A STUDY OF CHEMICAL VARIATION OF CERTAIN DYKES AT CHIBOUGAMAU, P. Q.

by

Matthew Blecha

A STUDY OF THE VARIATION IN CHEMICAL COMPOSITION OF CERTAIN DYKES AT THE CAMPBELL CHIBOUGAMAU MINE.

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Matthew Blecha

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

Department of Geological Sciences,
McGill University,
Montreal, Quebec

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INTRODUCTION

General Statement

The importance of dykes and sills as structural controls of ore deposits has been recognized in many mining districts. In the Chibougamau area such controls have long been suspected, but their nature has not been well understood. One of the main problems has been the difficulty in correlating of dyke intersections from one drill hole to another. The reliability of such correlation is essential for a clear understanding of the spatial relation of the dykes to the mineralized zones.

The main purpose of this thesis is to investigate the possibility of correlating the dykes on the basis of their chemical compositions. Also, it is hoped that the analytical data presented here, may provide a better basis for speculation as to the origin of the dykes, and their genetic relationships.

Location and Access

The Chibougamau area lies approximately 300 miles due north of Montreal, just south of the 50th parallel. It is reached by air from Montreal, via La Tuc, and Roberval, and by a 150-mile all-weather road from St. Felicien. The Canadian National Railways make the area accessible from St. Felicien, and from Beattyville, about 32 miles north of Senneterre, in the Noranda area.

The Campbell Chibougamau Mine is situated on Merrill Island, in Lake Dore, 3 miles south of the Chibougamau Townsite. The Island is linked to the mainland by a causeway, and is connected to the main highway by gravel roads.

History

The long history of prospecting and mine development of the Chibougamau area began in 1870, with an expedition headed by J. Richardson, a geologist with the Geological Survey of Canada. His reports, commenting on promising mineral occurrences, prompted other visits to the area, and before long Chibougamau acquired a reputation as a potential copper and asbestos mining district.

Despite a pessimistic report by the Chibougamau Mining Commissioner in 1910, the area continued to attract many prospectors, geologists and prominent men of the Canadian mining industry. Among the pioneers whose names are intimately linked with the early history of the district, were P. McKenzie, A.P. Low, J. Obalski, E. Dulieux, T.E. Barlow, J.C. Gwillim, and many others.

The original discovery of copper mineralization on Merrill Island was made by Captain Blake in 1920. Blake Mine Syndicate was formed, and later reorganized as Blake Development Mining Company. In 1929 the ground was acquired by Northern Investment Company.

At the same time, Chibougamau Prospectors Limited obtained control of four water claims, offshore of Merrill Island, situated along strike of Blake's mineralized zone. In 1934 Consolidated Chibougamau Goldfields, a subsidiary of the Consolidated Mining & Smelting Company, acquired the water claims but soon had to suspend all exploration work owing to low metal prices and unfavourable mining conditions. Very little activity took place until the post-war years.

The construction of a new all-weather highway in 1949 provided the needed stimulus for the resumption of operations.

In 1950, Campbell Chibougamau Mines Limited, headed by E.O.D. Campbell, a New York broker, acquired all assets of Chibougamau Consolidated Goldfields. A vigorous surface exploration program, involving 41,183 feet of diamond drilling developed the original Blake showing into a major orebody. A lease was obtained on the adjacent land held by Merrill Island, and in 1951 underground operations began. Hydro electric power was brought into Chibougamau from Lake St. John, and a 1,700 ton per day concentrator was erected. With ore reserves of 2,750,000 tons containing an estimated 160 million pounds of copper and 200,000 ounces of gold, formal production began on July 1st, 1955.

In subsequent years the development included deepening of the shaft to 2,550 feet, and opening of new levels at depth. In late 1960 sinking of a winze began from the 1,900 level, and by mid-1962 the winze was completed to a depth of 3,900 feet.

The discovery and development of the Henderson Mine in 1957 necessitated an increase of the capacity of the concentrator to its present 3,000 tons per day.

The concentrate is shipped to the Noranda Smelter by rail, over a distance of 275 miles.

Production

At present, the production of ore comes from four sources:

1) The Main Mine, including the "A" ore and "B" ore, the latter being leased from Merrill Island Mining Corporation,

2) The Kokko Creek orebody, leased under the same agreement, 3) The Cedar Bay Mine, and 4) the Henderson Mine.

In the period from June 30th, 1963 to June 30th, 1964 the Main Mine produced 362,126 tons of ore, representing 41.6 per cent of the total production. By June 30th, 1964 the ore reserves totalled 1,189,626 tons of proven and probable ore, grading 1.81 per cent Cu, and 0.034 oz/ton Au (Canadian Mines Handbook, 1965).

Previous Work

The first systematic mapping in the Chibougamau area was done in 1929 by Retty for the Quebec Department of Mines (Retty, 1929). In the years 1930 and 1934 Mawdsley and Norman mapped the entire area west of Lake Chibougamau on a scale of 1 mile to 1 inch. Their findings were published in the Geological Survey of Canada Memoir No. 185, which to this date remains as the classic report on the geology of Chibougamau.

Following the construction of the highway in 1949, the Quebec Department of Mines mapped most of the local township on a scale of 1 inch to 1,000 feet. The geology of the immediate vicinity of the Campbell Mine is covered in reports by Graham, (1956), Smith and Allard, (1957), and Horsecroft, (1958).

The geology of the Campbell Mine to the 1900 level was thoroughly described by Jeffery, (1959). Certain aspects of the geology of the Campbell Mine were investigated by Raychandhuri, in his "Study of Trace Elements in the Sulphides" (1960), and by Hawkins, (1960), in his spectrochemical study of rocks associated with the sulphide deposits of Chibougamau.

Acknowledgement

The writer wishes to express his indebtedness to Campbell Chibougamau Mines Limited, for allowing this thesis to be written. Special thanks go to R. Hinse, chief geologist, Campbell Mines, who arranged sampling of the dyke rocks and for providing maps and sections, and other necessary information; to Dr. S.E. Malouf, consulting geologist, who suggested the problem, and to other members of the staff, who assisted the writer in many ways.

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At McGill University, the advice and encouragement by Dr. J.E. Gill were essential for the completion of this work. The author wishes to express his thanks to Dr. R. Webber, who provided valuable advice on spectrographic work, and to Mr. J. Jellema, who discussed and suggested improvements in the analytical procedures.

GENERAL GEOLOGY

Regional Setting

The Chibougamau area lies in the easternmost part of the Superior Province of the Canadian Shield. This province is characterized by east-west trending structures, and typically contains belts of volcanic and sedimentary rocks, intruded by basic and ultrabasic sills and by granitic, dioritic and gabbroic stocks and batholiths. The volcanic and sedimentary belts are separated by larger areas of granitic and gneissic rocks.

In the east, the rocks of the Superior Province are truncated by northeasterly trending structures of the Grenville Province. The Grenville Front, which marks the boundary between the 2 Provinces, is located about 10 miles east of the Campbell Mine.

The southeastern part of the Superior Province, extending through much of Quebec and Ontario, has been Canada's major source of metals. Many of the largest nickel, copper, cobalt, zinc, gold and silver ore bodies are found in a wide belt, extending from Sudbury northeast toward Chibougamau. Gill, (1948) names this belt the Sudbury-Chibougamau metallogenic province, and suggests that the southwestern extension may be formed by the Keweenawan copper deposits of Michigan.

Geology of the Chibougamau Area

As the geology of the Chibougamau area has been thoroughly described by many workers, only a brief description is presented here. Numerous works on Chibougamau containing detailed accounts of the general geology are listed in the bibliography.

Lithology

The oldest rocks in the Chibougamau area are folded and faulted metamorphosed volcanic and sedimentary rocks, representing the eastern extension of the Mattagami-Waconichi greenstone belt. These Keewatin-type rocks have steep to vertical dips, and generally trend in an east-west direction. They are intruded by masses of granites, diorites, gabbros, anorthosites and by sills of pyroxenites and peridotites. The most important of these intrusions is the Chibougamau intrusive complex, which is the host to most of the copper deposits in the area. It will be discussed in some detail in the following section.

The youngest consolidated rocks of the Chibougamau area are flat-lying sediments of the Mistassini and Chibougamau series. They occur in a few patches north of Lake Chibougamau, and overlie the older formation with an unconformity.

Table I

Table of Formation (after Jeffery, 1956)

Cenozoic	Recent and Pleistocene	Clay, sand, gravel, morainic material, peat.
Precambrian		Diabase dykes.
	Mistassini Group	Dolomitic limestones, sandstones and shale.
	Chibougamau Group	Conglomerate, arkose, greywacke, quartzite.
		Dykes of granodiorite, gabbro, feldspar and quartz-feldspar porphyry; granite, diorite and related rocks; anorthosite and associated gabbro and serpentines; 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 Chibougamau intrusive is a roughly oval mass, 35 miles long and 15 miles wide. Its long axis trends N70°E, and terminates against the Grenville Front in the east. The Chibougamau intrusive consists of a stratified gabbro-anorthosite body, named Dore Lake complex by Allard, (1956), and of masses of granites and related rocks, which seem to intrude the Dore Lake complex in the centre.

In the northern and western part of the Dore Lake complex, the primary strata dip to the north and west respectively. The eastern part is not as yet well known. It appears, however, from the available fragmentary data, that the sense of dips is in the opposite direction, suggesting an anticlinal or domal structure.

The stratification of the Dore Lake complex is locally well defined, and has been compared to the stratification of the Sudbury norites, (Malouf and Hinse, 1956). It consists of compositional bands, ranging from pyroxenites to granophyres, and of alternating layers of coarse and fine grained phases of the anorthosites.

Acidic dykes of grey feldspar porphyry and quartz-feldspar porphyry, are common in the entire area especially near Lake Dore. They are mineralogically similar to the granitic mass comprising the central portion of the Chibougamau intrusive, and are considered to be its differentiates. The dykes have a regional northwesterly trend, dip vertically or steeply to the northeast or southwest, and are commonly associated with ore-bearing shear zones. The study of their chemical composition forms the subject of this thesis.

The acidic dykes are cut by younger, more basic dykes, locally termed gabbroic and dioritic. The youngest dyke of the Chibougamau area is a diabase, which trends northeasterly across Lake Chibougamau.

Structure and Metamorphism

The Keewatin-type lavas and sediments, which represent the eastern extension of the Mattagami-Waconichi belt, are tightly folded into several east-west trending synclines and anticlines. Top determinations north of Lake Chibougamau suggest that the northern belt of volcanics forms part of a syncline whose axis lies some 3 miles north of Gilman Lake. A major anticline is indicated south of the Chibougamau complex, between the La Dauversiere and Fancamp granitic stocks. As mentioned above, the attitudes of the primary stratification of the Dore Lake complex itself, suggest a domal or anticlinal structure, with its axis striking in a northeasterly direction.

The regional metamorphism of the rocks of the Chibougamau area is that of the greenschist facies. The metamorphism of the gabbro-anorthositic complex, however, is enigmatic. The alteration of plagioclase to zoisite, clinozoisite and sericite, and of pyroxene to chlorite, involves addition of great masses of water, the origin of which still remains as one of the greatest problems of the local geology.

Faulting

The Chibougamau area is transected by two major sets of faults and shears. The northeast trending set is by far the most prominent one. It is represented by a series of three major faults that parallel the Grenville Front to the south, and converge with it in the north, northeast of Lake Waconichi.

The second, northwest set of shears is smaller in magnitude, but of much greater importance economically, as it controls all of the copper deposits in the area, with the exception of the Henderson orebody.

Although the age relationship between these two major structural sets has not yet been definitely determined, there seems to be general agreement that the northeast set is younger, (Graham, 1956, Mawdsley and Norman, 1935).

Geology of the Campbell Mine.

The ore bodies of the Campbell Chibougamau Mine are tabular and lenticular replacement deposits within a major composite shear. This structure has an average strike of N70°W, and dips from 60° south to 80° north. The ore bodies, pitching irregularly to the west, extend on the neighbouring Merrill Island property, and westward under Lake Dore for an over-all strike-length of 900 feet. The mineralized zones average 30 feet in width, and are continuous to a depth of 1900 feet. At this horizon the ore bottoms out, but mineralization resumes again on the 2700 level. This lower part of the deposit is made accessible by a winze, which reaches to a depth of 3,900 feet.

The ore zones are wholly enclosed in meta-anorthosite, and commonly occur along the footwalls of steeply dipping dykes which are concentrated along the main shears.

The ore mineral, chalcopyrite, is associated with pyrrhotite, minor quantities of pyrite, and sphalerite and galena. Cubanite, valleriite, tetradymite and magnetite are rare. Although gold occurs in recoverable quantities, its distribution is unknown. Visible gold has been noted rarely, and Jeffery, (1956), assumes that the bulk of the gold is associated with pyrite. The mode of occurrence of silver is also uncertain.

In the proximity of the mineralized zones the meta-anorthosite host rock is commonly sheared and altered. The alteration associated with the shearing consists of chloritization, sericitization and carbonatization. The shearing has locally destroyed the original texture of the anorthosite and has formed a rock that could be best described as a chlorite-sericite schist. In a few places, relatively massive anorthosite is found in a wallrock of the mineralized zones. It differs from the normal country rock by containing recrystallized zoisite and clinozoisite that can only be detected microscopically. Attempts to distinguish between regional metamorphism, shear alteration, and hydrothermal alteration accompanying ore emplacement, and subsequent attempts to use alteration as a guide to ore have been the subject of many investigations. The results, however, have been inconclusive.

The ore zones are structurally controlled by shears that traverse the meta-anorthosite at an average strike of N70°W. The widest portions of the zones are formed in the centre of the composite shear. At depth, the widths of the zones appear to be related to the amount of dip. The widest ore zones occur where the dips are relatively steep, or vertical, and the zones become narrower with flattening of the dip. Several barren shears trending north to N20°E have been observed in the mine workings.

These seem to be early structures, as they are offset by the later steeply dipping ore-bearing shears. All available evidence indicates that the amount of post-ore movement has been negligible.

The role of the primary layering of the anorthosite observed in the mine was investigated by Jeffery, (1956), but no relation with the mineralized zones was detected.

The importance of the dykes, and their relation to the mineralized zones will be discussed in greater detail in the following section.

STUDY OF THE DYKE ROCKS

1. DESCRIPTION OF THE DYKES

Dykes are a common feature within the entire anorthosite mass. With a few exceptions, they are conformable to the ore-bearing shear, and range in width from several inches to a hundred feet. The dykes increase in number toward the centre of the shear, where, in the vicinity of the mineralized zones, they constitute about 30 per cent of the rocks.

On the basis of age relations, as determined from field observations, the dykes can be classified into 3 main divisions.

1. The older diorite dyke
2. The "common" dykes
3. The amphibolite dyke

Of these three divisions, only the dykes of the second group are considered in this thesis. The common dykes are most abundant, and as will be shown in subsequent sections, are important factors in the structural control of the ore. The other two dykes have little importance with regard to mineralization, and will be described only briefly for the sake of completeness.

The Older Diorite Dyke

The older diorite dyke occurs on the 1,000 level, where it forms a tabular mass, about 50 feet wide, extending over a distance of 500 feet, along the footwall of the orebody. The dyke is dark green in colour, and consists of 35 to 60 per cent chlorite, with minor associated quartz, plagioclase, sericite and calcite. It is cut by some of the common dykes, and is, therefore, considered to be older. Apart from its occurrence on the 1,000-foot level the dyke is relatively rare in the mine workings, and has little significance in its relation to ore.

The Amphibole Dyke

This dyke forms a large continuous body, averaging about 30 feet in width, and striking almost parallel to the ore zones. It dips 50° north, and intersects the orebody near the 1900 level. The dyke is dark green, ranges in texture from coarse in the centre to fine at the margins, and consists of predominantly actinolite, with zoisite, clinozoisite, chlorite and quartz. The dyke cuts across some of the common dykes and is, therefore, considered to be younger. Although locally replaced by sulphides, its age relation to the mineralization is uncertain. Its contacts with the sulphides are mostly sharp, but locally tongues and veins of ore extend into the dyke. Jeffery favours the view that the dyke is pre-ore, mainly because of an apparent damming effect it seems to have had on the ore-bearing solutions.

The Common Dykes

Field Relations of the Common Dykes

The common dykes are conformable to the main ore-bearing shear. The dykes merge and divide both along the strike and down dip, forming a complex swarm whose greatest concentration occurs in the vicinity of the mineralized zones. Within the shear, the dykes are both massive and sheared, and are locally broken and separated into isolated lenses and blocks. Where sheared, the dykes are chloritized and sericitized to a degree which makes them often indistinguishable from altered anorthosite.

In the massive anorthosite the dykes are invariably massive and relatively fresh, with sharp, regular contacts. In places, small blocks of meta-anorthosite are contained by the dykes along their margins, indicating, that at least in part, the dykes have been emplaced by stoping. In general, their intrusion had little effect on the meta-anorthosite, which shows no signs of recrystallization or metamorphism at the contacts.

The margins of the dykes occasionally show chilling, but the grain gradation can usually be observed only under the microscope. Locally, polished and slickensided dyke walls indicate that the dyke contacts were zones of weakness along which a certain movement had taken place. The contacts are lined with quartz, carbonate, chlorite, and sericite, and commonly carry sulphide mineralization. This suggests that the contact zones may have been a part of the channelway systems that controlled the ascent of the ore bearing solutions.

Although there is general agreement among geologists that the emplacement of the common dykes preceded sulphide mineralization the relation of the dykes to the ore zones in not entirely clear. Along their margins the dykes are locally replaced by sulphides, whereas in the shear zone, barren isolated dyke fragments and masses are wholly enclosed by sulphides. In general, however, the dykes seem to have been less susceptible to replacement by sulphides than the meta-anorthosite. In places where the ore zones are in contact with the common dykes the extent of the mineralization seems to be controlled by the attitude of the dykes. The contacts are sharp, and the sulphides follow the footwall of the dykes with little or no replacement of the dyke rock. This relation gave rise to the suggestion, (Jeffery, 1956), that the dykes had a damming effect on the ascending ore-bearing solutions, producing local concentrations of high grade ore. The alternative explanation might be that the dykes behaved as stiffeners, preserving zones of dilation within the shear, in which the sulphides were readily deposited.

The relationship between the various common dykes is equally problematic. Seven distinct dyke rock types have been distinguished by Jeffery, (Table 2), but gradational stages between each of the dykes have been observed under the microscope, Jeffery, (1956, p.69). Although Jeffery states that no rapid variation in the compositions of the dykes has been observed, Graham, (1956, p.15), notes local fading of phenocrysts resulting in gradational transitions between porphyritic and equigranular dykes.

Careful structural correlation of diamond hole intersections of the common dykes, particularly in areas of close drilling, indicates, without doubt, that individual branches of the main dyke swarm are composed of more than one dyke rock type, (Figure 1).

Crosscutting relationships between the common dykes have rarely been observed in the mine workings. Graham, (1956, p.14), notes, however, that quartz diorite dykes cut some grey porphyry dykes, and are in turn cut by other grey feldspar porphyry dykes.

Classification of the Common Dykes

Examination of about one hundred thin sections of the common dykes has added little to Jeffery's treatment of the subject. His classification, presented here, has been only slightly modified.

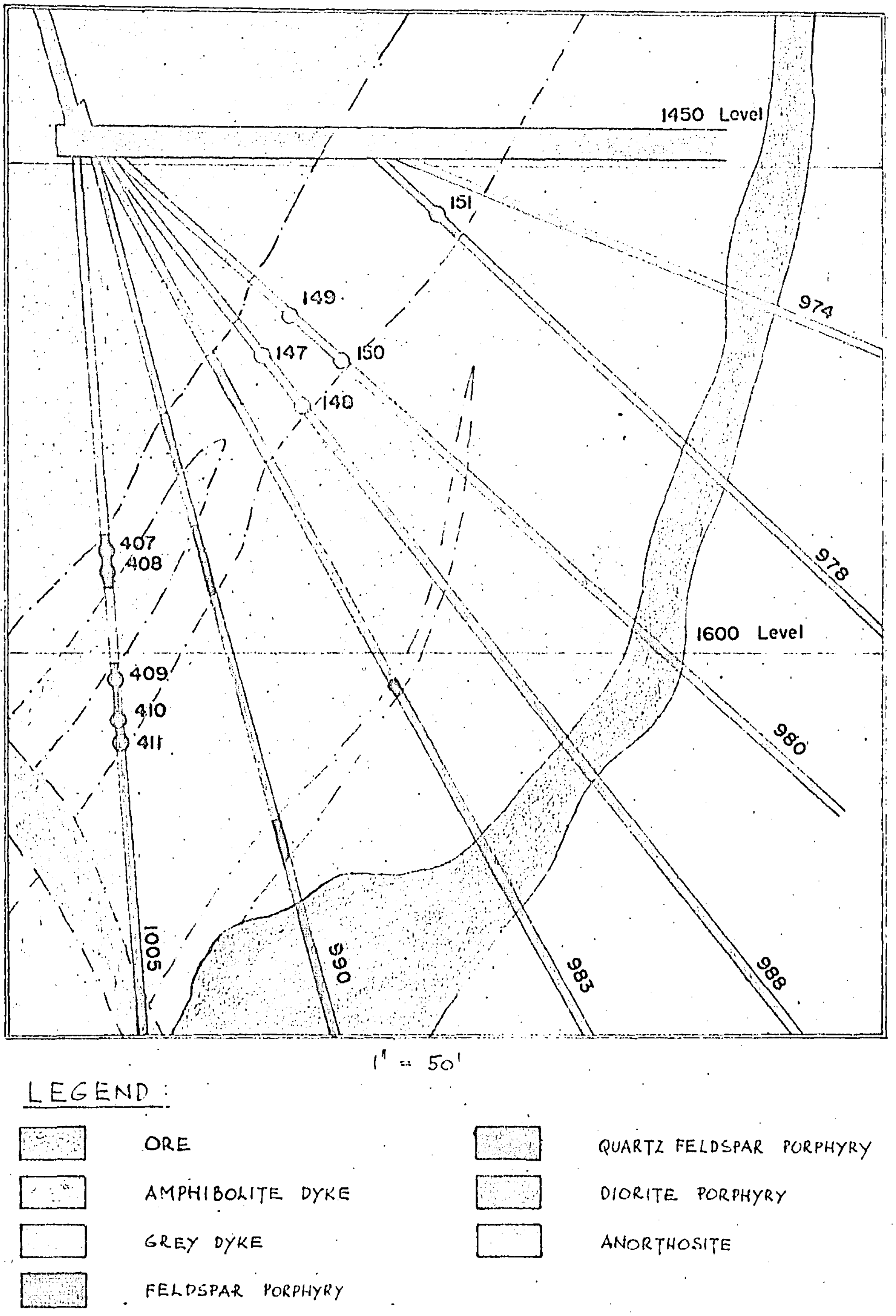

Figure 1. Vertical section 400 West. Note various dyke rock types contained in a single dyke.

Table 2

Classification of the Common Dykes

Matrix	Quartz Present				Quartz Absent
Phenocrysts	None	Feldspar Quartz	Quartz	Feldspar	
None	G				
< 10 per cent			P		
< 20 per cent				QD	D
20-60 per cent		Q		F	
> 60 per cent		Gr			

G - Grey Dyke
QD - Quartz Diorite Porphyry
D - Diorite Porphyry
Gr - Granitic
P - Quartz Porphyry Dyke
F - Feldspar Porphyry
Q - Quartz Feldspar Porphyry

Only four of the seven common dykes shown in the above table are distinguished by mine geologists. These are the grey, feldspar porphyry, quartz feldspar porphyry, and the granitic dykes.

The criteria used for megascopic identification of the various common dykes are texture and the nature of the phenocrysts. Since the size of the phenocrysts is relatively small, and their composition is commonly obscured by alteration, field identification of the dykes is often impossible. Owing to this difficulty, the relative abundance of the individual dyke rock types cannot be determined accurately. Judging by diamond drill logs, the grey and feldspar porphyry dykes are by far the most widely distributed.

The apparent abundance of the grey dyke, estimated as high as 50 per cent, is probably, however, misleadingly high. Microscopic examination disclosed a remnant prophyritic texture in many of the dykes previously logged as "grey". Whereas the feldspar porphyry and grey dykes seem to predominate in the deeper parts of the mine, quartz-feldspar porphyry dykes are more abundant on the upper levels, where they comprise about 20 per cent of all dykes. Granitic dykes are rare, and none have been identified by the author.

In addition to the megascopically distinguishable dykes two other distinct dykes have been identified in thin section. These are known as the diorite porphyry, and the quartz-diorite dykes. Although Jeffery states (p.74) that both are as widely distributed as the other common dykes, the relatively large proportion of the diorite porphyry dyke identified by the author from the randomly selected samples suggests that this rock type may be more abundant, (Table 3).

Petrography

Mineralogically, the composition of the common dykes is identical. The main constituents are plagioclase and quartz, with lesser amounts of sericite, muscovite, chlorite, carbonate, and the minerals of the epidote family. Minor accessory sphene and zircon have been identified in some specimens.

Variable amounts of secondary quartz, calcite and epidote have been noted in the majority of the dykes. These minerals occur in narrow stringers and veinlets, and in many instances extensively infiltrate the dyke matrix. Commonly associated with these secondary minerals are fine grains of disseminated pyrite, which constitutes one to two per cent of the rocks.

Grey Dykes. This term has been applied to fine grained equigranular rocks which differ from all the other common dykes by the absence of phenocrysts. Relatively unaltered grey dykes consist of 50 to 80 per cent fine anhedral quartz grains, and scattered clusters of zoisite 20-50 per cent , in a quartz-sericite-chlorite matrix. Only minor amounts of fine grained, subhedral plagioclase of unknown composition are present. Sphene and epidote are accessory minerals, comprising 1-2 per cent of the rock.

Figure 2. Sample no. 106, plane light, x 160.
Grey dyke.

Sheared grey dykes are characterized by an increase in chlorite and sericite, and by various degrees of parallelism of sericite shreds. Two types of chlorite are commonly present, one being colourless, the second pale green, and slightly pleochroic. Traces of pyrite and narrow stringers of secondary fine grained quartz, calcite and epidote have been detected in nearly all thin sections.

