides to ore within altered schist zones. Chemical differences in the wall rocks are easier to detect than mineralogical differences, and should be used to supplement mineralogical studies in searches for ore.

Conclusions

I Conclusions based on spectrographic studies:

1) Massive meta-anorthosite on the north side of Doré Lake is more gabbroic than in Lake Chibougamau. The meta-anorthosite in Lake Chibougamau is in turn slightly more gabbroic than normal anorthosite. These conclusions are based on the present chemical composition of least-altered rock in the two localities.
2) Most of the acidic dykes in the area are soda rich and could be genetically related to the sodic Chibougamau granite.
3) Three relative stages of hydrothermal alteration can be correlated with chemical changes found in different shear zones:

   Class I Shear Zone - an early stage of alteration characterized by an increase of silica, potash, iron, manganese, cobalt, and nickel, and a decrease of alumina, lime, magnesium, sodium, and strontium.

   Class II Shear Zone - a more advanced stage of alteration characterized by an increase of iron, nickel, cobalt, copper, manganese, potash, and commonly magnesia. Silica and potash show a tendency to migrate into the walls of a shear zone at this stage. The lime, soda, and strontium contents decrease.

Class III Shear Zone - (alteration accompanied by sulphide mineralization). This class of shear zones is characterized by a continued increase of iron, magnesia, manganese, copper, cobalt, nickel, and vanadium. Silica and potash show a well-defined tendency to migrate into the hanging wall of the sulphide zone. The mineralized section is depleted in lime, soda, silica, potash, and strontium.

4) Increasing alteration in schistose meta-anorthosite, and in acidic and basic dykes is marked by an increase of iron, manganese, nickel, cobalt, copper, and commonly magnesia.

5) The nickel-cobalt content of the meta-anorthosite is sufficient to supply some of the nickel-cobalt now present in the sulphide zones. A possible mechanism for the removal of some of these metals from the wall rocks could have been ionic diffusion in a hydrous fluid which filled all the available spaces in the rock.

Postulates

1) The ore-forming fluids were probably rich in alkalies, Fe, Mg, Cu, and S. Some metals and sulphur could have been derived from the wall rocks. More probably, the metals and volatiles were derived from a magmatic source at depth, possibly the granite.

2) Ore-forming fluids migrating up a shear zone could have become contaminated with nickel, cobalt, and other constituents from the anorthosite.

II Conclusions based on spectrographic and mineralogical studies:

1) The processes of silicification, chloritization, and pyritization were active preceding and accompanying the introduction of ore. Increasing effects of these processes within shear zones are reasonable indications of proximity to pyrite-chalcopyrite bodies. Sericitization was generally weak, compared with the other processes.

2) Sericite and secondary quartz, chiefly in the hanging walls of mineralized shear zones are evidence of mobility of potash and silica, probably from the mineralized sections which are low in these constituents.

3) The alteration mineral assemblage in the massive meta-anorthosite is the same as in Class I shear zones and in the walls of Class III shear zones.

4) It is difficult to determine, with the microscope alone, quantitative mineralogical trends toward known ore zones, and even more difficult toward altered but barren schist zones. Other tools such as infrared spectrophotometry, X-ray diffraction techniques, and differential thermal analysis would be more useful than the microscope alone in identifying fine-grained alteration minerals.

5) The "Black Schist" at Quebec Chibougamau Goldfields is indistinguishable chemically and mineralogically from shistose and altered meta-anorthosite.

STATEMENT OF CONTRIBUTION TO KNOWLEDGE

This thesis represents the first extensive spectrochemical investigation of rocks associated with sulphide deposits in the Chibougamau district, Quebec. This work supplements the detailed structural, petrological, and mineralogical studies carried out by Jeffery (1959) on the Campbell mine and by Miller (1957) on the Cedar Bay mine, and the work of Raychaudhuri (1959) on trace element distribution in some sulphide ores of the area.

Spectrographic methods of silicate analyses, adapted from Jaycox (1947, 1957), were tested and used on the JACO spectrograph in the Department of Geological Sciences, McGill University. The standards and working curves developed by the writer for the analysis of major and minor constituents of rocks can be used with little or no modification by other investigators on similar projects using the same spectrograph.

This study has shown the following:

1) Distribution patterns of 13 elements of the rocks with respect to the ore zones, - Si, Al, Fe, Mg, Ca, Na, K, Mn, Sr, Cu, Co, Ni, and V. The distribution patterns of some of these constituents, shown in the variation diagrams in Chapter VI, may be useful guides in searches for new ore deposits in the Chibougamau district.

2) Different stages of alteration within shear zones in meta-anorthosite. These stages have been detected and classified on

the basis of chemical changes. Knowledge of the stage of alteration within a shear zone may be a useful guide to new ore deposits.

3) That the observed alteration mineral assemblages near the ore deposits at Chibougamau are in fair agreement with those found and reported by workers in other mining areas in northwestern Quebec.

4) That there has been a convergence toward a similar mineral assemblage in different rock types brought about by hydrothermal alteration.

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APPENDIX 1

Analyses of Samples from Drill Holes

The analyses are presented as follows:

In per cent: SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, MnO, Na_2O, K_2O.

In parts per million: Ni, Co, Cu, V, Sr.

The analyses numbers follow one another from the collar to the end of the hole.

Abbreviations used:

n.d. . . . . not detected.

u. . . . . under; e.g. u15 means under 15 parts per million.

D.D.H. . . . diamond drill hole.

The terminology of the companies of the district is followed in this appendix, e.g.:

Y samples - - - those from the Chibougamau Mining and Smelting Company Limited property, formerly that of Yorcan Exploration Limited.

R samples - - - those from Copper Rand Chibougamau Mines Limited, from both surface and underground drilling. Company reference to a hole drilled from an underground station, e.g. 5-R-89 means: 500 level, Copper Rand, hole 89.

Q samples - - - those from Quebec Chibougamau Goldfields Limited, from both surface and underground drilling. Company reference to a hole drilled from an underground station, e.g. U-5-18 means: underground, 500 level, hole 18.

J samples - - - those from Chibougamau Jaculet Mines Limited. Company reference to a hole drilled from an underground station, e.g. 6-J-24 means: 600 level, Jaculet, hole 24.

C.C. samples - - - those from Campbell Chibougamau Mines Limited underground drilling. Company reference to such a hole, e.g. U-698 means: underground hole 698.

Cu samples - - - those from the Cedar Bay Mine, from both surface and underground drilling. Company reference to a:

1) Surface hole, e.g. C.S 82 means Cedar Bay surface hole 82.
2) Underground hole, e.g. CU-194 means Cedar Bay underground hole 194.

	Y-1	Y-2	Y-3	Y-4	Y-5	Y-6	Y-7
SiO_2	47.50	53.25	47.00	44.20	37.50	36.00	46.00
Al_2O_3	20.50	22.80	20.10	27.10	22.15	24.50	24.40
Fe_2O_3	3.50	4.80	5.20	1.25	1.80	2.60	3.22
MgO	8.82	3.78	4.90	1.72	3.00	3.22	3.45
CaO	13.00	17.30	16.50	14.70	15.30	15.40	15.50
MnO	0.355	0.042	0.081	0.035	0.225	0.050	0.071
Na_2O	1.85	2.33	1.25	1.98	2.85	2.10	1.70
K_2O	0.11	0.14	0.06	0.11	0.16	0.05	0.06
Ni	170	110	145	45	60	80	75
Co	55	40	50	35	30	35	40
Cu	70	35	45	40	20	70	45
V	15	20	20	15	20	u15	u15
Sr	45	45	40	50	50	50	45

	Y-8	Y-9	Y-10	Y-11	Y-12	Y-13	Y-14
SiO_2	47.40	46.00	46.30	44.25	53.75	51.85	44.75
Al_2O_3	24.60	24.40	25.00	18.65	21.25	20.35	20.05
Fe_2O_3	3.33	3.10	2.48	3.35	3.20	4.35	2.90
MgO	3.78	3.45	3.18	7.75	4.25	5.85	5.95
CaO	16.25	14.50	13.90	18.50	16.70	16.25	15.65
MnO	0.065	0.061	0.055	0.375	0.035	0.046	0.240
Na_2O	2.58	2.48	2.20	2.70	2.30	2.10	2.05
K_2O	0.06	0.06	0.07	0.12	0.08	0.08	0.11
Ni	70	90	90	80	120	170	85
Co	35	40	30	35	35	45	45
Cu	25	25	35	40	55	30	65
V	20	15	15	40	u15	20	20
Sr	45	45	50	35	45	40	40

Analyses Y-1 to Y-11 are on successive samples from D.D.H. T-7.

	Y-15	Y-16	Y-17	Y-18	Y-19	Y-20	Y-21
SiO_2	47.85	46.25	46.90	44.70	46.50	46.40	50.25
Al_2O_3	22.75	25.50	24.50	22.10	14.00	23.50	22.75
Fe_2O_3	2.50	3.25	2.55	3.50	11.35	3.65	4.05
MgO	4.25	8.25	4.25	5.35	8.55	4.85	6.45
CaO	14.20	15.10	16.30	15.20	12.20	15.90	15.25
MnO	0.06	0.048	0.055	0.36	0.144	0.056	0.048
Na_2O	2.05	2.08	2.50	3.30	0.72	1.87	2.25
K_2O	0.09	0.14	0.09	0.20	0.03	0.11	0.09
Ni	125	145	115	150	70	195	180
Co	40	50	40	40	55	50	40
Cu	50	95	u10	15	85	u10	u10
V	u15	20	u15	20	70	u15	15
Sr	45	40	45	35	25	45	40

	Y-22	Y-23	Y-24	Y-25	Y-26	Y-27	Y-28
SiO_2	46.25	44.50	47.10	41.75	40.50	44.75	46.10
Al_2O_3	23.50	24.55	24.15	18.75	21.55	21.65	26.75
Fe_2O_3	3.65	2.48	3.10	2.75	3.05	2.10	2.60
MgO	5.65	4.30	5.40	5.95	7.25	3.90	4.08
CaO	15.75	15.50	15.20	25.10	21.10	15.70	16.65
MnO	0.044	0.055	0.063	0.040	0.390	0.198	0.049
Na_2O	3.55	2.05	1.80	3.05	3.30	2.72	2.52
K_2O	0.07	0.06	0.09	0.11	0.19	0.16	0.20
Ni	135	165	225	165	145	140	95
Co	35	30	40	35	40	35	u30
Cu	35	u10	20	60	u10	35	u10
V	u15	u15	15	15	u15	15	20
Sr	40	40	40	40	50	50	50

Analyses Y-12 to Y-31 are on successive samples from D.D.H. T-8.

	Y-29	Y-30	Y-31	Y-32	Y-33	Y-34	Y-35
SiO_2	49.30	46.75	44.65	46.70	46.90	49.75	51.85
Al_2O_3	25.00	24.15	22.05	21.25	24.60	24.70	25.35
Fe_2O_3	3.15	2.15	2.55	2.95	3.85	3.15	2.75
MgO	5.80	3.20	4.55	2.70	3.77	2.95	2.95
CaO	16.85	14.80	14.25	14.60	13.50	17.45	14.50
MnO	0.047	0.039	0.0235	0.0365	0.0345	0.032	0.036
Na_2O	1.50	2.50	2.40	2.15	5.15	1.54	2.93
K_2O	0.18	0.14	0.11	0.06	0.15	0.05	0.08
Ni	115	90	150	30	75	35	35
Co	30	35	40	30	55	25	u30
Cu	15	15	30	u10	10	u10	15
V	20	25	20	25	40	25	20
Sr	50	50	50	50	50	50	50

	Y-36	Y-37	Y-38	Y-39	Y-40	Y-41	Y-42
SiO_2	51.90	49.25	56.05	46.55	50.35	52.75	53.50
Al_2O_3	22.85	22.35	19.45	27.15	26.25	28.75	23.65
Fe_2O_3	2.45	6.50	5.05	6.70	1.50	0.85	1.25
MgO	3.08	5.20	4.10	2.15	0.90	0.80	0.85
CaO	14.80	2.40	2.10	3.45	2.45	8.55	14.75
MnO	0.041	0.030	0.037	0.0190	0.050	0.0450	0.0190
Na_2O	1.52	4.70	2.40	4.45	3.95	2.90	1.10
K_2O	0.08	0.25	0.235	0.31	0.27	0.22	0.11
Ni	55	85	80	85	u30	u30	u30
Co	u30	u30	35	40	u30	u30	u30
Cu	u10	15	40	90	u10	u10	u10
V	20	20	20	u15	20	20	25
Sr	40	40	65	70	70	65	50

Analyses Y-32 to Y-48 are on successive samples from D.D.H. T-10.

	Y-43	Y-44	Y-45	Y-46	Y-47	Y-48	Y-49
SiO_2	64.30	49.25	54.85	57.25	47.80	48.80	50.85
Al_2O_3	19.45	27.15	26.25	28.75	23.65	24.85	26.70
Fe_2O_3	5.05	6.70	1.50	0.85	1.25	1.85	1.90
MgO	4.10	2.15	0.90	0.80	0.85	1.25	1.35
CaO	2.10	3.45	2.45	8.55	14.75	17.10	14.95
MnO	0.037	0.0190	0.050	0.0450	0.0190	0.025	0.033
Na_2O	2.40	4.45	3.95	2.90	1.10	1.05	2.10
K_2O	0.235	0.31	0.27	0.22	0.11	0.07	0.135
Ni	80	85	u30	u30	u30	u30	30
Co	35	40	u30	u30	u30	u30	u30
Cu	40	90	u10	u10	u10	10	15
V	20	u15	20	20	25	30	15
Sr	65	70	70	65	50	55	50

	Y-50	Y-51	Y-52	Y-53	Y-54	Y-55	Y-56
SiO_2	50.50	47.50	50.25	52.75	45.90	46.45	49.75
Al_2O_3	27.30	25.20	26.55	27.10	25.50	26.70	27.70
Fe_2O_3	1.65	1.75	1.35	1.75	1.50	1.75	1.63
MgO	0.82	2.20	2.20	2.20	1.90	2.25	1.97
CaO	17.65	13.50	14.60	16.20	14.65	15.65	13.25
MnO	0.033	0.023	0.020	0.035	0.031	0.030	0.023
Na_2O	0.75	1.65	1.20	1.30	2.50	1.65	2.00
K_2O	0.05	0.11	0.15	0.17	1.08	0.53	0.52
Ni	u30	u30	u30	u30	30	u30	u30
Co	u30	u30	u30	u30	u30	u30	u30
Cu	30	15	u10	u10	35	u10	15
V	15	u15	u15	u15	u15	20	15
Sr	50	50	50	50	50	55	55

Analyses Y-49 to Y-67 are on successive samples from D.D.H. T-16.

	Y-57	Y-58	Y=59	Y-60	Y-61	Y-62	Y-63
SiO_2	51.05	47.85	46.90	53.75	54.25	49.75	46.85
Al_2O_3	25.75	24.55	22.75	23.50	21.75	26.25	23.45
Fe_2O_3	1.44	2.65	2.95	2.85	3.65	1.15	1.15
MgO	1.70	4.80	3.80	1.15	3.95	1.70	1.05
CaO	17.65	14.85	12.55	17.25	15.80	17.20	18.85
MnO	0.026	0.030	0.033	0.042	0.040	0.0170	0.0185
Na_2O	1.75	1.80	2.45	1.20	1.53	2.85	1.75
K_2O	0.19	0.48	0.95	0.07	0.11	0.25	0.32
Ni	u30	u30	60	u30	85	u30	30
Co	u30	u30	35	u30	u30	u30	u30
Cu	10	10	40	35	15	10	15
V	15	25	25	25	20	u15	15
Sr	50	47	45	50	45	50	50

	Y-64	Y-65	Y-66	Y-67
SiO_2	46.25	44.90	50.10	49.80
Al_2O_3	19.15	20.90	21.40	24.25
Fe_2O_3	5.60	5.25	3.80	1.45
MgO	15.00	11.50	6.80	1.40
CaO	12.80	12.40	13.75	12.50
MnO	0.057	0.045	0.031	0.018
Na_2O	0.38	0.90	2.20	1.05
K_2O	0.03	0.18	0.38	0.24
Ni	350	275	185	u30
Co	55	45	40	u30
Cu	30	25	80	65
V	u15	u15	u15	u15
Sr	35	40	50	50

	R-1	R-2	R-3	R-4	R-5	R-6	R-7
SiO_2	47.85	50.55	53.5	38.25	55.00	71.45	51.55
Al_2O_3	15.45	22.90	16.35	12.50	17.50	4.15	19.35
Fe_2O_3	10.25	1.68	19.75	23.50	15.95	17.25	17.70
MgO	0.44	0.27	0.45	0.10	0.11	0.21	1.70
CaO	2.80	n.d.	n.d.	n.d.	n.d.	1.20	n.d.
MnO	0.10	n.d.	n.d.	n.d.	n.d.	0.018	0.068
Na_2O	2.45	1.33	1.90	0.37	0.60	n.d.	1.05
K_2O	3.00	5.80	2.60	1.42	2.41	0.07	3.35
Ni	45	40	50	40	50	35	40
Co	135	95	245	145	75	45	110
Cu	220	100	1720	2350	1510	370	640
V	u15	u15	u15	15	15	u15	20
Sr	15	25	10	n.d.	10	15	10

	R-8	R-9	R-10	R-11	R-12	R-13	R-14
SiO_2	49.55	57.75	53.05	59.75	54.10	53.80	57.75
Al_2O_3	20.25	22.90	21.55	17.40	10.25	20.30	20.40
Fe_2O_3	16.35	8.20	11.25	16.80	25.80	17.65	8.42
MgO	0.76	0.44	0.49	0.97	1.15	1.55	0.23
CaO	n.d.	0.74	1.09	1.40	1.20	n.d.	n.d.
MnO	0.043	0.0450	0.030	0.065	0.065	0.090	0.016
Na_2O	0.80	1.15	2.55	0.70	n.d.	0.95	2.15
K_2O	4.90	5.40	5.05	2.30	0.14	0.95	0.17
Ni	35	35	35	75	60	50	35
Co	55	95	55	130	90	135	55
Cu	120	85	90	1500	1500	150	125
V	u15	u15	u15	u15	u15	u15	15
Sr	15	20	25	15	10	20	35

Analyses R-1 to R-54 are on successive samples from D.D.H. R-45.

	R-15	R-16	R-17	R-18	R-19	R-20	R-21
SiO_2	51.15	48.45	55.25	53.50	54.20	52.85	50.45
Al_2O_3	21.85	12.40	11.95	14.20	11.80	21.60	19.15
Fe_2O_3	15.25	22.65	21.50	19.75	25.75	18.45	20.25
MgO	1.40	3.25	4.50	2.60	1.00	1.45	2.55
CaO	n.d.	n.d.	n.d.	1.80	n.d.	n.d.	n.d.
MnO	0.055	0.077	0.065	0.060	0.035	0.055	0.060
Na_2O	1.00	n.d.	n.d.	1.85	0.45	0.85	1.65
K_2O	4.31	0.63	0.06	0.70	1.01	2.95	2.85
Ni	35	60	90	80	60	65	40
Co	45	95	120	135	165	170	90
Cu	125	500	725	1050	1425	1250	275
V	ul5	20	30	20	ul5	ul5	ul5
Sr	20	10	10	15	15	15	15

	R-22	R-23	R-24	R-25	R-26	R-27	R-28
SiO_2	60.15	52.20	49.50	48.65	69.55	55.65	64.75
Al_2O_3	20.10	18.30	17.65	14.95	0.88	3.85	10.70
Fe_2O_3	9.75	17.50	20.20	23.25	14.50	21.70	16.85
MgO	1.25	2.75	4.00	2.80	0.10	0.52	4.35
CaO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MnO	0.034	0.070	0.065	0.082	n.d.	0.022	0.057
Na_2O	1.40	1.65	1.05	0.65	n.d.	n.d.	n.d.
K_2O	3.00	2.65	2.80	1.25	0.05	0.15	0.06
Ni	70	60	60	80	50	75	75
Co	105	115	100	190	215	135	50
Cu	635	640	540	1350	5700	6000	310
V	20	20	15	15	ul5	ul5	45
Sr	25	20	15	10	n.d.	n.d.	15

	R-29	R-30	R-31	R-32	R-33	R-34	R-35
SiO_2	58.15	58.40	55.80	53.30	59.70	52.75	52.05
Al_2O_3	12.70	13.90	13.85	11.15	12.75	13.50	11.90
Fe_2O_3	18.25	15.80	18.50	25.10	12.80	19.15	20.10
MgO	4.90	5.45	4.90	3.10	4.05	6.50	7.15
CaO	n.d.	0.77	n.d.	n.d.	1.00	n.d.	n.d.
MnO	0.095	0.099	0.120	0.110	0.110	0.155	0.139
Na_2O	0.35	0.32	n.d.	0.34	1.45	n.d.	n.d.
K_2O	0.17	0.19	0.09	0.15	0.67	0.06	0.05
Ni	50	110	65	115	50	95	125
Co	40	55	45	135	50	65	70
Cu	220	130	136	1100	105	145	385
V	25	40	35	25	30	45	45
Sr	15	50	15	10	20	20	15

	R-36	R-37	R-38	R-39	R-40	R-41	R-42
SiO_2	49.20	47.30	50.9	55.60	63.10	51.20	44.80
Al_2O_3	14.65	18.75	13.1	22.40	22.50	20.60	16.50
Fe_2O_3	17.45	11.95	11.20	10.95	6.75	2.20	15.55
MgO	8.75	5.40	11.80	3.50	2.30	2.65	4.65
CaO	1.42	12.40	3.90	0.57	0.95	13.20	8.60
MnO	0.140	0.110	0.099	0.069	0.055	0.031	0.145
Na_2O	n.d.	1.80	2.50	4.05	3.80	2.45	2.25
K_2O	0.04	0.06	0.28	0.97	1.06	0.63	0.58
Ni	140	100	175	110	60	95	165
Co	60	75	95	90	60	55	115
Cu	160	170	590	135	115	45	465
V	25	30	65	50	30	45	30
Sr	20	35	20	40	45	45	20

	R-43	R-44	R-45	R-46	R-47	R-48	R-49
SiO_2	40.85	13.20	42.30	47.90	46.35	52.25	52.10
Al_2O_3	17.50	3.00	7.80	6.05	22.25	23.10	21.05
Fe_2O_3	5.30	0.73	0.90	0.85	5.30	4.40	6.40
MgO	4.10	0.33	0.40	0.42	3.40	2.45	4.05
CaO	16.10	40.00	32.30	34.00	12.25	13.10	12.65
MnO	0.120	0.180	0.070	0.110	0.060	0.075	0.100
Na_2O	5.90	0.70	0.70	0.65	5.40	4.25	1.95
K_2O	0.60	0.18	0.57	0.24	0.54	0.30	0.20
Ni	65	35	60	35	60	60	75
Co	50	u30	55	u30	45	45	60
Cu	50	40	10	15	25	35	55
V	25	20	25	15	25	30	25
Sr	35	15	35	20	35	45	40

	R-50	R-51	R-52	R-53	R-54	R-55	R-56
SiO_2	51.45	45.80	45.60	50.80	42.35	50.80	46.25
Al_2O_3	20.80	19.75	23.80	22.75	19.45	20.00	17.80
Fe_2O_3	2.80	5.25	5.75	5.45	3.35	7.75	18.50
MgO	0.40	2.60	2.50	2.60	2.80	4.65	8.35
CaO	21.25	12.75	7.80	12.75	12.30	11.90	5.85
MnO	0.070	0.086	0.090	0.088	0.073	0.089	0.155
Na_2O	0.85	3.95	4.60	3.70	4.50	3.26	2.90
K_2O	0.12	0.58	0.55	0.53	0.49	0.71	0.17
Ni	35	65	65	70	65	140	210
Co	30	40	55	50	50	65	85
Cu	20	55	75	35	95	85	275
V	35	25	25	20	25	20	u15
Sr	50	35	35	40	40	35	20

Analyses R-45 to R-74 are on successive samples from D.D.H. R-53.

	R-57	R-58	R-59	R-60	R-61	R-62	R-63
SiO_2	44.85	52.25	43.25	50.75	49.60	46.15	47.85
Al_2O_3	17.70	22.90	11.50	22.40	20.65	12.30	18.40
Fe_2O_3	4.90	3.25	14.25	5.15	7.90	13.50	5.80
MgO	3.75	1.85	6.65	2.15	3.00	5.30	3.60
CaO	16.90	13.50	13.25	12.35	10.90	14.10	12.10
MnO	0.100	0.064	0.093	0.060	0.098	0.160	0.112
Na_2O	3.35	2.70	0.27	2.95	3.90	0.34	5.00
K_2O	0.58	0.49	0.04	0.63	0.85	0.20	0.75
Ni	70	45	160	40	55	80	50
Co	45	35	75	40	40	75	50
Cu	55	50	55	75	55	45	30
V	20	25	165	40	35	45	50
Sr	35	45	n.d.	40	30	15	40

	R-64	R-65	R-66	R-67	R-68	R-69	R-70
SiO_2	45.15	43.85	46.25	47.50	48.25	46.25	44.70
Al_2O_3	12.40	17.05	11.30	16.90	13.25	16.80	15.75
Fe_2O_3	13.75	9.10	14.30	10.85	9.85	13.25	12.95
MgO	5.85	4.50	4.80	4.65	3.85	6.45	6.50
CaO	15.10	11.90	15.75	11.50	11.25	14.50	11.50
MnO	0.150	0.110	0.240	0.190	0.098	0.147	0.125
Na_2O	0.70	2.40	0.80	2.00	0.70	1.30	1.85
K_2O	0.17	0.54	0.13	0.32	0.20	0.04	0.03
Ni	80	90	75	65	130	130	100
Co	50	50	60	45	85	75	90
Cu	85	25	105	65	90	350	80
V	50	40	50	55	40	150	140
Sr	15	25	15	20	25	25	25

	R-71	R-72	R-73	R-74	R-75	R-76	R-77
SiO_2	43.75	80.20	42.85	43.10	55.10	52.25	50.50
Al_2O_3	12.70	6.25	14.50	14.05	19.75	18.10	20.80
Fe_2O_3	15.50	4.25	12.80	9.80	9.20	6.45	8.75
MgO	7.00	2.40	6.55	10.85	4.00	3.70	4.60
CaO	12.25	5.20	10.40	16.75	9.30	15.50	9.50
MnO	0.156	0.110	0.170	0.214	0.048	0.07	0.056
Na_2O	1.40	0.76	2.12	3.50	4.05	2.25	2.90
K_2O	0.05	0.11	0.33	0.05	0.60	0.77	1.15
Ni	75	35	85	85	90	80	100
Co	60	u30	65	70	75	75	90
Cu	105	65	45	40	150	50	65
V	115	25	90	70	25	30	40
Sr	20	25	25	25	35	35	30

	R-78	R-79	R-80	R-81	R-82	R-83	R-84
SiO_2	48.00	48.60	46.25	47.45	50.25	47.85	54.75
Al_2O_3	19.30	21.35	19.10	21.60	20.90	21.30	22.05
Fe_2O_3	6.30	9.65	6.80	8.75	7.05	6.95	5.10
MgO	1.30	4.20	6.60	4.90	3.85	4.25	2.60
CaO	18.00	9.35	10.75	9.30	15.00	10.50	12.25
MnO	0.087	0.065	0.110	0.077	0.058	0.152	0.053
Na_2O	2.80	2.00	2.55	2.60	1.20	1.17	0.95
K_2O	0.78	0.45	0.44	0.56	0.20	0.29	0.18
Ni	95	100	105	105	90	100	80
Co	80	65	80	80	75	145	60
Cu	55	70	105	95	75	120	95
V	25	40	35	45	45	25	30
Sr	35	35	35	35	35	35	40

Analyses R-75 to R-113 are on successive samples from D.D.H. R-52 and D.D.H. R-52-W. D.D.H. R-52-W is a wedged continuation of R-52 at 450 feet.

	R-85	R-86	R-87	R-88	R-89	R-90	R-91
SiO_2	67.25	59.50	58.25	49.85	47.85	51.75	50.65
Al_2O_3	14.90	13.20	18.50	23.60	20.60	19.80	23.75
Fe_2O_3	9.00	12.90	5.80	7.85	8.45	17.30	8.85
MgO	1.37	0.34	2.60	3.15	3.20	4.80	2.80
CaO	0.66	0.54	1.10	2.35	3.20	1.60	1.39
MnO	0.29	0.47	0.027	0.035	0.051	0.070	0.025
Na_2O	2.25	1.38	1.30	3.00	5.40	1.95	2.75
K_2O	0.49	1.06	0.82	0.87	0.82	0.67	0.72
Ni	60	45	75	95	55	60	85
Co	105	195	45	95	65	100	60
Cu	115	115	100	135	100	145	100
V	20	u15	35	55	40	25	55
Sr	35	25	35	40	45	25	40

	R-92a	R-92b	R-92c	R-92d	R-92e	R-93	R-94
SiO_2	47.50	58.55	46.75	48.45	45.85	48.85	52.25
Al_2O_3	21.15	20.50	14.25	15.40	6.30	14.30	23.85
Fe_2O_3	12.20	10.25	19.10	23.25	29.25	17.90	5.65
MgO	3.55	3.40	4.70	4.30	3.00	7.10	1.90
CaO	1.90	1.90	0.20	0.20	0.25	0.30	1.50
MnO	0.048	0.044	0.078	0.077	0.048	0.100	0.100
Na_2O	2.50	2.65	1.40	0.45	0.49	0.78	4.60
K_2O	1.07	0.91	1.12	1.12	0.04	0.25	0.44
Ni	80	95	220	190	675	170	60
Co	75	85	190	220	1000	110	80
Cu	110	275	530	570	2650	135	50
V	25	30	30	20	30	45	60
Sr	25	30	15	n.d.	n.d.	n.d.	45

	R-95	R-96	R-97	R-98	R-110	R-111	R-112
SiO_2	49.65	46.50	48.10	45.95	46.75	45.70	43.85
Al_2O_3	17.60	18.90	16.95	19.40	19.80	18.70	17.80
Fe_2O_3	3.05	8.10	9.10	4.85	5.75	6.42	7.75
MgO	2.10	3.25	3.65	2.40	2.60	7.00	3.90
CaO	11.50	8.65	11.10	10.85	7.95	10.35	15.25
MnO	0.072	0.077	0.140	0.073	0.073	0.10	0.074
Na_2O	4.40	3.25	2.00	3.50	3.55	2.85	1.25
K_2O	0.38	0.37	0.50	0.53	0.38	0.29	0.54
Ni	35	95	90	45	80	115	125
Co	70	75	85	40	85	80	105
Cu	60	100	90	95	65	45	30
V	45	30	40	30	50	25	30
Sr	50	35	25	40	40	40	40

	R-113	R-114	R-115	R-116	R-117	R-118	R-119
SiO_2	44.75	54.75	48.35	52.25	30.85	52.25	67.10
Al_2O_3	18.90	22.20	12.85	19.05	16.50	17.05	7.30
Fe_2O_3	7.95	4.45	14.00	8.10	22.40	8.95	5.95
MgO	5.85	2.70	6.55	5.20	14.00	5.30	3.65
CaO	10.55	7.50	9.05	7.90	5.75	8.00	10.05
MnO	0.075	0.083	0.235	0.162	0.40	0.155	0.135
Na_2O	1.45	5.80	0.35	5.15	2.10	4.10	1.04
K_2O	0.25	0.47	0.03	0.24	0.08	0.29	0.05
Ni	150	50	120	75	115	55	35
Co	80	55	75	75	70	80	30
Cu	30	15	100	40	45	20	20
V	20	25	60	35	25	35	15
Sr	35	55	20	45	15	50	20

Analyses R-114 to R-134 are on successive samples from D.D.H. R-72.

	R-120	R-121	R-122	R-123	R-124	R-125	R-126
SiO_2	49.85	43.65	42.50	45.20	66.50	46.90	40.10
Al_2O_3	17.90	17.80	15.45	10.40	8.30	17.45	17.30
Fe_2O_3	7.45	14.55	15.50	17.85	2.75	5.10	12.65
MgO	6.25	6.90	6.50	9.70	1.13	1.30	4.85
CaO	11.15	6.80	7.00	7.50	7.50	6.90	7.25
MnO	0.22	0.178	0.225	0.42	0.140	0.062	0.125
Na_2O	8.10	3.20	2.65	0.64	1.52	4.30	2.35
K_2O	0.24	0.09	0.27	0.05	0.38	0.85	0.91
Ni	50	90	80	80	35	70	145
Co	55	70	55	65	35	55	95
Cu	25	85	70	40	30	90	135
V	60	110	110	80	15	20	50
Sr	40	25	20	15	30	45	25

	R-127	R-128	R-129	R-130	R-131	R-132	R-134
SiO_2	45.85	47.60	44.50	38.45	40.85	44.90	41.90
Al_2O_3	18.90	17.15	16.00	13.25	11.15	10.80	10.20
Fe_2O_3	10.80	11.70	13.10	18.60	18.75	16.75	14.15
MgO	4.90	7.95	6.25	9.30	10.55	12.40	10.90
CaO	6.75	8.75	5.05	7.20	6.00	5.10	9.40
MnO	0.112	0.145	0.125	0.220	0.196	0.185	0.380
Na_2O	4.70	5.90	4.25	0.90	0.35	0.85	2.30
K_2O	0.86	1.05	1.00	0.54	0.04	0.05	0.66
Ni	100	70	90	105	100	80	90
Co	65	70	70	75	75	55	75
Cu	50	20	20	85	215	40	45
V	40	60	80	120	90	40	65
Sr	30	30	25	15	n.d.	15	15

	R-135	R-136	R-137	R-138	R-139	R-140	R-141
SiO_2	43.85	41.65	44.10	46.50	47.20	45.90	49.65
Al_2O_3	13.50	15.85	18.35	17.45	19.95	17.80	17.80
Fe_2O_3	6.90	8.65	7.60	7.35	6.65	7.90	8.50
MgO	7.65	5.25	4.80	4.60	3.50	4.65	5.00
CaO	8.95	8.95	8.50	9.05	7.95	10.30	9.50
MnO	0.147	0.135	0.110	0.112	0.066	0.089	0.135
Na_2O	3.30	1.75	2.80	2.85	2.90	3.15	3.10
K_2O	0.28	0.44	0.47	0.44	0.37	0.32	0.36
Ni	60	65	65	65	55	65	50
Co	75	75	90	75	55	70	50
Cu	15	35	20	45	20	85	15
V	20	35	60	40	60	65	65
Sr	30	25	35	35	35	30	25

	R-142	R-143	R-144	R-145	R-146	R-147	R-148
SiO_2	66.25	39.55	56.05	50.60	50.50	53.10	53.05
Al_2O_3	12.25	15.30	17.20	17.20	14.30	14.90	18.20
Fe_2O_3	5.50	8.50	9.80	10.95	13.90	12.50	10.55
MgO	5.10	8.50	5.90	6.15	8.40	9.10	6.70
CaO	7.85	16.00	7.75	9.00	11.20	9.75	7.00
MnO	0.153	0.345	0.120	0.150	0.205	0.148	0.093
Na_2O	1.80	5.90	2.95	2.80	1.80	3.20	3.85
K_2O	0.28	0.49	0.27	0.30	0.058	0.038	0.36
Ni	55	55	70	100	105	105	85
Co	55	65	55	90	90	105	85
Cu	20	35	10	95	100	35	40
V	35	50	55	80	80	80	45
Sr	25	30	25	20	20	20	20

Analyses R-135 to R-149 are on successive samples from D.D.H. R-70.

	R-149	R-150	R-151	R-152	R-153	R-154	R-155
SiO_2	46.45	45.90	43.90	49.30	44.15	58.60	51.15
Al_2O_3	17.10	10.65	10.80	10.15	10.30	11.40	11.00
Fe_2O_3	6.30	12.75	12.85	14.25	16.95	9.80	14.60
MgO	6.85	8.10	6.15	7.45	6.60	2.15	9.05
CaO	12.75	17.80	14.50	15.00	11.90	8.15	10.55
MnO	0.098	0.020	0.215	0.220	0.220	0.260	0.220
Na_2O	8.20	1.35	2.90	2.05	1.35	2.55	2.90
K_2O	0.15	0.19	0.20	0.05	0.29	2.60	0.06
Ni	40	95	75	85	195	35	80
Co	35	95	85	90	175	u30	60
Cu	155	125	100	140	3375	85	115
V	u15	70	50	60	45	20	85
Sr	35	15	15	15	n.d.	25	15

Analysis R-150 is on a sample from D.D.H. 5-R-66
Analysis R-151 is on a sample from D.D.H. 5-R-69
Analysis R-152 is on a sample from D.D.H. 5-R-87
Analyses R-153 and R-154 are on samples from D.D.H. 5-R-89

	R-156	R-157	R-158	R-159	R-160	R-161
SiO_2	59.40	47.15	51.55	53.40	50.15	66.50
Al_2O_3	12.45	11.65	12.35	10.80	11.75	12.60
Fe_2O_3	8.20	12.85	17.05	3.95	12.25	3.90
MgO	2.05	7.65	3.80	1.45	8.35	2.15
CaO	7.65	14.40	7.75	7.15	14.85	6.95
MnO	0.380	0.280	0.66	0.130	0.260	0.230
Na_2O	2.10	1.75	1.30	3.15	2.00	3.60
K_2O	2.50	0.70	1.20	2.20	0.42	2.00
Ni	60	105	35	35	85	35
Co	90	105	65	u30	85	30
Cu	285	440	150	70	115	105
V	20	80	20	15	75	u15
Sr	20	20	n.d.	25	15	25

Analyses R-155 and R-156 are on samples from D.D.H. 5-R-138
Analyses R-157 to R-159 are on samples from D.D.H. 5-R-139
Analyses R-160 and R-161 are on samples from D.D.H. 5-R-140.

	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7
SiO_2	48.90	46.75	49.90	55.40	60.75	51.15	63.20
Al_2O_3	20.95	19.65	22.10	21.35	15.15	20.55	15.10
Fe_2O_3	5.20	4.20	4.95	5.60	7.40	7.70	5.45
MgO	2.00	1.35	2.90	3.00	3.90	6.30	1.80
CaO	11.15	12.20	9.50	12.15	5.00	8.40	6.40
MnO	0.110	0.145	0.150	0.165	0.120	0.174	0.083
Na_2O	2.25	3.30	3.45	3.20	7.05	4.10	6.30
K_2O	0.56	1.31	0.54	0.32	0.10	1.06	0.78
Ni	55	35	65	95	80	155	u30
Co	45	35	40	60	55	75	45
Cu	130	110	85	85	50	105	45
V	20	20	30	40	40	20	20
Sr	40	40	45	45	45	35	35

	Q-8	Q-9	Q-10	Q-11	Q-12	Q-13	Q-14
SiO_2	55.60	73.10	73.80	67.35	46.80	52.10	61.50
Al_2O_3	17.40	13.60	14.20	15.05	18.70	20.30	16.30
Fe_2O_3	8.05	3.45	2.65	4.70	7.95	7.55	6.25
MgO	5.90	1.65	1.20	3.05	5.30	4.50	3.00
CaO	9.75	3.10	2.80	4.60	10.10	9.15	7.15
MnO	0.195	0.071	0.055	0.110	0.190	0.190	0.190
Na_2O	3.35	5.45	5.15	4.25	5.00	4.15	1.95
K_2O	0.50	0.53	0.88	0.62	0.71	2.00	1.36
Ni	195	30	u30	55	195	115	75
Co	80	u30	30	35	80	65	45
Cu	45	25	25	45	60	50	110
V	15	u15	u15	15	15	15	u15
Sr	40	40	40	50	40	50	35

Analyses Q-1 to Q-26 are on successive samples from D.D.H. Q-118

	Q-15	Q-16	Q-17	Q-18	Q-19	Q-20	Q-21
SiO_2	49.95	41.40	44.65	44.90	66.20	50.25	53.05
Al_2O_3	17.45	18.85	19.30	19.30	14.10	18.35	17.60
Fe_2O_3	14.10	8.15	7.45	7.00	7.10	9.20	10.85
MgO	5.60	4.70	3.60	3.60	3.60	5.15	5.30
CaO	9.25	9.60	4.90	8.20	5.90	11.30	7.80
MnO	0.350	0.265	0.190	0.220	0.180	0.365	0.42
Na_2O	2.90	2.65	3.30	2.05	1.60	1.45	2.50
K_2O	1.25	1.32	0.67	2.10	1.60	1.38	1.25
Ni	175	170	135	130	50	160	180
Co	75	65	75	80	65	50	70
Cu	90	45	45	55	90	60	70
V	30	15	20	40	30	20	20
Sr	25	25	35	30	25	25	25

	Q-22	Q-23	Q-24	Q-25	Q-26	Q-27	Q-28
SiO_2	64.45	47.20	47.10	46.70	47.30	64.10	55.45
Al_2O_3	14.30	16.65	13.85	16.75	14.90	15.90	13.90
Fe_2O_3	2.60	9.85	10.85	10.20	10.30	8.85	5.80
MgO	1.05	8.20	7.25	5.50	6.60	2.75	2.10
CaO	4.20	10.20	8.85	6.60	12.45	5.80	5.60
MnO	0.072	0.260	0.250	0.185	0.230	0.320	0.230
Na_2O	3.85	1.75	0.90	3.30	2.90	2.45	1.35
K_2O	1.30	0.36	0.17	0.49	0.26	1.70	1.17
Ni	u30	310	135	185	250	40	30
Co	u30	75	75	60	70	35	40
Cu	30	70	130	45	95	35	35
V	u15	20	65	20	20	25	20
Sr	35	25	20	30	25	30	30

Analyses Q-27 to Q-47 are on successive samples from D.D.H. Q-119

	Q-29	Q-30	Q-31	Q-32	Q-33	Q-34	Q-35
SiO_2	49.25	55.75	47.40	52.50	48.60	62.25	49.85
Al_2O_3	20.05	15.25	20.45	16.65	20.25	13.70	19.90
Fe_2O_3	6.90	6.50	6.65	5.10	5.10	6.60	6.90
MgO	2.10	1.70	2.25	2.45	1.95	2.30	2.20
CaO	6.40	4.20	9.10	7.10	8.90	5.15	9.05
MnO	0.265	0.245	0.220	0.165	0.170	0.185	0.250
Na_2O	2.20	0.95	2.75	1.85	2.25	1.45	2.80
K_2O	3.10	1.50	2.95	1.16	2.60	1.67	1.42
Ni	60	45	40	40	40	u30	55
Co	55	60	50	35	35	u30	35
Cu	35	25	35	35	25	30	100
V	25	20	20	20	30	15	20
Sr	55	30	35	40	40	35	40

Note: No Sample at Q-37

	Q-36	Q-38	Q-39	Q-40	Q-41	Q-42	Q-43
SiO_2	58.65	61.40	49.45	53.25	47.20	70.35	48.55
Al_2O_3	15.80	19.70	22.05	20.50	23.15	13.60	22.05
Fe_2O_3	5.65	4.30	7.60	8.15	6.35	1.90	6.40
MgO	3.35	2.35	10.50	8.10	6.15	3.70	6.55
CaO	6.80	7.40	8.15	6.55	10.40	4.40	8.90
MnO	0.130	0.130	0.190	0.200	0.125	0.037	0.109
Na_2O	2.05	3.30	1.95	2.50	3.15	3.65	2.85
K_2O	0.47	0.73	0.38	0.66	0.27	0.42	0.17
Ni	45	90	205	190	150	30	185
Co	35	55	60	50	45	30	70
Cu	35	110	55	30	45	25	70
V	20	30	25	20	25	u15	25
Sr	40	40	30	35	45	50	40

	Q-44	Q-45	Q-46	Q-47	Q-48	Q-49	Q-50
SiO_2	48.40	50.40	51.50	45.85	47.65	49.65	45.20
Al_2O_3	23.10	20.85	19.15	23.70	14.15	16.25	21.25
Fe_2O_3	6.65	7.15	8.90	8.10	8.35	9.65	8.10
MgO	7.65	6.60	6.05	6.20	6.75	9.50	7.75
CaO	9.60	9.75	11.65	6.50	9.55	9.30	9.85
MnO	0.116	0.154	0.140	0.195	0.175	0.225	0.200
Na_2O	2.30	3.55	3.25	1.85	2.45	0.75	2.39
K_2O	0.11	0.22	0.17	1.20	0.53	0.03	0.12
Ni	195	210	175	135	180	180	1.45
Co	65	50	60	55	70	85	80
Cu	30	40	40	30	60	155	45
V	25	20	20	20	25	60	45
Sr	35	35	40	25	30	25	35

	Q-51	Q-52	Q-53	Q-54	Q-55	Q-56	Q-57
SiO_2	47.85	48.75	66.05	47.60	64.20	66.40	47.65
Al_2O_3	12.45	16.55	14.10	17.85	12.10	13.85	14.50
Fe_2O_3	10.15	7.30	7.65	8.35	5.40	5.70	9.80
MgO	10.35	7.60	2.10	8.10	2.15	2.10	6.10
CaO	11.60	9.85	5.15	7.20	7.80	5.70	8.40
MnO	0.200	0.180	0.185	0.285	0.175	0.190	0.480
Na_2O	n.d.	2.30	1.35	1.90	1.75	1.35	0.76
K_2O	0.03	0.62	1.30	1.17	1.05	1.68	0.58
Ni	115	155	35	140	u30	u30	110
Co	65	90	u30	70	30	30	70
Cu	95	50	35	90	20	135	80
V	65	40	15	25	20	20	55
Sr	25	30	25	25	40	35	20

Analyses Q-49 to Q-79 are on successive samples from D.D.H. Q-121.