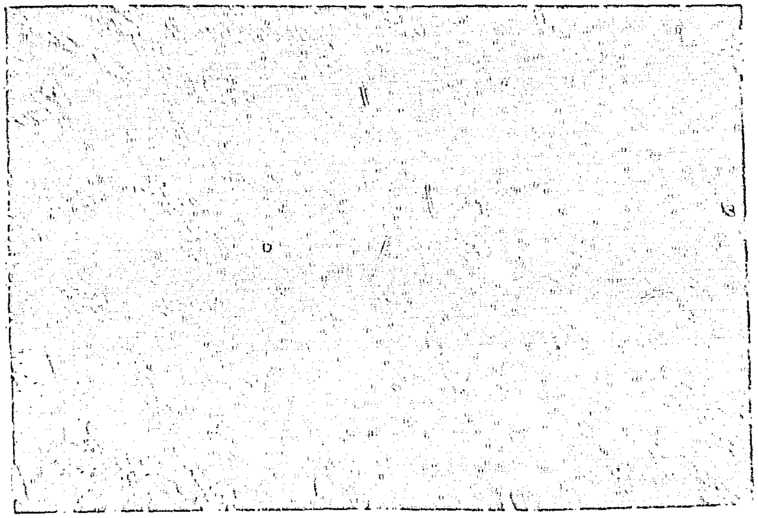

Figure 3. Sample no. 162, crossed nicols, x 160.
Sheared grey dyke.

A gradation between grey and feldspar porphyry dykes has been observed both megascopically and in thin section. The gradation is marked by the appearance of fine, highly sericitized grains of feldspar, barely exceeding in size the minerals constituting the matrix. In several specimens clusters of zoisite and sericite may have formed from the complete alteration of feldspar phenocrysts. For the purpose of chemical analyses, such rocks were classified as of uncertain rock type.

<u>Feldspar Porphyry Dykes.</u> Feldspar porphyry dykes are grey, fine grained rocks, consisting of 20-60 per cent pale grey, subhedral plagioclase phenocrysts, embedded in a fine, slightly darker grey matrix. The plagioclase is albitic, ranging in composition from An_7 to An_{10}, and is commonly sericitized, even in specimens megascopically described as fresh.

The matrix consists of a fine grained aggregate of quartz, plagioclase, sericite and chlorite, with minor epidote and sphene. As with the grey dykes, traces of pyrite, secondary carbonate, quartz and epidote have been observed in all specimens. Because of the fine grained nature of the plagioclase present in the matrix, its composition could not be determined.

Figure 4. Sample no. 84, plane light, x 40.5.
Feldspar Porphyry dyke, showing
zoisitized phenocrysts.

Quartz Feldspar Porphyry Dykes. This rock differs from the feldspar porphyry only be the presence of quartz, which comprises up to 25 per cent of the phenocrysts. The quartz phenocrysts are rounded or subhedral, and show a wide range in size, attaining up to 6 mm. in diameter.

Gradation to feldspar porphyry has been noted in dykes in which quartz phenocrysts are less prominent, being only slightly larger than the grains comprising the matrix.

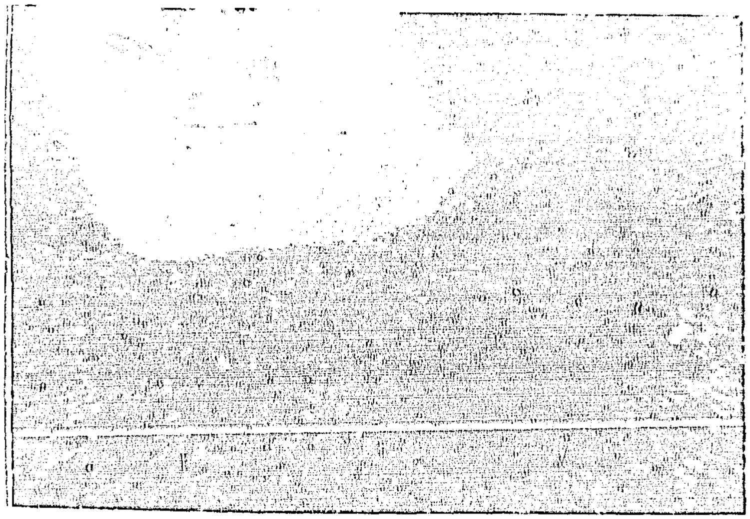

Figure 5. Sample no. 68, crossed nicols, x 40.5.
Quartz porphyry dyke.

Quartz Porphyry Dykes. These dykes are identical with the quartz-feldspar porphyry, except for the absence of feldspar phenocrysts. The quartz phenocrysts range in size from 1 mm. to 6 mm., and from about 5-10 per cent of the rock.

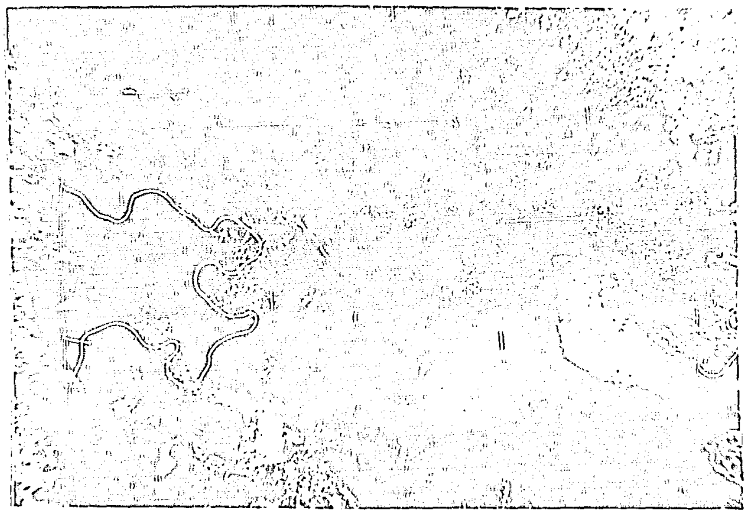

Figure 6. Sample no. 180-2, crossed nicols, x 40.5. Quartz porphyry dyke, showing wide range in size of phenocrysts.

Diorite Porphyry Dyke. The diorite porphyry, often logged as "grey" dyke in drill core, is, nevertheless a very distinct rock type in thin section. It differs from all other dykes by total absence of quartz, and is characterized by a matrix that consists of 75-90 per cent interlocking subhedral laths of plagioclase, with interstitial chlorite, epidote, and minor accessory sphene. Embedded in the matrix are subhedral phenocrysts of plagioclase which constitute 5-20 per cent of the rock. The phenocrysts, commonly twinned, are albitic in composition, and often contain minute inclusions of epidote. The plagioclase laths comprising the matrix range in size from 0.05 mm. to 0.2 mm., occasionally approaching the size of the phenocrysts. As in all other dykes sericitization of the plagioclase is extensive.

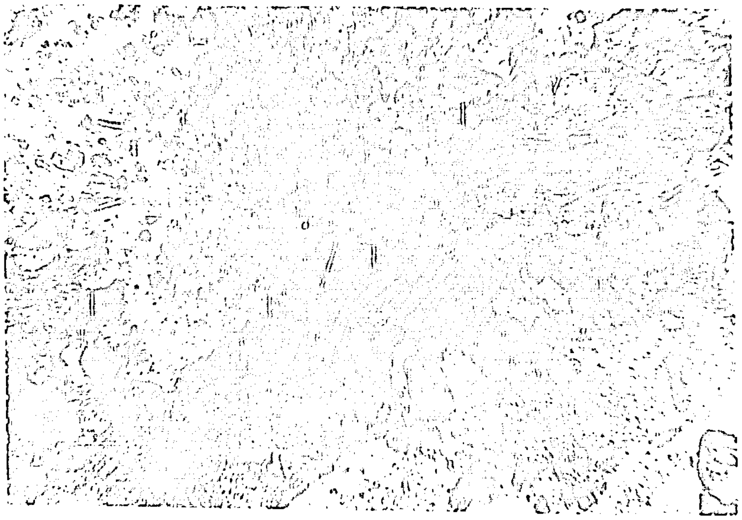

Figure 7. Sample no. 92-2, plane light, x 160. Zoisite veinlet cutting across a plagioclase phenocryst in a diorite porphyry.

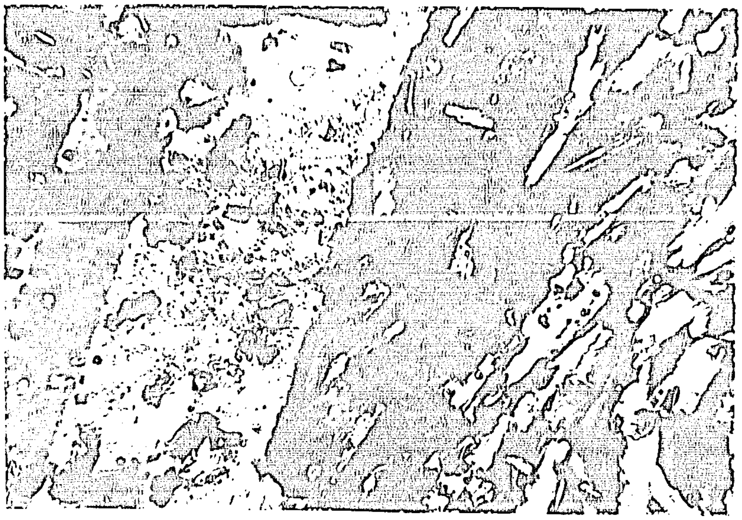

Figure 8. Sample no. 409, crossed nicols, x 160. Diorite porphyry dyke.

Quartz Diorite Dyke. This rock has not been identified by the author. According to Jeffery, it is a variety of the diorite porphyry, and differs from it only by the presence of quartz in the matrix, and by a decrease in the amount of phenocrysts.

Granitic Dykes. Granitic dykes are rare in the Campbell Mine, and have not been noted among the samples selected by the writer. According to Jeffery, the rock is characterized by a medium grained granitic texture, and is composed of plagioclase and quartz phenocrysts, embedded in a matrix of quartz, sericite and chlorite. The granitic dykes appear to be a variety of the quartz feldspar porphyry, with a large proportion of quartz and feldspar phenocrysts.

2. SAMPLING

A total of eighty samples were selected from the diamond drill core stored at the Campbell Chibougamau Mine. The selections were made after a study of level plans and vertical sections, and after a careful structural correlation of the dykes based on diamond drill hole information. Samples were taken from seven distinct dyke branches; their distribution covers a vertical distance of 3050 feet, from the 550 level to the 3600 level, and a lateral distance of 1500 feet, from section 1100W to 400E. Although an attempt was made at a statistically random selection of samples, strict randomness was impeded by the unavailability of core from certain diamond drill holes, and by the necessity to make alternate selections. The location of the samples is listed in Table I, in the Appendix, and graphically illustrated on Plate 1.

To test the chemical homogeneity of the dykes, each of the first ten samples was treated in the following way. A complete intersection over the entire width of the dyke was split longitudinally, and one half of the core was analysed. The results were then compared to the analysis of the second half of a one-foot long section of the core from the central part of the dyke. All ten comparisons showed a significant difference between the two samples (Table 3).

Table 3

COMPARISON OF ANALYSES OF BULK SAMPLES WITH ANALYSES OF SHORT SAMPLES

	Al	Fe	Mg	Ca	Na	Ti
A	14.55	4.70	1.11	6.70	2.40	0.20
B	15.00	3.70	0.92	4.60	2.50	0.26
C	0.45	1.00	0.19	2.10	0.10	0.06
A	17.25	3.85	1.21	3.45	3.30	0.23
B	16.25	5.15	1.95	4.14	4.55	0.35
C	1.00	1.30	0.74	0.70	1.20	0.18
A	14.50	2.72	0.86	3.90	2.68	0.21
B	16.50	3.15	0.97	5.20	3.55	0.20
C	2.00	0.43	0.07	1.30	0.87	0.01
A	14.40	6.95	0.74	6.30	1.05	0.23
B	12.50	6.60	0.40	4.55	0.68	0.17
C	1.90	0.35	0.34	1.75	0.37	0.06
A	13.80	4.30	0.92	4.90	1.68	0.21
B	13.95	3.45	0.76	5.90	1.53	0.17
C	0.15	0.85	0.16	1.00	0.15	0.04
A	13.75	3.65	0.82	3.78	3.00	0.19
B	14.25	3.68	0.67	3.95	4.70	0.23
C	0.50	0.03	0.15	0.17	0.70	0.04
A	18.00	4.60	1.58	6.00	5.40	0.41
B	15.75	3.95	1.48	5.00	5.10	0.32
C	2.25	0.65	0.10	1.00	0.30	0.09
A	13.00	< 10.00	4.70	7.88	<0.20	1.73
B	11.75	< 10.00	4.95	6.45	<0.20	1.58
C	1.25	-	0.15	1.43	-	0.15

A	Analysis of the entire width of the dyke.
B	Analysis of a 1 foot central portion.
C	Difference between A and B.

Since the suspected variation in composition across the width of the dyke could not be determined from bulk samples of entire intersections, all subsequent dykes were sampled by selecting 2 to 3-foot sections of core at more or less regular intervals.

Crushing and Grinding

All crushing and grinding was done by the writer in the laboratories of the Department of Geological Sciences at McGill University. The samples were crushed in a jaw crusher set at 1/8 inch, and subsequently ground in a pulverizer filled with ceramic plates. The screen analysis showed that approximately 75 per cent of the material was minus 150 mesh. About 100 grams of the pulverized sample were then packaged in capped plastic vials and retained for the analysis.

Throughout the entire crushing and grinding procedure, care had to be taken to prevent unnecessary contamination. The equipment was thoroughly cleaned with brushes and compressed air, and a portion of the next sample was run through the crusher and the pulverizer after each run. Even with these precautions certain amount of contamination, particularly by iron and possibly other metals present in the jaw crusher, was unavoidable. It can be assumed, however, that the amount of foreign material introduced into the samples was constant.

Prior to the crushing and grinding, another precaution was considered necessary, to minimize the distortion of analyses by secondary minerals. All visible quartz and carbonate stringers were carefully eliminated from the drill core by knocking off and by scraping. If retained, the analyses for silica, calcium, and a number of trace elements would have been misleadingly high.

3. SPECTROCHEMICAL ANALYSES

Principles

The fundamental principle of quantitative spectrochemical analysis is based on the assumption that the intensity, I_0, of a given line in the emission spectrum is proportional to the number of atoms in the source, N. It is further assumed, for the purpose of practical spectrochemical analysis, that N is directly proportional to the concentration, C, of a given element in the sample. These assumptions are expressed by the equation:

$$I_0 = KC \qquad (1)$$

or

$$\log I_0 = \log K + \log C \qquad (2)$$

where K is a constant.

Expressed graphically, the logarithms of two variables, I_0 and C form a line, referred to as the working curve. Theoretically, according to equation (1), the graph is a straight line with a unit slope. In practice, however, the working curves deviate from linearity and unit slope, owing to the presence of background intensity, impurity in the standards, and self-absorption.

Analysis of Major Elements

The method used by the author for the analysis for Si, Al, Fe, Mg, Na, Ca, and Ti, was developed at the Department of Geological Sciences at McGill University, (Webber and Jellema, 1962). Lithium is used as an internal standard.

Procedure

Two grams of lithium metaborate were mixed with 200 milligrams of ground sample in a mullite mortar. The mixture was placed in a graphite crucible, and fused in a muffle furnace at 1000° C for eight minutes. The resulting glass bead was crushed in a steel mortar, and the product thoroughly mixed with 200 milligrams of graphite. A part of the mixture was packed in graphite electrodes for the analysis, and the remaining material was stored in small, labelled, plastic vials. Throughout this procedure care was taken to prevent contamination by cleaning the mortars and pestles with soft rubber erasers.

Working curves were prepared by using analyses of the following National Bureau of Standards samples:

1a	argillaceous limestone
69a	bauxite
88	dolomite
97	flint clay
98	plastic clay
99	soda feldspar
102	silica brick
104	burned magnesite
mixture of 1a and 99	
mixture of 1a and 104	

Apparatus specifications and operating conditions are given in Table 2, in the Appendix.

Analysis for Trace Elements

A semi-quantitative spectrochemical method was used for the analysis of the following elements:

B, Be, Co, Cr, Cu, Ga, Mn, No, Ni, Pb, Sc, Sn, Sr,
Ta, V, Y, Zn and Zr

The method is based on the same principles as the quantitative analysis for major elements. Instead of using internal standards, however, the concentration of each element is determined by comparison of the intensity of spectral lines of given elements with the intensity of line Fe 3202, obtained by the analysis of a sample of known composition, on each spectrographic plate.

The method is a relatively rapid one, since the preparation of samples involves only the mixing of 100 milligrams of a pulverized sample, with an equal amount of graphite.

The details of operating conditions, and the analytical lines used for each element are given in Table 2, in the Appendix.

Accuracy and Precision

To check the accuracy of the spectrochemical analyses of the major elements, four samples were analysed by the Quebec Department of Mines, and in the laboratories of the Department of Geological Studies at McGill University. The results, presented in Table 4, indicate consistently high values for silica, and low values for soda as determined by the author. The analyses of other elements show reasonable deviations from the results obtained by the two other analysts.

Table 4

COMPARISON OF FOUR ANALYSES OF DYKE SAMPLES

	54-1			92-2			151			174		
	I	II	III	I	II	III	I	II	III	I	II	III
SiO_2	68.30	68.23	74.10	56.9	58.11	66.00	55.0	55.14	61.0	68.9	68.6	75.0
Al_2O_3	15.40	14.84	13.40	16.50	16.04	17.00	20.5	20.58	21.8	15.1	14.30	15.7
Fe(total)	3.54	3.05	3.40	8.93	6.35	7.28	6.38	4.85	5.50	2.41	1.86	2.40
CaO	3.86	3.95	2.75	4.66	4.54	3.75	4.18	3.83	3.39	3.97	3.93	3.50
MgO	2.06	1.04	0.95	2.69	2.36	2.55	2.80	2.74	3.08	1.12	1.02	0.99
Na_2O	3.57	3.34	2.15	4.54	3.72	2.80	4.68	3.80	2.36	2.83	1.86	1.64
TiO_2	0.32	0.33	0.19	0.79	0.61	0.50	0.42	0.40	0.25	0.27	0.17	0.19
MnO	0.03	0.03	0.10	0.10	0.08	0.07	0.10	0.10	0.05	0.01	0.05	0.05
K_2O	0.28	0.31		0.77	0.21		1.37	0.82		1.01	0.81	
P_2O_5	0.12			0.22			0.21			0.16		
CO_2	5.78	0.33		1.65	0.07		1.39	1.25		2.28	2.87	
H_2O	1.06	1.60		1.73	2.62		2.95	3.57		1.13	2.52	

I	Chemical analysis by Department of Geological Sciences, McGill University.
II	Chemical analysis by Quebec Department of Mines.
III	Spectrochemical analysis by the writer.

To check the precision of the analyses for major and minor elements, the author made ten runs for sample no. 106. The sample was divided into ten portions, and each treated separately according to procedure outlined on page 30. The precision is expressed in terms of standard deviation, and per cent relative deviation, at a confidence level of 95 per cent.

Standard Deviation, $s = \sqrt{\frac{\sum x^2}{n} - (\bar{x})^2}$

where

x^2 = sum of squares of individual analyses,

$(\bar{x})^2$ = square of the average of all analyses,

n = number of samples,

then

Per cent Relative Deviation, $C = \frac{t\ s}{\bar{x}\sqrt{n}}\ 100$

where the value of (Student's) t is a function of probability, and degrees of freedom, obtainable in published tables.

Table 5

Precision

Element	$\bar{x}$	s	C
SiO_2	61.00 per cent	6.23	7.30
Al_2O_3	12.80	2.88	11.45
MgO	5.28	0.25	3.45
CaO	7.74	1.24	11.48
TiO_2	1.42	0.15	7.30
Be	15.4 ppm	4.71	21.84
Co	37.0	7.20	13.83
Cr	54.6	9.38	12.28
Cu	171.4	28.97	12.08
Ga	10.6	0.97	6.56
Mn	550.0	17.93	2.33

-- (cont'd) --

Table 5, cont'd.

	$\bar{x}$	s	C
Mo	5.8 ppm	0.55	6.75
Ni	40.6	11.37	20.02
Sc	22.7	9.21	28.99
Sn	6.1	0.37	6.53
Sr	265.5	37.37	10.06
V	132.0	16.64	9.01
Y	44.4	8.29	13.35
Zr	556.0	59.98	7.71

$\bar{x}$ = average of 10 runs

s = standard deviation

C = relative deviation

Since sample No. 106 contained more than 10 per cent total Fe, and only a trace of Na_2O, the precision for these two constituents could not be expressed in terms of per cent relative deviation. An indication of the reproducibility for the analyses of these two elements, however, can be obtained from the mean deviation of the duplicates of all analysed samples, (Table 6).

Table 6

Mean Deviation of Duplicate Analyses

Fe (tot.)	0.205 per cent
Na_2O	0.165 per cent

In order to give an indication of the contribution of the analytical error to the chemical variation of the analysed samples, the writer compared graphically the analytical confidence limits of the mean values of sets of n samples with confidence limits of the mean calculated from individual analyses of each of the n samples, (Plates 34 a-d).

The comparisons show that the analytical confidence limits are considerably narrower than the confidence limits of the mean calculated from the individual analyses of the n samples. Therefore it is concluded that the analytical imprecision alone does not account for the variation in chemical composition of the analysed samples.

Presentation of Data.

The analytical results of all eighty samples are given in Table III in the Appendix. The concentrations of the major elements are expressed as per cent oxides. As the distinction between ferric and ferrous oxides cannot be made in spectrographic analyses, the total concentration of iron, Fe total, is given. The concentration of trace elements, determined semi-quantitatively, is expressed as parts per million, (ppm).

In order to give a clear indication of the statistical distribution, the analyses are presented graphically, as well as in table form.

4. STATISTICAL TREATMENT OF ANALYTICAL RESULTS

The solution of the problems that are the subject of this investigation ultimately involves the determination of the significance of the difference between sample means of two or more groups of samples. The most efficient and widely accepted statistical methods applied to problems of this type are the Student's t-test, and the F-test. These tests function on the assumption that the population is normally distributed, and are most efficient when the number of samples is relatively high.

Histograms of the analytical data presented in the Appendix indicate, however, considerable deviations from normality. Several of the elements show skewed, bimodal or otherwise irregular distributions. In such cases the applications of the t-tests and F-tests are unjustified. It is mainly for this reason that nonparametric methods have to be employed.

"A nonparametric test is a test whose model does not specify conditions about the parameters of the population from which the sample was drawn"*. Nonparametric tests are ideally suited for problems presented here because of the relatively small number of samples. For samples as small as n = 6, there is, in fact, no alternative to using nonparametric statistics, unless the distribution of the parent population is known exactly. Another advantage in the application of such methods lies in the fact that the detrimental effects of analytical errors are considerably reduced using ranks, rather than actual values of the analytical data.

Siegel, 1956, p.31. *

Ranking involves the arrangement of all samples according to the relative amounts of particular elements present. Thus, the sample containing the least amount of a given element is assigned a rank of 1, the sample containing the next highest amount is given rank 2, and so on. Samples containing identical amounts are given identical ranks. The ranking of samples according to their SiO_2 is shown in Table 9.

The competence of nonparametric statistics in comparison to other tests can be expressed by means of "power-efficiency". The concept of power-efficiency is based on the fact that the competence of any statistical method is proportional to the number of samples involved.

Let A be the most powerful known test of its type, and let B be another nonparametric test, which is just as powerful with N_B samples, as A is with N_A samples. Then

$$\text{Power-Efficiency of B} = \frac{N_A}{N_B}\ 100 \text{ per cent.}$$

For example, a power-efficiency of 80 per cent means that in order to make a B test as powerful as an A test, ten samples have to be used for the B test for every eight samples used in A.

The percentage of power-efficiency will be given for each of the statistical tests used below.

In the statistical treatment of the analytical data, only 14 of the 25 analysed elements are considered. In a great majority of samples the concentrations of B, Cr, Ga, Mo, Sc, Sn, Y, Zn, Be, Pb, Ta, are not dectectable. The study of the distribution of those samples in which the above trace elements occur in detectable quantities revealed no pattern. For these reasons, the analytical data for these elements are not considered in any of the statistical tests.

Variation in Composition Between Dyke Branches

Sixty one samples have been drawn from seven different branches of the main dyke swarm, without regard to their rock types, (Table 7). The branches, designated by letters A to G, are shown in Plate.2.

Table 7

Samples Drawn from Different Dyke Branches

	A	B	C	D	E	F	G
	180	51-1	55-2	74	148	68	93-1
	181	56	55-3	83	147	71	98-1
	182	64-2	59	80	150	173	98-2
	183-5	64-3	157-1	84	151	174	98-4
	184-2	64-4	157-2	92-1	176A-1		101
	185-2	103		92-2	176A-3		
	186-2	106		92-4	176A-5		
	187-2	152-2			176B-6		
	187-1	152-3			176B-7		
		153-1			176B-8		
		153-2					
		154-1					
		154-2					
		156					
		159					
		160-1					
		160-2					
		160-3					
		160-4					
		161					
		162					
n =	9	21	5	7	10	4	5

The analyses, presented in range charts in the Appendix, indicate overlaps in the compositions of samples taken from different branches. This shows that none of the dyke branches can be identified by a single chemical analysis. The mean compositions, however, show considerable variations from dyke to dyke, and the question arises whether the difference between the means is real, or whether it could have arisen by chance.

Table 8

Average Composition of Dyke Branches

	A	B	C	D	E	F	G
SiO_2(%)	62.57	68.6	71.0	63.68	70.4	70.1	70.1
Al_2O_3	11.88	16.24	15.12	16.23	17.9	14.39	14.64
Fe(total)	4.38	4.76	3.61	6.51	4.15	5.18	3.90
MgO	1.94	1.74	1.46	2.96	1.81	1.66	1.83
CaO	7.28	4.71	4.32	5.59	3.99	4.98	4.50
Na_2O	1.84	1.43	2.27	1.50	1.79	0.95	2.25
TiO_2	0.25	0.39	0.26	0.44	0.30	0.20	0.26
Mn ppm	594	314	289	853	472	576	445
Co	21	28	13	23	13	82.5	17
Cu	134	220	108	172	99	411	144
Ni	18	29	11	17	13.7	10.5	9
Sr	174	240	319	273	236	150	272
V	40	55	38	135	42	33	65
Zr	167	280	291	244	166	185	252
Fe/mg	2.2	3.4	2.6	2.4	2.16	3.75	2.84

To solve this problem, the Kruskal-Wallis "one-way analysis of variance" has been chosen as the most appropriate test. This test assumes an underlying continuous distribution of the parent population, and tests the null hypothesis that the seven groups of samples, representing the various dyke branches, came from the same population.