	Q-58	Q-59	Q-60	Q-61	Q-62	Q-63	Q-64
SiO_2	61.45	65.10	50.75	50.50	49.10	68.50	49.40
Al_2O_3	12.80	15.75	24.25	14.35	18.25	15.70	19.80
Fe_2O_3	12.45	12.30	8.50	12.15	8.75	3.95	6.70
MgO	1.45	2.50	5.75	12.10	4.35	2.35	4.55
CaO	1.80	2.65	4.80	7.70	12.35	2.75	12.70
MnO	0.275	0.335	0.275	0.260	0.150	0.070	0.145
Na_2O	0.59	0.95	3.65	0.900	4.05	3.70	3.15
K_2O	1.49	1.08	1.05	0.05	0.35	0.54	0.31
Ni	u30	70	130	95	160	35	115
Co	u30	55	65	75	115	35	65
Cu	65	105	125	110	120	35	55
V	u15	20	30	85	35	20	45
Sr	20	20	30	30	35	45	40

	Q-65	Q-66	Q-67	Q-68	Q-69	Q-70	Q-71
SiO_2	46.45	48.80	46.35	46.15	48.80	43.90	44.20
Al_2O_3	18.80	24.10	20.20	20.80	18.35	20.85	18.55
Fe_2O_3	7.85	4.70	3.35	5.50	3.90	6.80	6.75
MgO	3.90	2.45	1.15	2.85	1.60	3.90	3.90
CaO	10.30	10.60	18.75	8.10	16.55	11.20	3.55
MnO	0.150	0.118	0.135	0.110	0.150	0.125	0.180
Na_2O	3.25	2.20	1.30	2.30	0.52	3.25	2.70
K_2O	0.77	0.44	0.20	0.92	0.14	0.81	0.88
Ni	120	55	u30	60	45	80	95
Co	80	55	35	50	45	70	70
Cu	35	30	80	65	60	60	100
V	25	30	40	40	30	25	25
Sr	35	45	55	40	40	40	30

	Q-72	Q-73	Q-74	Q-75	Q-76	Q-77	Q-78
SiO_2	45.50	48.85	61.25	45.65	55.60	44.85	47.65
Al_2O_3	16.80	18.40	13.50	17.80	14.30	17.50	13.50
Fe_2O_3	7.75	7.80	7.25	11.20	6.90	10.05	10.45
MgO	3.50	3.75	2.40	3.95	2.80	3.90	6.70
CaO	10.05	5.20	6.0	5.25	8.15	9.85	8.85
MnO	0.160	0.180	0.140	0.205	0.160	0.245	0.210
Na_2O	2.15	2.30	1.45	1.65	1.60	2.45	0.70
K_2O	1.18	1.45	1.30	1.29	0.95	0.78	0.16
Ni	85	100	40	110	60	105	110
Co	75	95	70	140	85	100	100
Cu	55	135	30	175	70	155	50
V	20	20	20	20	25	25	60
Sr	25	25	25	20	30	25	25

	Q-79	Q-80	Q-81	Q-82	Q-83	Q-84	Q-85
SiO_2	46.15	47.75	61.15	48.65	46.90	48.55	48.30
Al_2O_3	17.85	16.40	12.40	14.70	19.75	12.95	15.45
Fe_2O_3	12.15	10.50	6.50	9.10	8.65	10.85	8.20
MgO	5.05	3.80	3.40	5.15	3.55	7.25	5.10
CaO	8.90	12.20	6.45	10.90	5.25	10.85	13.25
MnO	0.235	0.210	0.110	0.180	0.195	0.235	0.200
Na_2O	2.00	3.35	3.25	2.95	3.45	0.95	3.65
K_2O	0.60	0.50	0.17	0.59	1.16	0.03	0.53
Ni	105	135	80	120	60	125	105
Co	105	95	125	65	60	80	75
Cu	50	145	320	80	65	130	30
V	25	35	35	25	40	65	30
Sr	25	35	30	35	35	20	35

Analyses Q-80 to Q-104 are on successive samples from D.D.H. Q-146

	Q-86	Q-87	Q-88	Q-89	Q-90	Q-91	Q-92
SiO_2	53.25	49.15	47.25	47.15	45.50	52.25	47.80
Al_2O_3	15.45	20.35	19.30	20.25	20.15	16.60	19.85
Fe_2O_3	10.40	9.65	7.90	5.10	6.75	9.10	5.05
MgO	3.05	4.60	2.95	2.65	4.65	4.40	2.95
CaO	11.05	10.60	7.05	10.10	9.50	13.10	9.65
MnO	0.26	0.190	0.190	0.113	0.125	0.18	0.087
Na_2O	3.50	3.45	2.10	3.40	2.20	4.30	3.80
K_2O	1.60	0.77	1.52	0.44	0.44	0.37	0.73
Ni	100	110	60	60	120	115	30
Co	90	90	65	55	60	85	45
Cu	80	60	70	35	65	70	30
V	25	40	35	50	30	55	40
Sr	25	30	30	40	35	35	40

	Q=93	Q-94	Q-95	Q-96	Q-97	Q-98	Q-99
SiO_2	57.45	48.80	52.40	49.50	50.25	53.50	62.25
Al_2O_3	15.30	21.90	11.85	19.85	13.10	17.20	14.80
Fe_2O_3	5.85	4.40	13.90	6.80	13.50	13.10	6.35
MgO	1.65	1.85	4.80	2.65	7.50	2.40	2.30
CaO	12.90	7.75	8.40	7.50	11.25	6.80	5.10
MnO	0.160	0.095	0.280	0.100	0.260	0.320	0.195
Na_2O	4.05	1.90	0.35	3.40	0.55	2.50	1.25
K_2O	1.25	1.55	0.14	2.15	0.04	4.35	2.10
Ni	40	u30	90	60	120	65	55
Co	50	50	75	85	85	75	65
Cu	60	30	125	110	145	55	65
V	35	25	65	35	80	25	25
Sr	40	40	15	35	20	20	35

	Q-100	Q-101	Q-102	Q-103	Q-104	Q-105	Q-106
SiO_2	64.85	64.10	55.45	48.25	47.80	65.75	50.10
Al_2O_3	13.05	15.85	13.20	18.10	14.40	16.10	19.15
Fe_2O_3	5.70	5.85	10.85	12.25	8.70	3.25	6.60
MgO	1.80	1.70	2.80	6.55	3.85	1.35	4.90
CaO	9.90	5.10	7.95	12.32	11.45	3.60	12.80
MnO	0.220	0.145	0.26	0.32	0.21	0.055	0.110
Na_2O	2.80	1.75	3.15	2.95	2.85	4.80	4.35
K_2O	1.90	1.55	1.55	0.68	0.77	1.45	0.96
Ni	30	60	160	230	225	30	150
Co	35	45	85	95	95	50	75
Cu	45	110	95	100	170	40	40
V	20	25	25	25	25	20	30
Sr	35	35	25	25	25	40	30

	Q-107	Q-108	Q-109	Q-110	Q-111	Q-112	Q-113
SiO_2	59.85	53.50	61.45	52.75	48.65	50.50	47.35
Al_2O_3	15.10	17.45	17.00	17.60	18.45	19.90	19.30
Fe_2O_3	13.05	6.25	4.05	6.80	5.85	6.45	7.15
MgO	6.75	4.55	2.75	4.40	3.75	4.10	4.60
CaO	11.05	11.50	5.70	11.75	11.35	12.60	11.50
MnO	0.210	0.090	0.050	0.085	0.061	0.082	0.078
Na_2O	0.850	4.60	4.65	3.85	6.05	4.20	3.95
K_2O	0.05	0.98	0.63	0.42	0.59	0.34	0.24
Ni	75	100	60	170	115	165	175
Co	100	70	50	75	45	85	75
Cu	95	35	20	35	20	35	50
V	75	35	20	25	25	25	25
Sr	20	45	50	40	40	40	40

Analyses Q-105 to Q-145 are on successive samples from D.D.H. Q-190

	Q-114	Q-115	Q-116	Q-117	Q-118	Q-119	Q-120
SiO_2	51.40	50.65	49.45	56.50	47.15	49.65	50.40
Al_2O_3	20.15	19.50	19.85	12.90	18.90	20.25	15.20
Fe_2O_3	7.05	8.90	6.80	14.15	7.50	6.65	9.60
MgO	4.95	4.90	4.05	4.50	3.90	3.85	4.30
CaO	14.10	13.50	14.90	10.05	10.85	12.55	9.40
MnO	0.090	0.145	0.080	0.130	0.080	0.090	0.135
Na_2O	2.65	2.90	3.65	2.30	3.70	3.20	4.70
K_2O	0.14	0.38	0.40	0.08	0.28	0.24	0.20
Ni	155	165	130	130	145	145	90
Co	60	75	55	125	95	65	60
Cu	30	75	55	150	115	60	60
V	15	20	20	65	45	25	40
Sr	35	35	35	20	40	40	40

	Q-121	Q-122	Q-123	Q-124	Q-125	Q-126	Q-127
SiO_2	51.15	56.80	46.15	48.20	46.90	52.15	65.05
Al_2O_3	21.05	13.40	20.70	20.15	14.25	18.10	13.15
Fe_2O_3	7.50	11.70	7.25	9.65	11.10	9.00	7.40
MgO	4.35	5.15	4.25	3.95	3.95	3.80	1.60
CaO	14.40	10.30	11.10	9.75	11.80	12.05	6.95
MnO	0.110	0.125	0.102	0.110	0.140	0.156	0.161
Na_2O	3.90	1.30	4.20	4.65	2.70	3.80	2.20
K_2O	0.33	0.12	0.45	0.67	0.33	1.04	1.35
Ni	130	105	130	130	95	55	100
Co	55	100	85	85	70	50	60
Cu	35	65	65	120	50	65	100
V	20	50	25	20	50	u15	15
Sr	40	20	30	20	25	25	45

	Q-128	Q-129	Q-130	Q-131	Q-132	Q-133	Q-134
SiO_2	61.80	42.30	47.95	38.50	42.75	45.85	46.60
Al_2O_3	13.05	17.20	15.30	5.15	18.90	19.40	20.95
Fe_2O_3	9.80	12.60	8.55	6.40	7.55	8.10	7.90
MgO	2.85	5.75	5.45	4.95	4.55	3.60	3.80
CaO	9.70	11.20	10.25	24.85	10.20	10.95	10.75
MnO	0.280	0.260	0.135	0.225	0.100	0.105	0.113
Na_2O	1.70	2.25	2.25	1.15	4.60	2.65	2.20
K_2O	1.60	1.22	0.53	0.06	0.50	0.88	0.63
Ni	30	220	215	165	170	130	120
Co	50	75	45	85	60	110	55
Cu	115	230	25	130	80	50	110
V	20	20	20	125	25	20	25
Sr	20	20	25	15	35	35	30

	Q-135	Q-136	Q-137	Q-138	Q-139	Q-140	Q-141
SiO_2	40.75	45.40	39.65	46.85	37.90	37.10	50.65
Al_2O_3	8.90	18.60	13.80	15.80	13.85	12.70	12.85
Fe_2O_3	15.25	9.85	7.85	15.55	26.75	29.10	24.50
MgO	3.95	6.55	4.30	4.60	4.45	2.75	2.55
CaO	21.80	11.40	20.55	12.70	6.15	9.75	3.70
MnO	0.400	0.170	0.360	0.410	0.460	0.59	0.36
Na_2O	6.45	3.30	2.35	2.30	1.10	n.d.	1.00
K_2O	0.09	0.55	0.72	1.30	0.50	0.40	0.08
Ni	220	225	165	145	140	95	50
Co	160	90	80	125	150	505	110
Cu	160	20	130	125	285	1050	220
V	30	25	45	115	20	20	ul
Sr	n.d.	25	20	15	n.d.	n.d.	n.d.

	Q-142	Q-143	Q-144	Q-145	Q-147	Q-150	Q-151
SiO_2	38.50	63.10	53.95	43.95	44.80	44.80	55.75
Al_2O_3	7.65	15.05	13.25	19.20	18.90	18.70	14.20
Fe_2O_3	26.85	10.90	7.40	8.90	8.75	12.50	8.40
MgO	2.05	2.40	2.55	4.65	3.65	3.80	2.10
CaO	4.00	5.40	7.65	11.50	14.15	10.85	8.45
MnO	0.190	0.195	0.175	0.140	0.210	0.245	0.190
Na_2O	0.60	2.80	2.20	3.90	3.50	3.00	2.45
K_2O	1.25	0.80	0.8.	0.8.	1.26	1.65	1.22
Ni	125	45	50	145	80	120	50
Co	490	50	45	65	50	70	70
Cu	430	95	85	60	80	95	90
V	u15	u15	20	25	25	20	20
Sr	n.d.	25	35	30	25	20	15

Analysis Q-147 is on a sample from D.D.H. U-3-17

	Q-152	Q-153	Q-154	Q-155	Q-156	Q-157	Q-158
SiO_2	43.90	47.65	46.75	51.05	48.55	47.75	42.25
Al_2O_3	20.20	14.20	15.10	17.15	19.50	21.10	19.15
Fe_2O_3	8.50	6.45	7.60	9.40	9.30	6.90	10.25
MgO	3.15	2.60	3.45	3.35	3.40	3.15	4.40
CaO	11.60	18.20	17.10	13.40	11.10	12.50	11.90
MnO	0.150	0.160	0.165	0.170	0.110	0.105	0.115
Na_2O	5.05	3.90	3.75	3.95	4.35	4.90	3.45
K_2O	1.42	1.13	1.05	0.99	1.17	1.51	1.60
Ni	75	60	85	90	75	60	105
Co	60	50	45	60	60	45	55
Cu	80	85	75	95	100	85	75
V	20	15	15	15	15	20	15
Sr	30	25	25	20	20	25	20

Analyses Q-150 to Q-158 are on successive samples from D.D.H. U-5-5.

	Q-159	Q-160	Q-161	Q-162	Q-163	Q-164	Q-165
SiO_2	47.50	48.50	55.45	46.15	44.15	44.30	47.85
Al_2O_3	19.35	13.80	16.60	17.30	19.25	19.30	17.60
Fe_2O_3	16.35	28.05	14.60	13.80	9.30	11.95	17.50
MgO	2.10	1.70	2.00	3.50	4.60	3.20	2.40
CaO	5.05	5.40	5.80	11.50	15.25	6.75	5.45
MnO	0.640	0.620	0.230	0.270	0.185	0.285	0.460
Na_2O	1.20	0.60	1.90	2.25	3.45	1.50	2.05
K_2O	0.87	0.51	3.55	1.22	0.75	0.80	4.20
Ni	45	50	50	80	85	80	65
Co	45	65	60	65	45	75	70
Cu	80	45	90	85	30	90	95
V	u15	u15	15	15	15	u15	u15
Sr	15	15	20	25	25	20	15

Analyses Q-159 and Q-160 are on samples from U-5-24.
Analyses Q-161 to Q-163 are on successive samples from U-5-13.
Analyses Q-164 and Q-165 are on samples from U-5-16

	Q-166	Q-167	Q-168	Q-169	Q-170	Q-171	Q-172
SiO_2	45.10	54.25	47.15	46.85	45.90	47.85	47.25
Al_2O_3	17.60	14.35	17.45	15.90	18.80	18.75	20.15
Fe_2O_3	9.90	9.80	10.05	10.45	9.90	10.15	10.40
MgO	4.15	2.50	4.30	5.10	4.45	3.60	4.65
CaO	16.05	12.40	13.20	10.50	12.25	11.20	11.90
MnO	0.360	0.270	0.29	0.30	0.275	0.23	0.265
Na_2O	2.70	2.05	3.50	2.90	3.05	2.40	2.90
K_2O	3.45	1.36	1.15	1.23	1.30	1.38	0.91
Ni	80	45	100	125	100	95	85
Co	40	40	60	60	75	75	50
Cu	35	85	85	30	85	100	100
V	u15	u15	20	20	u15	20	u15
Sr	25	25	20	15	30	25	30

Analyses Q-166 and Q-167 are on samples from U-5-18
Analysis Q-168 is on a sample from U-6-5
Analysis Q-169 is on a sample from U-6-8
Analysis Q-170 is on a sample from U-6-12
Analyses Q-171 and Q-172 are on samples from U-8-4

	Q-173	Q-174	Q-175
SiO_2	46.70	44.35	55.50
Al_2O_3	19.65	19.50	12.95
Fe_2O_3	9.20	10.05	9.70
MgO	4.05	4.45	2.35
CaO	11.50	11.75	15.25
MnO	0.167	0.197	0.290
Na_2O	2.70	2.70	1.78
K_2O	0.90	0.70	1.35
Ni	105	100	85
Co	60	55	90
Cu	95	65	375
V	20	20	15
Sr	25	20	20

Analyses Q-173 and Q-174 are on samples from U-8-5.

Analysis Q-175 is on a sample from U-3-16.

	J-1	J-2	J-3	J-5	J-6	J-7	J-8
SiO_2	46.25	35.50	38.10	43.75	45.55	55.10	49.50
Al_2O_3	7.20	6.75	6.55	11.50	11.60	13.40	11.25
Fe_2O_3	24.25	32.50	35.50	26.00	19.00	16.15	17.75
MgO	5.10	3.35	3.50	4.05	5.95	4.35	2.30
CaO	4.00	2.70	2.95	8.30	9.35	10.20	2.55
MnO	3.65	4.45	4.65	0.380	0.440	0.600	0.650
Na_2O	1.20	0.50	1.10	0.42	0.52	1.05	0.70
K_2O	2.50	1.90	1.65	0.97	1.35	2.30	3.45
Ni	95	80	55	100	80	75	90
Co	130	215	150	120	60	85	125
Cu	145	375	115	470	160	130	370
V	40	35	25	35	30	60	45
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-1 to J-3 are on successive samples from D.D.H. 3-J-1, Section 5200 E.
Analyses J-5 to J-7 are on successive samples from D.D.H. 3-J-2, Section 5400 E.

	J-9	J-10	J-11	J-12	J-13	J-14	J-15
SiO_2	47.30	48.75	42.80	45.35	42.55	41.50	44.80
Al_2O_3	12.60	8.60	2.85	10.85	10.30	8.05	10.60
Fe_2O_3	22.25	11.65	28.00	28.25	21.50	27.00	15.75
MgO	2.80	2.15	3.45	4.40	4.75	3.65	5.70
CaO	10.00	5.95	10.50	3.10	7.10	4.50	8.25
MnO	0.75	1.80	3.80	2.30	0.900	0.930	0.520
Na_2O	1.55	2.15	0.45	2.45	0.90	0.85	0.55
K_2O	2.20	2.45	0.17	2.05	1.75	0.93	0.57
Ni	80	75	75	70	80	85	70
Co	110	90	155	100	85	175	100
Cu	170	70	495	145	145	340	125
V	95	50	15	40	40	30	20
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-8 and J-9 are on samples from D.D.H. 3-J-3, Section 5500 E.
Analysis J-10 is on a sample from D.D.H. 3-J-S, Section 5600 E.
Analyses J-11 to J-15 are on successive samples from D.D.H. 3-J-7, Section 5100 E.

	J-16	J-17	J- 18	J-19	J-20	J-21	J-22
SiO_2	32.10	46.70	43.50	49.10	42.00	54.25	49.50
Al_2O_3	6.05	10.15	11.00	7.85	9.50	10.05	9.60
Fe_2O_3	32.20	18.10	15.55	33.00	26.50	15.75	18.55
MgO	4.60	6.15	5.85	3.80	2.95	8.90	10.40
CaO	5.05	9.25	8.65	3.30	3.85	11.50	8.10
MnO	5.65	0.65	0.46	4.15	3.20	0.250	0.215
Na_2O	1.25	1.75	1.10	0.95	0.85	n.d.	n.d.
K_2O	0.88	0.82	0.72	0.70	0.73	0.04	0.04
Ni	75	75	65	90	50	85	80
Co	150	85	65	215	70	90	70
Cu	80	80	70	150	110	175	115
V	15	35	40	30	25	25	80
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-16 to J-22 are on successive samples from D.D.H. 3-J-8, Section 5000 E.

	J-23	J-24	J-25	J-26	J-27	J-28	J-29
SiO_2	51.50	50.30	49.35	47.25	49.50	49.05	35.25
Al_2O_3	10.40	11.85	10.95	11.40	12.30	12.65	9.00
Fe_2O_3	14.85	24.50	26.25	22.75	15.65	14.50	14.85
MgO	6.00	3.80	2.75	4.10	8.05	11.15	7.75
CaO	13.15	4.95	3.40	6.85	9.65	13.40	11.10
MnO	0.52	1.95	3.05	0.850	0.390	0.330	0.600
Na_2O	2.50	1.45	1.75	1.75	1.10	0.84	1.80
K_2O	0.82	1.30	1.12	0.85	1.95	0.06	0.52
Ni	100	60	60	90	80	75	75
Co	75	95	90	100	65	65	60
Cu	120	75	145	940	90	70	135
V	30	25	25	25	45	45	35
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-23 to J-28 are on successive samples from D.D.H. 3-J-9, Section 4900 E.

Analyses J-29 to J-31 are on successive samples from D.D.H. 3-J-10, Section 4800 E.

	J-30	J-31	J-32	J-33	J-34	J-35	J-36
SiO_2	56.50	51.05	42.75	42.00	39.50	33.75	38.75
Al_2O_3	10.85	7.60	8.50	10.90	7.40	4.75	6.80
Fe_2O_3	16.80	21.40	24.35	20.75	29.75	29.25	29.75
MgO	4.40	4.70	5.90	3.00	3.30	4.10	3.25
CaO	8.90	8.40	11.90	7.95	3.10	4.60	2.15
MnO	0.940	3.60	2.00	0.800	3.05	4.10	3.90
Na_2O	1.45	1.45	1.25	0.60	0.75	0.85	1.85
K_2O	0.67	0.55	0.34	0.58	1.35	0.41	2.15
Ni	70	60	70	75	70	85	100
Co	75	105	80	115	120	85	145
Cu	120	145	345	130	165	330	2000
V	40	20	30	35	25	15	u15
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-32 to J-33 are on samples from D.D.H. 3-J-11, Section 4700 E.
Analysis J-34 is from D.D.H. 3-J-17, Section 5000 E.
Analysis J-35 is from D.D.H. 3-J-19, Section 4700 E.
Analyses J-36 and J-37 are from D.D.H. 3-J-21, Section 5800 E.

	J-37	J-38	J-39	J-40	J-41	J-42	J-43
SiO_2	40.50	47.65	42.75	41.75	47.40	42.80	40.50
Al_2O_3	10.80	7.10	11.00	7.65	20.05	10.90	5.30
Fe_2O_3	16.55	25.65	11.40	27.35	19.15	17.50	30.75
MgO	4.75	3.05	4.85	2.70	3.10	1.60	1.65
CaO	11.40	1.65	12.90	1.80	3.60	9.35	1.10
MnO	0.340	3.90	0.40	2.15	0.74	0.75	4.10
Na_2O	n.d.	0.65	1.60	0.86	2.10	0.48	0.55
K_2O	0.77	2.35	1.45	2.40	2.70	2.55	1.27
Ni	130	60	70	55	35	60	60
Co	90	105	85	120	65	95	125
Cu	585	570	300	750	615	300	285
V	45	15	45	u15	u15	30	15
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d	n.d.

Analyses J-38 and J-39 are from D.D.H. 3-J-22, Section 5900 E.
Analyses J-40 and J-41 are from D.D.H. 3-J-24, Section 5700 E.
Analyses J-42 to J-44 are from D.D.H. 3-J-26, Section 6000 E.

	J-44	J-45	J-46	J-47	J-48	J-49	J-50
SiO_2	48.10	50.50	43.75	49.50	43.30	42.80	45.25
Al_2O_3	12.50	11.10	9.35	11.65	8.15	11.00	11.30
Fe_2O_3	14.05	13.50	16.40	18.75	20.80	25.75	19.75
MgO	3.60	2.55	3.15	2.30	6.60	2.95	3.65
CaO	13.15	14.50	16.70	10.45	6.35	7.50	7.70
MnO	0.270	0.30	0.36	0.24	0.87	0.72	0.72
Na_2O	1.70	1.30	1.30	1.20	1.00	1.30	1.65
K_2O	0.28	0.48	0.18	0.27	0.90	1.35	1.38
Ni	85	95	80	80	85	95	60
Co	70	140	105	140	95	105	55
Cu	120	105	90	235	225	190	105
V	40	40	15	50	50	60	40
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analysis J-45 is on a sample from D.D.H. 6-J-53, Section 4800 E
Analyses J-46 and J-47 are from D.D.H. 6-J-52, Section 4900 E.
Analysis J-48 is from D.D.H. 6-J-51, Section 5000 E.
Analysis J-49 is from D.D.H. 6-J-50, Section 5100 E.
Analyses J-50 to J-52 are from D.D.H. 6-J-49, Section 5200 E.

	J-51	J-52	J-53	J-54	J-55	J-56	J-57
SiO_2	49.35	49.50	42.75	46.25	41.75	36.25	35.25
Al_2O_3	12.30	9.40	9.05	9.95	10.60	11.85	8.90
Fe_2O_3	18.75	11.75	23.10	21.75	24.50	10.35	25.25
MgO	2.95	4.40	3.56	2.45	2.80	2.15	3.60
CaO	6.40	7.85	3.85	4.80	6.25	23.20	8.10
MnO	0.80	0.80	0.87	1.70	0.80	0.28	0.68
Na_2O	1.80	1.85	1.95	1.95	1.35	2.70	2.05
K_2O	2.00	1.55	3.20	2.90	2.10	1.25	1.35
Ni	90	70	75	70	70	135	125
Co	100	100	150	95	105	100	145
Cu	160	255	185	230	460	1600	1800
V	35	30	30	35	25	35	15
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-53 and J-54 are from D.D.H. 6-J-2, Section 5400 E.
Analyses J-55 and J-56 are from D.D.H. 6-J-4, Section 5500 E.
Analyses J-57 to J-59 are from D.D.H. 6-J-7, Section 5600 E.