The Kruskal-Wallis analysis of variance involves the replacement of N values by ranks. All values from the seven groups of samples, (totalling 61 analyses) are ranked into a single series, beginning with 1, and ending with 61. Rank number one represents the lowest, rank number 61 the highest content of a given element, respectively. The sum of the ranks in each group is thus found. If the null hypothesis (stating that all groups come from identical populations) is true, then H, as defined below, is distributed as Chi-square.

$$H = \frac{12}{N(n+1)} \sum_{i}^{K} \frac{Ri^2}{n_i} -3(n+1) \qquad (1)$$

where
K = number of groups
n = number of samples in each group
N = total number of samples
R_i= sum of ranks in 7th group
Df= degrees of freedom = K - 1

The probabilities of the calculated values of H occurring under H_0 (null hypothesis), are determined from published tables of the critical values of Chi-square.*

---

*Siegel, 1956, Table C.

At the 99 per cent level of confidence, with Df = 6, the critical value of Chi-square $H_c = 16.81$. The region of rejection of the null hypothesis will, therefore, consist of all those values of H that are equal, or larger than the critical value of 16.81.

The power-efficiency of the Kruskal-Wallis one-way analysis of variance, as compared to the parametric F-test approaches PE = 95.5 per cent, (Siegel, 1956, p. 193).

Calculation of the Kruskal-Wallis Test

The calculation of the test for SiO_2 will serve as an example of the use of ranking methods in all subsequent nonparametric tests.

The arrangement of concentrations of SiO_2 in order of magnitude, and the corresponding ranks are shown in Table 9.

Table 9

Ranking of SiO_2 Values for Dyke Branches

A	B	C	D	E	F	G
52.1 1						
	52.6 2					
54.2 3			57.5 4			
			60.0 5			
60.2 6						
	60.3 7			61.0 9		
	61.0 9			61.0 9		
	61.2 11.5		61.2 11.5			
				62.0 13		
				63.3 14		
				63.6 15		
63.8 16.5						63.8 16.5
64.0 18						
65.0 19						
			65.2 20			
66.0 22.5						
66.0 22.5	66.0 22.5		66.0 22.5			
					66.3 25	
			66.8 26.5		66.8 26.5	
	67.0 29			67.0 29		67.0 29
				68.0 31		
	68.4 32.5			68.4 32.5		
	68.7 34					
	69.0 35					
	69.4 36					
	69.4 37					
		69.6 38				
		69.6 39				
	70.0 40.5					
	70.0 40.5					
			70.3 42			
				70.4 43		
		70.6 44				
71.5 46	71.5 46					71.5 46
	71.6 48					
				71.8 49		
					72.2 50	
		72.4 51.5				72.4 51.5
	72.5 53					
	73.0 54.5	73.0 54.5				
	74.1 56					
	74.6 57					
					75.0 58	
	75.5 59					
	75.6 60					
						76.0 61
R_a=155.5	R_b=768.0	R_c=227.0	R_d=131.5	R_e=244.5	R_f=159.5	R_g=205.0
n_a= 9	N_b= 21	n_c= 5	n_d= 7	n_e= 10	n_f= 4	n_g= 5

R = sum of ranks n = number of samples

By substituting the values obtained in Table 9 for R_i and n_i, the values of H can be computed according to equation (1).

$$H = \frac{12}{N(N+1)} \sum_{i}^{k} \frac{R_i^2}{n_i} - 3\ (N+1) \qquad (1)$$

$$H = \left[\frac{12}{61(61+1)} \quad \frac{(155.5)^2}{9} + \frac{(768.0)^2}{21} + \frac{(227.0)^2}{5} + \frac{(131.5)^2}{7} + \frac{(244.5)^2}{10} + \frac{(159.5)^2}{4} + \frac{(205.}{5} \right.$$

$$- 3(61+1)$$

$$H = (0.003173 \times 64,292.74) - 168$$

$$H = 18.00$$

The comparison of the obtained values of H with the critical value of Chi-square (H_c) at a 99 per cent level of confidence indicates that

$$H > H_c$$

The value of H thus falls within the rejection region of H_o, (null hypothesis), and we can conclude with 99 per cent confidence that the seven dyke branches differ significantly in their SiO_2 contents.

The results of calculation of the values of H for other elements are given in Table 10.

Table 10

Values of H, and Associated Probabilities for Various Dyke Branches

	H	P
SiO_2	18.0	99
Al_2O_3	20.8	99
Fe(tot)	9.0	80
MgO	9.2	70
CaO	7.1	50
Na_2O	7.3	70
TiO_2	7.5	70
MnO	14.8	95
B	16.4	98
Co	9.3	90
Cu	5.8	50
Ni	20.0	50
Sr	9.0	80
V	9.4	80
Zr	14.1	95

H = value calculated using equation (1).

p = probability of H occurring within the rejection region of H_o (null hypothesis), expressed in per cent.

The data presented in the above table indicate that five elements differ in their respective concentration at confidence levels of over 90 per cent. Of these elements, two (silica and alumina) differ significantly at the 99 per cent confidence level.

Variation in Composition Between Various Rock Types

Of the eighty samples analysed, 63 have been identified as belonging to five petrologically distinct dyke rock types. Four samples have been identified as altered anorthosite, and the classification of the remaining thirteen specimens is uncertain. The 63 positively identified dyke samples are listed and classified in Table 11.

Table 11

Rock Type Classification of Dyke Samples

Feldspar Porphyry F	Diorite Porphyry D	Grey G	Quartz-Feldspar Porphyry Q	Quartz Porphyry P
14	21	48	54-1	68
25	55-2	83	54-2	173
26	55-3	107	98-4	174
51-2	74	106	156	180-2
59-1	92-2	147		182
64-2	104	148		
64-3	150	153-1		
64-4	151	153-2		
80	176B-6	162		
84	176B-7	176A-1		
92-1	176B-8	176A-3		
92-4	409	176A-5		
93-1	410			
98-1	411			
98-2				
101				
103				
152-2				
152-3				
154-1				
154-2				
157-1				
157-2				
159				
160-1				
160-2				
407				
408				
n = 28	14	12	4	5

The average composition of the five rock types are given in Table 12.

Table 12

Average Composition of Rock Types

	F	D	G	Q	P	Anorth.
SiO_2	69.07	64.05	66.2	73.0	70.3	48.65
Al_2O_3	15.43	18.13	14.55	15.55	11.61	24.90
Fe(total)	4.23	4.77	6.39	3.56	4.67	6.50
MgO	1.42	2.08	3.20	1.16	1.45	4.59
CaO	4.39	4.51	6.38	3.06	6.29	10.58
Na_2O	1.92	2.59	0.53	2.25	0.70	0.78
TiO_2	0.23	0.37	0.73	0.20	0.17	0.15
Mn	359 ppm	538 ppm	653 ppm	166 ppm	675 ppm	588 ppm
B	13	6	16	10	15	12.5
Co	19	14	30	14	10	36
Cu	177	89	178	145	189	110
Ni	14	13	42	9	10	44
Sr	223	381	279	220	198	177
V	48	84	101	35	34	66
Zr	237	273	295	280	165	31
Fe/Mg	3.56	2.49	2.18	3.10	3.4	1.5

The ranges in concentration of 15 elements in the various rock types, including the anorthosite, are shown in range charts in the Appendix. As with the range charts for compositions of various dyke branches, the compositions of the various dyke rock types show considerable overlaps. The statistical evaluation of the analytical data, however, indicates surprisingly different results.

The null hypothesis, as applied to this problem, states that the samples comprising the five groups come from the same parent population; in other words, that there is no significant difference between the chemical compositions of the five rock types. To test this hypothesis, the Kruskal-Wallis one way analysis of variance can again be applied.

N = total number of samples = 63
K = number of groups = 5
Df = degrees of freedom = $K - 1$ = 4

Critical value of Chi-square at a significance level of 0.01 = 13.28.*

By substituting the values of R_i and n_i in the equation (1), the values of H are calculated for each constituent. The results are presented in Table 13.

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*Siegel, 1956, Table C.

Table 13

The Values of H, and Associated Probabilities for Various Dyke Rock Types

	H	P
SiO_2	17.1	99
Al_2O_3	20.3	99.9
Fe(tot)	10.4	95
MgO	20.44	99.9
CaO	8.42	90
Na_2O	35.23	99.9
TiO_2	22.61	99.9
MnO	28.78	99.9
Co	8.44	90
Cu	10.72	95
Ni	13.63	99
Sr	11.00	98
V	11.94	98
Zr	8.85	90

H = value calculated using equation (1).

p = probability of H occurring within the rejection region of H_0 (null hypothesis), expressed in per cent.

Table 13 shows that all elements differ in their concentrations in the various rock types at a minimum confidence level of 90 per cent. Significant differences in the concentrations of nine elements are detectable at a confidence level of at least 99 per cent.

Chemical Variation due to Alteration

It was noted earlier that the main alteration products were chlorite and sericite, commonly accompanied by the introduction of carbonates.

The question arises as to whether the alteration is reflected in the chemical composition of the rocks.

For this purpose 28 samples of the feldspar porphyry dykes were classified into two groups according to the intensity of alteration (Table 14). The amount of chlorite present in the rock was used as a basis for the classification. Samples of dykes with less than 10 per cent chlorite were classed as "relatively fresh", and samples in which chlorite constituted more than 10 per cent of the rock as altered. This criterion was chosen because it was found that a fair approximation of the freshness could be made megascopically, by colour and by the hardness of the rock. Since in the examined specimens the degree of sericitization was roughly proportional to the amount of chlorite, the effect of the variation in the degree of sericitization on the changes of the chemical composition of the rocks could, for this purpose, be considered to be negligible.

Table 14

Classification of Feldspar Porphyry Dykes on the Basis of Alteration

	Fresh	Altered
Sample No.	25	14
	51-2	26
	59-1	64-2
	84	64-3
	98-1	64-4
	98-2	92-1
	101	92-4
	103	80
	152-2	154-1
	152-3	154-2
	407	157-1
	408	160-1
	93-1	160-2
		157-2
		159
	$n_f = 13$	$n_a = 15$

To determine the significance of the difference between the chemical compositions of the two groups, the Mann-Whitney U-test was chosen. This test is considered to be one of the most powerful nonparametric tests. It is used as an alternate to the parametric t-test, wherever the assumptions of the latter are unjustifiable. The power-efficiency of the Mann-Whitney U-test as compared to the t-test is close to 95 per cent, (Siegel, 1956). As with the Kruskal-Wallis analysis of variance, the Mann-Whitney U-test examines the null hypothesis that the two independent groups of samples come from the same population.

The test involves the ranking of the analytical data into one continuous series, and the subsequent computation of the factor U by the equation:

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \qquad (2a)$$

or similarly

$$U^1 = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \qquad (2b)$$

where n_1 = number of samples in smaller group
n_2 = number of samples in larger group
R_1 = sum of ranks in smaller group
R_2 = sum of ranks in larger group

The values of U obtained from equations (2a) and (2b) are not identical; the smaller value is used in the test. The two values of U are related by the following equation:

$$U = n_1 n_2 - U^1 \qquad (3)$$

where $U > U^1$

The rejection region of the null hypothesis (H_o) consists of all those values of the computed U test that are equal or smaller than the critical values of U_c given in published tables.

The calculation of the value of U for SiO_2 will serve as an example of the calculations of the Mann-Whitney test.

$n_1 = 13$ $R_1 = 185$
$n_2 = 15$ $R_2 = 221$

Substituting the above values in equation (2a)

$$U = 13 \times 15 + \frac{13(13 + 1)}{2} - 185$$

$$U = 101$$

Substituting the values in equation (2b)

$$U^1 = 13 \times 15 + \frac{15(15 + 1)}{2} - 221$$

$$U^1 = 94$$

According to equation (3)

$$101 = 13 \times 15 - 94$$

$$101 = 101$$

Since $U^1 < U$, the value of U^1 is used in the test.

As the calculated value of U^1 is larger than the critical value of U_c for the 99 per cent confidence level, (Table 15), the null hypothesis is accepted, and we conclude that the difference between the mean concentrations of SiO_2 in the altered and unaltered dyke samples could have arisen by chance.

The results of the calculations of the values of U for other elements are shown in Table 15.

Table 15

The Values of U for Elements in Altered and Unaltered Samples

	Fresh	Altered	n_1	n_2	U	U_c =0.01	U_c =0.05
SiO_2	69.0	69.5	13	15	94	47	61
Al_2O_3	15.4	15.7	13	15	112	47	61
Fe(tot)	4.03	4.60	12	15	65	42	55
MgO	1.66	1.15	13	15	93.5	47	61
CaO	3.44	4.53	13	15	70	47	61
Na_2O	2.33	1.63	13	15	45	47	61
TiO_2	0.23	0.22	13	15	79.5	47	61
MnO	385	309	12	15	87	42	55
Co	15	22	12	15	67.5	42	55
Cu	135	213	12	15	60	42	55
Ni	9	15	12	15	85.5	42	55
Sr	251	192	12	15	80	42	55
V	51	35	10	15	46	42	55
Zr	232	232	12	15	No difference between mear		
Fe/Mg	2.98	4.04	12	15	54.5	42	55

n_1 = number of samples in smaller group

n_2 = number of samples in larger group

U = computed value

U_c (=0.01) = critical value at 99 per cent significance level

U_c (=0.05) = critical value at 95 per cent significance level

<u>NOTE</u>: The discrepancy in n_1 is due to only a partial analysis of sample No. 152-2.

The above table indicates that on the 95 per cent level of confidence the two groups of samples show a significant difference in the concentrations of soda, vanadium, and in the Fe/Mg ratio. The impoverishment of the altered samples in soda can be also detected at the 99 per cent confidence level. The significance of these results will be discussed in the summary.

Chemical Variation of the Dykes with Depth

In order to detect possible chemical variations of the dykes with depth, the mean compositions of 34 samples from the upper levels were compared with 21 samples taken from the horizons below the 1900 level, (Table 16).

Table 16

Grouping of Samples from Upper and Lower Levels of the Mine

Samples From Below the 1900 Level		Samples From Above the 1900 Level		
21	153-1	48	93	174
25	153-2	51	98-1	176-A-1
26	154-1	68	98-2	176-A-3
64-2	154-2	71	98-4	176-A-5
64-3	159	74	101	176-B-6
64-4	160-1	80	147	176-B-7
106	160-2	83	148	176-B-8
107	160-3	84	150	407
152-2	160-4	92-1	151	408
152-3	161	92-2	170	409
	162	92-4	173	410
				411

The Mann-Whitney test was applied to determine the significance of the difference between the mean chemical compositions of the two groups of samples.

For such a large number of samples the sampling distribution of U approaches normality, and the test involves the evaluation of the factor "z".

$$z = \frac{U - \mu_0}{\sigma} \qquad (4)$$

where

$$U = n_1 \; n_2 \quad \frac{n_1 (n+1)}{2} - R_1 \qquad (2a)$$

$$\sigma = \text{standard deviation}$$

$$\sigma = \sqrt{\frac{n_1 \; n_2 \; (n_1 + n_2 + 1)}{12}} \qquad (5)$$

$$\mu_0 = \text{mean} = \frac{n_1 + n_2}{2} \qquad (6)$$

The rejection region of the null hypothesis, the two groups of samples coming from the same population , consists of all those values of z whose associated probabilities are equal to, or less than 0.01.

As with all previous tests, the calculation of the value of "z" for SiO_2 will serve as an example of the calculations.

$$n_1 = 21 \qquad R_1 = 691.5$$

$$n_2 = 34 \qquad R_2 = 848.5$$

$$U = n_1 \, n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \tag{2a}$$

$$U = 253.5$$

$$U^1 = n_1 \, n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \tag{2b}$$

$$U^1 = 460.5$$

According to equation (3),

$$253.5 = 21 \times 34 - 460.5$$

Then,

$$\mu_u = \frac{n_1 + n_2}{2} = 357 \tag{6}$$

And

$$\sigma = \sqrt{\frac{n_1 \, n_2 \, (n_1 + n_2 + 1)}{12}} \tag{5}$$

$$\sigma = \sqrt{\frac{714 \times 56}{12}}$$

$$\sigma = 57.7335$$

Finally,

$$z = \frac{U - \mu_u}{\sigma} \tag{4}$$

$$z = \frac{253.5 - 357}{57.7335}$$

$$z = -1.79$$

According to published tables, (Siegel, 1956, Table A), the probability (p) of the associated $z = -1.79$ is

$$p = 0.04$$

The value of "z" for SiO_2 thus falls outside the rejection region of null hypothesis, and we can conclude that at a confidence level of 99 per cent, the difference between the mean concentrations of SiO_2 in the samples of the two groups is not significant.

The results of the calculations of the Mann-Whitney test for all other elements are shown in Table 17.

Table 17

Calculated Values of "z" and their Associated Probabilities for Dyke Samples from Upper and Lower Levels

	Mean Concentration			
	Upper	Lower	z	p
SiO_2	66.3	68.5	-1.79	0.04
Al_2O_3	16.4	16.1	-0.86	0.19
Fe tot	4.82	5.24	-0.56	0.29
MgO	2.08	1.91	-1.46	0.07
CaO	4.38	5.35	-1.17	0.11
Na_2O	2.02	1.34	-1.70	0.04
TiO_2	0.33	0.47	-0.56	0.29
Mn ppm	579	358	-1.84	0.03
Co	25	25	No difference between means	
Cu	160	227	-2.36	0.009
Ni	13.1	13.4	-1.02	0.15
Sr	235	235	No difference between means	
V	69	63	-1.27	0.15
Zr	237	280	-0.80	0.21

The results listed in Table 17 indicate that the difference between the mean compositions of the two groups of samples are significant at the 95 per cent confidence level in case of four elements, SiO_2, Na_2O, Mn, and Cu. Of these, only copper shows a significant difference at the 99 per cent confidence level.

DISCUSSION OF THE RESULTS

The main purpose of this work has been the investigation of the possibility of correlating the dykes on the basis of their chemical composition. The range charts of element contents of the various dyke branches indicate that none of the investigated dykes has a sufficiently characteristic composition to make it distinguishable from any other dyke branch without further statistical tests. This fact alone makes the chemical method of correlation impractical, because of the large number of analyses that would be necessary to obtain a correlation at a significant level of confidence.

Statistical comparisons indicate that the dyke branches differ in the concentrations of three elements, (Si, Al, Ni), at the 99 per cent confidence level. Similar tests applied to the composition of samples of various dyke rock types, without regard to their position in particular dyke branches, show that the dyke rock types differ from each other in the concentrations of seven elements, (Si, Al, Ni, Mg, Na, Ti, and Mn). It appears that the differences between the chemical compositions of the various dyke rock types are more distinct than those between dyke branches, and that a given dyke sample basically owes its chemical composition to its petrological character rather than to its membership in a particular dyke branch. Since a single dyke branch may be composed of more than on rock type, as had been shown earlier, neither the chemical composition, nor the petrological character of a dyke provides a sound basis for its correlation with another dyke.

The fact that the various dyke branches show a significant difference in the concentrations of three elements, is attributed to the contamination effect caused by the uneven distribution of samples of various rock types in the various dyke branches.

One of the more striking results of the analyses is the wide variation in the chemical composition of samples taken from single dyke intersections within relatively short distances. This variation is best shown in the range charts and by the comparisons of analyses of bulk samples with the analyses of short, one foot samples, (Table 3). This inhomogeneous chemical character of the dykes is probably due to the contamination caused by secondary quartz, carbonate, and epidote stringers, as well as by the uneven intensity of hydrothermal alteration.

The study of the chemical effects of hydrothermal alteration indicates a decrease in the soda and vanadium concentrations, detected on the 99 per cent level of confidence, and an increase in the Fe/Mg ratio, detected on the 95 per cent level.

The decrease in the soda content in altered dykes is probably the result of metasomatism involving the addition of potassium at the expense of soda, and resulting in the sericitization of the plagioclases. While no analyses for potassium have been made by the writer, complete analyses of four dyke samples made by other laboratories, (Table 4), show an increase in potassium in the altered and sheared rocks. Indications of this trend were also noted by Jeffery in his study of the comparisons of altered and relatively fresh meta-anorthosites. The feasibility of such alkali ion exchange during metamorphism has been demonstrated by Orville, (1963).

The increase in the Fe/Mg ratio in the altered dyke specimens is probably related to the changes in the composition of chlorite. Two types of chlorite have been identified by Jeffery in nearly all rocks at the Campbell mine. Chlorite I., rich in magnesium, is characteristic of barren, massive, and relatively fresh anorthosite, whereas chlorite II., rich in iron, is most abundant in altered and sheared rocks. Since sulphide mineralization favours the sheared host rock, the increase in the Fe/Mg ratio is probably accentuated by the iron present in the introduced sulphides.

The decrease in vanadium in the altered specimens was detected on the 99 per cent confidence level. Vanadium occurs in igneous rocks mostly in magnetite, as well as in ferromagnesian minerals, in which it substitutes for the ferric ion. It is suggested that the vanadium may be present in chlorite, but its impoverishment in the altered dyke samples remains unexplained.

There is general agreement among workers that the mineralogical similarity of the common dykes indicates their close genetic relationship. Jeffery believes that the dykes originated from the same parent magma, and postulates a sequence of introduction on the basis of their mineralogy. Noting that feldspar would crystallize first, and that crystallization would proceed with an ever decreasing feldspar content and with an increase in quartz, Jeffery suggests the following order of emplacement:

1. Diorite Porphyry
2. Quartz Diorite
3. Feldspar Porphyry
4. Quartz Feldspar Porphyry
5. Quartz Porphyry
6. Fine Grained, grey Dykes

The chemical composition of the dykes analyzed by the writer is too strongly masked by the alteration to enable the determination of the sequence of introduction on a chemical basis. The close similarity of the common dykes, however, is obvious. It suggests that the dykes were introduced within a relatively short period of time during which the parent magma could not attain a high degree of differentiation. It is proposed that some of the later dykes were emplaced while the consolidation of the earlier dyke material was still incomplete. The resulting mixture of chemically similar differentiates would leave little trace of the contact zones between the various dyke rock types, particularly if later obscured by shearing, and hydrothermal alteration. This mode of emplacement would account for the puzzling observation that individual dyke branches may be composed of more than one rock type. It would explain the local fading of phenocrysts, and the gradational relationship between the various dyke rock types. It would explain why neither the chemical nor the petrological character of the dykes forms a reliable criterion for the correlation of the individual dyke branches.

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APPENDIX A

TABLE I

LOCATION OF SAMPLES

Sample No.	D.D.H. No.	Footage	Section	Level	Rock Type
14	U-2010	407	1100W	2020'	F
21	U-2335	96	1100W	3080'	D
25	U-2277	135	1100W	3540'	F
26	U-2284	81	1100W	3520'	F
48-1	U-1408	148	600W	1900'	G
51-2	U-1402	82	600W	1970'	F
54-1	U-1928	322	600W	2150'	Q
54-2	U-1928	332	600W	2160'	Q
55-2	U-1928	356	600W	2178'	D
55-3	U-1928	362	600W	2180'	D
56	U-1928	487	600W	2285'	?
59-1	U-1929	596	600W	2450'	F
64-2	U-2128	37	600W	2715'	F
64-3	U-2128	46	600W	2720'	F
64-4	U-2128	51	600W	2725'	F
68	U-79	112	300W	450'	P
71	U-108	49	350W	250'	?
74	U-638	61	300W	1190'	D
80	U-970	90	275W	1450'	F
83	U-1154	103	300W	1600'	G
84	U-1154	119	300W	1600'	F

Sample No.	D.D.H. No.	Footage	Section	Level	Rock Type
92-1	U-1270	113	300W	1650'	F
92-2	U-1270	124	300W	1650'	D
92-4	U-1270	133	300W	1650'	F
93-1	U-1270	212	300W	1700'	F
98-1	U-1195	250	300W	1820'	F
98-2	U-1195	256	300W	1820'	F
98-4	U-1195	241	300W	1820'	Q
101	U-1274	230	300W	1900'	F
103	U-2036	405	300W	2230'	F
104	U-2036	578	300W	2370'	D
106	U-1993	1121	300W	2790'	G
107	U-1993	1218	300W	2830'	G
147	U-988	76	400W	1510'	G
148	U-988	96	400W	1520'	G
149	U-980	70	400W	1490'	An.
150	U-980	90	400W	1510'	D
151	U-978	25	400W	1465'	D
152-1	U-2125	31	700W	2700'	An.
152-2	U-2125	36	700W	2700'	F
152-3	U-2125	42	700W	2700'	F
153-1	U-2125	53	700W	2700'	G
153-2	U-2125	54	700W	2700'	G

Sample No.	D.D.H. No.	Footage	Section	Level	Rock Type
154-1	U-2121	130	800W	2700'	F
154-2	U-2121	142	800W	2700'	F
156	U-2105	222	800W	2430'	Q
157-1	U-1037	311	600W	1750±	F
157-2	U-1037	331	600W	1750±	F
159	U-2153	137	800W	3000'	F
160-1	U-2169	66	800W	3190'	F
160-2	U-2169	68	800W	3190'	F
160-3	U-2169	70	800W	3200'	?
160-4	U-2169	75	800W	3200'	?
161	U-2186		800W	3320±	G
162	U-2200	156	800W	3660'	G
162-1	U-2200	153	800W	3660'	G
170	U-1610	92	200W	1340'	?
173	U-87	4	300W	550'	P
174	U-84	4	300W	550'	P
175	U-93	3	300W	550'	An.
176-A-1	U-1090	25	500W	1450'	G
176-A-3	U-1090	36	500W	1450'	G
176-A-5	U-1090	47	500W	1450'	G
176-B-6 6	U-1090	75	500W	1450'	D
176-B-7 7	U-1090	81	500W	1450'	D
176-B-8 8	U-1090	86	500W	1450'	D
180-2	U-1911	1150	400E	550'	P
181	U-961	560	1000W	550'	

Sample No.	D.D.H. No.	Footage	Section	Level	Rock Type
182	U-986	470	1200W	550'	?
183-5	U-1926	671	100E	1150'	?
184-2	U-1699	820	1100W	1050'	?
185-2	U-905	636	1600	1600'	?
186-1	U-1356	681		2100'	An.
186-2	U-1356	683		2100'	?
187-2	U-1699	1332	1100W	1000'	?
187-3	U-1699	1356	1100W	1000'	?
407	U-1005	120	400W	1570'	F
408	U-1005	126	400W	1570'	F
409	U-1005	160	400W	1600'	D
410	U-1005	172	400W	1620	D
411	U-1005	180	400W	1630'	D

Rock Types:

G = Grey Dyke
QD = Quartz Diorite Porphyry
D = Diorite Porphyry
P = Quartz Porphyry
F = Feldspar Porphyry
P = Quartz Feldspar Porphyry
An = Anorthosite
? = Undetermined rock type

TABLE II

APPARATUS AND SPECTROGRAPHIC OPERATING CONDITIONS

Spectrograph: JACO, Model JA-7102, 3.4 meter planegrating Spectrograph.

Electrodes: lower (sample) electrode: 3/16" diameter; "spectrotech" electrode, (ST-45), with cavity 4 mm. diameter, 5 mm deep.

upper (counter) electrode: 1/8" diameter; spectrotech electrode (ST-40).