	J-58	J-59	J-60	J-61	J-62	J-63	J-64
SiO_2	44.00	42.35	36.15	34.15	41.50	44.10	41.25
Al_2O_3	7.15	5.40	7.15	9.70	15.15	5.50	12.70
Fe_2O_3	25.80	32.50	21.85	25.50	22.05	28.25	20.25
MgO	3.15	3.00	2.95	2.60	1.55	2.35	2.15
CaO	2.70	2.45	4.80	2.10	2.00	2.30	7.50
MnO	0.95	2.60	2.60	0.98	0.49	1.90	0.80
Na_2O	1.35	1.95	1.45	0.95	0.70	0.70	1.10
K_2O	2.15	2.55	0.88	2.10	1.95	1.80	1.68
Ni	80	70	65	60	45	125	60
Co	155	185	130	85	80	170	85
Cu	945	830	325	150	195	2450	465
V	25	20	15	30	15	15	15
Sr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Analyses J-60 to J-63 are from D.D.H. 6-J-9, Section 5700 E.
Analyses J-64 to J-67 are from D.D.H. 6-J-5, Section 5800 E.

	J-65	J-66	J-67	J-68	J-69
SiO_2	39.05	38.20	44.10	35.85	50.60
Al_2O_3	9.55	4.95	10.55	7.25	3.80
Fe_2O_3	22.65	31.50	24.50	18.50	23.25
MgO	3.95	2.20	2.60	3.70	4.30
Cao	5.00	3.15	2.70	10.90	4.90
MnO	3.30	2.50	1.85	0.95	4.70
Na_2O	1.30	0.85	1.75	1.10	2.10
K_2O	1.70	0.66	3.70	0.81	0.63
Ni	60	50	65	60	80
Co	90	115	110	80	145
Cu	155	860	375	800	710
V	25	u15	55	25	u15
Sr	n.d.	n.d.	n.d.	n.d.	n.d.

Analysis J-68 is from D.D.H. 6-J-6, Section 5800 E.
Analysis J-69 is from D.D.H. 6-J-10, Section 5900 E.

	CU-4	CU-5	CU-6	CU-7	CU-8	CU-9	CU-10
SiO_2	49.50	55.35	58.60	57.80	59.05	60.35	56.50
Al_2O_3	16.85	15.05	12.15	13.90	10.10	13.70	14.80
Fe_2O_3	15.60	15.50	15.05	15.75	18.50	18.90	15.10
MgO	3.70	3.45	1.60	3.10	2.90	1.95	5.20
CaO	10.00	6.90	6.15	7.20	7.20	3.40	6.10
MnO	0.240	0.550	0.550	0.640	0.570	0.460	0.250
Na_2O	2.60	1.40	1.50	1.70	0.76	1.10	2.50
K_2O	2.75	1.82	2.08	1.45	0.31	2.45	1.88
Ni	75	60	45	45	105	65	100
Co	45	60	65	35	145	130	75
Cu	205	130	140	385	170	775	260
V	25	25	25	25	35	25	50
Sr	15	10	10	n.d.	n.d.	n.d.	15

Analyses CU-4 to CU-7 are from D.D.H. C.S. 88, Section 100 W.
Analyses CU-8 and CU-9 are from D.D.H. C.S. 82, Section 0.

	CU-11	CU-12	CU-13	CU-14	CU-15	CU-16	CU-17
SiO_2	50.20	50.80	51.75	48.90	51.20	51.25	51.75
Al_2O_3	15.35	15.20	13.20	12.80	7.75	14.20	16.90
Fe_2O_3	14.25	13.90	14.80	15.85	13.90	21.10	13.75
MgO	3.25	4.75	6.20	6.60	8.60	6.25	2.55
CaO	10.30	11.80	8.10	9.95	17.15	3.50	7.60
MnO	0.260	0.380	0.340	0.340	0.600	0.340	0.360
Na_2O	2.30	2.05	2.20	1.70	n.d.	1.80	3.35
K_2O	1.78	1.58	1.75	0.82	0.07	1.78	3.55
Ni	110	85	95	160	280	70	40
Co	55	50	50	60	75	55	45
Cu	975	130	120	190	200	150	110
V	45	60	60	55	100	40	25
Sr	15	10	15	n.d.	n.d.	n.d.	15

Analyses CU-10 to CU-16 are from D.D.H. CU 321, Section 0
Analyses CU-17 to CU-23 are from D.D.H. CS-75, Section 100 E.

	CU-18	CU-19	CU-20	CU-21	CU-22	CU-23	CU-24
SiO_2	52.50	51.55	50.00	44.35	49.25	51.75	47.50
Al_2O_3	17.10	16.90	15.25	18.10	19.70	16.80	16.85
Fe_2O_3	14.75	17.50	19.90	20.55	9.40	14.10	16.90
MgO	3.00	2.80	3.15	4.35	3.75	3.65	5.50
CaO	7.10	6.10	7.20	5.30	7.55	7.80	7.80
MnO	0.620	0.450	0.620	0.460	0.380	0.540	0.380
Na_2O	2.40	1.85	1.65	1.40	2.10	3.10	2.30
K_2O	3.10	3.30	1.87	1.78	3.40	2.78	2.08
Ni	45	55	95	95	65	90	225
Co	55	55	50	60	40	95	70
Cu	55	120	135	115	115	120	250
V	25	30	35	35	55	30	35
Sr	15	10	10	15	15	15	15

Analyses CU 24 to CU-31 are from D.D.H. CS 69, Section 200 E

	CU-25	CU-26	CU-27	CU-28	CU-29	CU-30	CU-31
SiO_2	46.90	47.85	50.25	47.75	48.20	49.20	54.15
Al_2O_3	16.95	18.10	16.45	22.10	16.90	19.05	12.60
Fe_2O_3	16.50	16.60	12.70	12.50	14.15	12.50	9.60
MgO	5.05	5.40	4.65	3.95	4.90	3.00	1.55
CaO	8.85	7.85	8.76	5.75	8.85	6.20	5.90
MnO	0.270	0.260	0.320	0.300	0.500	0.480	0.440
Na_2O	2.40	3.40	3.00	2.00	1.95	2.65	1.40
K_2O	2.40	2.73	3.45	4.18	3.38	4.50	2.76
Ni	165	190	85	90	90	60	u30
Co	65	95	40	50	40	45	35
Cu	105	140	135	80	110	80	85
V	30	25	35	45	45	45	15
Sr	15	15	15	15	15	15	15

	CU-32	CU-33	CU-34	CU-35	CU-36	CU-37	CU-38
SiO_2	47.25	44.75	50.25	51.65	49.50	51.55	48.25
Al_2O_3	15.05	14.35	17.20	15.95	16.05	18.35	17.55
Fe_2O_3	17.85	20.25	17.35	15.05	13.20	11.40	10.85
MgO	4.20	5.30	4.20	3.90	4.40	2.95	3.10
CaO	9170	8.40	3.25	9.80	10.50	8.85	11.20
MnO	0.410	0.290	0.230	0.220	0.270	0.170	0.190
Na_2O	1.15	1.20	2.30	2.35	2.90	3.30	2.85
K_2O	1.70	1.15	2.50	1.56	2.25	2.35	2.08
Ni	90	120	85	120	80	80	95
Co	75	65	140	85	45	75	60
Cu	170	250	280	300	80	105	85
V	35	60	40	55	65	45	50
Sr	n.d.	n.d.	15	20	15	20	20

Analyses CU-32 and CU-33 are from D.D.H. CU-411, Section 200 E.
Analyses CU-34 to CU-40 are from D.D.H. CU-383, Section 250 E.
Analysis CU-42 is from D.D.H. CU-399, Section 80 E

	CU-39	CU-40	CU-42	CU-43	CU-44	CU-45	CU-46
SiO_2	50.45	47.85	58.35	57.35	54.85	52.55	47.65
Al_2O_3	19.50	8.80	13.65	14.85	15.10	14.80	13.25
Fe_2O_3	12.85	18.65	6.15	9.00	8.40	13.20	16.65
MgO	4.70	2.55	2.40	3.10	3.75	4.20	5.15
CaO	7.50	12.50	10.35	9.10	8.05	9.90	9.15
MnO	0.240	0.500	0.120	0.150	0.140	0.250	0.310
Na_2O	3.15	0.65	2.35	4.90	4.05	4.30	2.70
K_2O	2.72	0.38	0.41	0.50	0.28	0.74	0.41
Ni	105	100	30	45	50	75	95
Co	60	190	30	35	40	45	60
Cu	45	1350	40	80	60	90	260
V	50	30	20	40	40	25	35
Sr	15	n.d.	20	45	40	n.d.	20

Analysis CU-43 is from D.D.H. CU-331, Section 400 E.
Analysis CU-44 is from D.D.H. CU-319, Section 450 E.
Analysis CU-45 is from D.D.H. CU-358, Section 750 E.
Analysis CU-46 is from D.D.H. CU-228, Section 835 E.

	CU-47	C.C.1	C.C.2	C.C.3	C.C.4	C.C.5	C.C.6
SiO_2	56.75	65.00	70.30	55.85	61.25	64.50	68.60
Al_2O_3	14.20	12.30	13.60	12.60	14.05	14.30	12.85
Fe_2O_3	10.50	3.75	3.80	4.20	5.95	3.75	3.05
MgO	3.05	1.95	1.65	3.15	2.60	1.70	1.15
CaO	10.90	7.05	7.25	10.40	11.10	9.00	6.80
MnO	0.270	0.060	0.060	0.075	0.120	0.080	0.065
Na_2O	4.25	5.40	2.85	4.10	3.10	3.75	3.45
K_2O	0.63	0.90	1.37	1.67	1.05	1.06	1.75
Ni	55	u30	u30	50	35	u30	u30
Co	50	u30	u30	40	35	40	35
Cu	95	65	75	105	110	80	65
V	40	20	20	35	30	25	20
Sr	20	40	35	25	30	30	30

Analysis CU-47 is from D.D.H. CU-194, Section 960 E.
Analyses C.C.1 and C.C.2 are from D.D.H. U-510
Analysis C.C.3 is from D.D.H. U-371
Analysis C.C.4 is from D.D.H. U-379
Analysis C.C.5 is from D.D.H. U-698
Analysis C.C.6 is from D.D.H. U-950

	C.C.7	C.C.8	C.C.9	C.C.10
SiO_2	66.25	60.10	54.90	62.40
Al_2O_3	14.05	14.80	15.65	15.20
Fe_2O_3	5.95	7.40	4.10	6.45
MgO	2.35	4.30	1.70	2.05
CaO	10.50	10.50	10.90	10.90
MnO	0.100	0.110	0.068	0.100
Na_2O	2.75	4.45	4.75	4.05
K_2O	1.72	1.10	2.30	2.40
Ni	u30	50	u30	u30
Co	50	45	40	35
Cu	100	85	80	65
V	20	30	25	25
Sr	30	30	35	30

Analyses C.C.7 and C.C.8 are from D.D.H. U-575
Analyses C.C.9 and C.C.10 are from D.D.H. U-715

APPENDIX II

WORKING CURVES

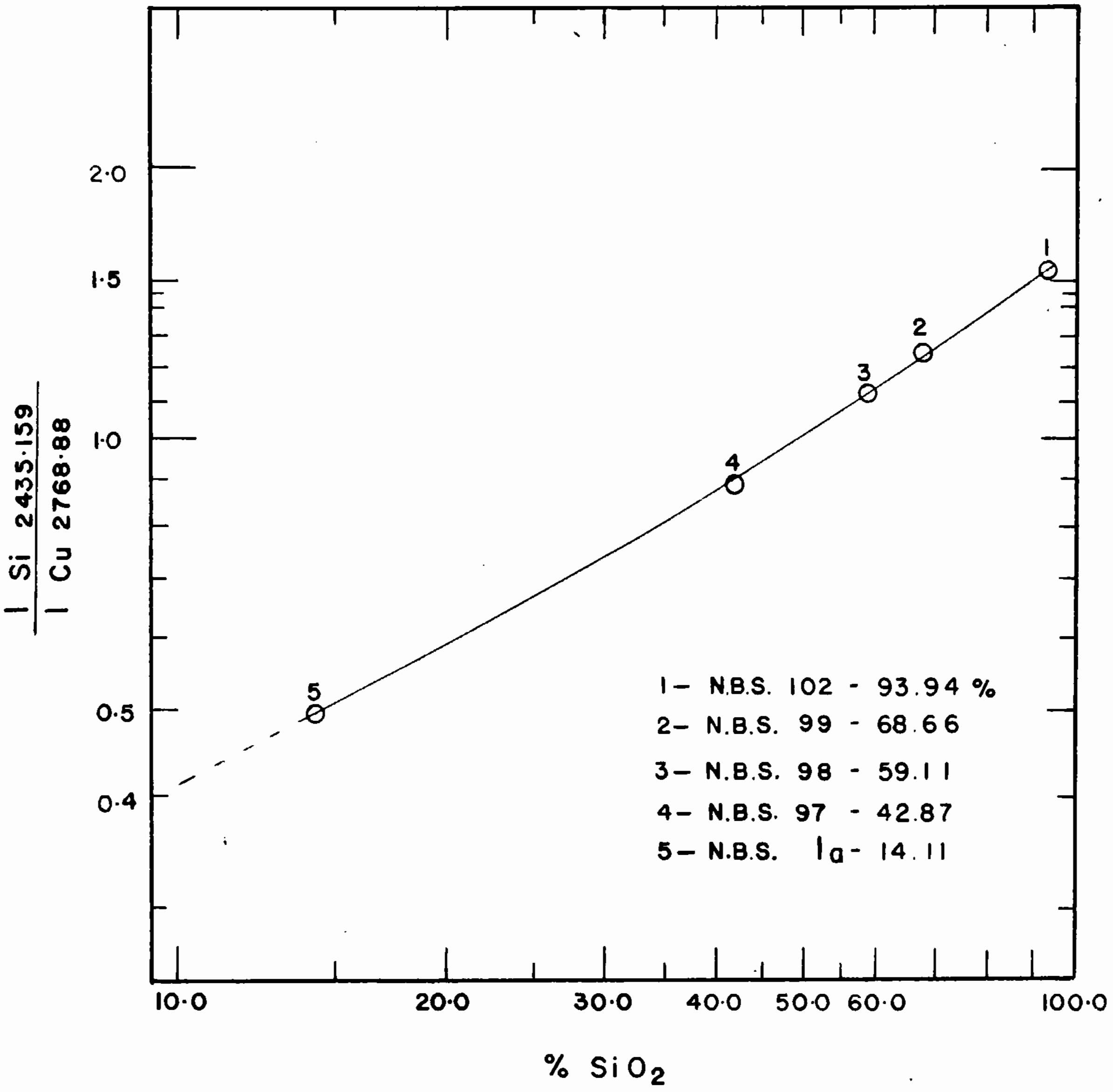


Fig. I WORKING CURVE FOR SILICA

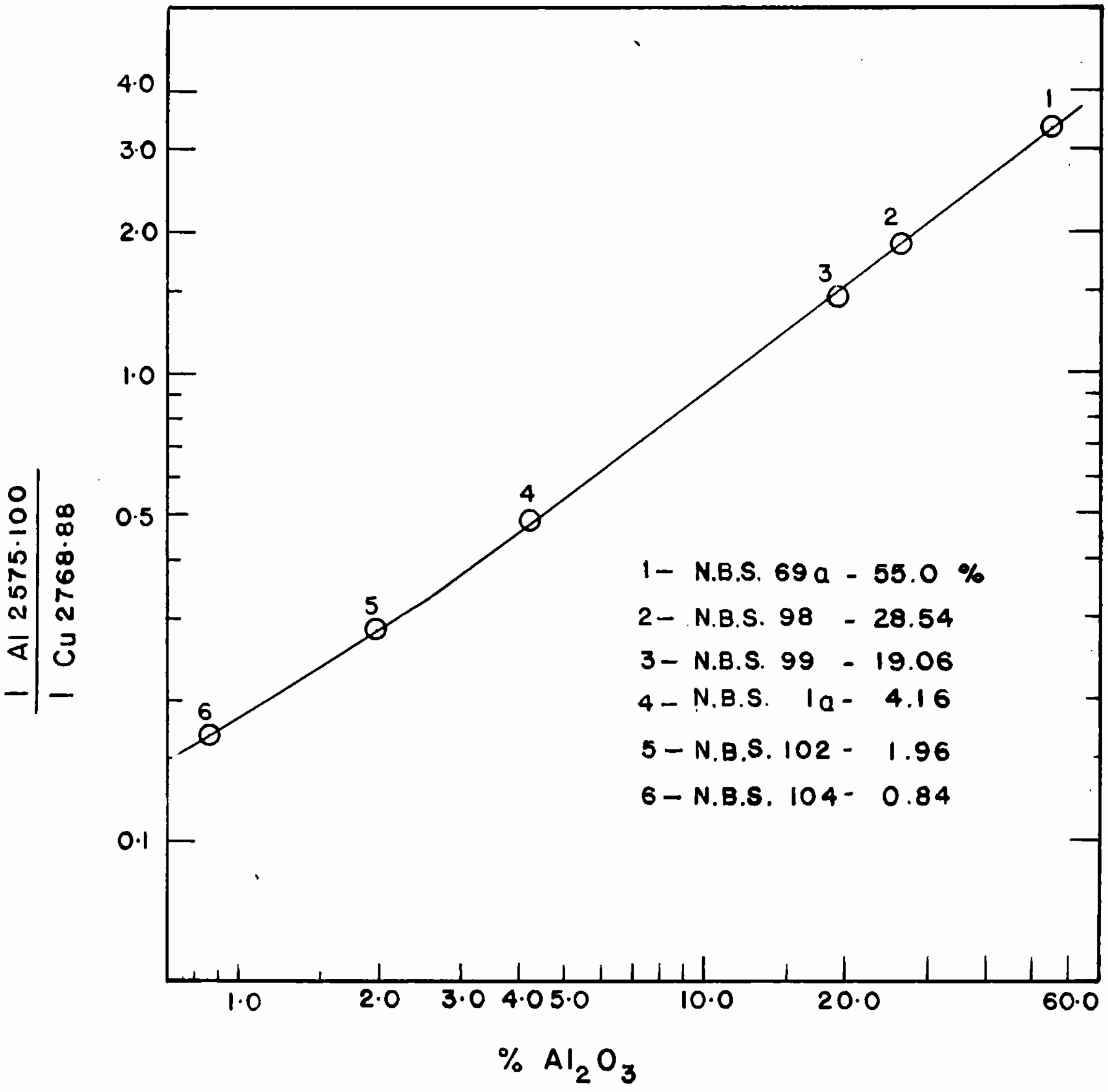


Fig.2 WORKING CURVE FOR ALUMINUM

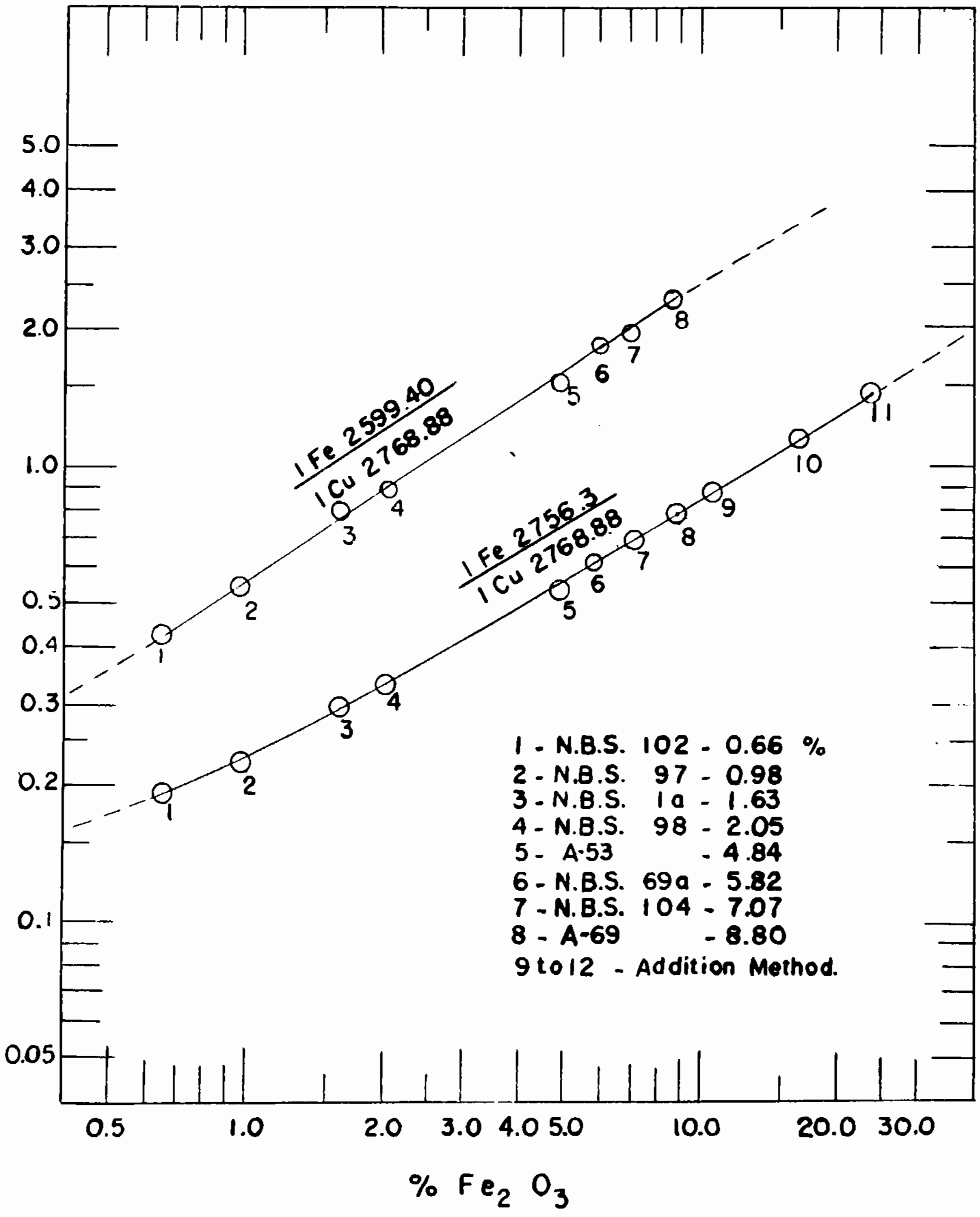


Fig. 3. WORKING CURVE FOR IRON

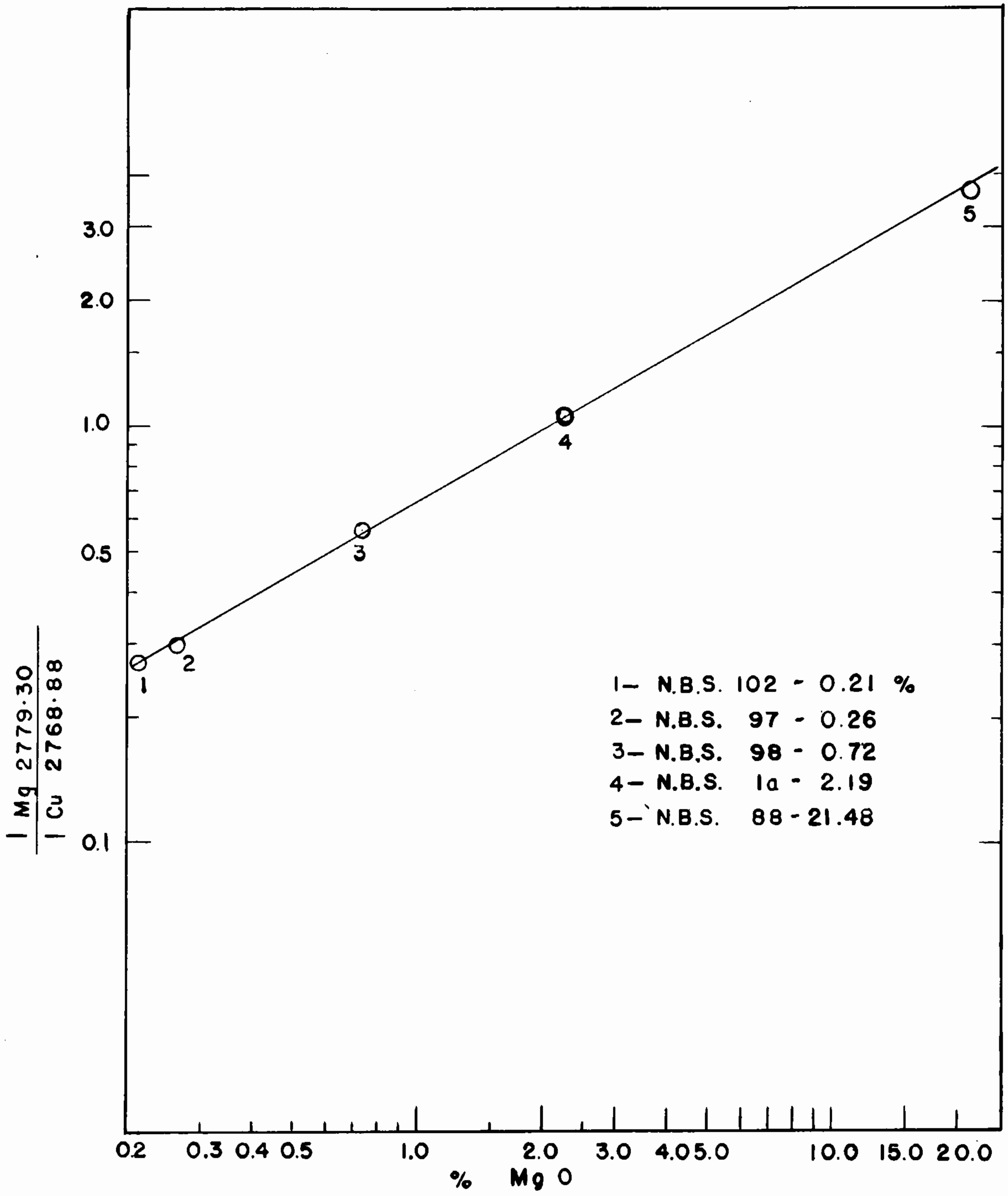


Fig. 4 WORKING CURVE FOR MAGNESIUM

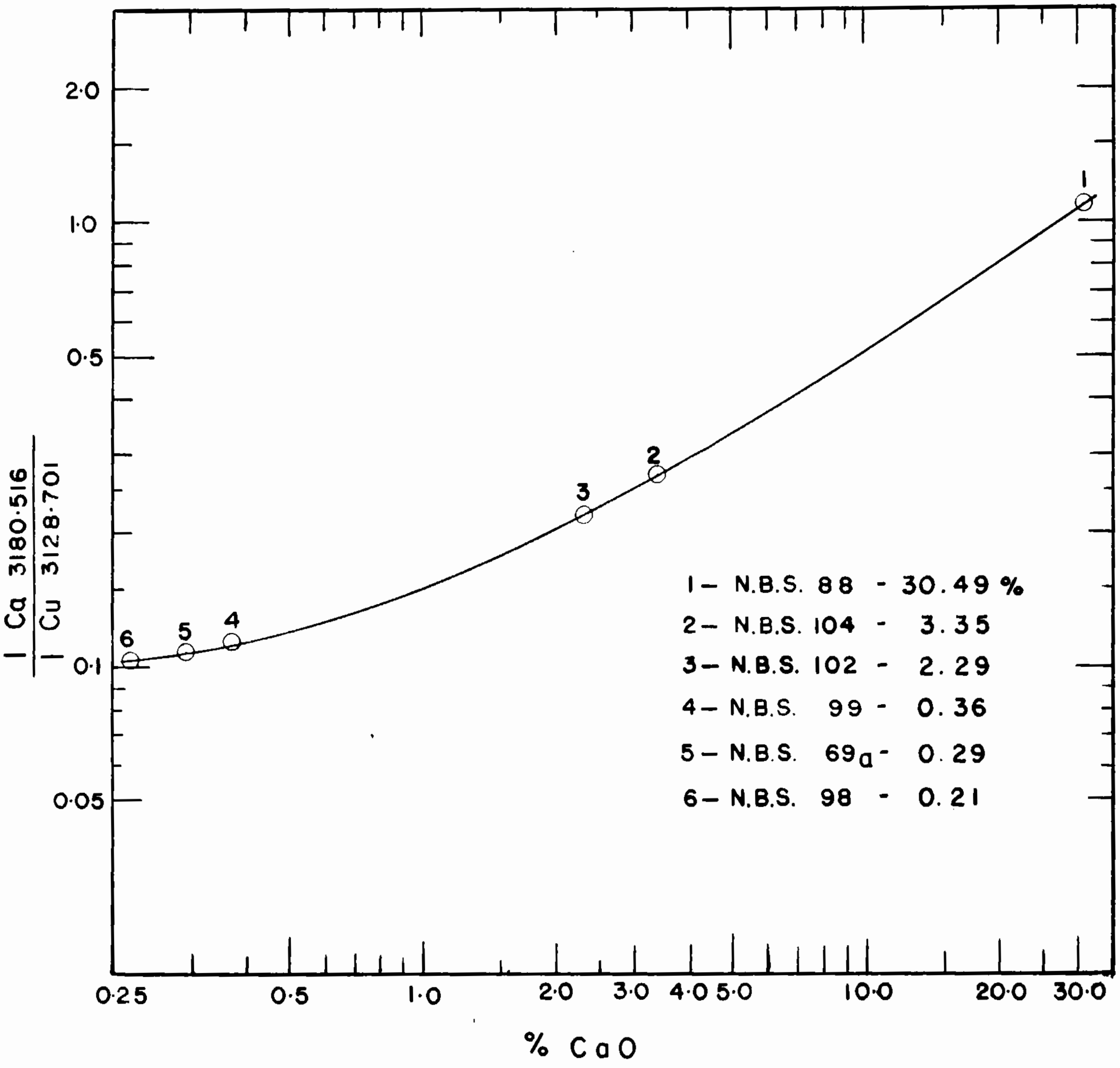


Fig. 5 WORKING CURVE FOR CALCIUM

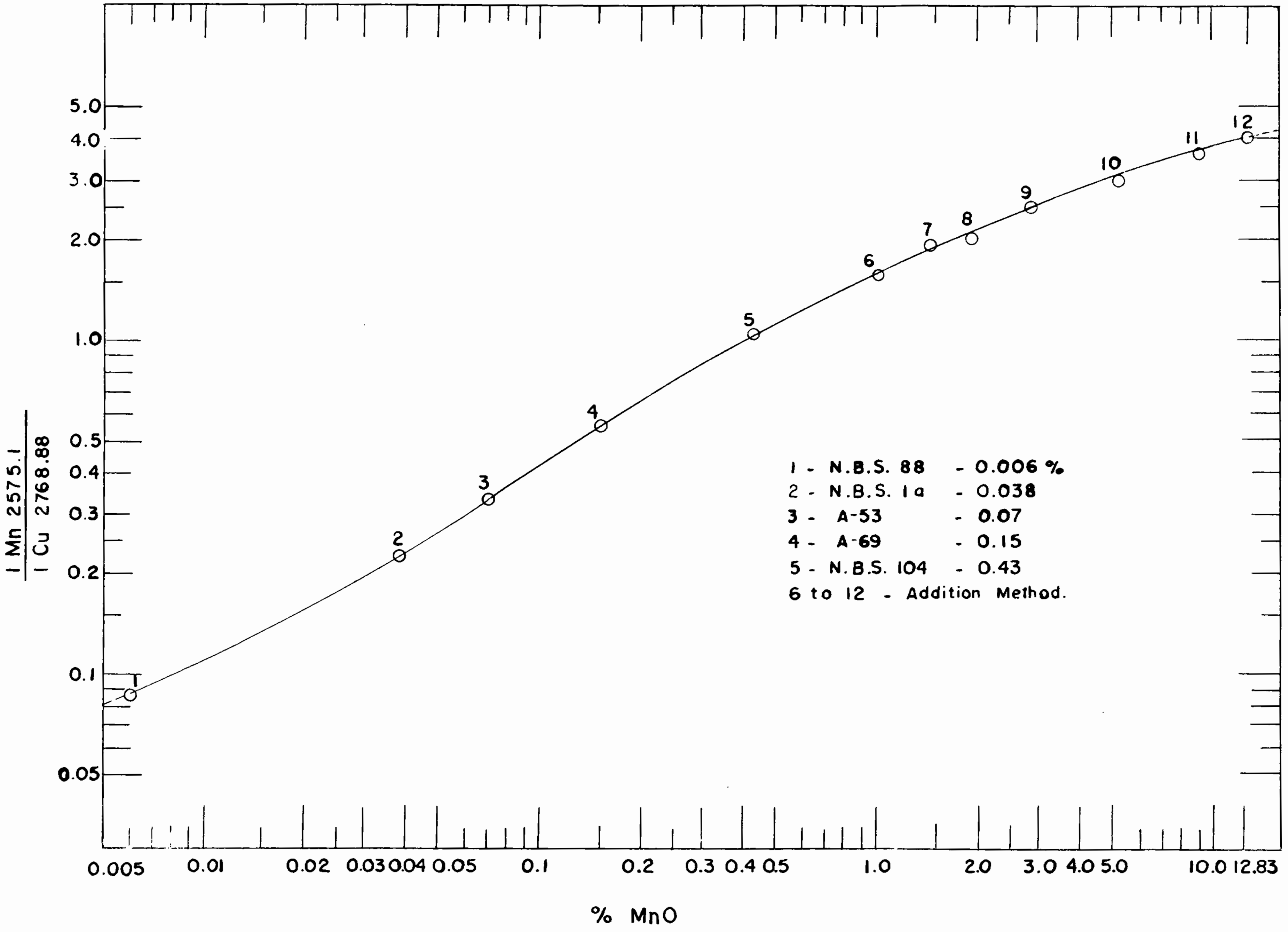


Fig. 6 WORKING CURVE FOR MANGANESE

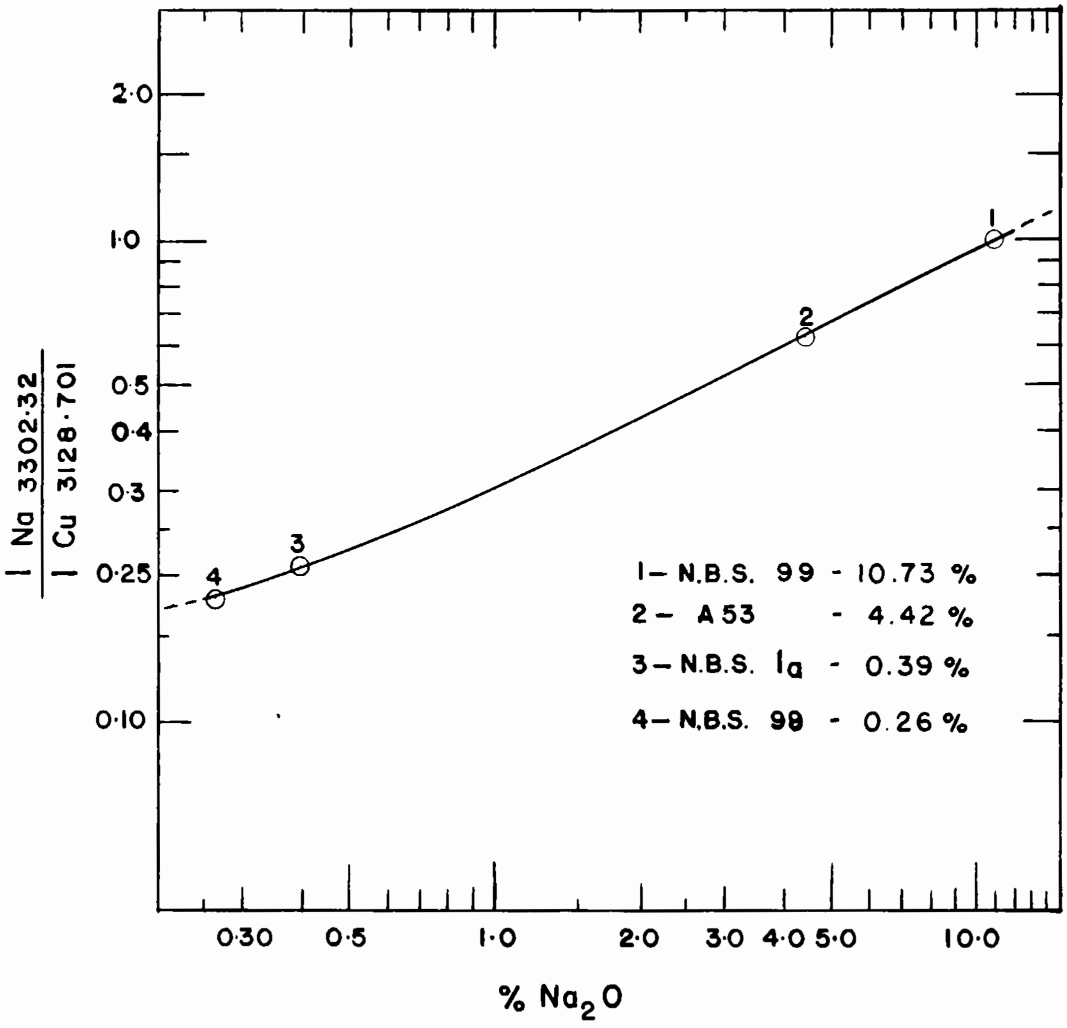


Fig.7 WORKING CURVE FOR SODIUM

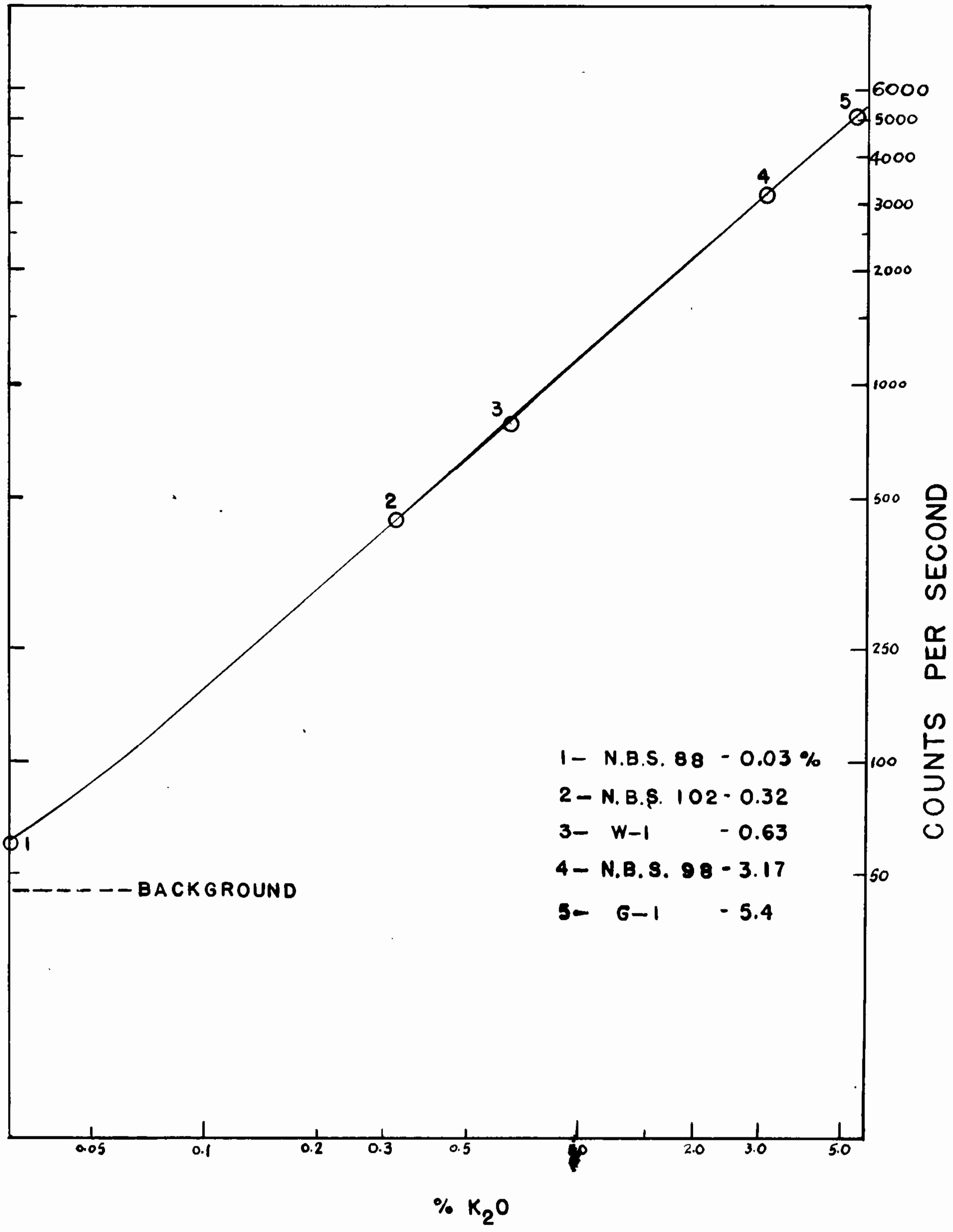


Fig. 8 WORKING CURVE FOR POTASSIUM

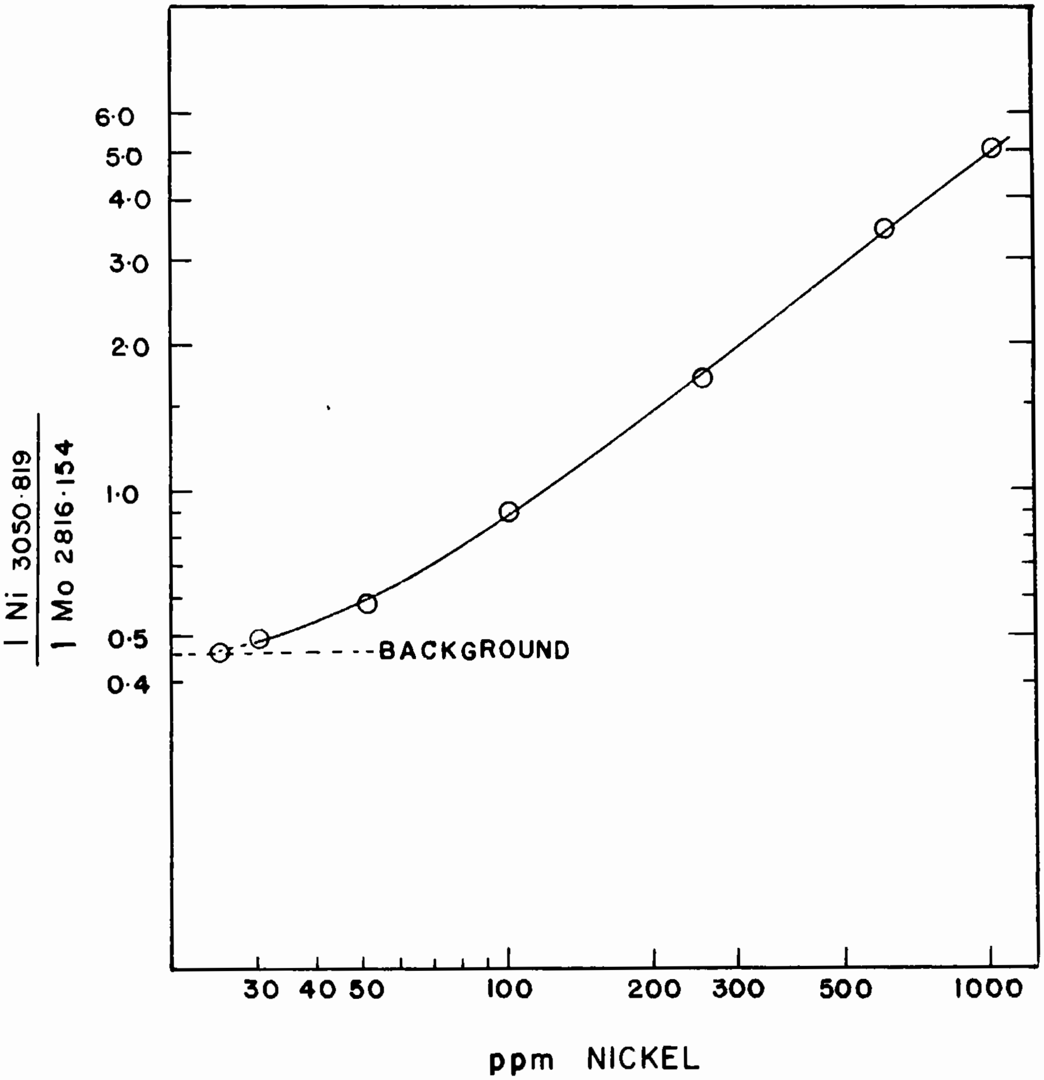


Fig.9 WORKING CURVE FOR NICKEL

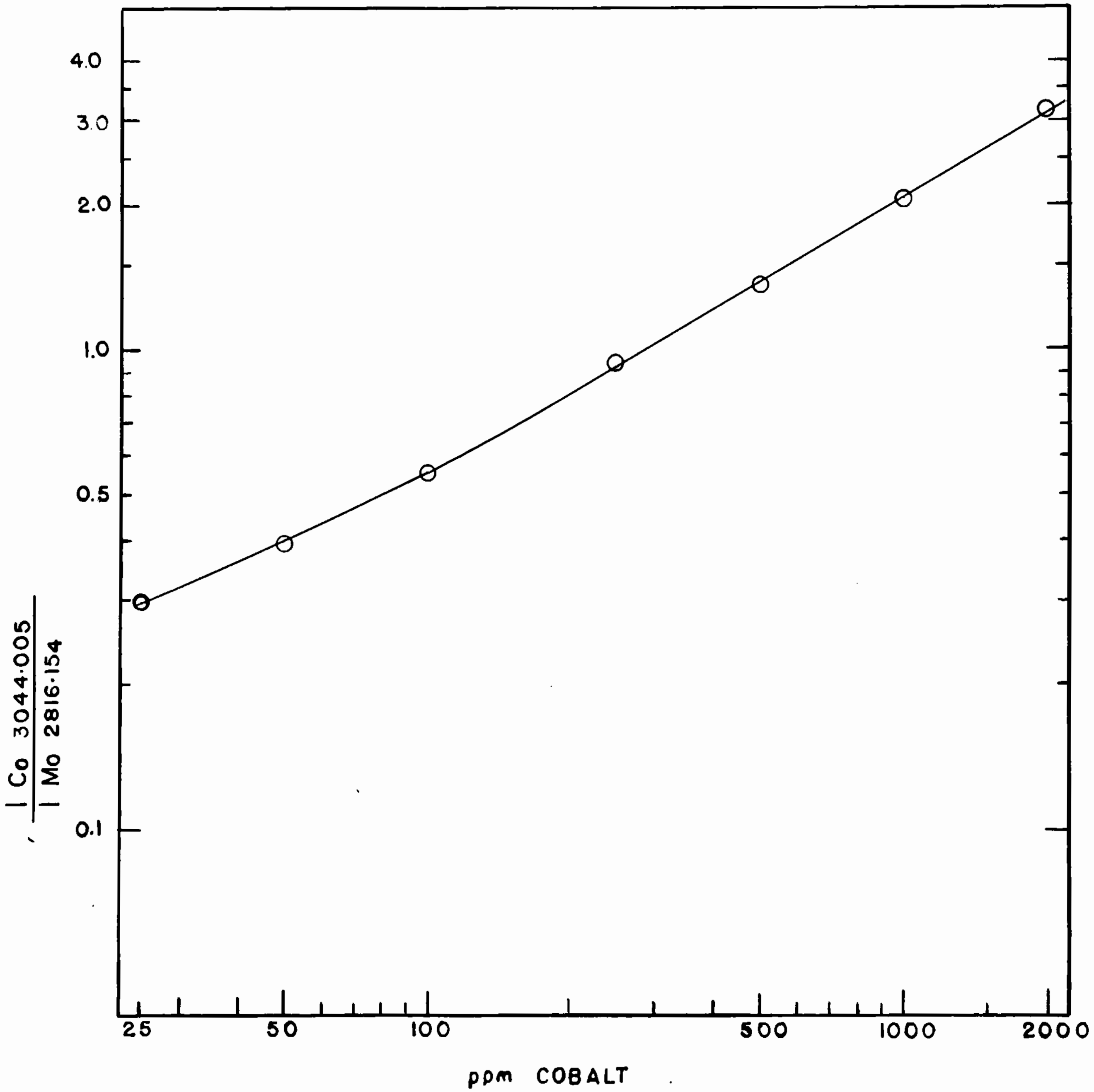


Fig.10 WORKING CURVE FOR COBALT