Exposure Conditions:

slit width	10
slit height	5 mm
filter	steps 3,4,5,6
preburn time	1/2 sec.
exposure time	To exposure; usually 2'45' ± 5 sec.
focus	16

Photography:
photographic emulsion: Kodak SA-3
developer: Kodak D-19, 3 min., at 20°C
plate calibration (major elements): 2 step method of Churchill *.

Spectral Lines:

Major - Si 2987; Fe 2599, Al 2652, Ca 3158, Mg 2781, Ti 3361, Mn 2576
Interval standard: Li 2741

Trace Elements -
Ag 3382
B 2497
Ba 3071
Be 3130
Co 3453
Cr 2843
Cu 3273
Ga 2943
Ma 2576
Mo 3170
Mi 3414
Pb 2833
Sn 3175
Sr 3464
Ta 2714
Ti 3370
V 3185
Y
Zn 3345
Zr 3391

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* Churchill (1944).

TABLE III

ANALYSES OF SAMPLES

Sample No.	14	21	25	26	48-1	51-2	54-1	54-2	55-2
SiO_2%	64.7	71.2	73.0	73.0	68.9	70.8	74.1	72.9	69.6
Al_2O_3	14.55	17.25	14.50	14.40	10.00	13.10	13.40	14.70	14.80
Fe(tot)	4.70	3.85	2.72	6.95	9.90	2.65	3.40	4.20	3.70
MgO	1.11	1.21	0.86	0.74	4.70	0.93	0.95	1.30	1.63
CaO	6.70	3.45	3.90	6.20	8.50	2.75	2.75	2.90	5.80
Na_2O	2.40	3.30	2.68	1.05	1.20	2.75	2.15	2.43	3.25
TiO_2	0.20	0.23	0.21	0.23	1.27	0.14	0.19	0.16	0.45
B ppm	14	u 5	u 5	u 5	16	23	14	u 5	u25
Be	u 5	u 5	u 5	u 5	11	5	u 5	-	5
Co	21	20	15	28	38	16	17	18	17
Cr	Tr	Tr	Tr	88	Tr	Tr	Tr	Tr	Tr
Cu	284	375	138	107	115	180	140	115	57
Ga	11	11	u10	u10	15	15	u10	u10	u10
Mn	450	360	173	155	2200	290	113	250	380
Mo	5	u 5	8	7	8	6	5	u 5	-
Ni	10	9	5	8	25	5	9	10	10
Pb	-	-	-	-	-	-	-	-	-
Sc	u 5	u 5	u 5	u 5	35	u 5	u 5	u 5	5
Sn	-	-	-	-	Tr	-	-	-	-
Sr	95	105	120	105	320	290	250	250	680
Ta	-	-	-	-	Tr	-	-	-	-
V	31	34	27	25	230	46	28	41	57
Y	10	18	Tr	Tr	28	18	Tr	Tr	20
Zr	270	325	205	220	540	310	310	295	335
Zn	Tr	Tr	-	-	-	-	0	250	-
Fe/Mg	4.2	3.2	3.2	9.4	2.1	2.9	3.6	3.2	2.3
S.G.	2.83	2.82	2.78	2.88	2.97	2.97	2.77	2.76	2.81

Tr = Trace
\- = not detected
u = less than

Sample No.	55-3	56	59-1	64-2	64-3	64-4	68	71	74	80
SiO_2%	69.6	73.0	72.4	75.5	75.6	71.6	71.2	66.3	61.2	60.0
Al_2O_3	16.00	13.80	13.00	13.30	12.10	13.50	11.60	16.75	18.50	15.50
Fe(tot)	4.00	4.30	3.30	3.03	2.55	4.35	3.92	u10.00	8.00	4.95
MgO	1.98	0.92	1.36	u0.65	0.78	0.78	0.55	3.08	2.80	1.80
CaO	4.30	4.90	1.88	1.30	3.95	3.10	6.35	2.25	2.70	7.65
Na_2O	3.25	1.68	2.93	1.93	1.65	2.35	1.83	0.97	1.88	1.37
TiO_2	0.32	0.21	0.20	0.13	0.17	0.16	0.14	0.36	0.38	0.36
B ppm	u 5	u 5	u 5	u 5	-	u 5	u 5	29	18	7
Be	5	u 5	u 5	u 5	u 5	u 5	4	5	5	5
Co	13	15	15	15	11	31	22	290	18	11
Cr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	53	52	Tr
Cu	19	190	130	168	158	330	300	825	300	41
Ga	10	u10	u10	u10	u10	u10	12	10	14	u10
Mn	390	205	213	u100	215	160	360	1000	700	610
Mo	Tr	6	u 5	14	Tr	8	-	6	45	Tr
Ni	12	8	9	6	u 5	40	u 5	21	15	12
Pb	-	-	-	-	-	-	Tr	-	-	-
Sc	5	u 5	u 5	u 5	u 5	u 5	u 5	u 5	5	u 5
Sn	-	-	-	-	-	-	-	-	Tr	-
Sr	400	150	165	290	245	220	230	-	230	300
Ta	-	-	-	-	-	-	-	-	-	-
V	55	25	28	15	24	25	27	41	46	48
Y	20	Tr	Tr	17	17	16	19	18	19	19
Zr	355	188	305	170	173	24	190	225	220	330
Zn	-	-	Tr	-	-	-	Tr	Tr	-	-
Fe/Mg	2.0	4.7	2.4	4.7	3.3	5.6	7.1	3.3	2.9	2.8
S.G.	S	2.78	2.73	2.76	2.76	2.73	2.77	3.09	D	2.8

Tr = Trace
- = Not detected
u = less than

Sample No.	83	84	92-1	92-2	92-4	93-1	98-1	98-2	98-4	101
SiO_2%	65.2	57.5	70.3	66.0	66.8	63.8	72.4	67.0	76.0	71.5
Al_2O_3	17.25	15.50	13.10	17.00	16.75	16.50	13.10	13.60	16.25	13.75
Fe(tot)	6.30	8.10	3.70	7.25	7.25	7.30	2.98	2.80	2.75	3.65
MgO	5.10	4.55	1.36	2.55	2.55	5.15	0.94	0.97	1.16	0.82
CaO	9.90	8.70	2.63	3.78	3.78	9.60	3.05	3.05	3.00	3.78
Na_2O	0.15	0.44	0.84	2.80	2.55	0.59	2.50	2.35	2.82	3.00
TiO_2	0.51	0.34	0.15	0.56	0.53	0.51	0.18	0.21	0.23	0.19
B ppm	67	10	24	11	21	24	16	21	18	17
Be	8	7	5	6	7	10	6	5	5	5
Co	38	28	11	26	32	37	11	10	13	14
Cr	84	58	-	63	70	93	-	-	-	-
Cu	73	73	120	210	385	78	200	190	158	100
Ga	13	u10	12	14	14	14	13	13	14	13
Mn	1850	840	520	650	800	1500	170	210	170	175
Mo	8	Tr	10	16	51	8	7	8	-	8
Ni	26	16	7	20	24	29	u 5	u 5	u 5	u 5
Pb	-	-	-	-	-	-	-	-	-	-
Sc	11	13	5	6	7	12	u 5	u 5	u 5	u 5
Sn	Tr	-	-	-	Tr	Tr	-	-	-	-
Sr	430	370	180	220	180	370	240	240	220	290
Ta	-	-	-	-	-	-	-	-	-	-
V	105	98	35	540	74	140	54	44	39	50
Y	23	21	19	19	21	23	-	-	-	-
Zr	190	170	310	230	270	220	270	250	260	260
Zn	-	-	-	-	-	-	-	-	-	-
Fe/Mg	1.2	1.8	2.7	2.8	2.8	1.4	3.0	2.9	2.4	4.5
S.G.	2.96	2.92	2.81	2.85	2.88	2.88	2.74	2.77	2.74	2.41

Tr = Trace
\- = not detected
u = less than

Sample No.	103	104	106	107	147	148	149	150	151	152-1
SiO_2%	71.5	69.2	61.0	67.5	70.4	71.0	48.0	63.3	61.0	42.8
Al_2O_3	16.75	18.0	12.8	12.30	16.0	15.2	22.5	18.6	21.8	27.0
Fe(tot)	3.10	4.60	10.0	10.00	3.60	2.05	3.95	4.30	5.50	6.10
MgO	1.06	1.58	5.28	5.00	1.21	1.24	2.03	2.23	3.08	4.48
CaO	3.35	6.00	7.74	9.55	1.83	1.75	11.30	5.05	3.93	12.70
Na_2O	2.80	5.40	u0.02	Tr	0.83	1.45	1.81	2.78	2.36	0.42
TiO_2	0.24	0.41	1.42	1.35	0.16	0.15	0.14	0.27	0.25	0.31
B ppm	20	u 5	u 5	-	34	20	21	u 5	15	u 5
Be	5	5	15	17	4	4	7	5	7	10
Co	-	14	37	33	13	9	18	11	17	27
Cr	-	Tr	55	45	-	Tr	30	Tr	73	54
Cu	66	6	171	118	180	120	120	Tr	77	143
Ga	11	u10	11	11	11	10	10	13	12	13
Mn	100	430	550	595	210	180	380	605	540	565
Mo	-	-	6	7	u 5	u 5	26	u 5	u 5	9
Ni	u 5	13	41	33	11	9	13	14	21	47
Pb	-	-	-	-	-	-	-	-	-	-
Sc	u 5	5	23	44	u 5	7	8	8	8	7
Sn	-	-	6	Tr	-	-	u 5	-	-	u 5
Sr	340	430	266	300	210	230	230	490	325	300
Ta	-	-	-	-	-	-	-	-	-	-
V	21	41	132	168	24	20	78	54	80	110
Y	-	19	44	61	-	-	u20	20	u20	u20
Zr	130	330	556	108	200	158	-	350	205	-
Zn	-	-	-	Tr	-	-	-	-	-	-
Fe/Mg	2.9	2.9	1.9	2.0	2.0	1.7	1.9	1.9	1.8	1.4
S.G.	2.78	2.80	2.87	3.00	2.98	2.98	2.84	2.78	2.78	3.18

Tr = Trace
\- = not detected
u = less than

Sample No.	152-2	152-3	153-1	153-2	154-1	154-2	156	157-1	157-2
SiO_2%	70.0	72.5	52.6	66.0	61.2	74.6	69.0	70.6	73.0
Al_2O_3	16.9	16.69	20.4	13.3	17.5	15.0	17.8	15.3	16.5
Fe(tot)	-	4.10	9.50	7.75	4.95	4.85	3.40	2.77	4.30
MgO	1.17	1.14	3.70	5.35	1.14	1.28	1.21	1.10	1.21
CaO	3.75	3.90	12.40	9.20	3.15	3.35	3.60	4.38	5.25
Na_2O	2.29	1.65	Tr	Tr	2.30	2.63	1.63	0.79	1.15
TiO_2	0.14	0.20	1.35	1.18	0.21	0.14	0.22	0.14	0.17
B ppm		7	u 5	u 5	u 5	u 5	u 5	21	u 5
Be		4	15	16	4	4	4	4	4
Co		21	78	51	18	14	9	9	9
Cr		u10	70	56	u20	u20	u20	u20	u20
Cu		200	450	245	215	230	165	120	215
Ga		12	17	13	13	11	11	10	12
Mn		168	635	750	130	180	130	235	225
Mo		u 5	9	7	u 5	u 5	u 5	u 5	u 5
Ni		11	255	37	11	10	12	9	15
Pb		-	-	-	-	-	-	-	-
Sc		u 5	20	21	u 5	u 5	u 5	u 5	u 5
Sn		-	11	6	-	-	-	-	-
Sr		255	400	300	145	165	160	175	175
Ta		-	-	Tr	-	-	-	-	-
V		33	165	175	31	28	30	23	28
Y			37	41	Tr	Tr	Tr	Tr	Tr
Zr		255	640	510	255	263	255	180	280
Zn		-	-	-	-	-	-	-	-
Fe/Mg		4.9	2.6	1.4	4.3	3.8	3.2	2.5	3.6
S.G.		2.79			2.78	2.77	2.80	2.76	2.83

Tr = Trace
\- = not detected
u = under

Sample No.	159	160-1	160-2	160-3	160-4	161	162	170	173	174
SiO_2%	70.0	60.3	69.4	69.2	68.7	67.0	68.4	66.0	66.8	75.0
Al_2O_3	17.9	16.9	20.5	12.6	25.3	15.8	19.1	18.3	13.5	15.7
Fe(tot)	5.60	3.08	2.80	5.10	2.53	6.55	4.50	4.01	4.40	2.40
MgO	2.05	0.83	0.65	1.92	0.70	2.95	2.03	1.32	2.00	0.99
CaO	8.15	8.40	1.60	9.48	1.82	4.38	3.65	2.76	7.90	3.50
Na_2O	0.34	0.94	1.15	0.70	1.11	0.98	1.05	0.94	0.36	0.64
TiO_2	0.47	0.20	0.22	0.13	0.15	0.73	0.41	0.25	0.12	0.19
B ppm	u 5	13	35	u 5	40	5	10	16	10	16
Be	7	4	5	u 5	5	8	6	u 5	u 5	-
Co	75	20	23	29	19	63	11	23	9	9
Cr	43	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Cu	470	120	183	152	185	450	77	120	335	185
Ga	10	u10	u10	u10	u10	u10	u10	u10	u10	u10
Mn	375	655	260	810	265	370	250	280	410	535
Mo	9	8	u 5	6	6	59	Tr	4	Tr	-
Ni	78	10	11	9	9	13	11	12	8	9
Pb	-	-	-	-	-	-	-	-	-	-
Sc	11	6	6	4	4	13	6	4	4	5
Sn	Tr	Tr	-	Tr	-	Tr	-	-	-	185
Sr	285	183	200	153	220	270	223	175	185	31
Ta	-	-	-	-	-	-	-	-	-	-
V	75	30	32	33	39	88	41	25	31	Tr
Y	23	17	Tr	-	Tr	22	21	18	Tr	160
Zr	315	195	290	115	245	380	340	315	163	-
Zn	-	-	-	Tr	-	-	-	-	Tr	u 5
Fe/Mg	2.7	3.8	4.3	2.7	3.6	2.2	2.2	2.0	2.2	2.4
S.G.	2.87	2.80	2.80	2.78	2.77	2.91	280	2.80	2.75	2.75

Tr = Trace
\- = not detected
u = less than

Sample No.	175	176 A-1	176 A-3	176 A-5	176 B-6	176 B-7	176 B-8	180-2	181	182
SiO_2%	50.8	67.0	68.0	68.4	61.0	62.0	63.6	66.0	54.2	71.5
Al_2O_3	29.0	19.8	14.8	18.3	17.6	18.0	19.1	11.45	9.80	5.80
Fe(tot)	7.85	5.75	3.50	1.80	4.40	4.00	4.55	3.18	4.80	9.45
MgO	5.0	2.65	1.00	1.13	2.20	1.75	1.60	1.18	3.70	2.55
CaO	7.30	4.25	5.10	2.70	2.90	5.20	7.20	4.84	15.05	8.85
Na_2O	0.82	0.75	0.90	1.14	4.00	2.35	1.34	0.68	0.20	Tr
TiO_2	0.11	0.51	0.15	0.25	0.39	0.34	0.56	0.23	u0.05	0.15
B ppm	21	12	12	6	-	u 5	u 5	15	u 5	u 5
Be	u 5	6	u 5	u 5	5	u 5	u 5	u 5	u 5	u 5
Co	42	24	16	9	12	10	8	Tr	53	10
Cr	60	52	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Cu	350	187	265	140	u10	4	u10	28	515	97
Ga	u10	u10	u10	u10	u10	u10	u10	u10	u10	u10
Mn	275	340	165	115	500	765	850	405	425	990
Mo	u 5	u 5	u 5	Tr	u 5	u 5	u 5	7	u 5	u 5
Ni	52	30	11	10	12	10	9	10	43	18
Pb	Tr	-	-	-	-	-	-	-	-	-
Sc	8	8	u 5	u 5	5	5	5	25	u 5	u 5
Sn	Tr	Tr	-	-	-	-	-	-	Tr	Tr
Sr	Tr	195	218	240	165	148	140	235	135	155
Ta	-	-	-	-	-	-	-	-	-	-
V	31	49	44	24	41	44	42	28	54	55
Y	Tr	21	Tr	Tr	18	20	18	15	-	18
Zr	74	60	270	19	9	288	155	110	22	200
Zn	Tr	-	-	-	-	-	-	-	-	Tr
Fe/Mg	1.5	2.2	3.5	3.4	3.0	2.3	2.8	2.7	1.3	2.6
S.G.	2.87	2.87	2.81	2.76	2.75	2.75	2.76	2.82	2.94	2.81

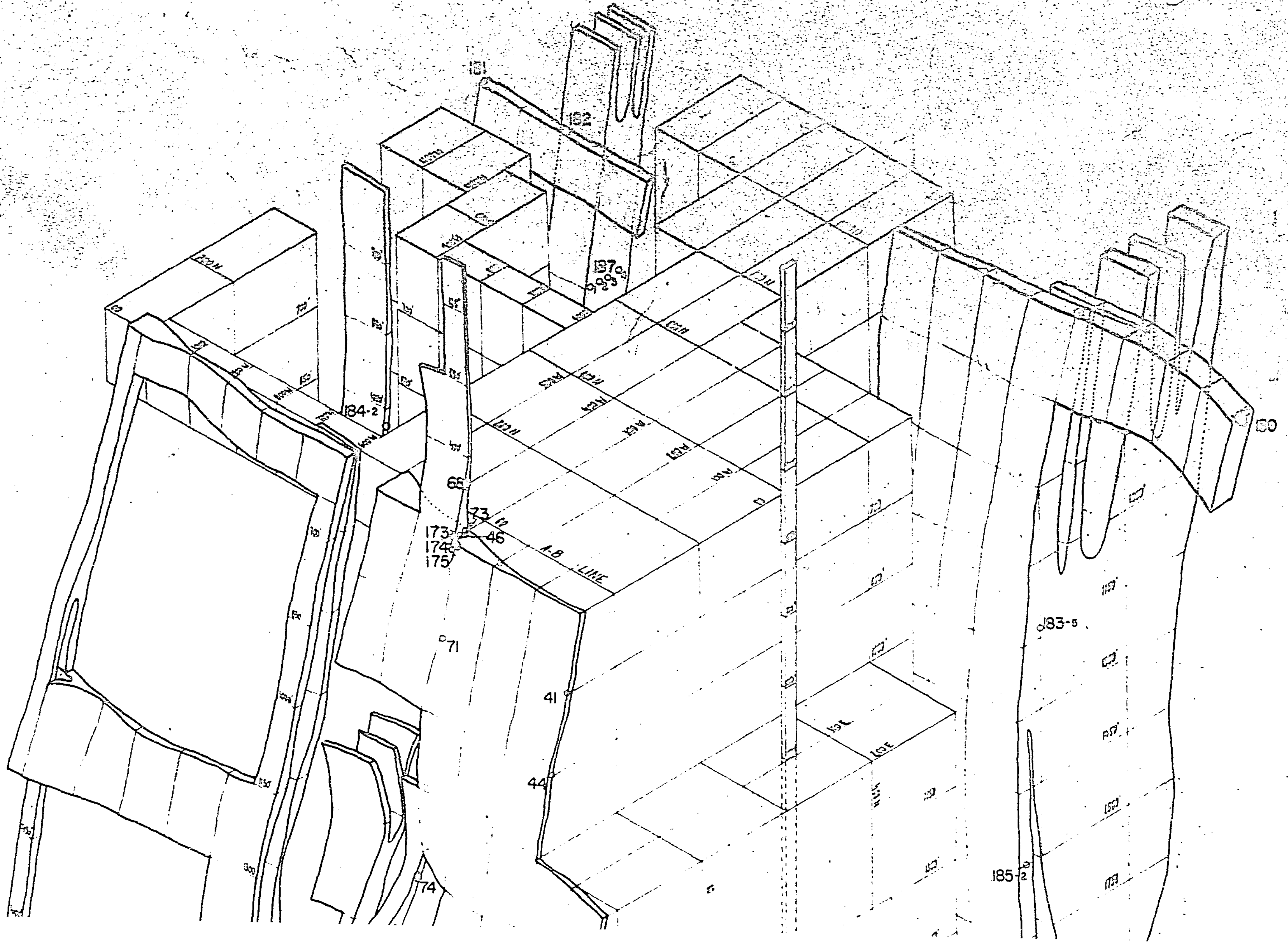
Tr = Trace
\- = not detected
u = less than

Sample No.	183-5	184-2	185-2	186-1	186-2	187-2	187-3	407	408
SiO_2%	64.0	60.6	52.10	53.0	63.8	65.0	66.0	62.8	72.2
Al_2O_3	12.0	10.3	16.1	21.25	15.0	13.75	12.75	19.7	17.0
Fe(tot)	2.25	5.90	6.55	8.10	2.80	1.75	2.75	3.55	4.00
MgO	1.00	2.60	3.20	6.75	1.20	0.90	1.10	1.38	1.25
CaO	4.00	10.35	9.75	11.00	4.70	4.65	3.70	2.80	2.85
Na_2O	2.95	2.65	0.86	0.86	2.90	2.45	2.85	2.90	2.90
TiO_2	0.22	0.42	0.27	0.05	0.32	0.32	0.25	0.28	0.21
B ppm	u 5	u 5	13	u 5	u 5	u 5	u 5	u 5	u 5
Be	u 5	5	u 5	u 5	u 5	u 5	u 5	u 5	u 5
Co	6	17	48	55	33	10	9	10	11
Cr	Tr	33	44	41	Tr	Tr	Tr	Tr	Tr
Cu	u 5	9	205	115	36	58	165	135	158
Ga	u10	u10	u10	u10	u10	u10	u10	u10	u10
Mn	330	725	1900	630	115	265	193	240	535
Mo	u 5	u 5	5	u 5	u 5	-	u 5	Tr	Tr
Ni	9	19	31	59	15	12	9	11	10
Pb	-	-	-	-	-	-	-	-	-
Sc	u 5	7	6	5	5	u 5	u 5	5	u 5
Sn	-	Tr	Tr	Tr	Tr	-	-	-	-
Sr	255	Tr	190	175	138	275	178	175	160
Ta	-	-	-	-	-	-	-	-	-
V	24	51	44	43	42	29	27	32	34
Y	Tr	19	18	Tr	18	17	Tr	Tr	Tr
Zr	182	182	68	50	295	255	193	295	175
Zn	-	-	-	Tr	-	-	-	-	-
Fe/Mg	2.3	2.3	2.0	1.2	2.3	1.9	2.5	2.6	3.2
S.G.		2.74	2.85	2.98	2.78	2.78		2.78	2.74

Tr = Trace
\- = not detected
u = less than

Sample No.	409	410	411
SiO_2%	63.4	55.4	60.2
Al_2O_3	18.8	18.6	19.7
Fe(tot)	4.45	4.60	3.60
MgO	2.40	2.18	1.95
CaO	4.10	5.00	3.70
Na_2O	5.20	6.50	5.85
TiO_2	0.33	0.33	0.32
B ppm	u to 5	u 5	u 5
Be	6	6	u 5
Co	13	15	Tr
Cr	Tr	32	25
Cu	58	5	110
Ga	u10	10	u10
Mn	490	525	350
Mo	u 5	u 5	u 5
Ni	13	10	13
Pb	-	-	-
Sc	7	u 5	5
Sn	Tr	Tr	-
Sr	163	350	115
Ta	-	-	-
V	49	51	43
Y	20	19	18
Zr	400	318	308
Zn	-	-	Tr
Fe/Mg	1.9	2.1	3.9
S.G.	2.74	2.75	2.74