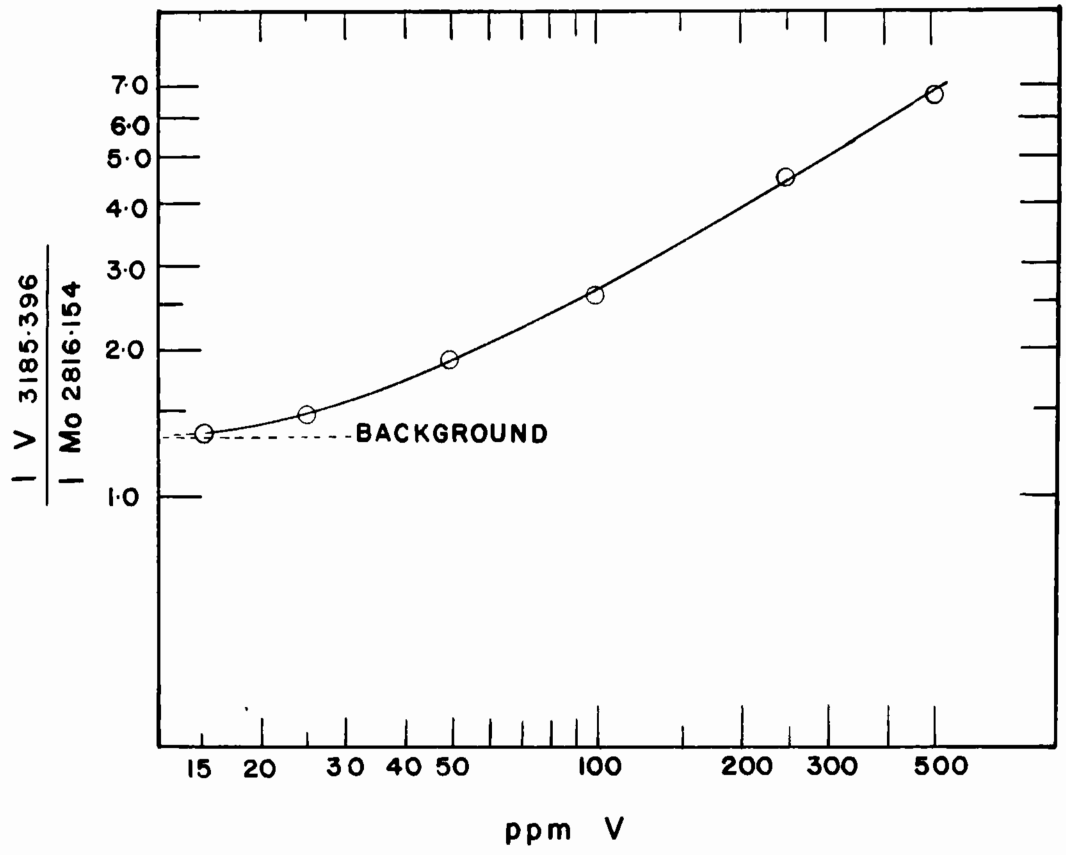


Fig. 11 WORKING CURVE FOR VANADIUM

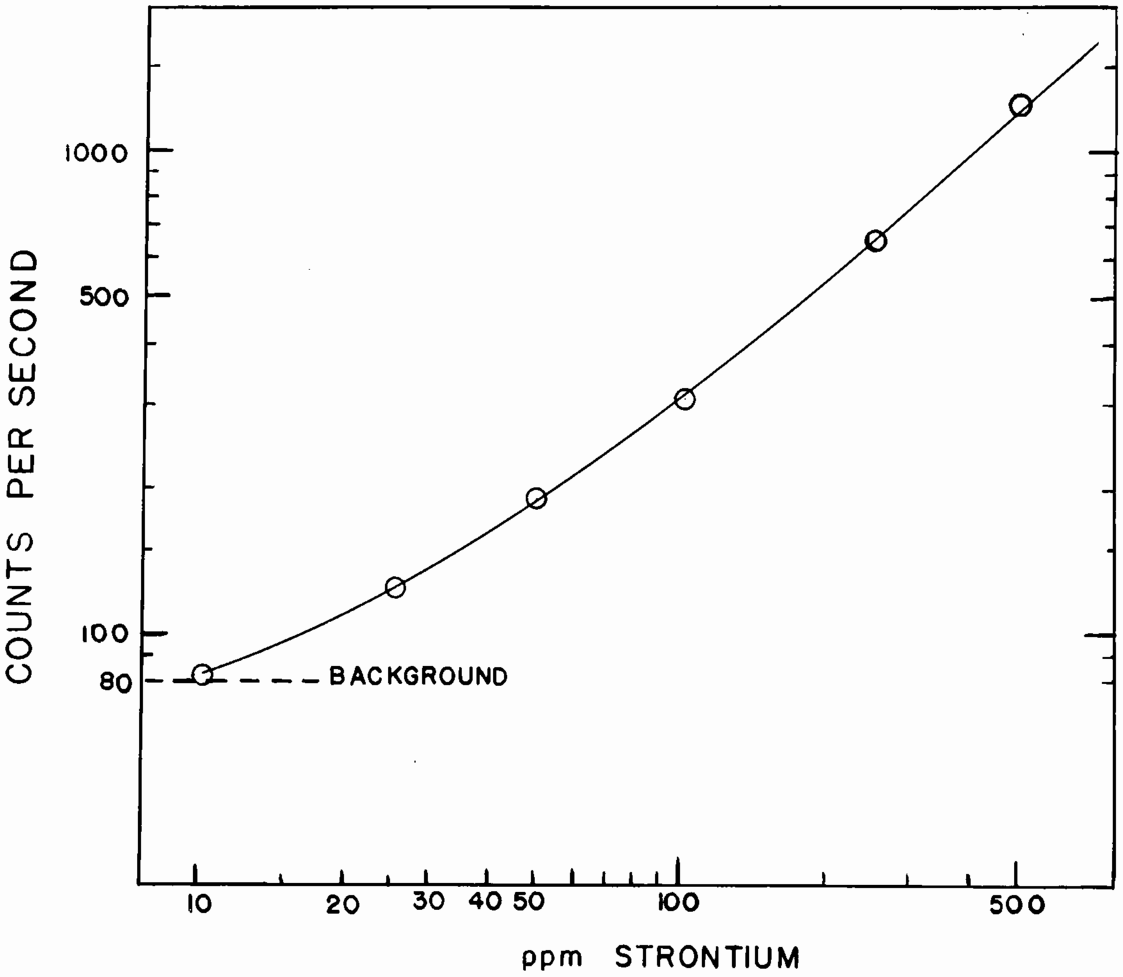


Fig.12 WORKING CURVE FOR STRONTIUM

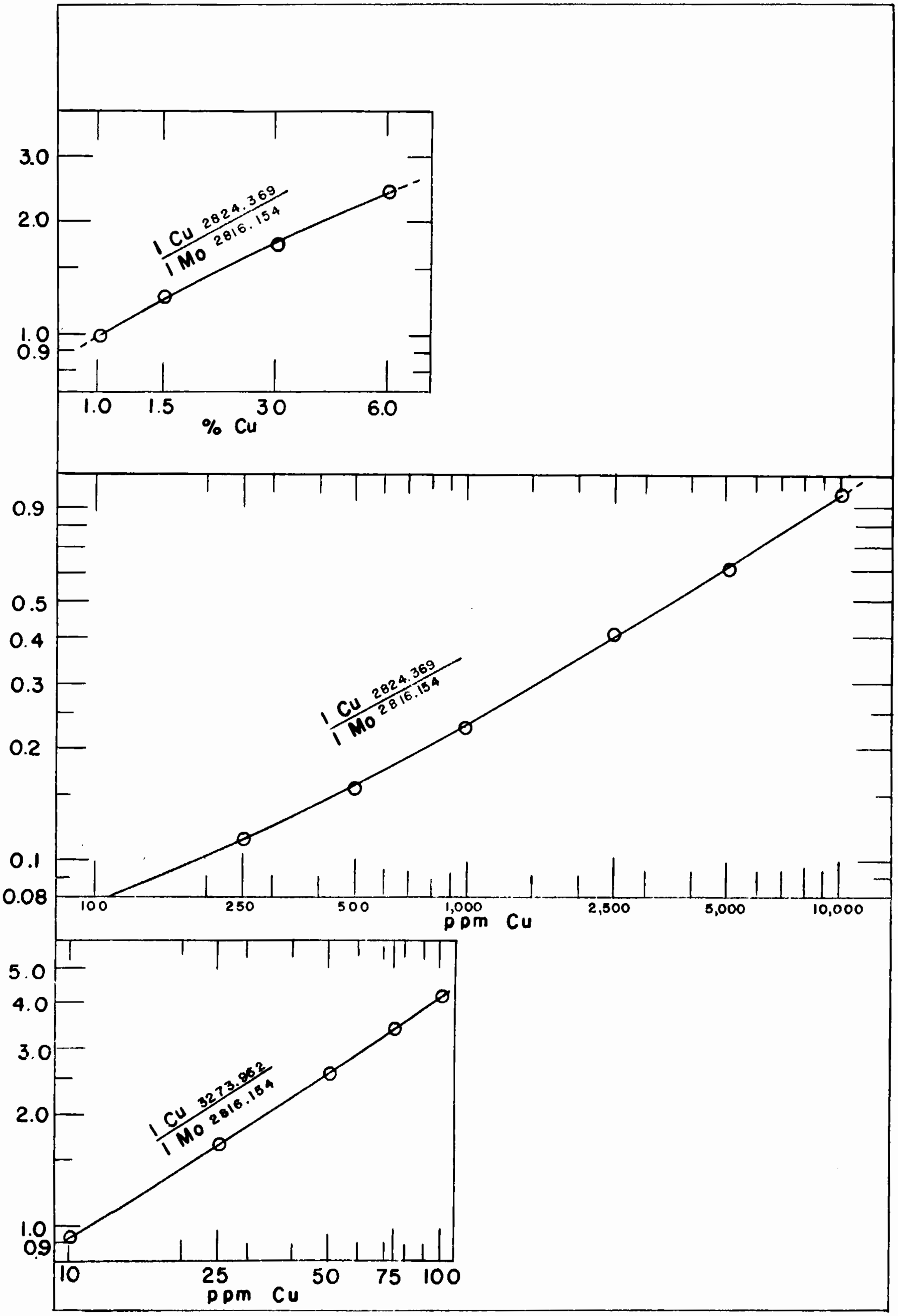


Fig. 13 WORKING CURVES FOR COPPER

APPENDIX III

Map 4 - 350-level, Quebec Chibougamau Goldfields, Ltd.

Map 5 - 500-level, " " " "

Map 6 - 650-level, " " " "

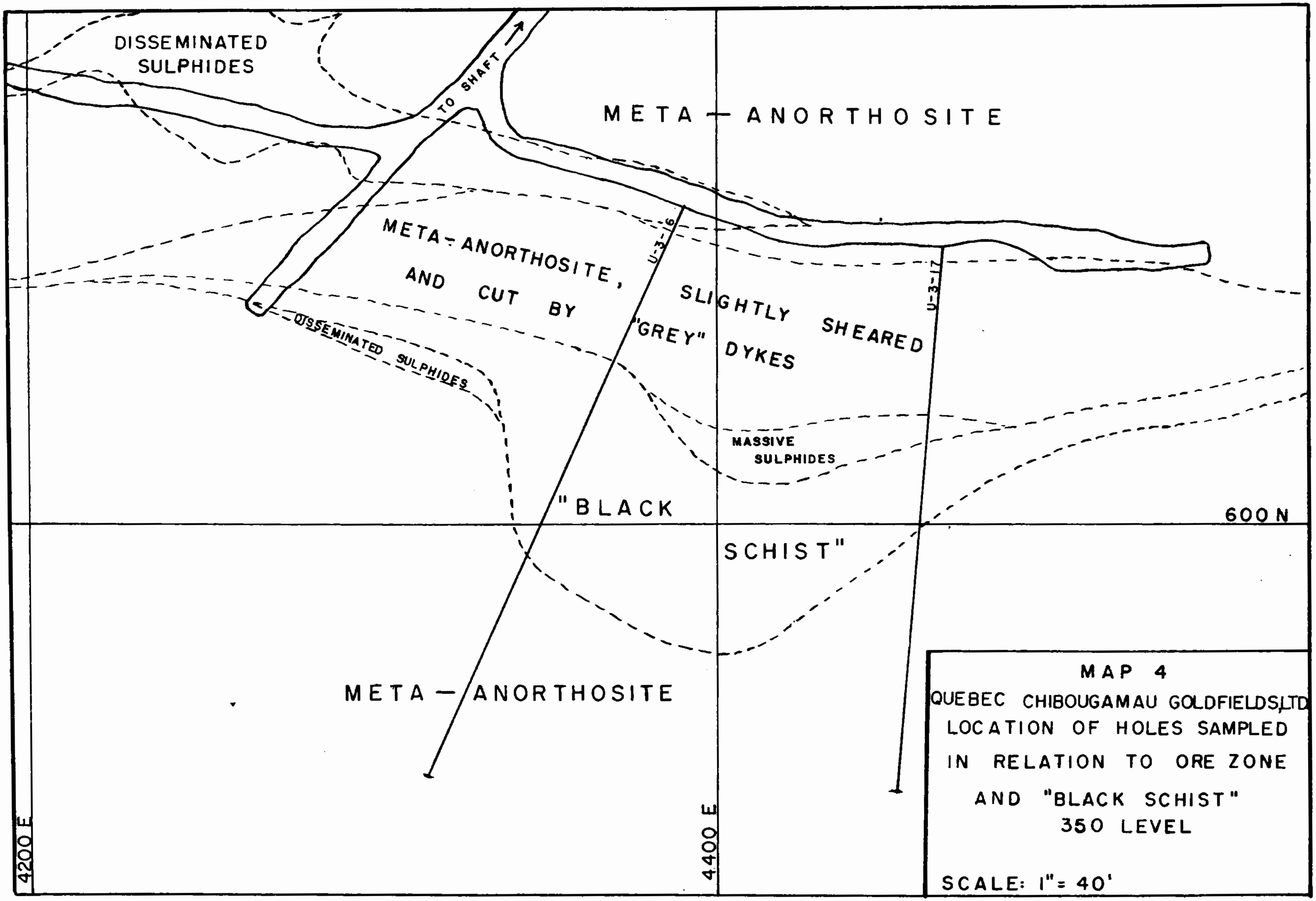
Map 7 - 800-level, " " " "

Map 13 - "Black" Dyke at Cedar Bay.

Map 15 - 300-level, Chibougamau Jaculet.

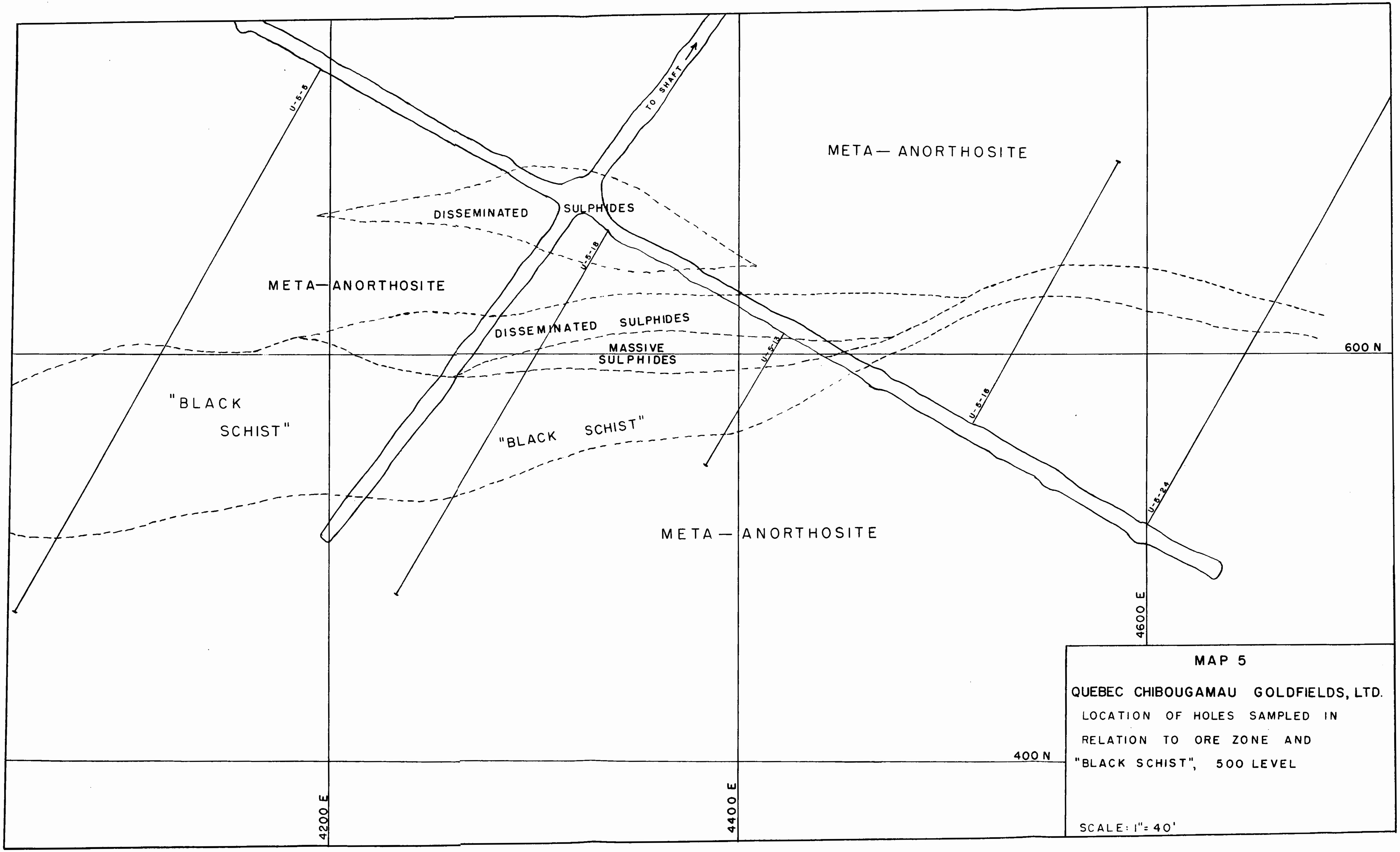
Map 16 - 600-level, " "

Map 17 - Surface Holes at Cedar Bay.



MAP 4
QUEBEC CHIBOUGAMAU GOLDFIELDS LTD
LOCATION OF HOLES SAMPLED
IN RELATION TO ORE ZONE
AND "BLACK SCHIST"
350 LEVEL

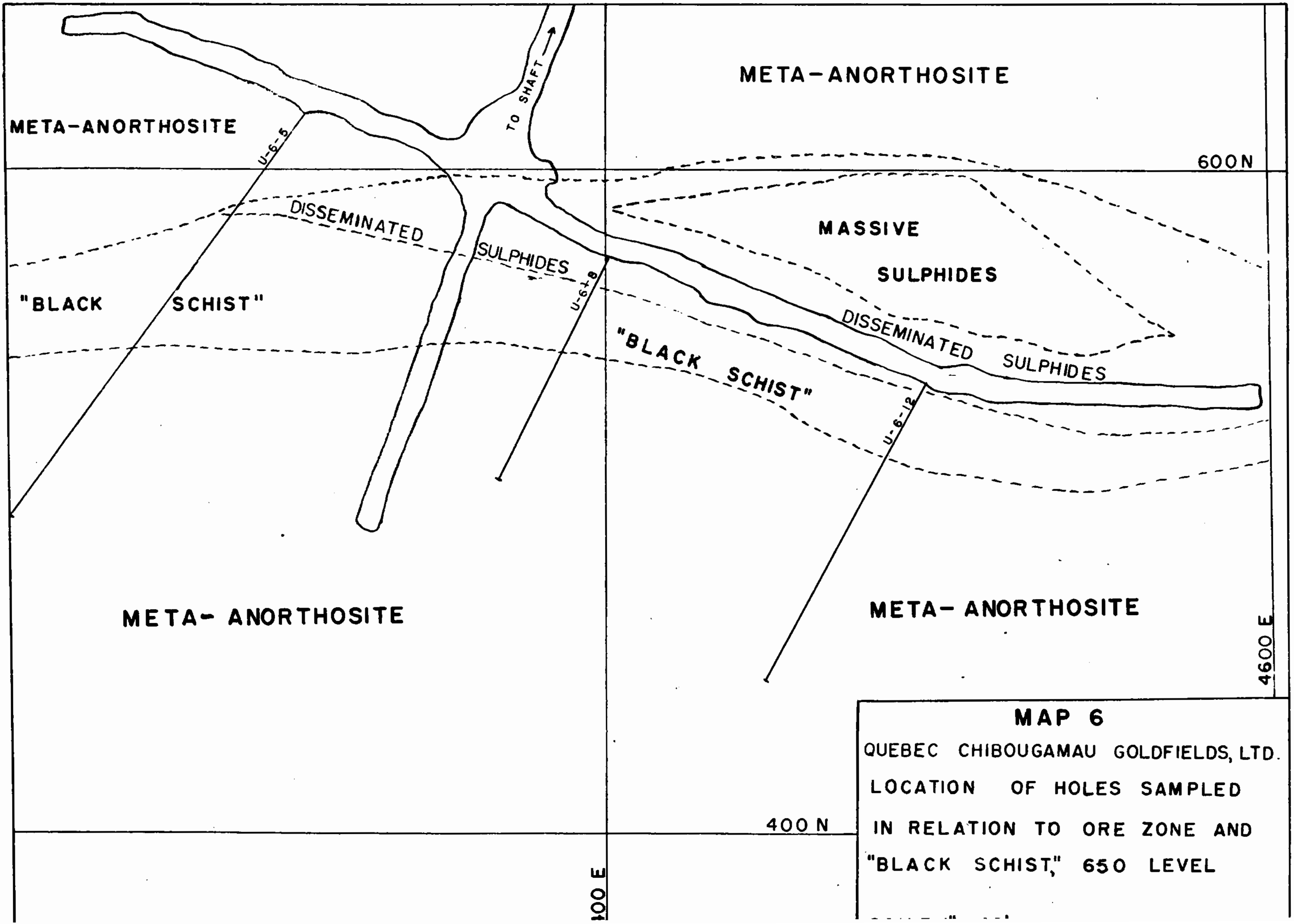
SCALE: 1" = 40'