Tr = Trace
\- = not detected
u = less than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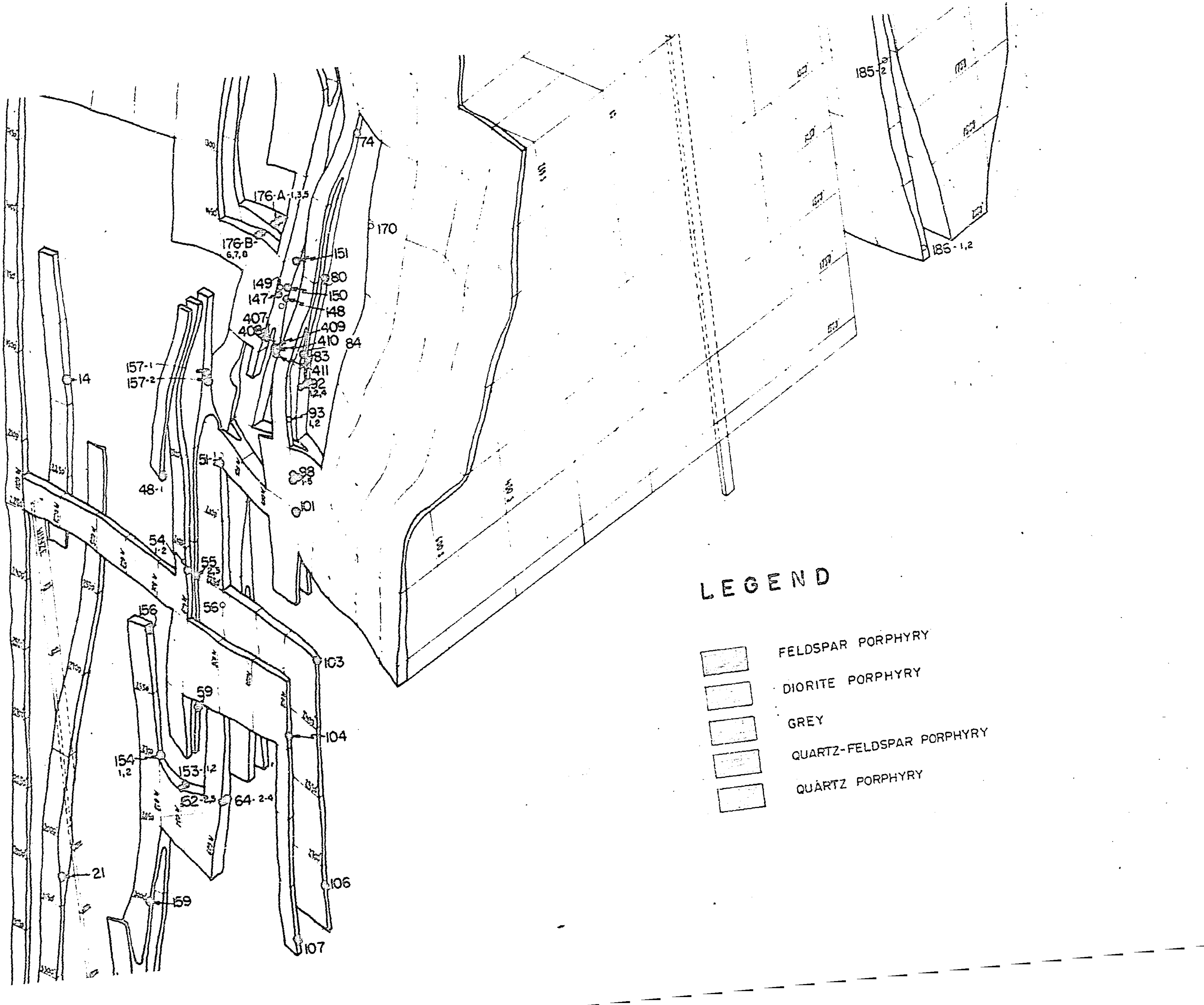
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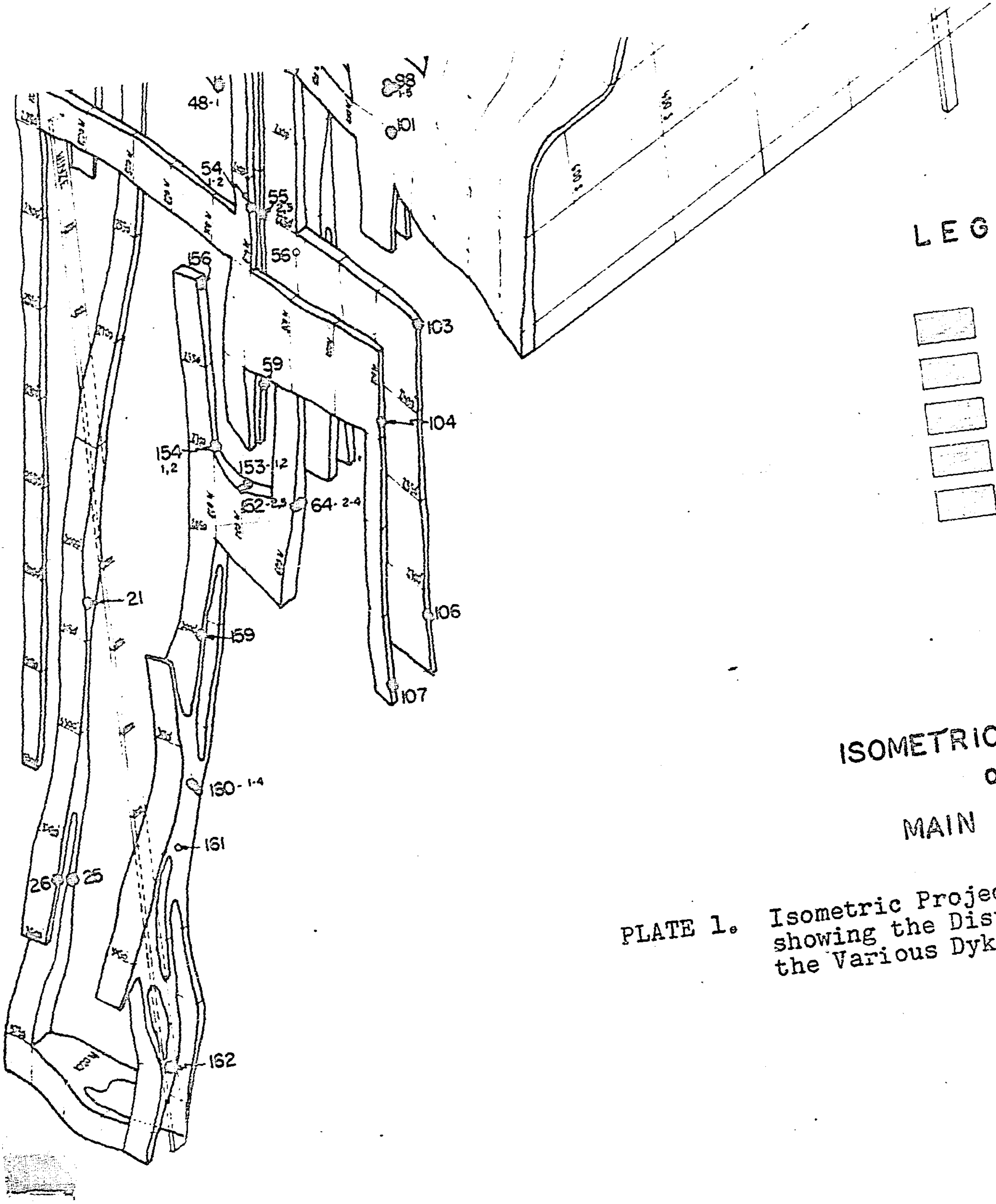
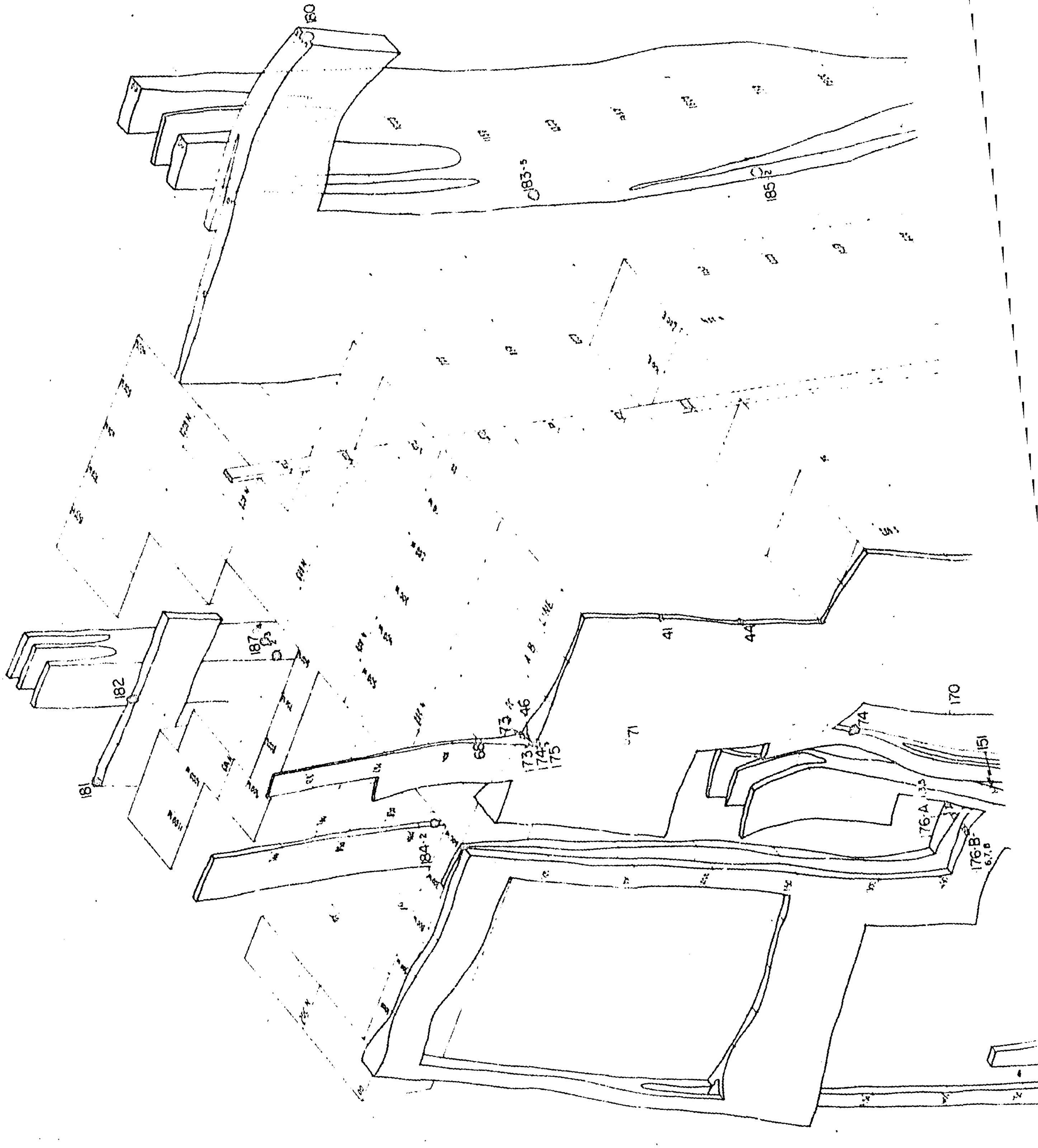
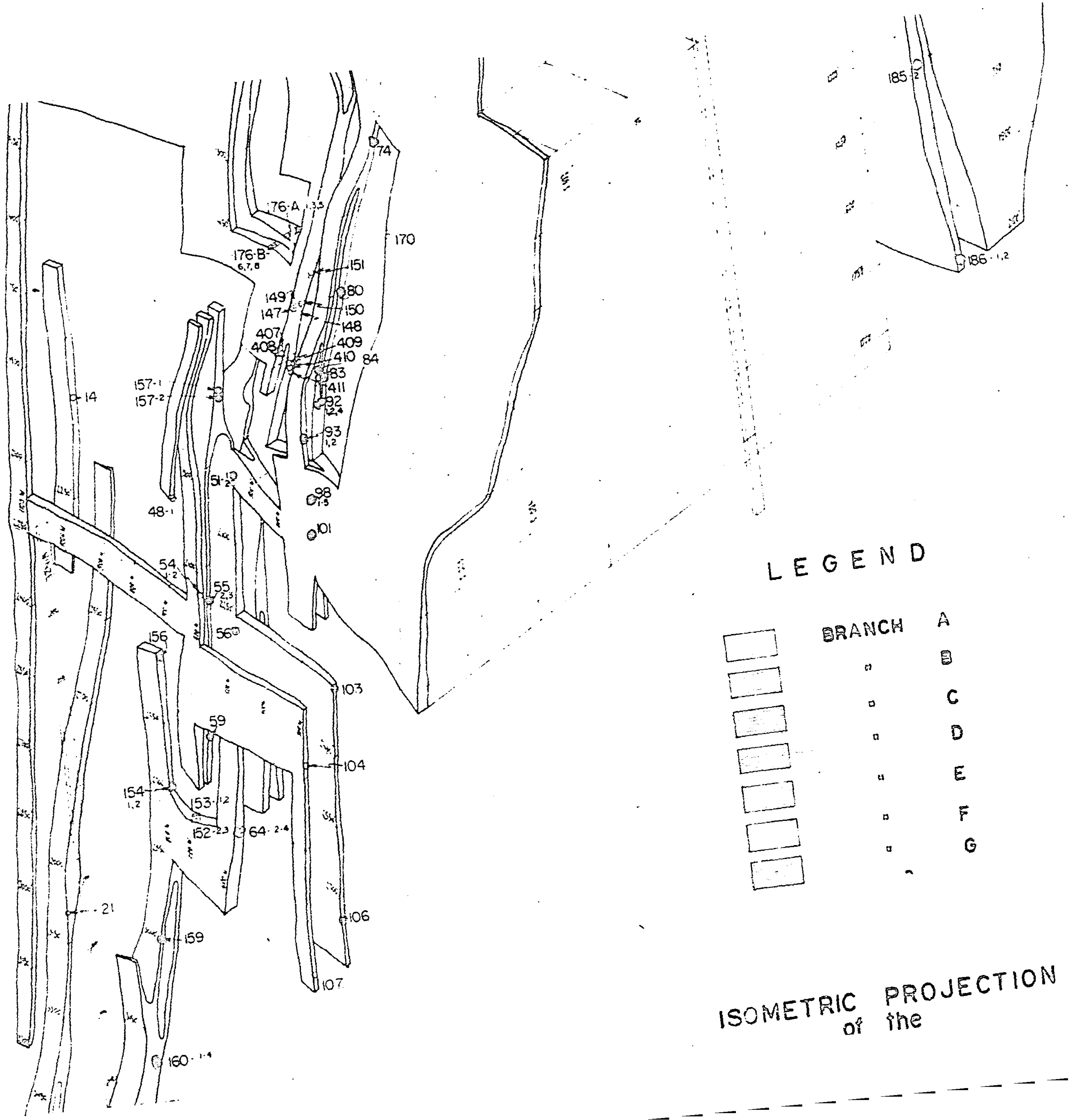
107
185-2
186-1,2
LEGEND
FELDSPAR PORPHYRY
DIORITE PORPHYRY
GREY
QUARTZ-FELDSPAR PORPHYRY
QUARTZ PORPHYRY



ISOMETRIC PROJECTION
of the
MAIN DYKE SWARM

PLATE 1. Isometric Projection of the Main Dyke Swarm, showing the Distribution of Samples drawn from the Various Dyke Rock Types.


180
183-5
185
187
182
181
41
44
46
173
174
175
68
71
170
74
151
176-A
176-B
184-2



LEGEND

▭ BRANCH A
▭ " B
▭ " C
▭ " D
▭ " E
▭ " F
▭ " G
▭

ISOMETRIC PROJECTION
of the

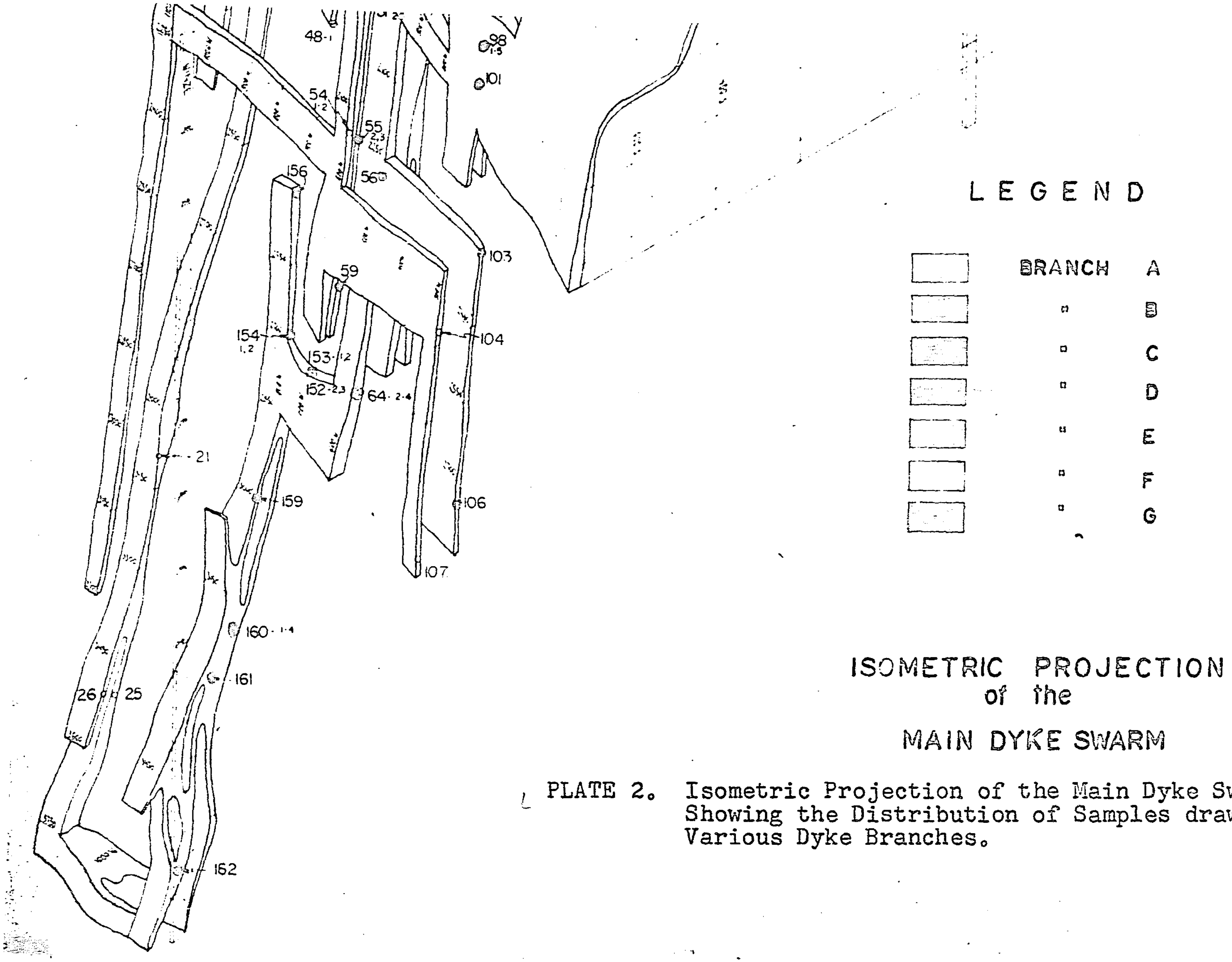
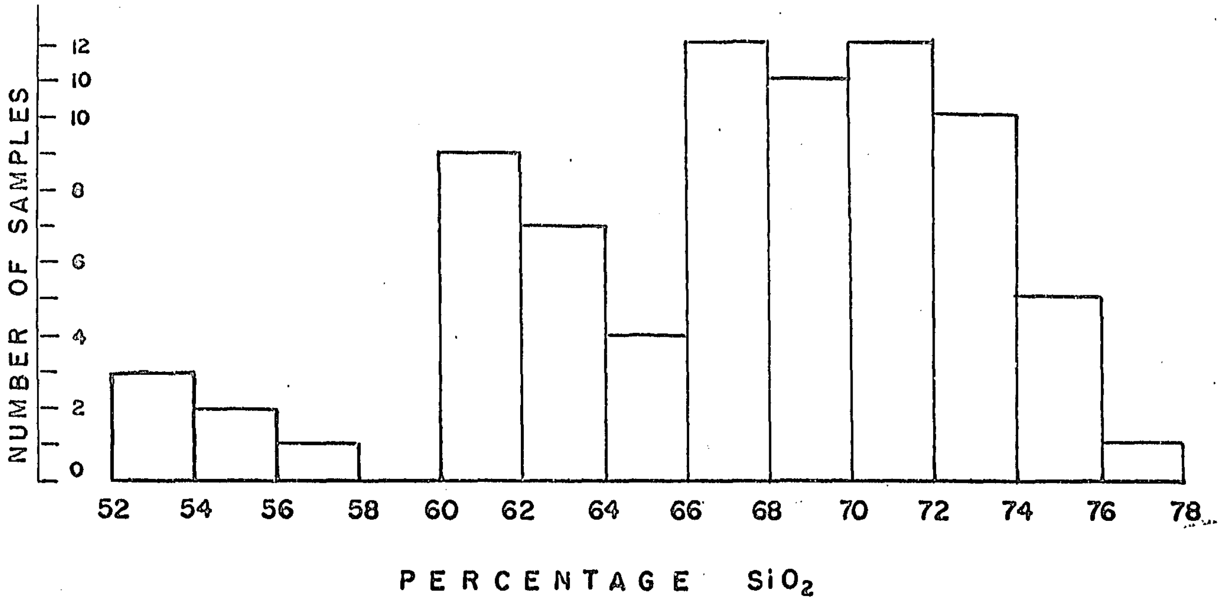
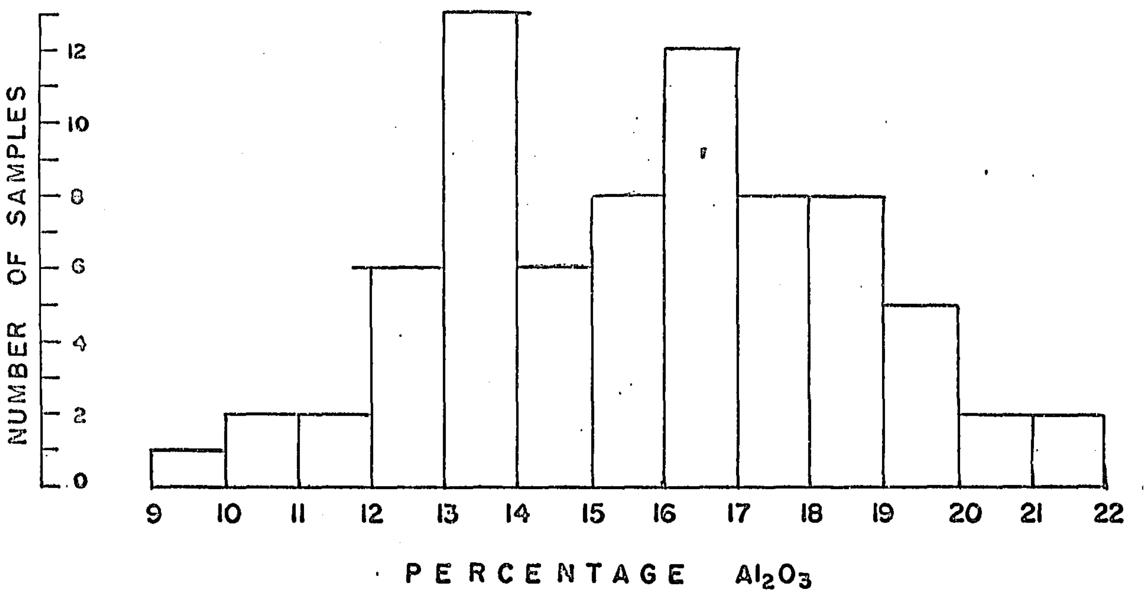


PLATE 2. Isometric Projection of the Main Dyke Swarm, Showing the Distribution of Samples drawn from Various Dyke Branches.



153·1	181	84	74	93·1	14	71	48·1	21	25	54·1	98·4
185·2	410		80	150	83·1	92·2	55·2	51·2	26	64·2	
186·1			151	176B·7	183·5	92·4	55·3	64·4	54·2	64·3	
			154·1	176B·8	187·2	98·2	104	92·1	56	154·2	
			160·1	407		107	156	101	59·1	174	
			176·B·6	409		153·2	160·2	103	68		
			184·2	186·2		161	160·3	147	98·1		
			411			170	160·4	148	152·3		
			106			173	162	152·2	157·2		
						176A·1	176A·3	157·1	408		
						180·2	176A·5	159			
						187·3		182			

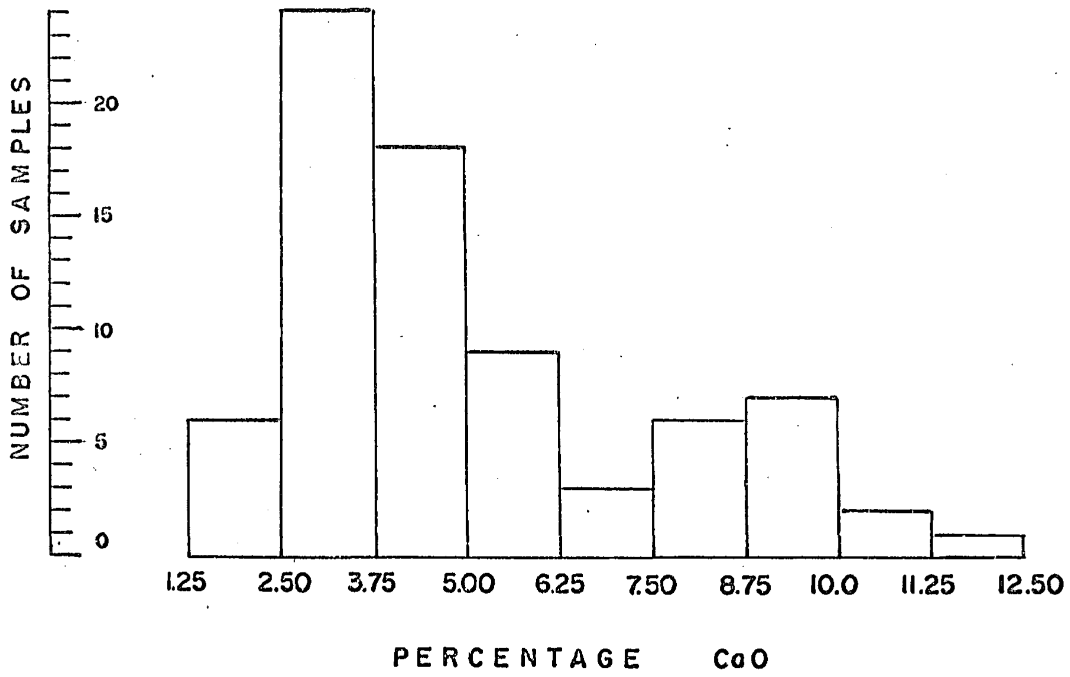
PLATE 3. Histogram, showing distribution of SiO_2



181	48·1	68	64·3	51·2	14	80	55·3	21	74	162	158·1	151
	184·2	180·2	107	54·1	25	84	71	83·1	104	176A1	160·2	188·1
			160·3	56	26	148	92·4	92·2	150	176B8		
			183·5	59·1	54·2	154·2	93·1	154·1	170	407		
			187·3	64·2	55·2	157·1	98·4	156	176A5	411		
			106	64·4	176A3	161	103	159	176B7			
				92·1		174	147	176B6	409			
				98·1		186·2	152·2	408	410			
				98·2			152·3					
				101			157·2					
				153·2			160·1					
				173			185·2					
				187·2								

NOT SHOWN: SAMPLE No. 160·4 (25.3 %)
182 (5.8 %)

PLATE 4. Histogram, showing distribution of Al_2O_3



59·1
64·2
147
148
160·2
160·4

21
51·2
54·1
54·2
64·4
71
74
92·1
98·1
98·2
98·4
103
154·1
154·2
156
162
170
174
176A5
176B6
187·3
407
408
411

25
55·3
56
64·3
92·2
92·4
101
151
152·2
152·3
157·1
161
176A1
180·2
183·5
186·2
187·2
409
84

26
55·2
104
150
157·2
176A3
176B7
410
106

14
68
176B8

80
173
48·1
84·
159
160·1

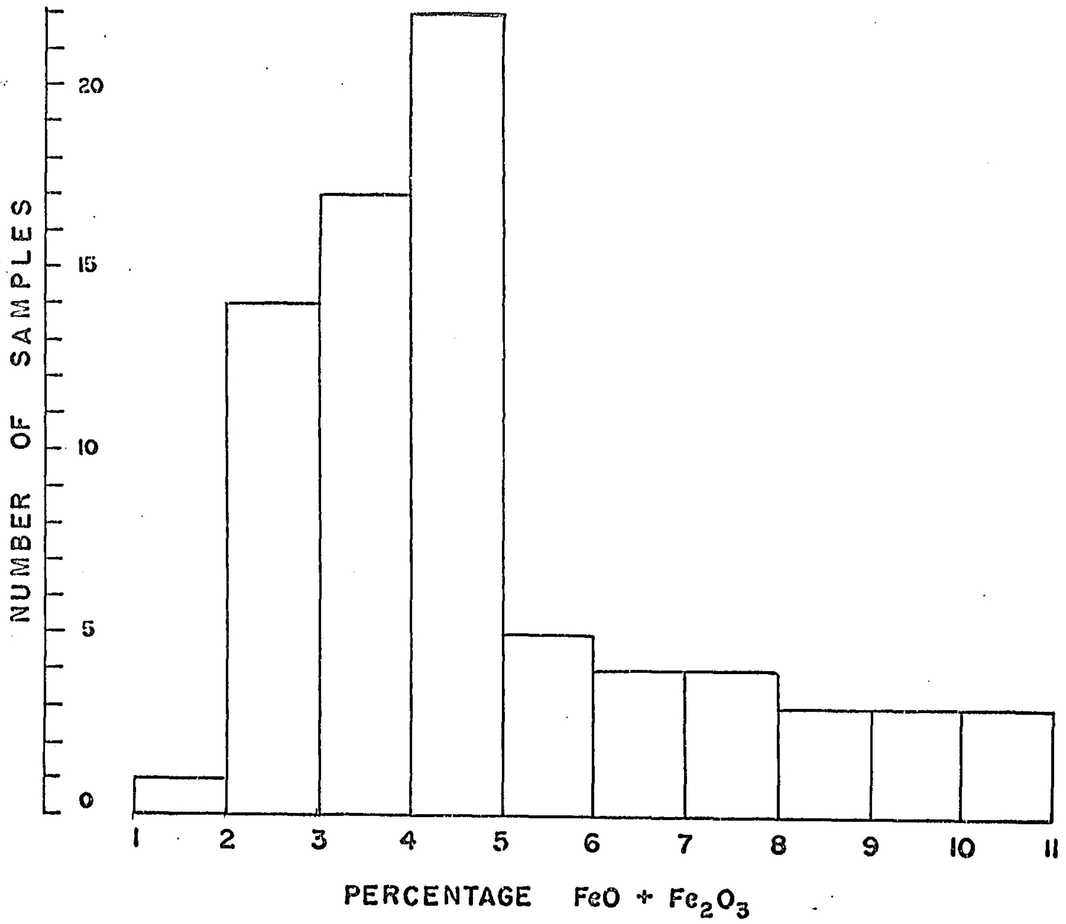
153·2
160·3
182
83·1
93·1
107
185·2

184·2
188·1

153·1

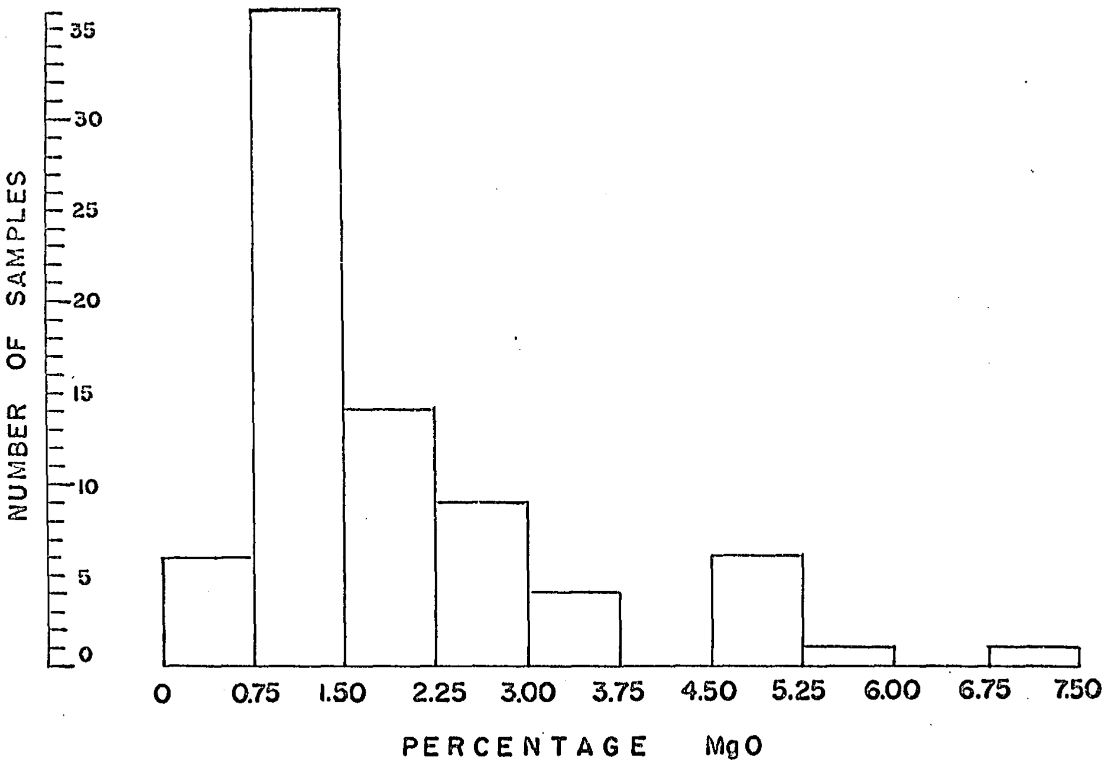
NOT SHOWN : No. 181 (15.05%)

PLATE 5. Histogram, showing distribution of CaO



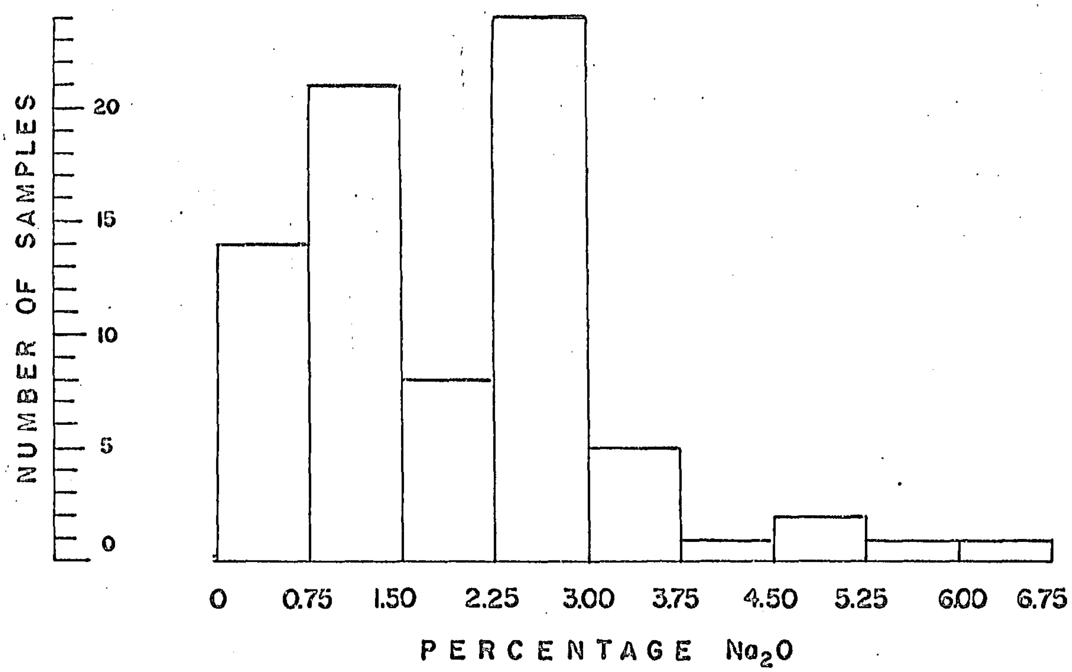
187·2	25	21	14	151	26	92·2	74	48·1	71
	51·2	54·1	54·2	159	83·1	92·4	84	153·1	107
	64·3	55·2	55·3	160·3	161	93·1	186·1	182	108
	98·1	59·1	56	176A1	185·2	163·2			
	98·2	64·2	64·4	184·2					
	98·4	68	80						
	148	92·1	104						
	157·1	101	150						
	160·4	103	152·3						
	174	147	154·1						
	183·5	156	154·2						
	186·2	160·1	157·2						
	160·2	176A3	162						
	187·3	176A5	170						
		180·2	173						
		407	176B6						
		411	176B7						
			176B8						
			181						
			408						
			409						
			410						

PLATE 6. Histogram, showing distribution of Fe (tot.)



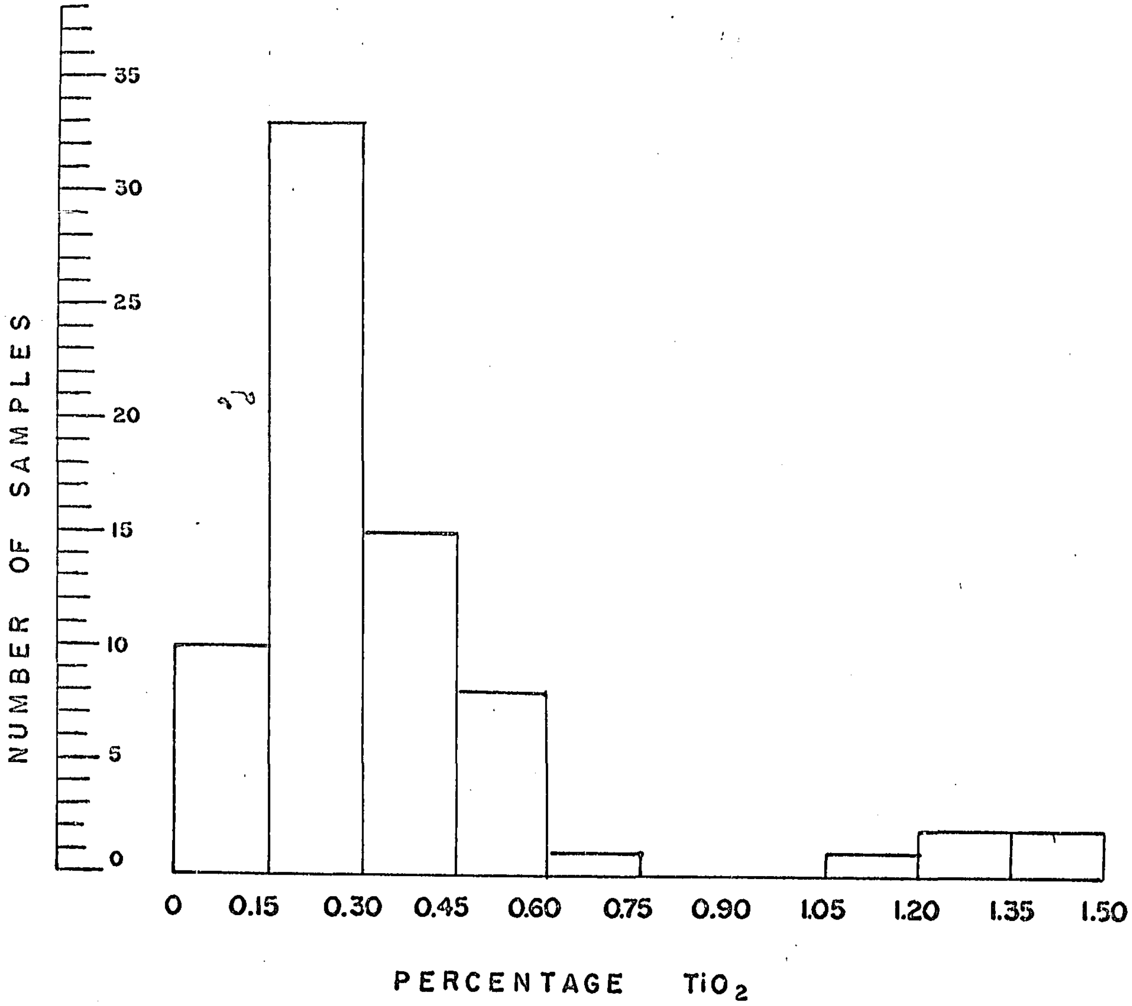
26	14	55·2	74	71	48·1	106	186·1
64·2	21	55·3	92·2	153·1	83·1		
64·3	25	80	92·4	181	84		
68	51·2	104	151	185·2	93·1		
160·2	54·1	150	161		107		
160·4	54·2	159	176A1		153·2		
	56	160·3	182				
	59·1	162	184·2				
	64·4	173	409				
	92·1	176B6					
	98·1	176B7					
	98·4	176B8					
	101	410					
	103	411					
	147						
174	148						
176A3	152·2						
176A5	152·3						
180·2	154·1						
183·5	154·2						
186·2	156						
187·2	157·1						
187·3	157·2						
407	160·1						
408	170						

PLATE 7. Histogram, showing distribution of MgO



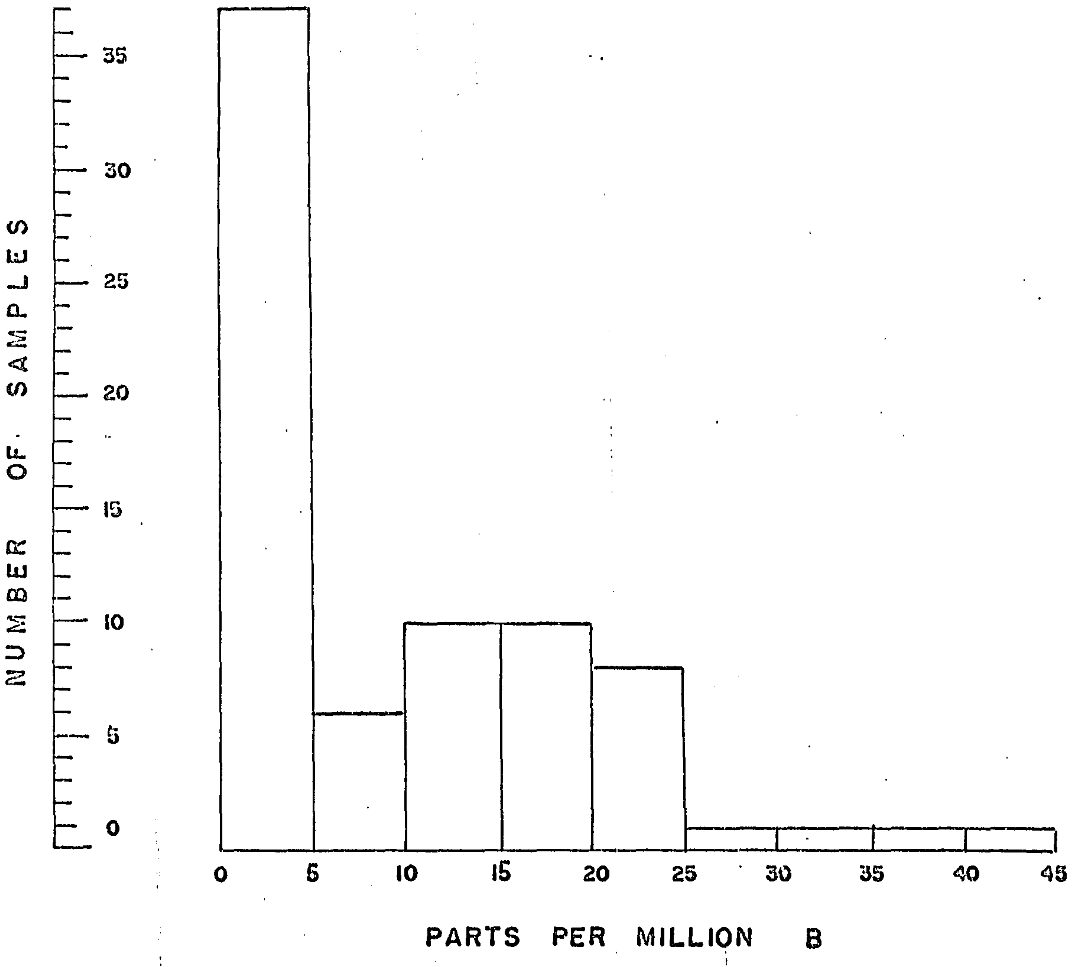
48·1	26	54·1	14	21	176B6	104	411	410
83·1	71	56	25	55·2		409		
93·1	80	64·2	51·2	55·3				
106	84	64·3	54·2	101				
107	92·1	68	59·1	187·2				
153·1	147	74	64·4					
153·2	148	152·3	92·2					
159	157·1	156	92·4					
160·3	157·2		98·1					
173	160·1		98·2					
174	160·2		98·4					
180·2	160·4		103					
181·	161		150					
182	162		151					
	170		152·2					
	176A1		154·1					
	176A3		154·2					
	176A5		176B7					
	176B8		183·5					
	185·2		184·2					
	186·1		186·2					
			187·3					
			407					
			408					

PLATE 8. Histogram, showing distribution of Na_2O



51·2	14	55·3	55·2	161	153·2	48·1	106
64·2	21	71	83·1			153·1	107
68	25	74	92·2				
152·2	26	80	92·4				
154·2	54·1	84	93·1				
157·1	54·2	104	159				
160·3	56	162	176A1				
173	59·1	176B6	176B8				
181	64·3	176B7					
186·1	64·4	184·2					
	92·1	186·2					
	98·1	187·2					
	98·2	409					
	98·4	410					
	101	411					
157·2	103						
160·1	147						
160·2	148						
160·4	150						
170	151						
174	152·3						
176A3	154·1						
176A5	156						
407	408						

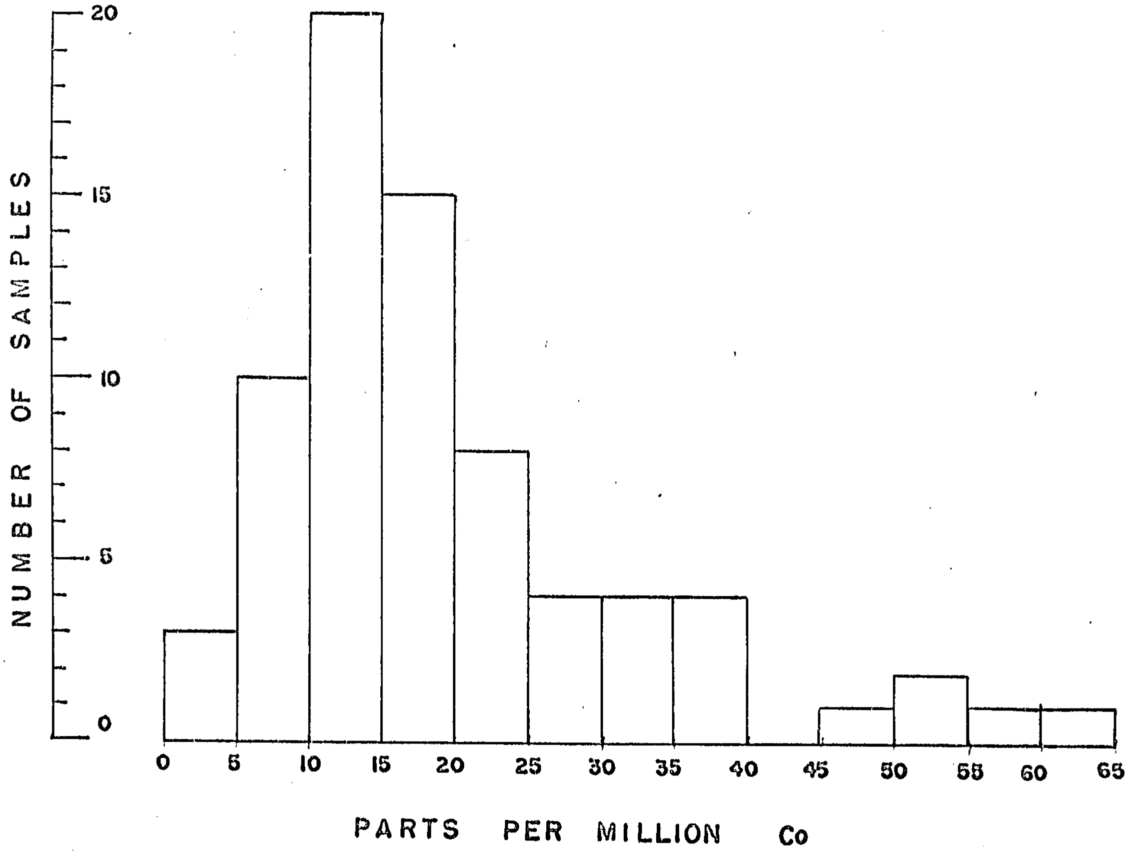
PLATE 9. Histogram, showing distributiob of TiO_2



21	80	14	48·1	51·2	68	147	160·2	160·4
25	152·3	54·1	71	92·1				
26	157·2	84	74	92·4				
54·2	159	92·2	98·1	93·1				
55·2	161	160·1	98·4	98·2				
55·3	176A5	162	101	103				
56		173	151	148				
59·1		176A1	170	157·1				
64·2		176A3	174					
64·3		185·2	180·2					
64·4	181							
104	182							
106	183·5							
107	184·2							
150	186·1							
153·1	186·2							
153·2	187·2							
154·1	187·3							
154·2	407							
156	408							
160·3	409							
176B6	410							
176B7	411							
176B8								

NOT SHOWN : No. 83·1 (67 ppm)

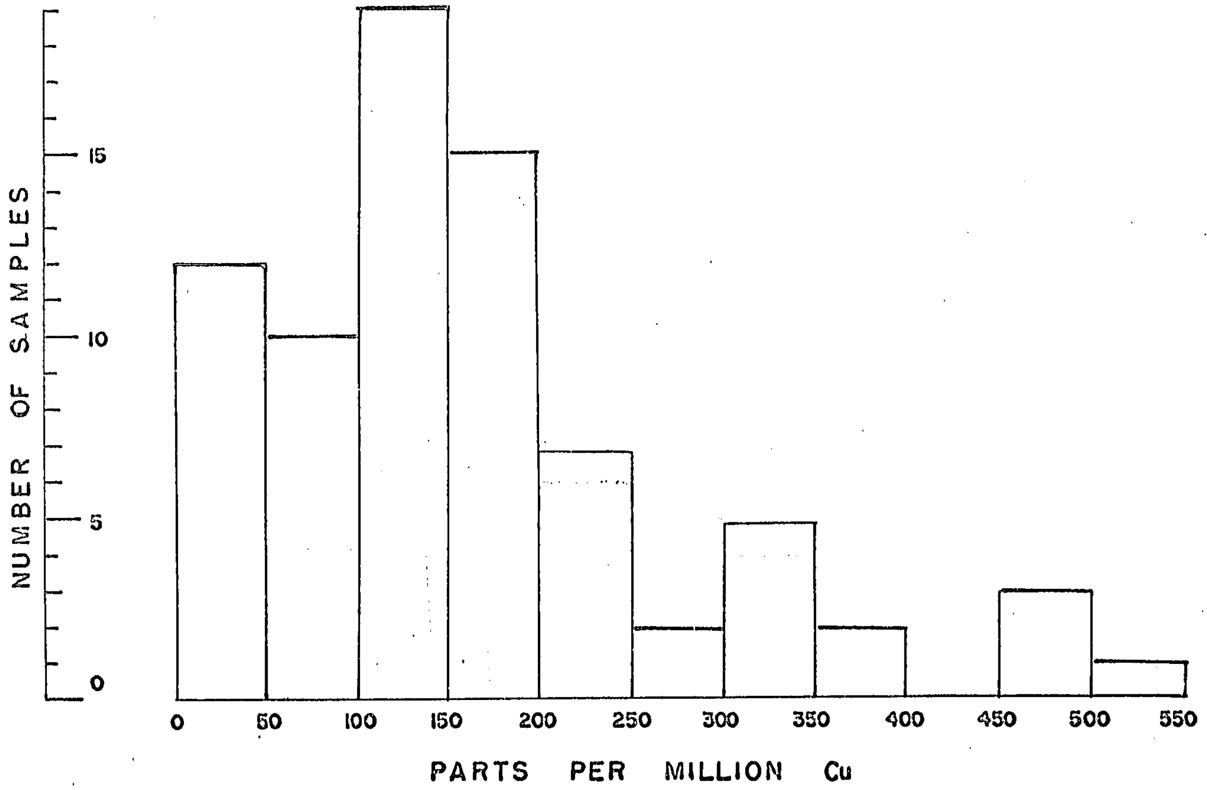
PLATE 10. Histogram, showing distribution of B



103	148	55·3	25	14	26	64·4	48·1	185·2	153·2	186·1	161
180·2	156	64·3	51·2	21	84	92·4	83·1		181		
411	157·1	80	54·1	68	92·2	107	93·1				
	157·2	92·1	54·2	152·3	160·3	186·2	106				
	173	98·1	55·2	160·1							
	174	98·2	56	160·2							
	176A5	98·4	59·1	170							
	176B8	101	64·2	176A·1							
	183·5	104	74								
	187·3	147	151								
		150	154·1								
		154·2	160·4								
		162	176A3								
		176B6	184·2								
		176B7	410								
		182									
		187·2									
		407									
		408									
		409									

NOT SHOWN : No 71 290 ppm
153·1 78
159 75

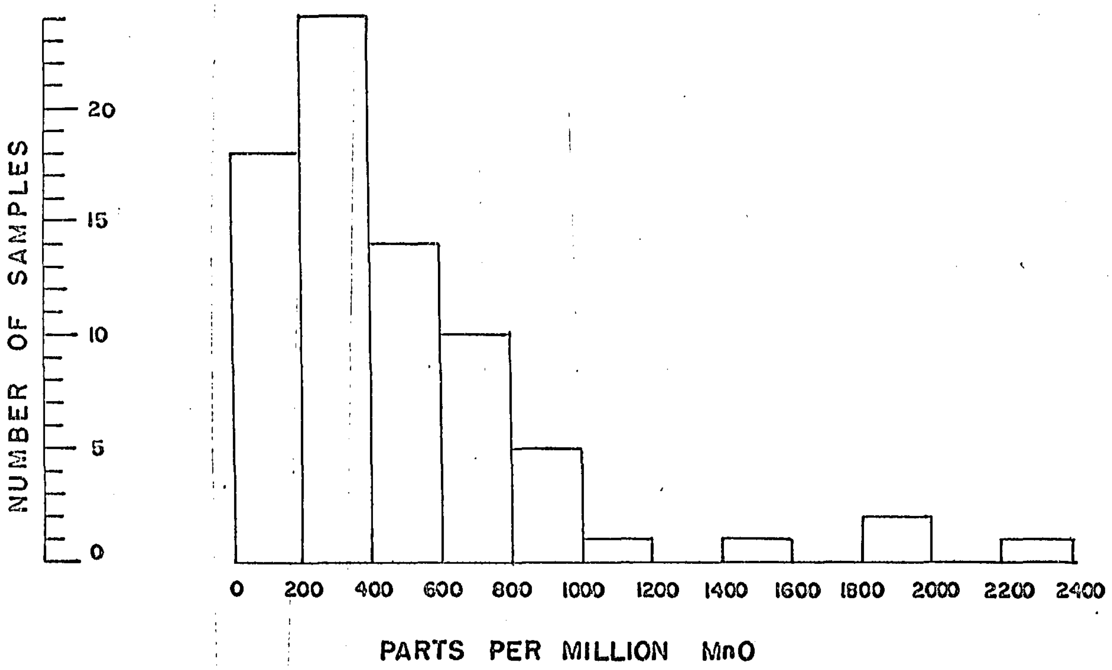
PLATE 11. Histogram, showing distribution of Co