MAP 5

QUEBEC CHIBOUGAMAU GOLDFIELDS, LTD.
LOCATION OF HOLES SAMPLED IN
RELATION TO ORE ZONE AND
"BLACK SCHIST", 500 LEVEL

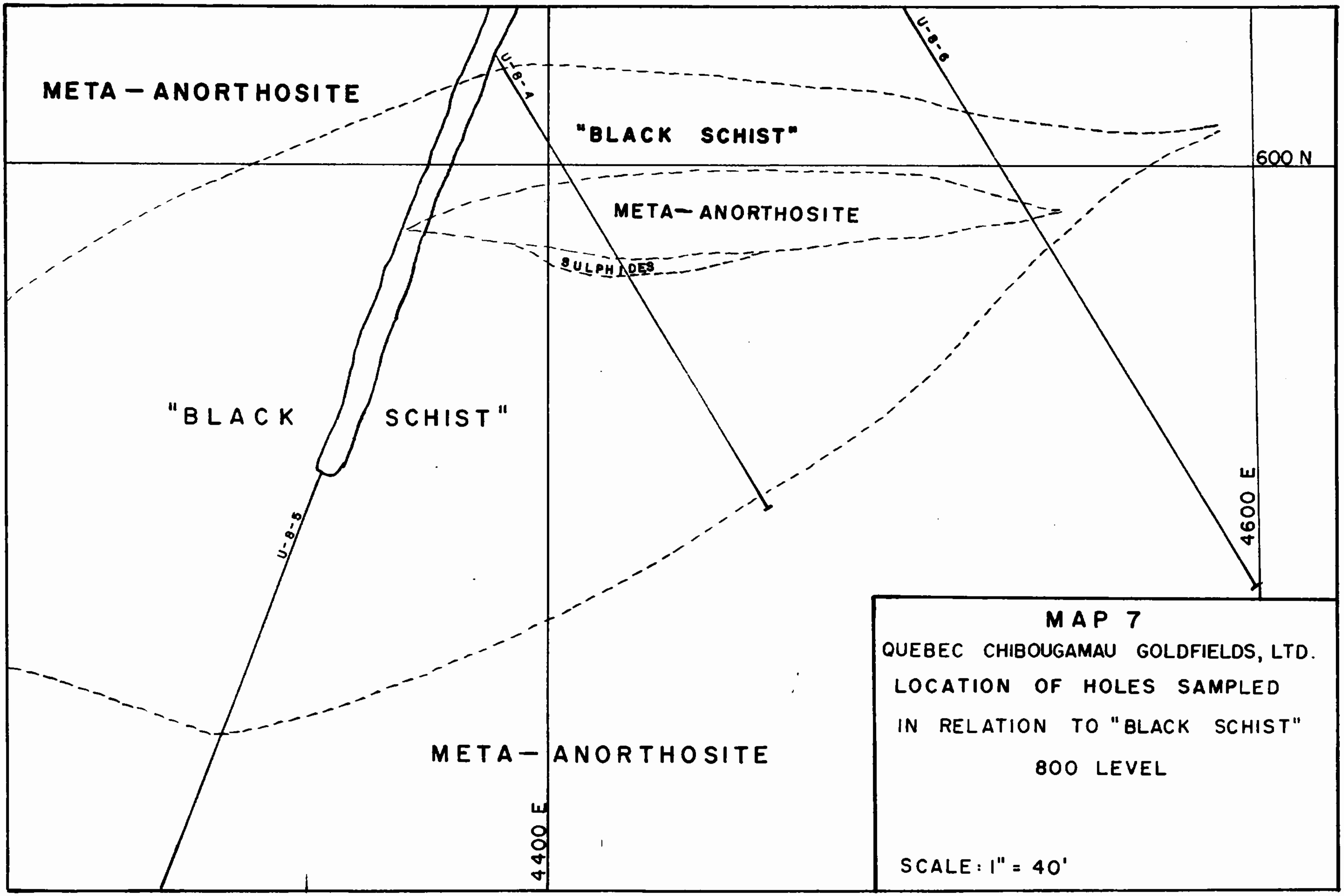
SCALE: 1" = 40'



MAP 6

QUEBEC CHIBOUGAMAU GOLDFIELDS, LTD.

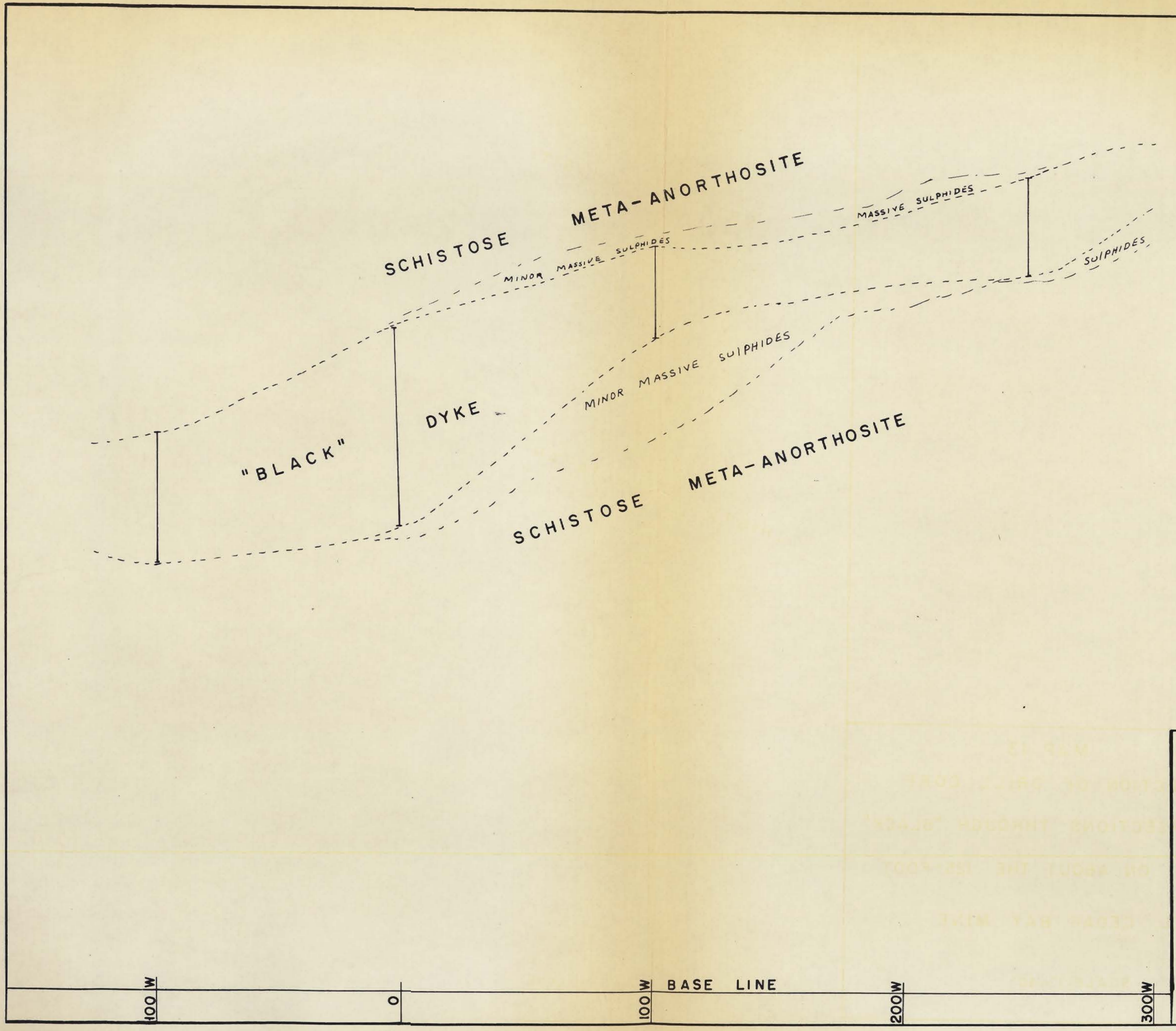
LOCATION OF HOLES SAMPLED
IN RELATION TO ORE ZONE AND
"BLACK SCHIST," 650 LEVEL



MAP 7

QUEBEC CHIBOUGAMAU GOLDFIELDS, LTD.
LOCATION OF HOLES SAMPLED
IN RELATION TO "BLACK SCHIST"
800 LEVEL

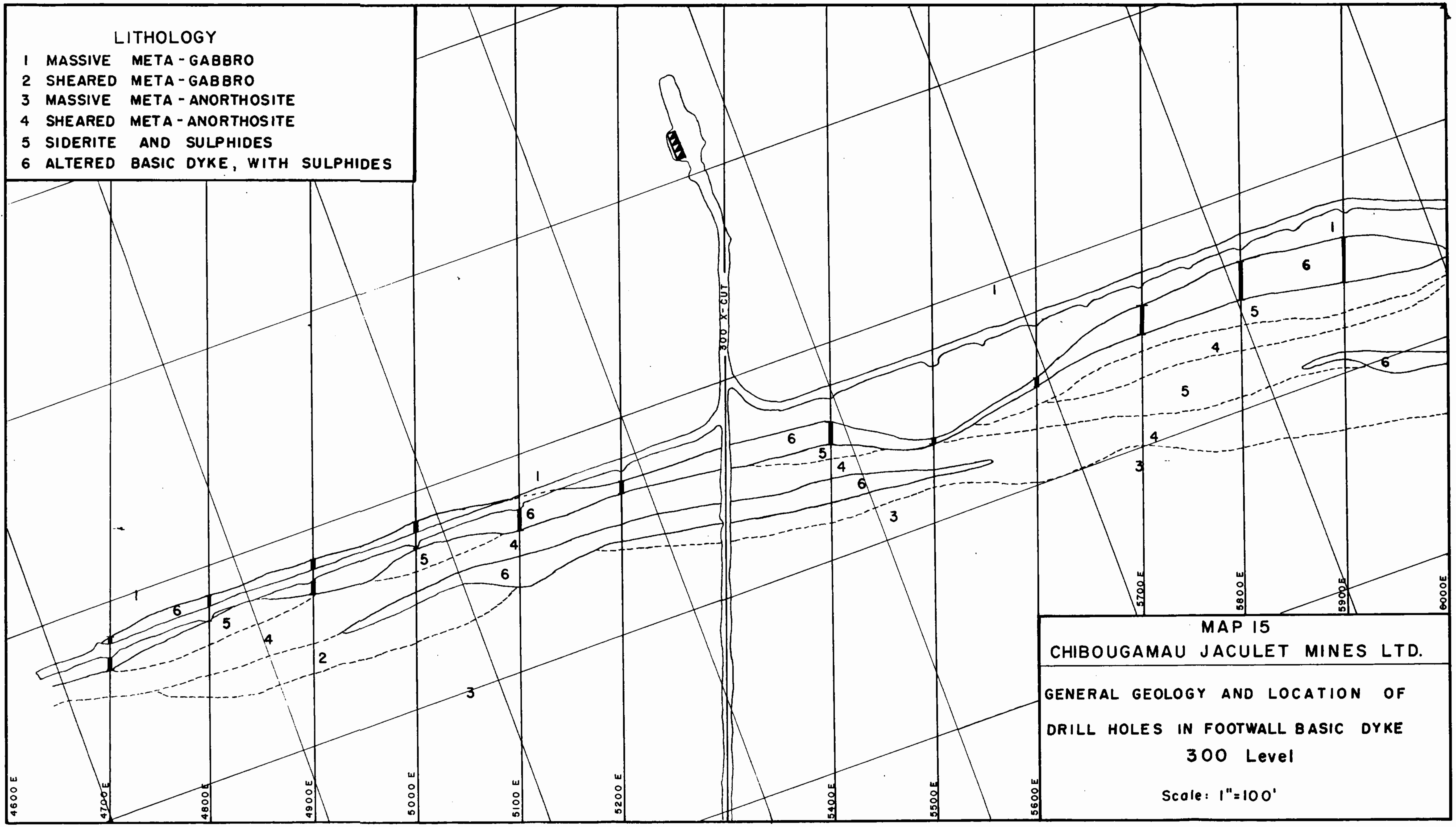
SCALE: 1" = 40'



MAP 13

PROJECTION OF DRILL CORE
INTERSECTIONS THROUGH "BLACK"
DYKE ON ABOUT THE 125-FOOT
LEVEL, CEDAR BAY MINE

SCALE: 1" = 40'



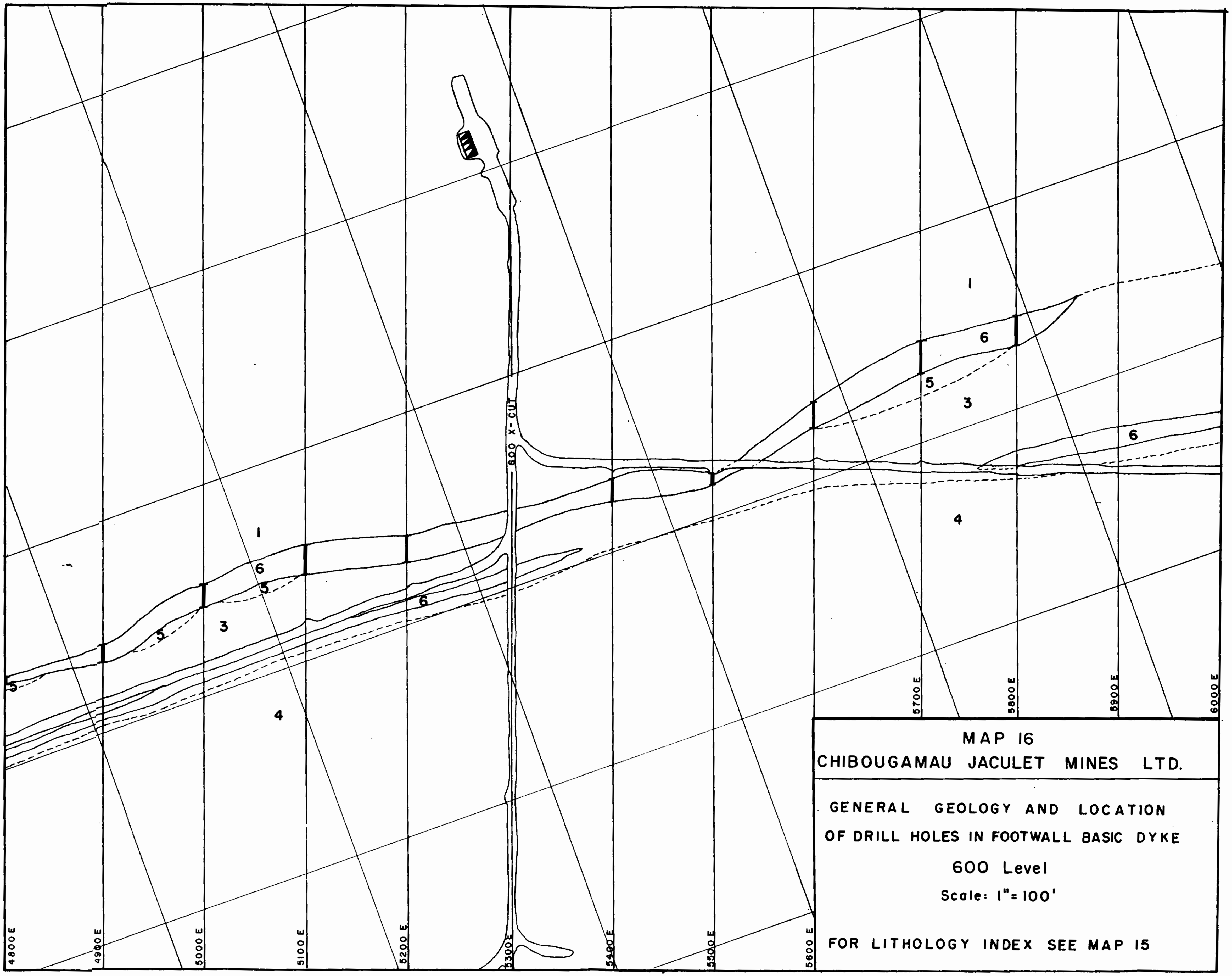
MAP 15

CHIBOUGAMAU JACULET MINES LTD.

GENERAL GEOLOGY AND LOCATION OF DRILL HOLES IN FOOTWALL BASIC DYKE

300 Level

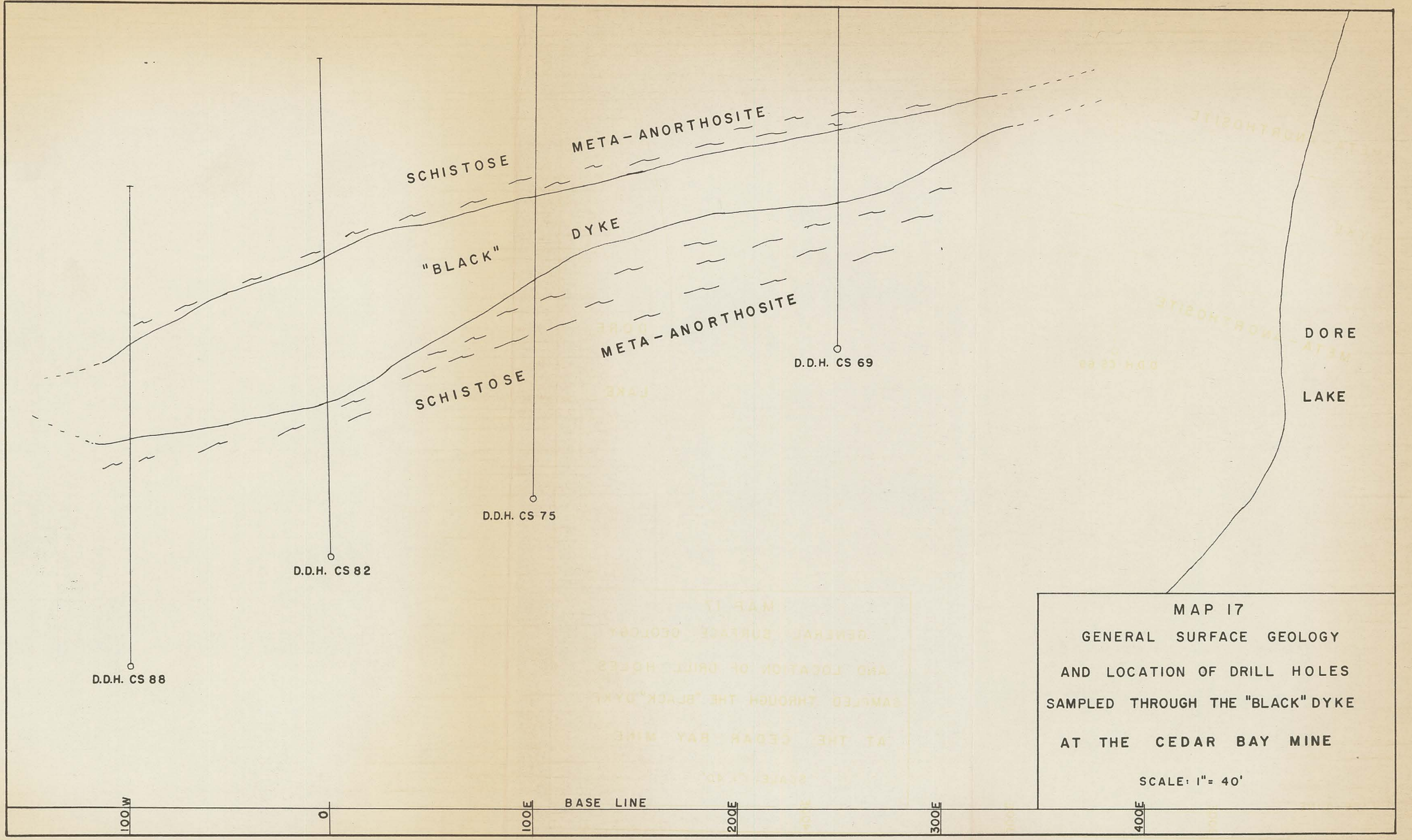
Scale: 1"=100'



MAP 16
CHIBOUGAMAU JACULET MINES LTD.

GENERAL GEOLOGY AND LOCATION
OF DRILL HOLES IN FOOTWALL BASIC DYKE
600 Level
Scale: 1" = 100'

FOR LITHOLOGY INDEX SEE MAP 15



MAP 17
GENERAL SURFACE GEOLOGY
AND LOCATION OF DRILL HOLES
SAMPLED THROUGH THE "BLACK" DYKE
AT THE CEDAR BAY MINE

SCALE: 1" = 40'

APPENDIX IV

A Note on the Classification of the Shear Zones

When the drill core intersections of the shear zones were examined, the relative intensities of alteration and the occurrences of sulphides were noted. These relative changes were classified as being characteristic of a particular shear zone, or part of a shear zone.

The term Class I was given to a shear zone which showed light to moderate hydrothermal alteration effects. The term Class II was given to a moderately to heavily sheared zone showing a good degree of hydrothermal alteration effects. The term Class III was given to a heavily sheared zone, showing intense alteration effects, and in which sulphides were present. However, traces of sulphides, especially pyrite, may be present locally in shear zones of Class I and Class II.

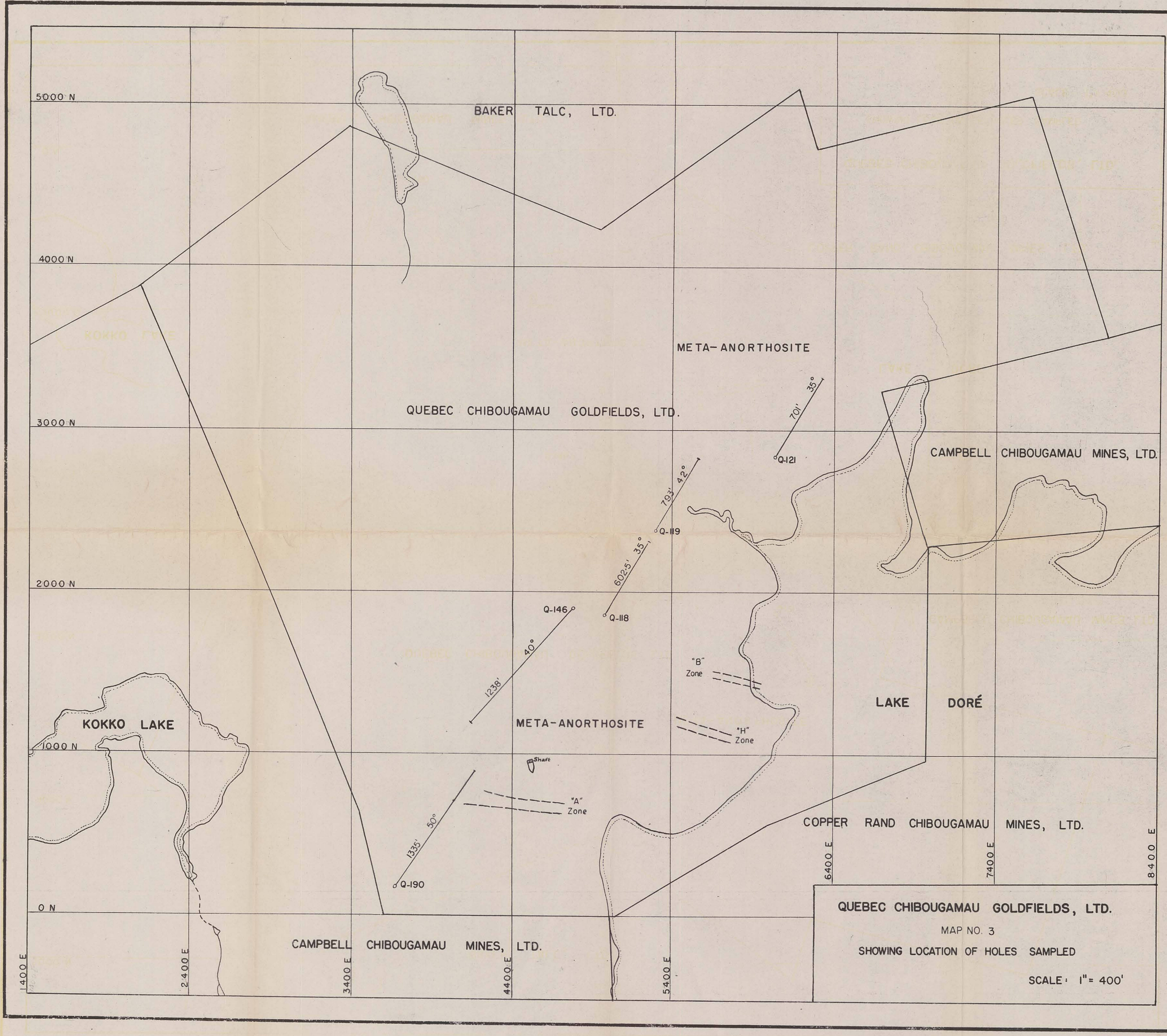
The shear zone intersections shown in the variation diagrams in Chapter VI are classified in each figure as follows:

	Class I	Class II	Class III
Figure 1	150' - 300'	300' - 400' 850' - 860'	
Figure 2	300' - 400' 725' -1020'		
Figure 3	400' - 500' 600' - 700'	500' - 600'	
Figure 4	360' - 390' 620' - 800'		
Figure 5	100' - 300' 650' - 700'	300' - 560'	560' - 610'
Figure 6		250' - 330' 340' - 480'	330' - 340'

	Class I	Class II	Class III
Figure 8	200' - 575'		
Figure 9		250' - 600'	600' - 700'
Figure 12		600' -1050'	1050' -1200'
Figure 13	800' -1000'		1250' -1335'
Figure 14	400' - 500'	250' - 350'	
Figure 15	450' - 500'	550' - 650'	
Figure 16	50' - 150'		

When the analytical results were plotted on the variation diagrams the chemical changes in the different classes of shear zones became evident. The increase, or decrease, in the concentration of an element was determined by comparison with the average concentration of that element in the massive rock in the same section.