55·3	55·2	25	51·2	92·2	14	64·4	21		153·1	181
80	83·1	26	56	98·1	176A3	68	92·4		159	
104	84	48·1	64·2	152·3		24			161	
150	93·1	54·1	64·3	154·1		173				
176B6	103	54·2	98·2	154·2		74				
176B7	151	59·1	98·4	157·2						
176B8	162	92·1	147	153·2						
180·2	182	101	156							
183·5	187·2	107	160·2							
184·2	409	148	160·3							
186·2		157·1	160·4							
410		176A5	174							
		160·1	176A1							
		170	185·2							
		186·1	408							
		187·3								
		407								
		411								
		106								

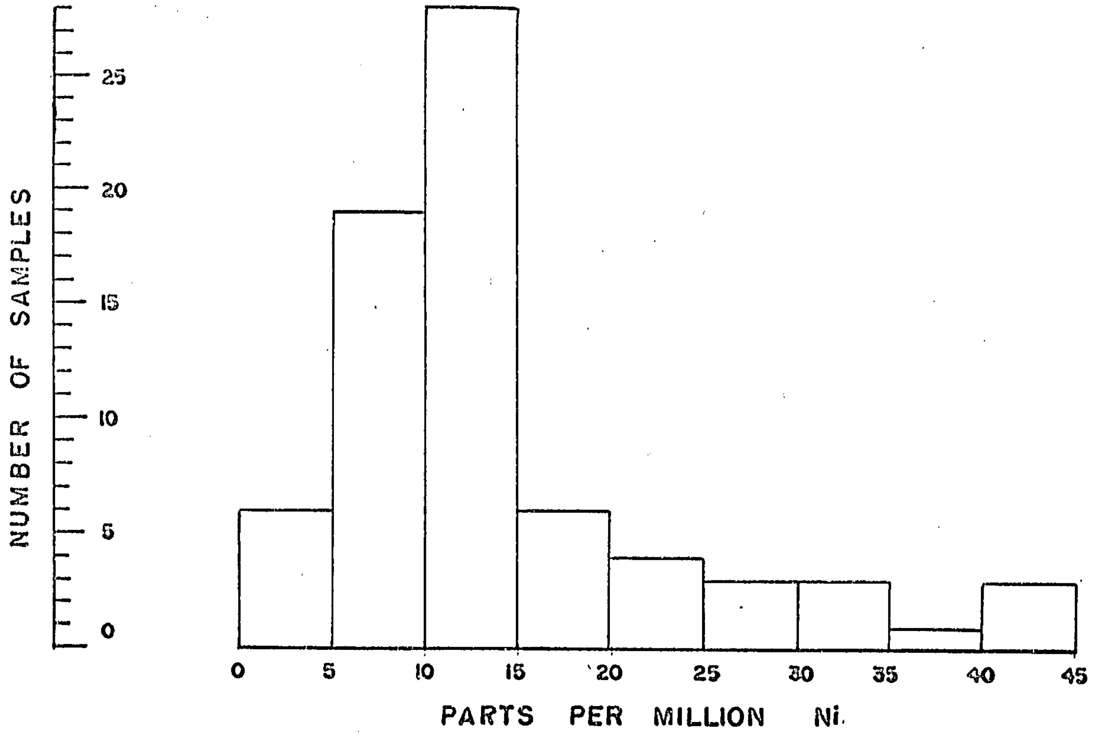
NOT SHOWN : No. 71 (825 ppm)

PLATE 12. Histogram, showing distribution of Cu



25	21	14	74	84	71	93·1	83·1	48·1
26	51·2	92·1	80	92·4			185·2	
54·1	54·2	104	92·2	160·3				
64·2	55·2	106	150	176B8				
98·1	55·3	107	153·1	182				
98·4	56	151	153·2					
101	59·1	173	160·1					
103	64·3	174	176B7					
148	68	176B6	184·2					
152·3	98·2	180·2	186·1					
154·1	147	181						
156	157·1	408						
176A3	157·2	409						
176A5	159	410						
186·2	160·2							
187·3	160·4							
64·4	161							
154·2	162							
	170							
	176A1							
	183·5							
	187·2							
	407							
	411							

PLATE 13. Histogram, showing distribution of MnO



68
98·1
98·2
98·4
101
103

21
25
26
51·2
54·1
56
59·1
64·2
64·3
92·1
148
157·1
160·3
160·4
173
174
176B8
183·5
187·3

14
54·2
55·2
55·3
80
104
147
150
152·3
154·1
154·2
156
160·1
160·2
161
162
170
176A3
176A5
176B6
176B7
180·2
187·2
407
408
409
410
411

74
84
157·2
182
184·2
186·2

71
92·2
92·4
151

48·1
83·1
93·1

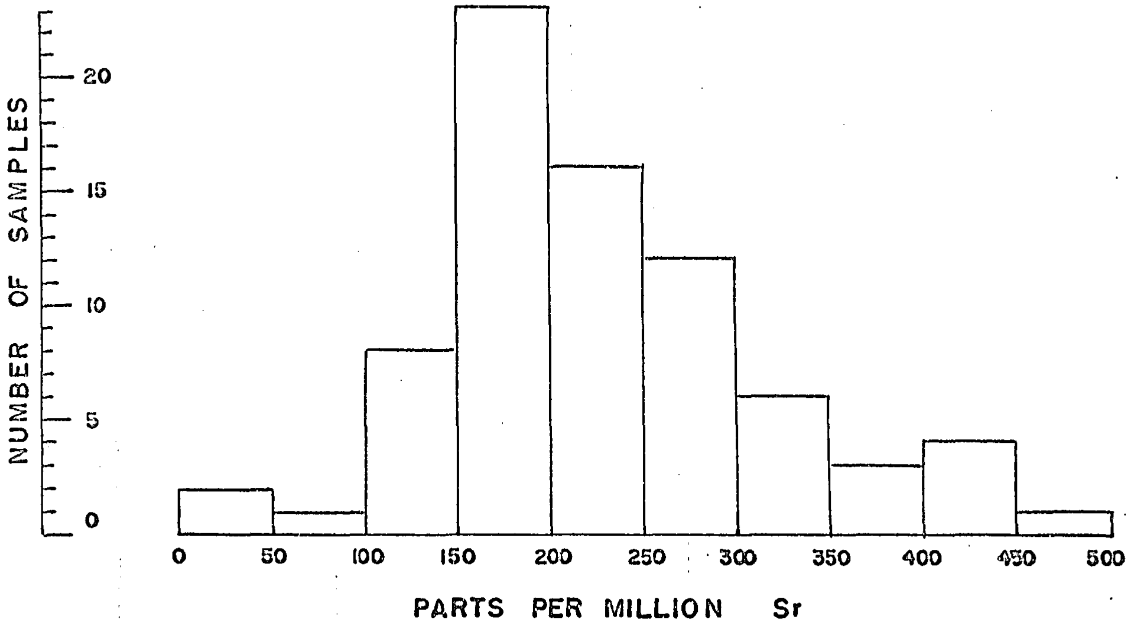
107
176A1
185·2

153·2

64·4
181
106

NOT SHOWN : No. 153·1 (255 ppm)
159 78 "
186·1 59 "

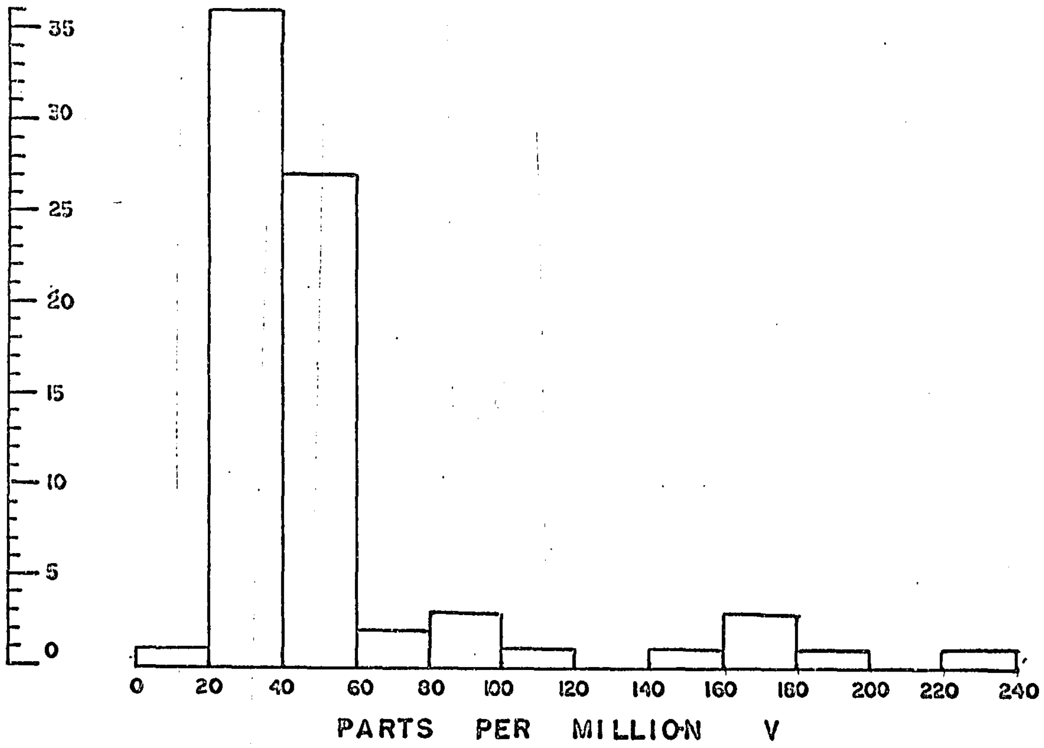
PLATE 14. Histogram, showing distribution of Ni



71	14	21	56	64·3	51·2	48·1	84	55·3	150
184·2		25	59·1	64·4	54·1	80	93·1	83·1	
		26	92·1	68	54·2	103	410	104	
		176B7	92·4	74	64·2	107		153·1	
		176B8	154·1	92·2	101	151			
		181	154·2	98·1	106	153·2			
		186·2	156	98·2	152·3				
		411	157·1	98·4	159				
			157·2	147	161				
			160·1	148	183·5				
			160·3	160·2	187·2				
			170	160·4					
			173	162					
			174	176A3					
			176A1	176A5					
			176B6	180·2					
			182						
			185·2						
			186·1						
			187·3						
			407						
			408						
			409						

NOT SHOWN : No. 55·2 (680 ppm)

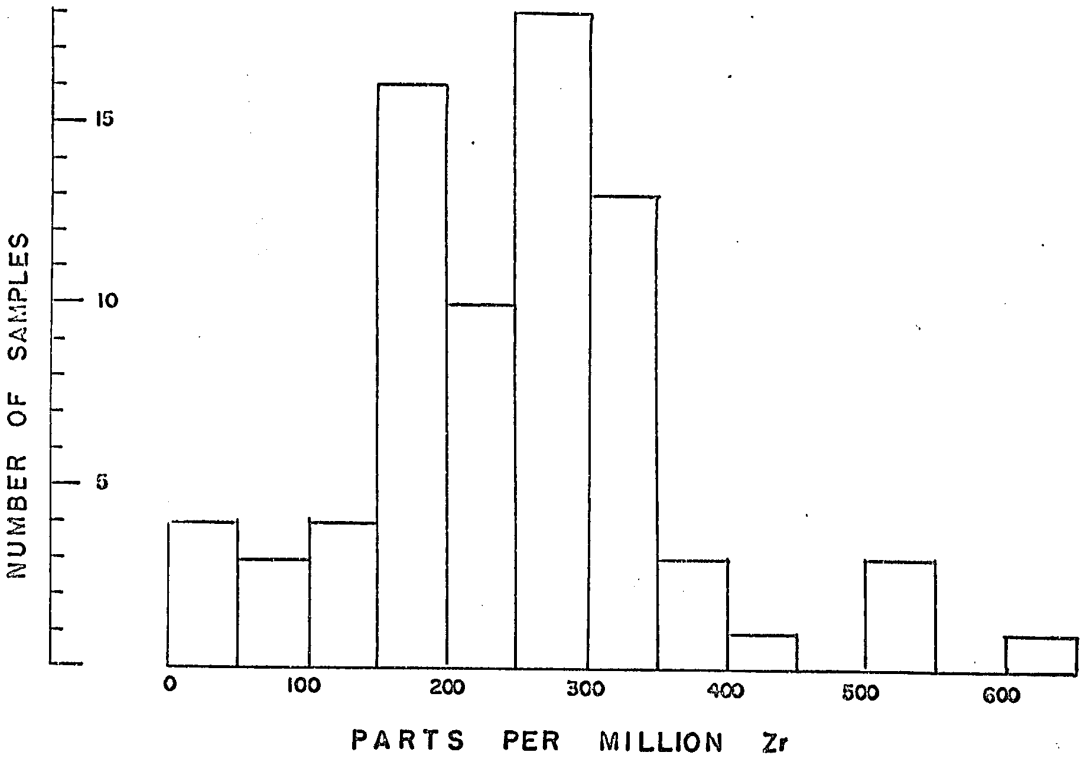
PLATE 15. Histogram, showing distribution of Sr



64·2	14	51·2	92·4	84	83·1	93·1	107	106	48·1
	21	54·2	159	151			153·1		
	25	55·2		161			153·2		
	26	55·3							
	541	71							
	56	74							
	59·1	80							
	64·3	98·1							
	64·4	98·2							
	68	101							
	92·1	104							
	98·4	150							
160·4	103	162							
170	147	176A1							
173	148	176A3							
174	1523	176B 6							
176A5	154·1	176B 7							
180·2	154·2	176B 8							
183·5	156	181							
187·2	157·1	182							
187·3	157·2	184·2							
407	160·1	185·2	409						
408	160·2	186·1	410						
	160·3	186·2	411						

NOT SHOWN : No. 92·2 (540ppm)

PLATE 16. Histogram, showing distribution of V



64·4	176A1	103	56	25	14	21	55·3	409		48·1		153·1
176A5	185·2	107	64·2	26	54·2	51·2	150			106		
176B6	186·1	160·3	64·3	71	92·4	54·1	161			153·2		
181		180·2	68	74	98·1	55·2						
			83·1	92·2	98·2	59·1						
			84	93·1	98·4	80						
			148	147	101	92·1						
			157·1	151	152·3	104						
			160·1	176A3	154·1	159						
			173	182	154·2	162						
			176B8		156	170						
			183·5		157·2	410						
			184·2		160·2	411						
			187·3		160·4							
			408		176B7							
			174		186·2							
					187·2							
					407							

PLATE 17. Histogram, showing distribution of Zr

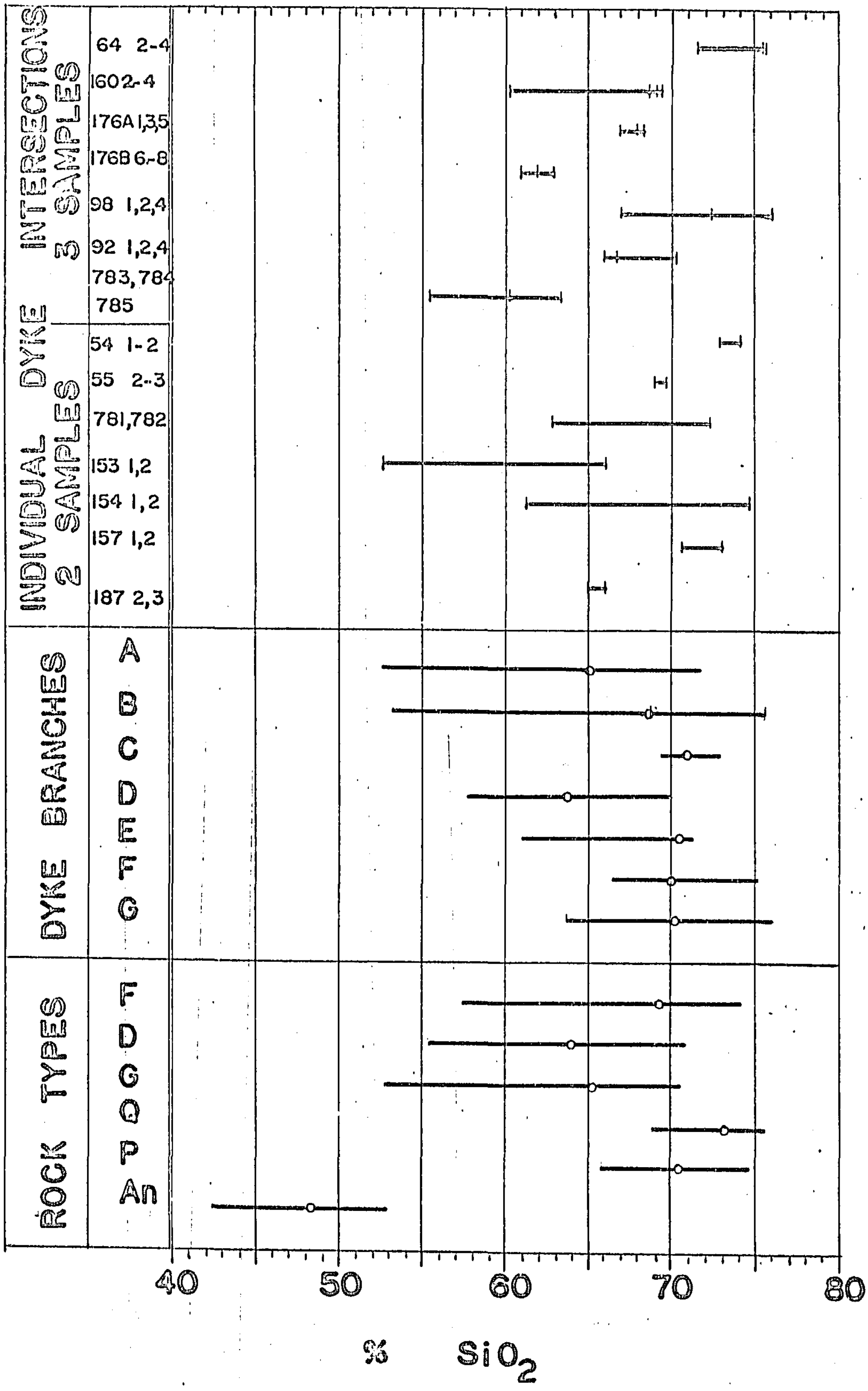


PLATE 18. Range Chart, showing distribution of SiO_2

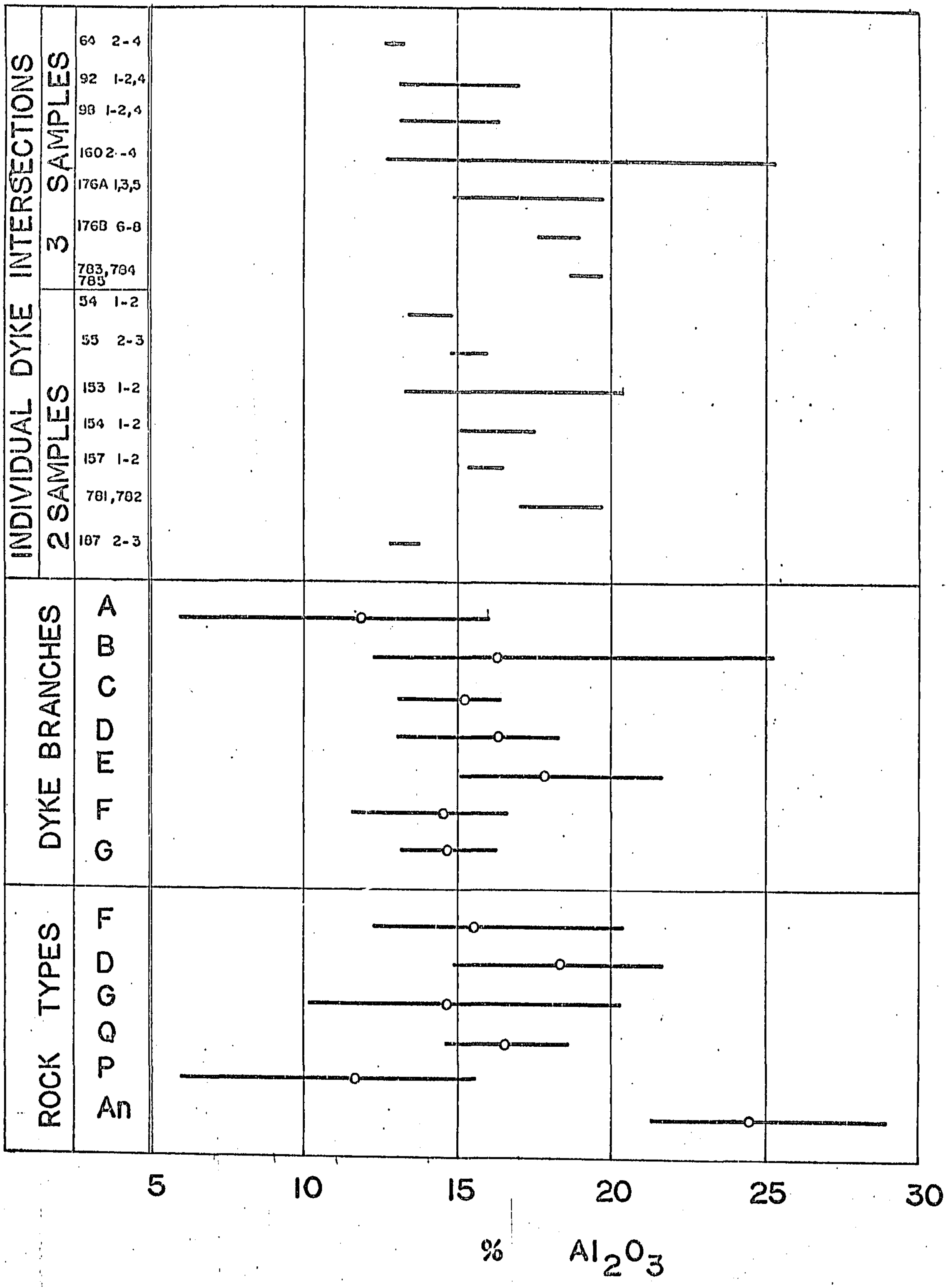


PLATE 19. Range Chart, showing distribution of Al_2O_3

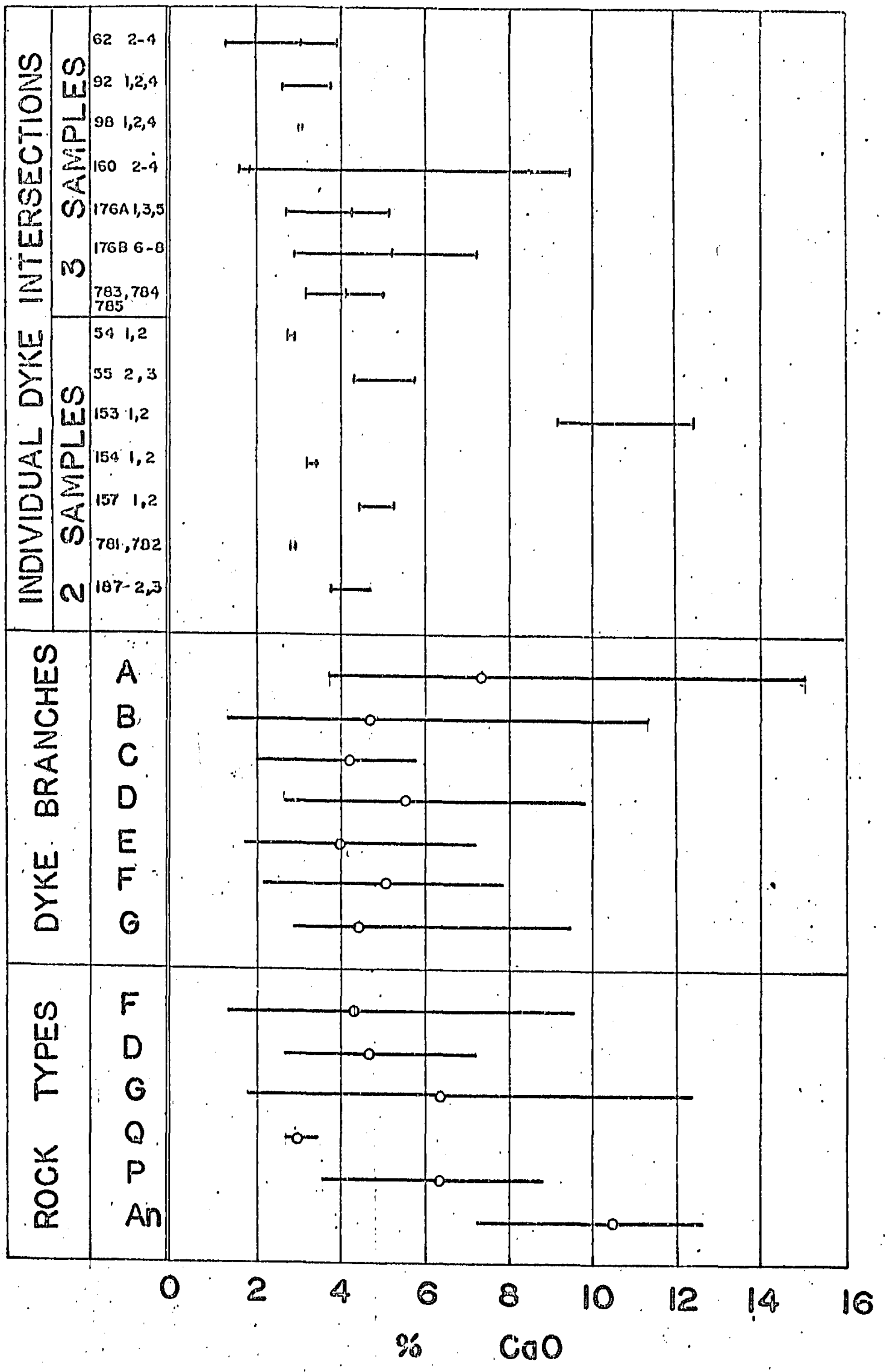


PLATE 20. Range Chart, showing distribution of CaO

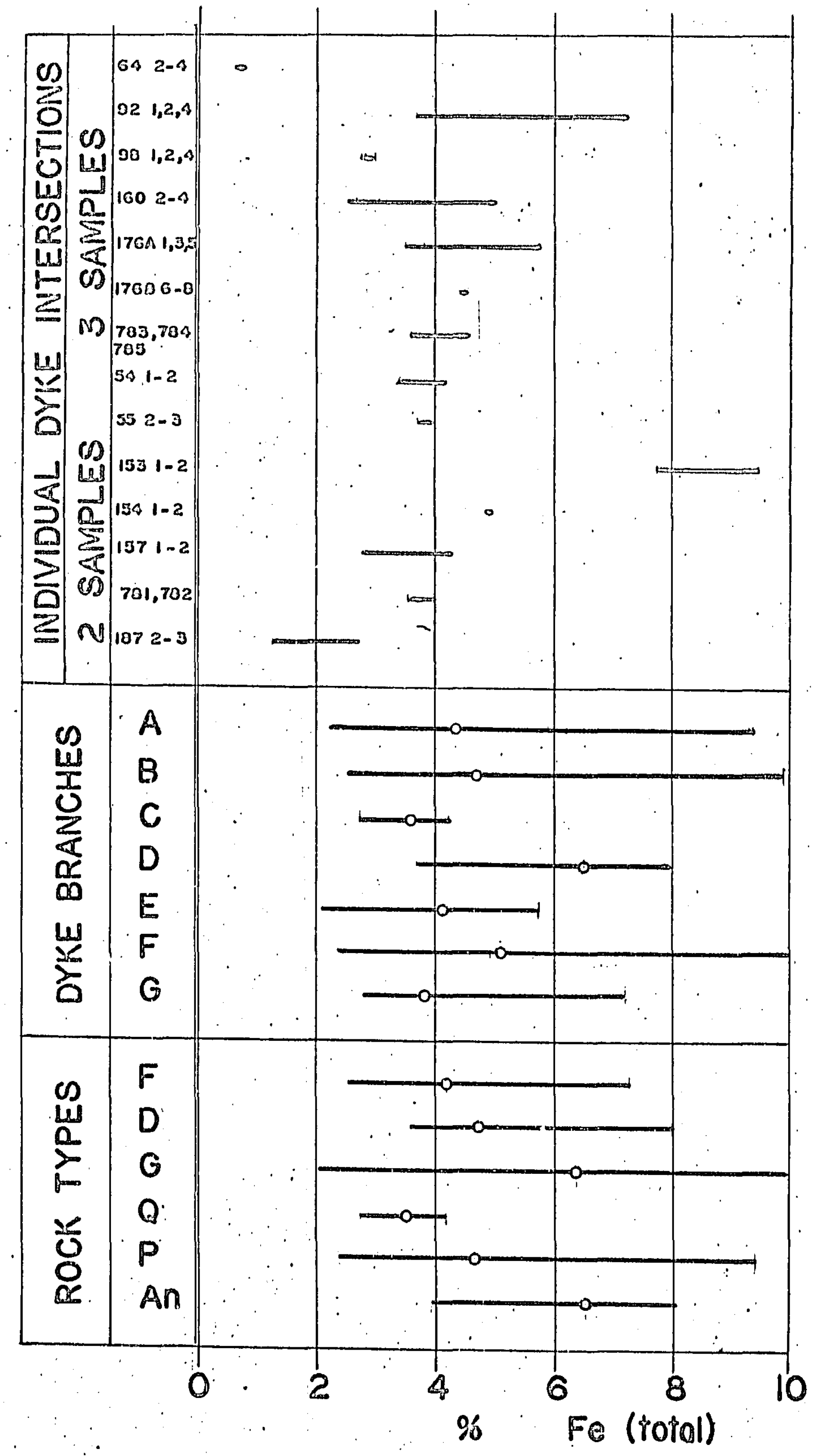


PLATE 21. Range Chart, showing distribution of Fe (tot.)