The increases and decreases in the concentration of each element in the classified shear zones shown in the variation diagrams were then tabulated. For example, if in 14 Class I shear zones, the concentration of potassium showed an increase in 10 of the zones, and a decrease in 4 zones, it was indicated in Table VIII that potassium shows an increase (marked by a +) in most of Class I shear zones. The increases or decreases in the other elements were derived in the same way for all 3 classes of shear zones. Where the amount of increase, or decrease, for an element was doubtful in a particular class of shear zone, this was indicated by a question mark.

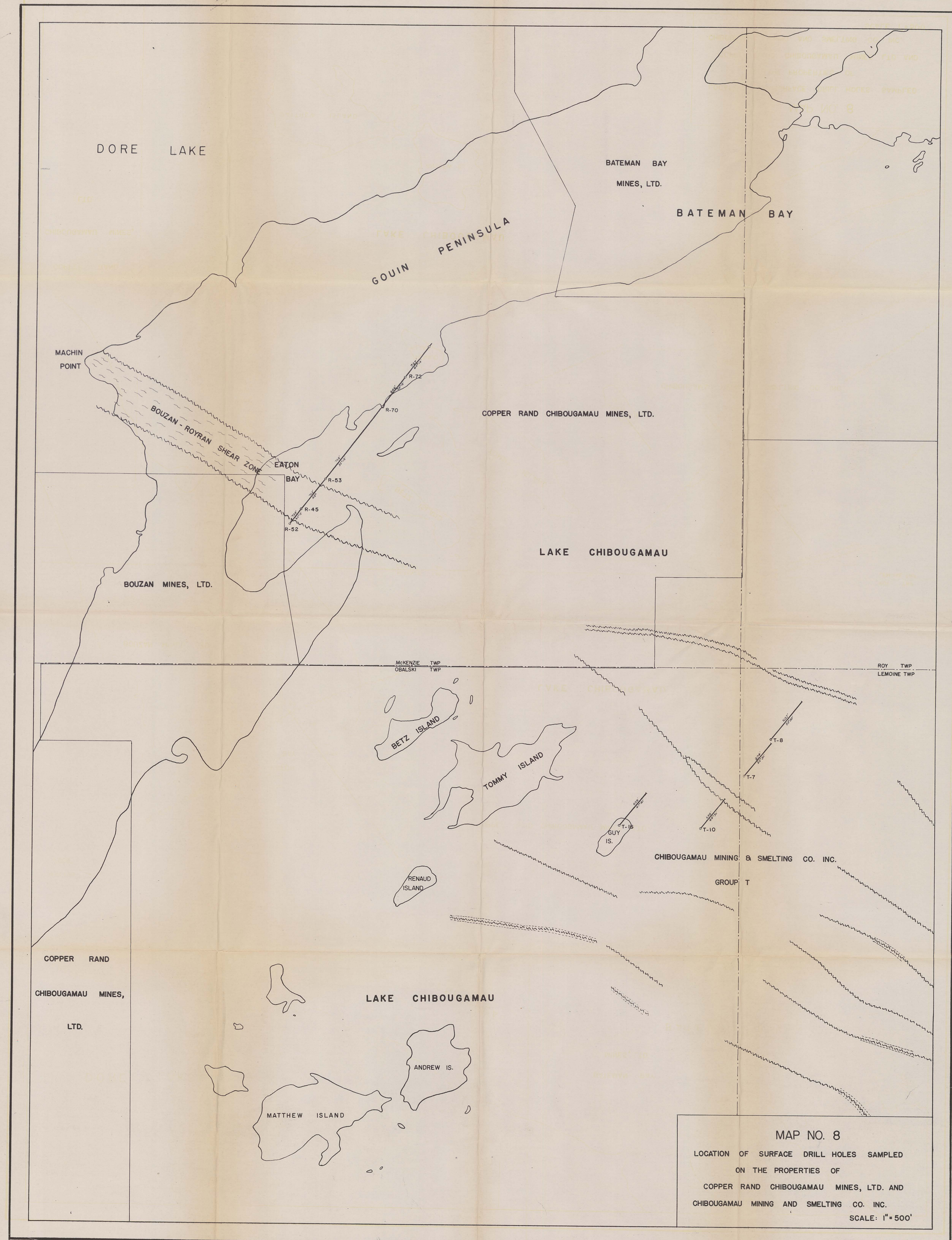


QUEBEC CHIBOUGAMAU GOLDFIELDS, LTD.

MAP NO. 3

SHOWING LOCATION OF HOLES SAMPLED

SCALE: 1" = 400'



MAP NO. 8

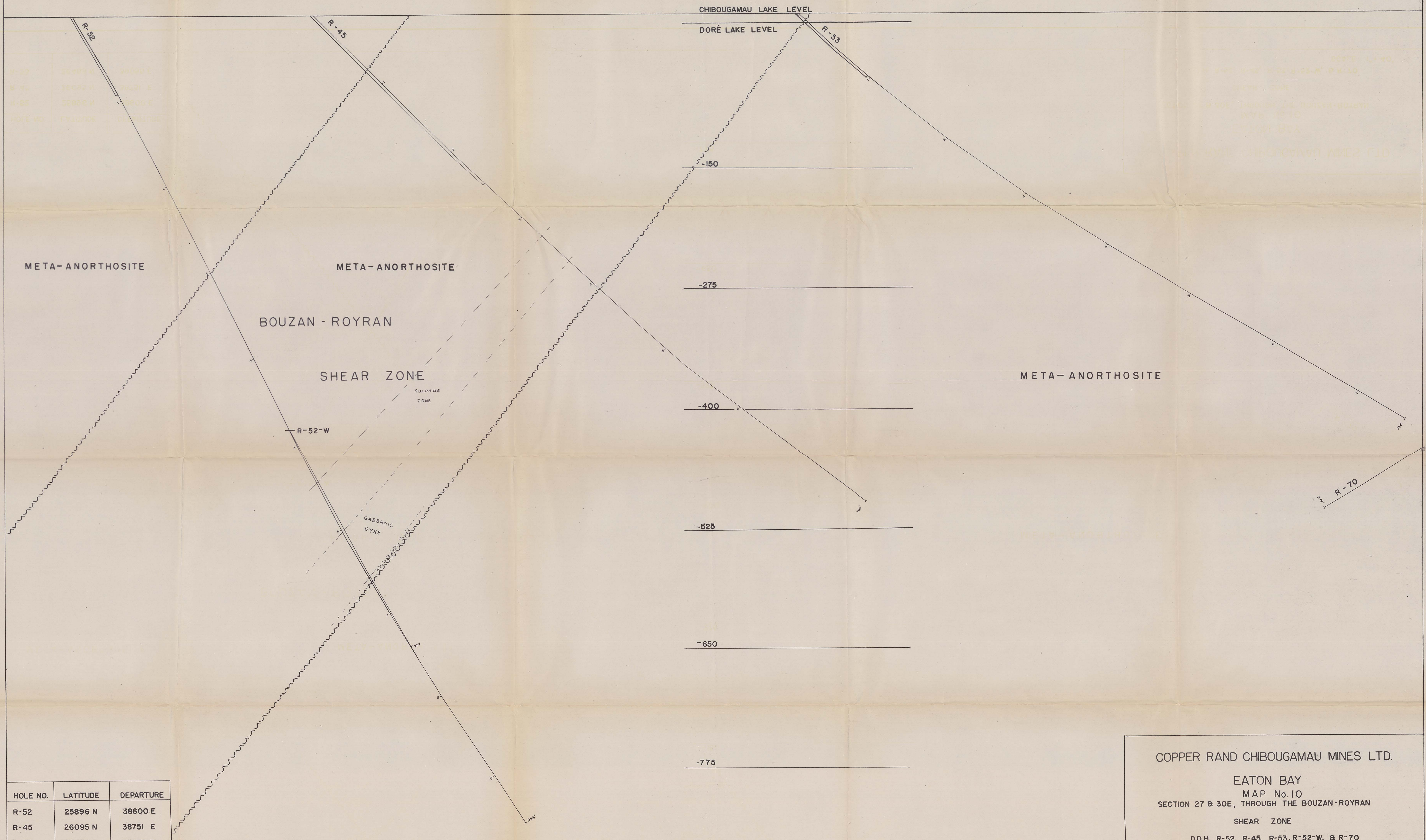
LOCATION OF SURFACE DRILL HOLES SAMPLED
ON THE PROPERTIES OF
COPPER RAND CHIBOUGAMAU MINES, LTD. AND
CHIBOUGAMAU MINING AND SMELTING CO. INC.

SCALE: 1" = 500'

CHIBOUGAMAU MINING AND SMELTING CO. INC.
MAP No. 9
VERTICAL SECTION LOOKING WEST

D.D.H. T-7, T-8, T-10, GROUP T

SCALE: 1" = 50'

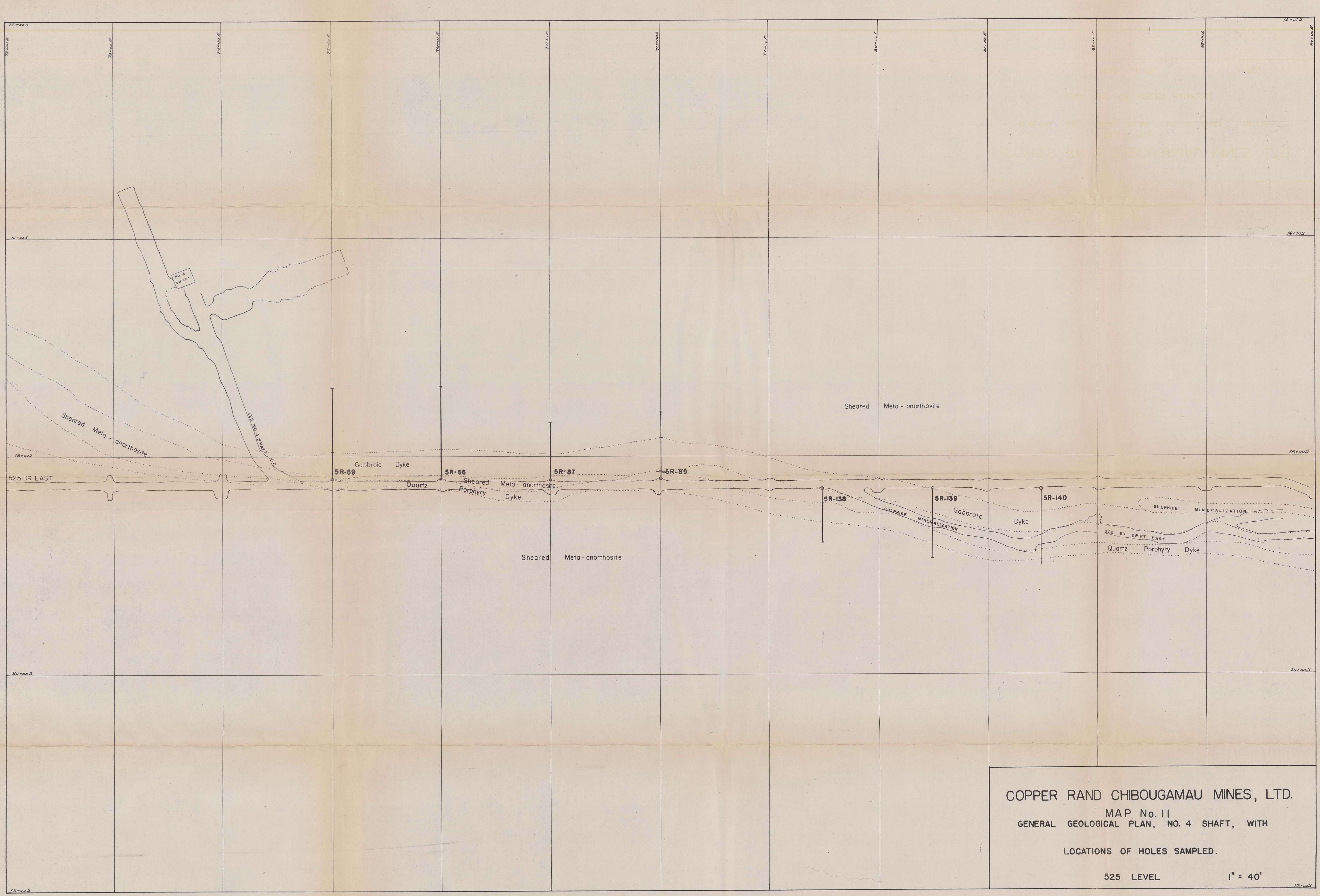


HOLE NO.	LATITUDE	DEPARTURE
R-52	25896 N	38600 E
R-45	26095 N	38751 E
R-53	26489 N	39055 E

COPPER RAND CHIBOUGAMAU MINES LTD.

EATON BAY
MAP No. 10
SECTION 27 & 30E, THROUGH THE BOUZAN-ROYRAN
SHEAR ZONE

D.D.H. R-52, R-45, R-53, R-52-W, & R-70
SCALE: 1" = 40'

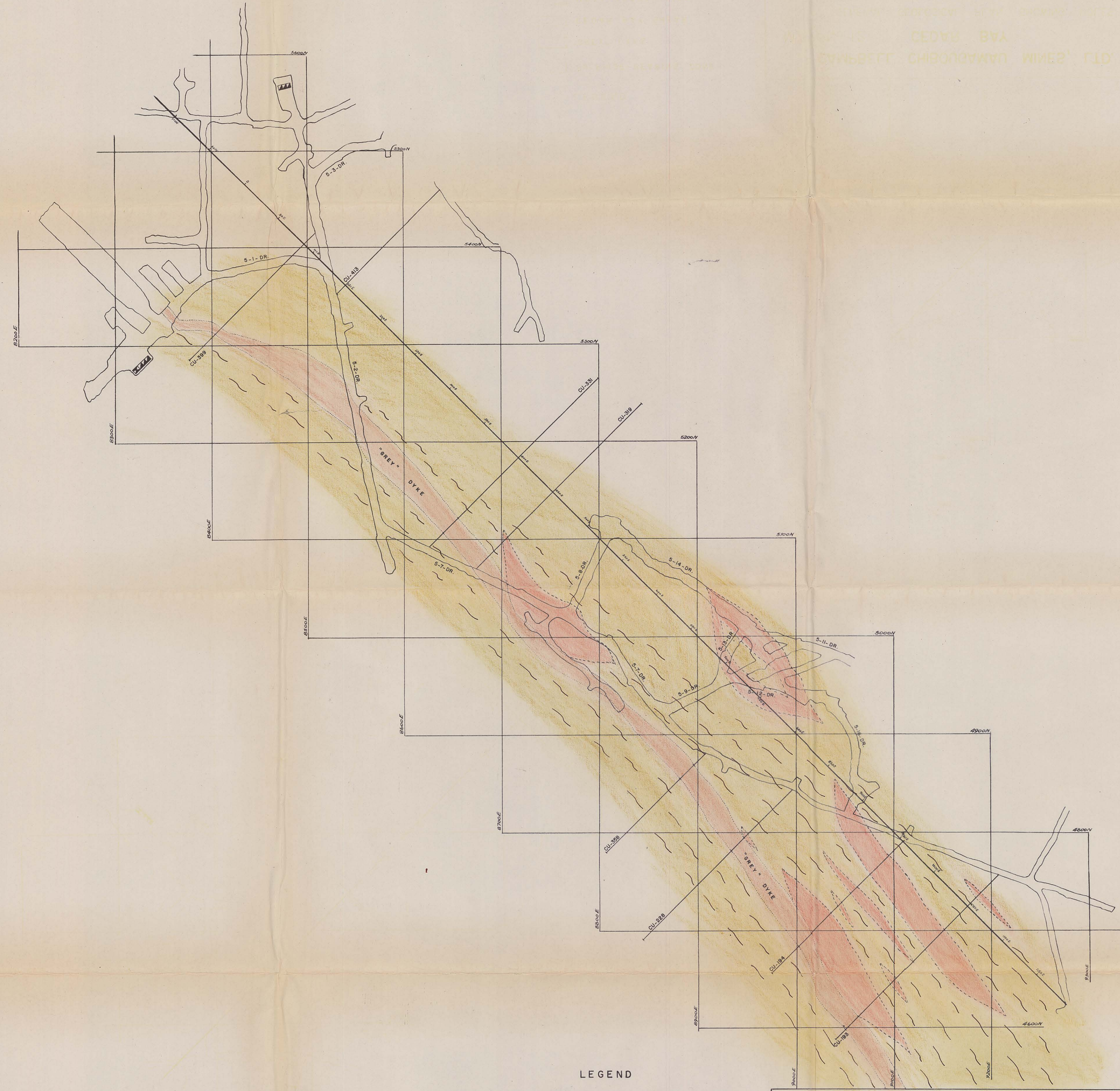


COPPER RAND CHIBOUGAMAU MINES, LTD.

MAP No. 11

GENERAL GEOLOGICAL PLAN, NO. 4 SHAFT, WITH LOCATIONS OF HOLES SAMPLED.

525 LEVEL 1" = 40'



LEGEND

🟥 SULPHIDE-BEARING ZONE

▨ "GREY" DYKE

≈ CEDAR BAY SHEAR

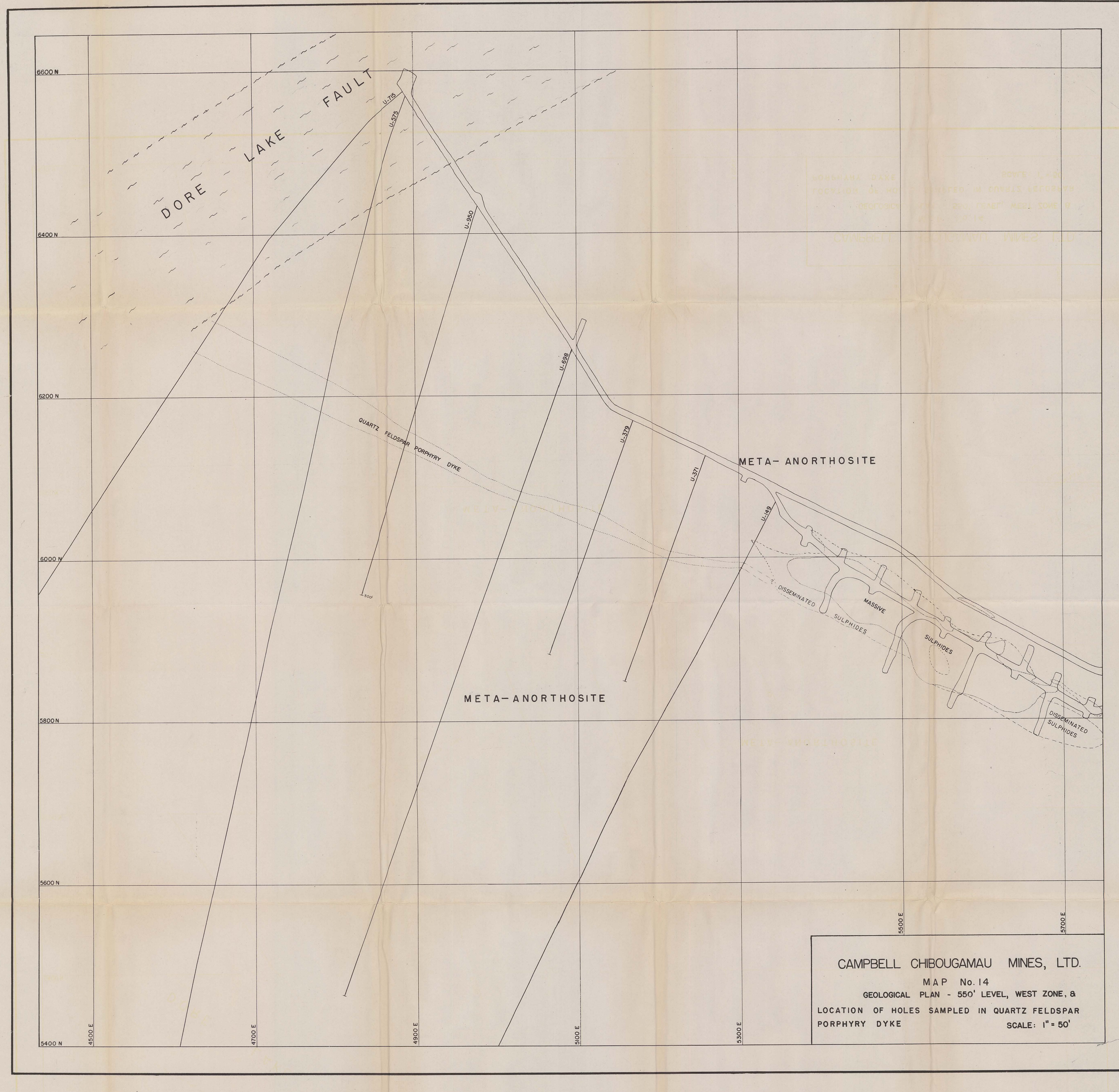
🟨 META-ANORTHOSITE

CAMPBELL CHIBOUGAMAU MINES, LTD.

MAP No. 12 **CEDAR BAY**

GENERAL GEOLOGICAL PLAN SHOWING HOLES
SAMPLED THROUGH "GREY" DYKE.

500 LEVEL SCALE: 1" = 60'



CAMPBELL CHIBOUGAMAU MINES, LTD.

MAP No. 14

GEOLOGICAL PLAN - 550' LEVEL, WEST ZONE, &
LOCATION OF HOLES SAMPLED IN QUARTZ FELDSPAR
PORPHYRY DYKE

SCALE: 1" = 50'