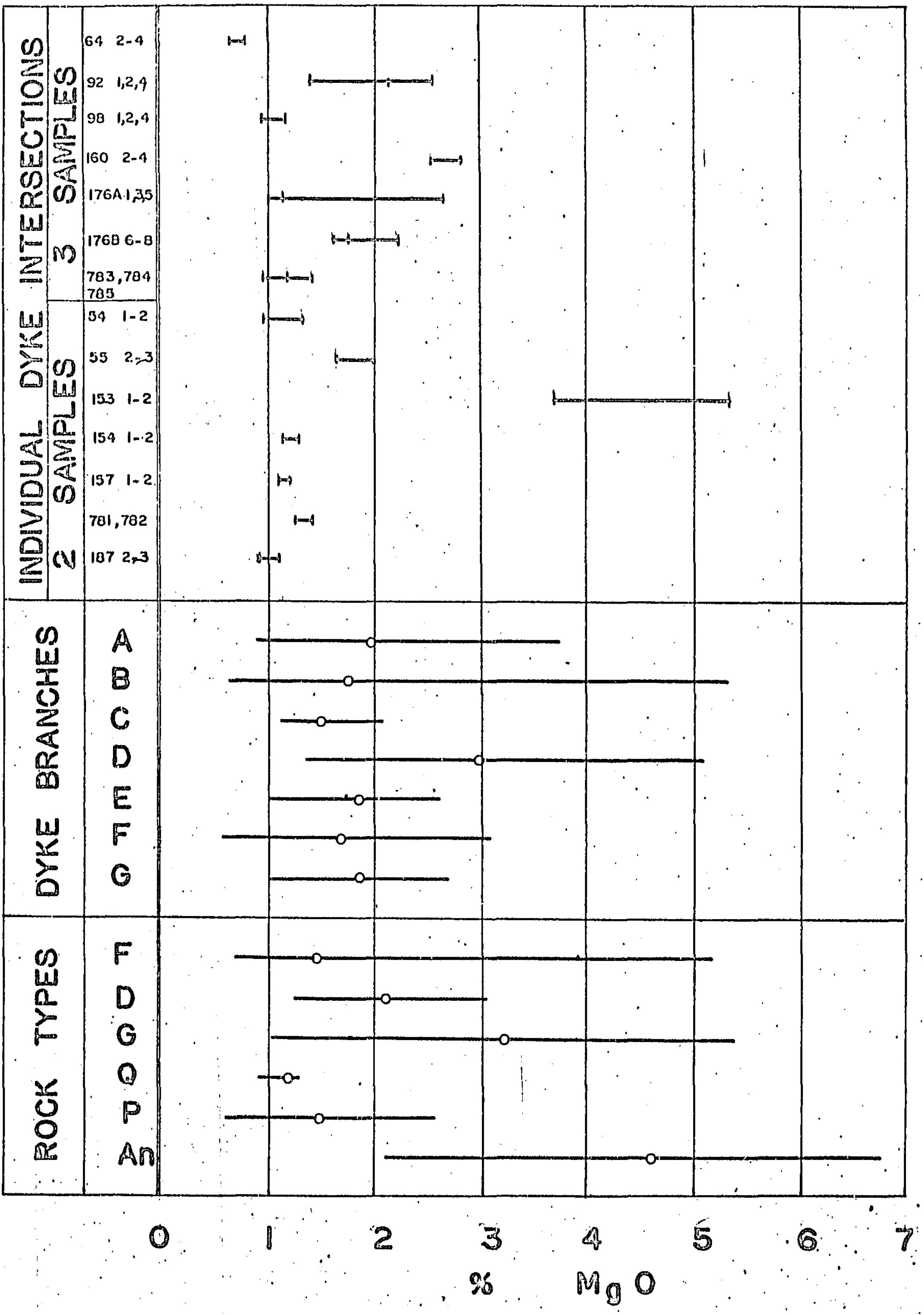


PLATE 22. Range Chart, showing distribution of MgO

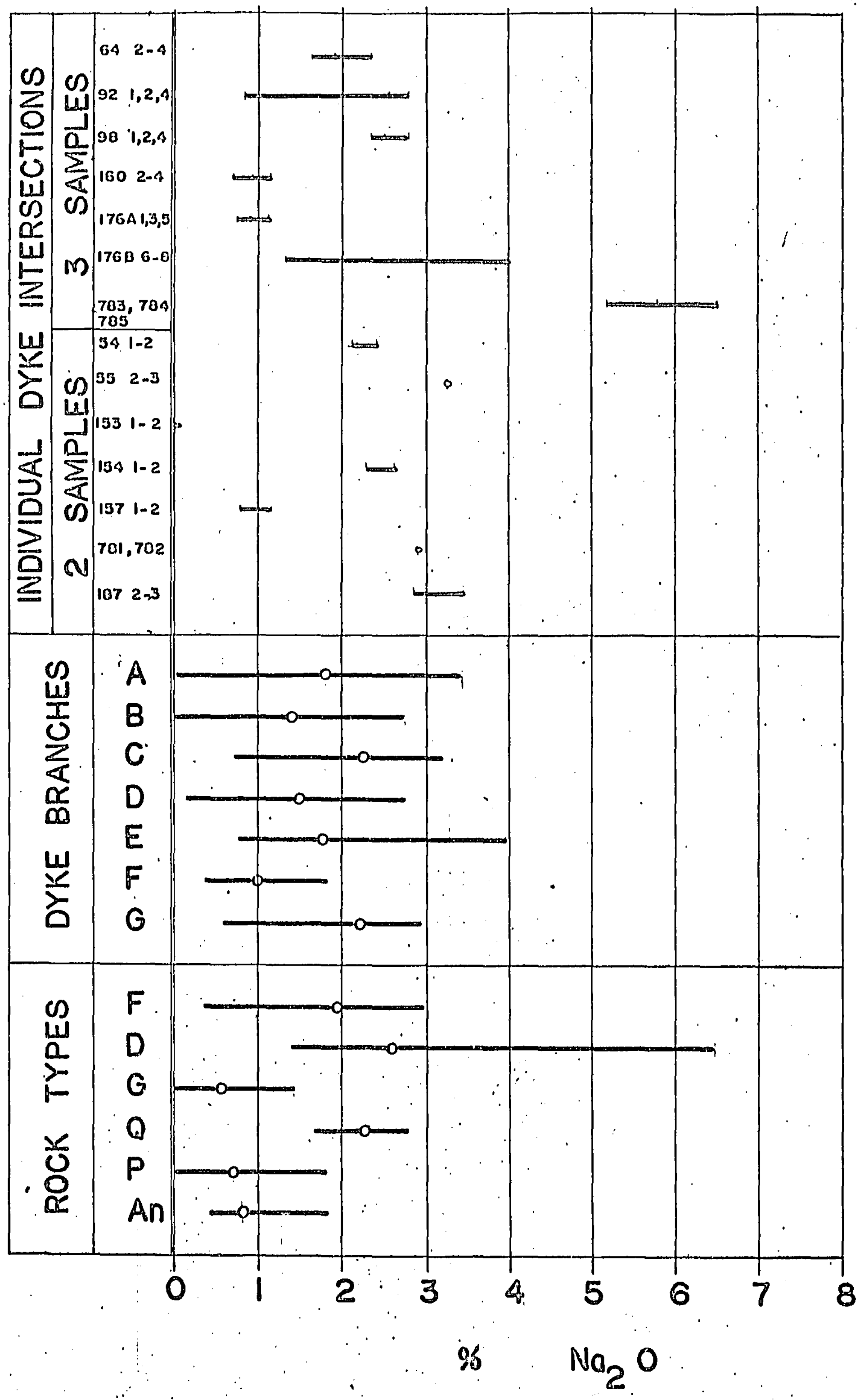


PLATE 23. Range Chart, showing distribution of Na_2O

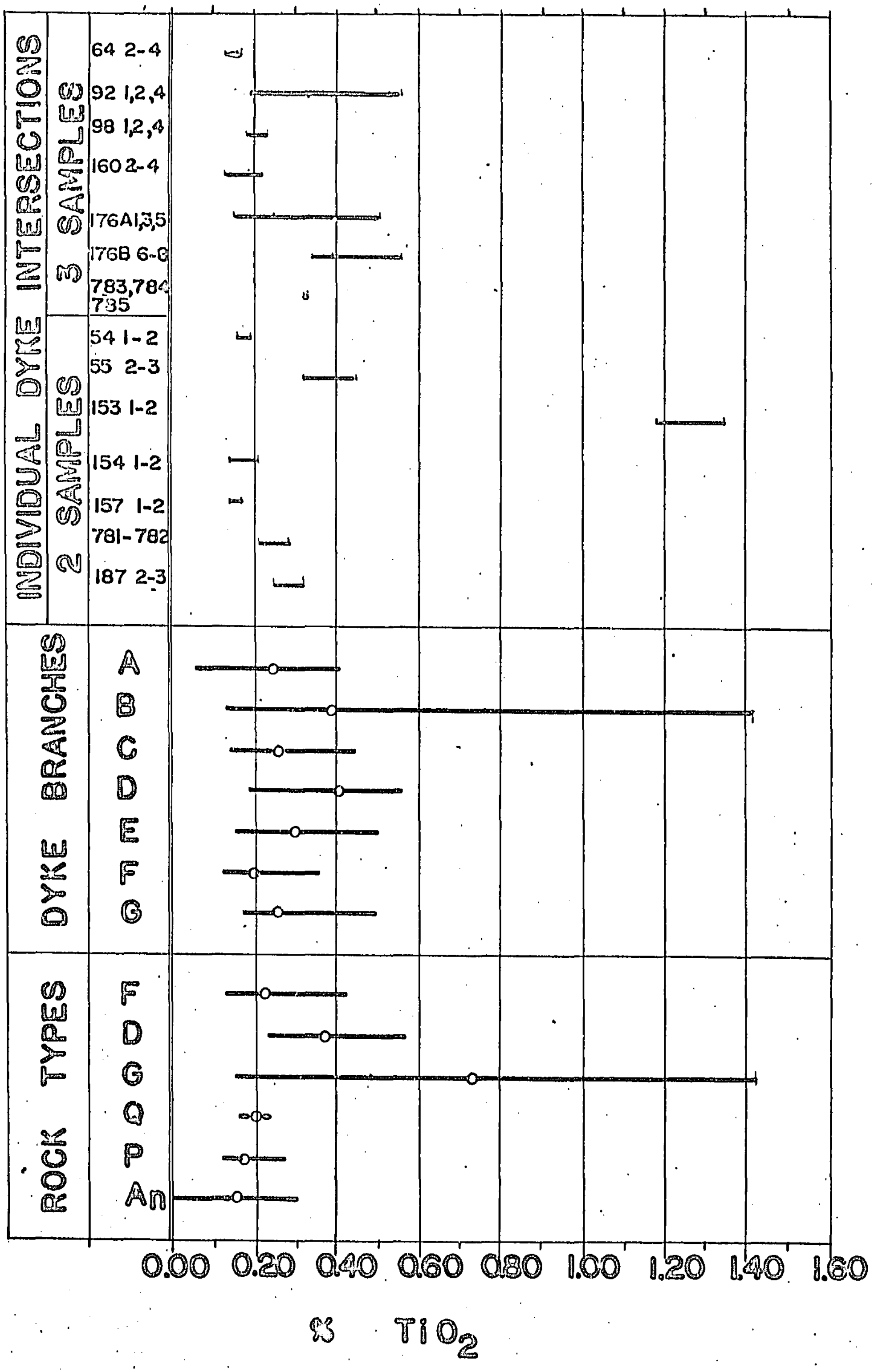


PLATE 24. Range Chart, showing distribution of TiO_2

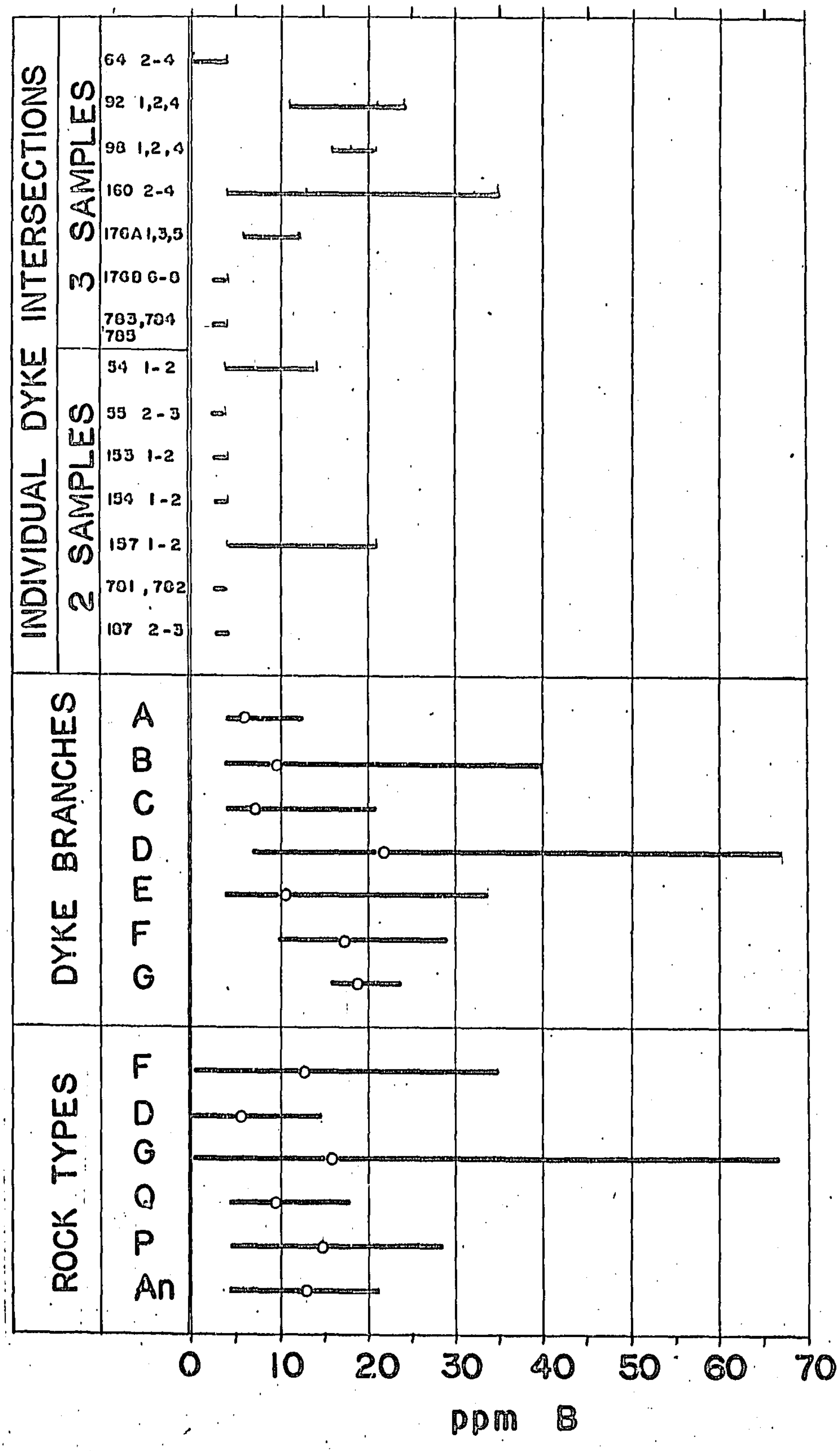


PLATE 25. Range Chart, showing distribution of B

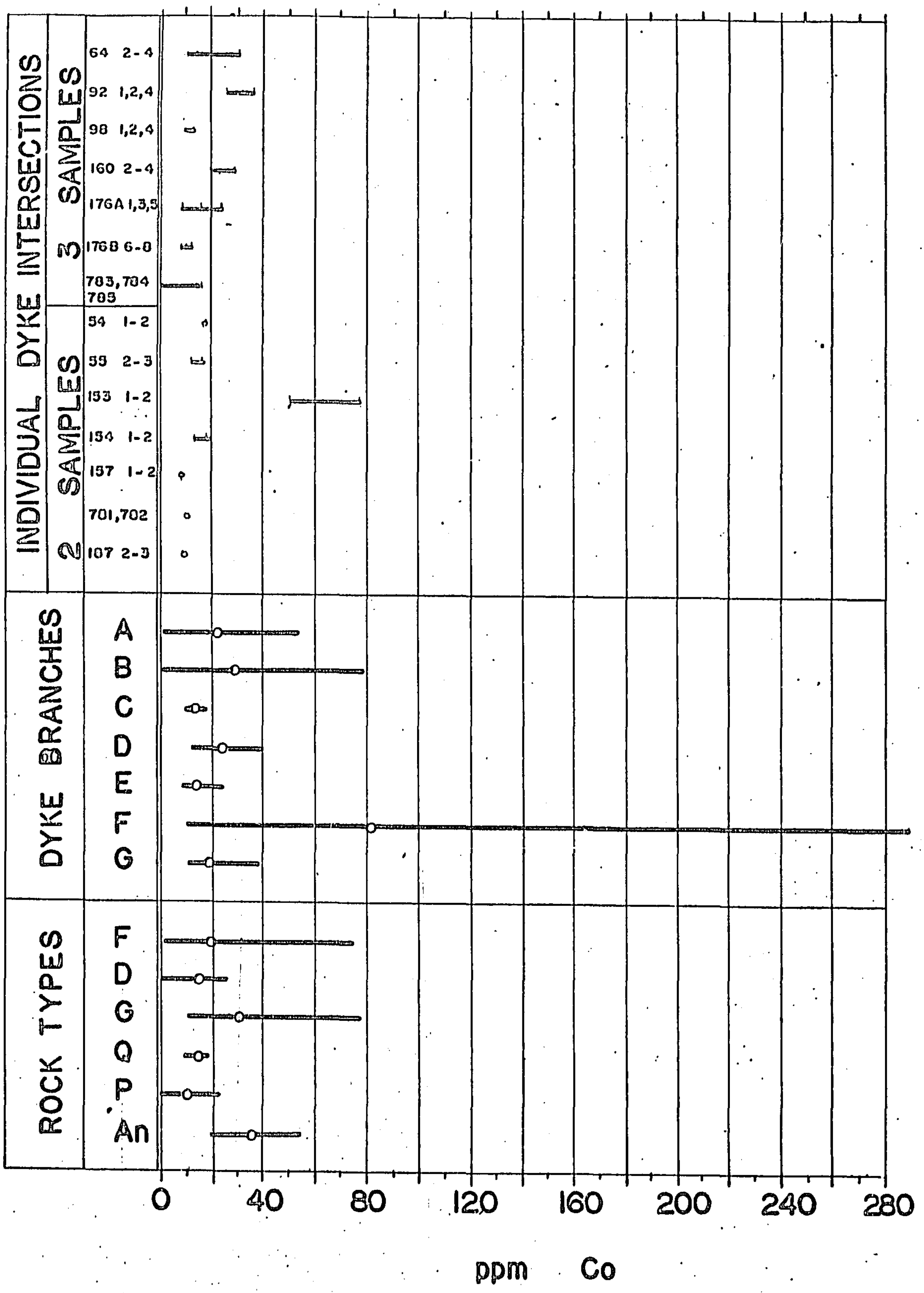


PLATE 26. Range Chart, showing distribution of Co

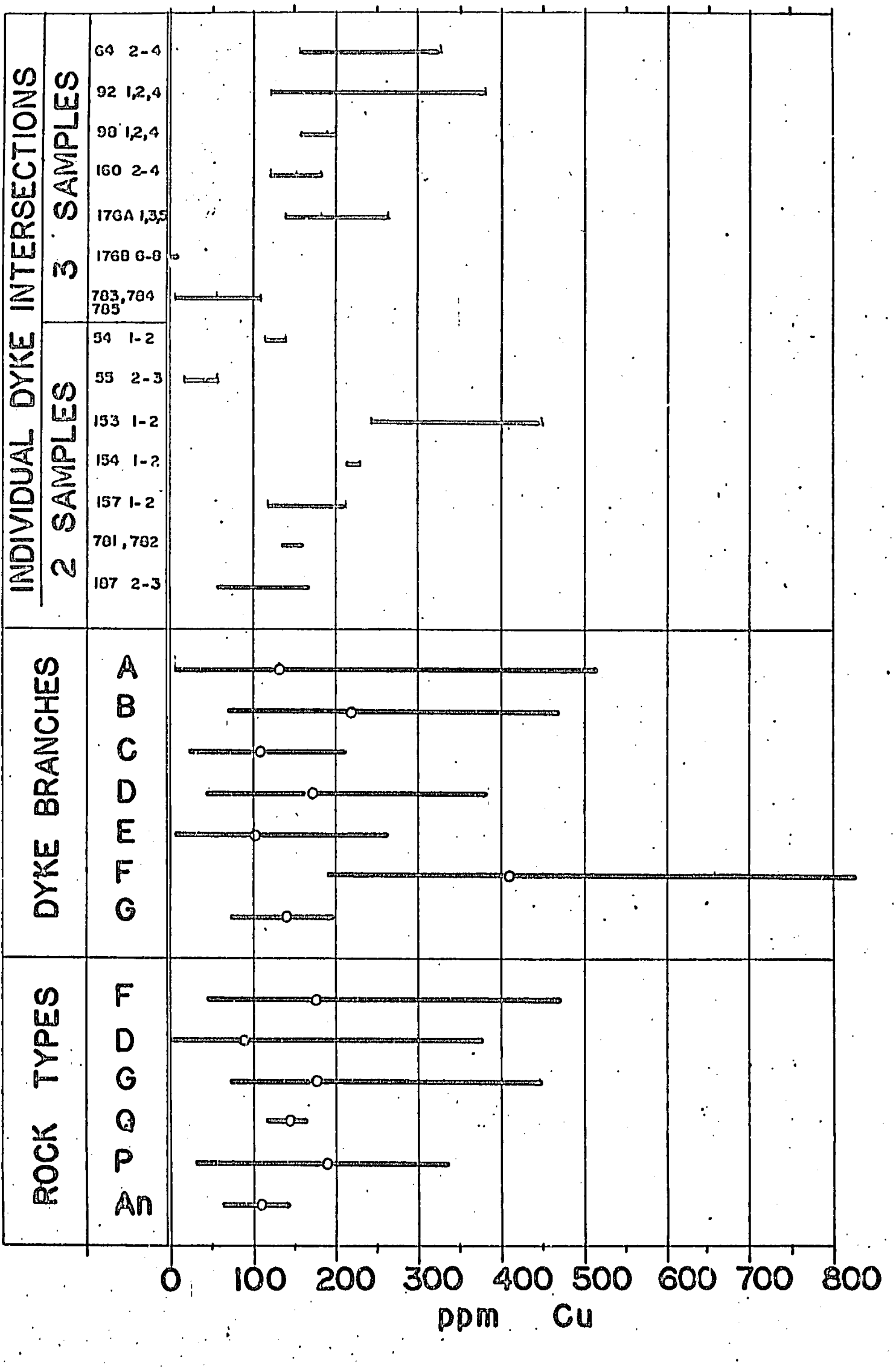


PLATE 27. Range Chart, showing distribution of Cu

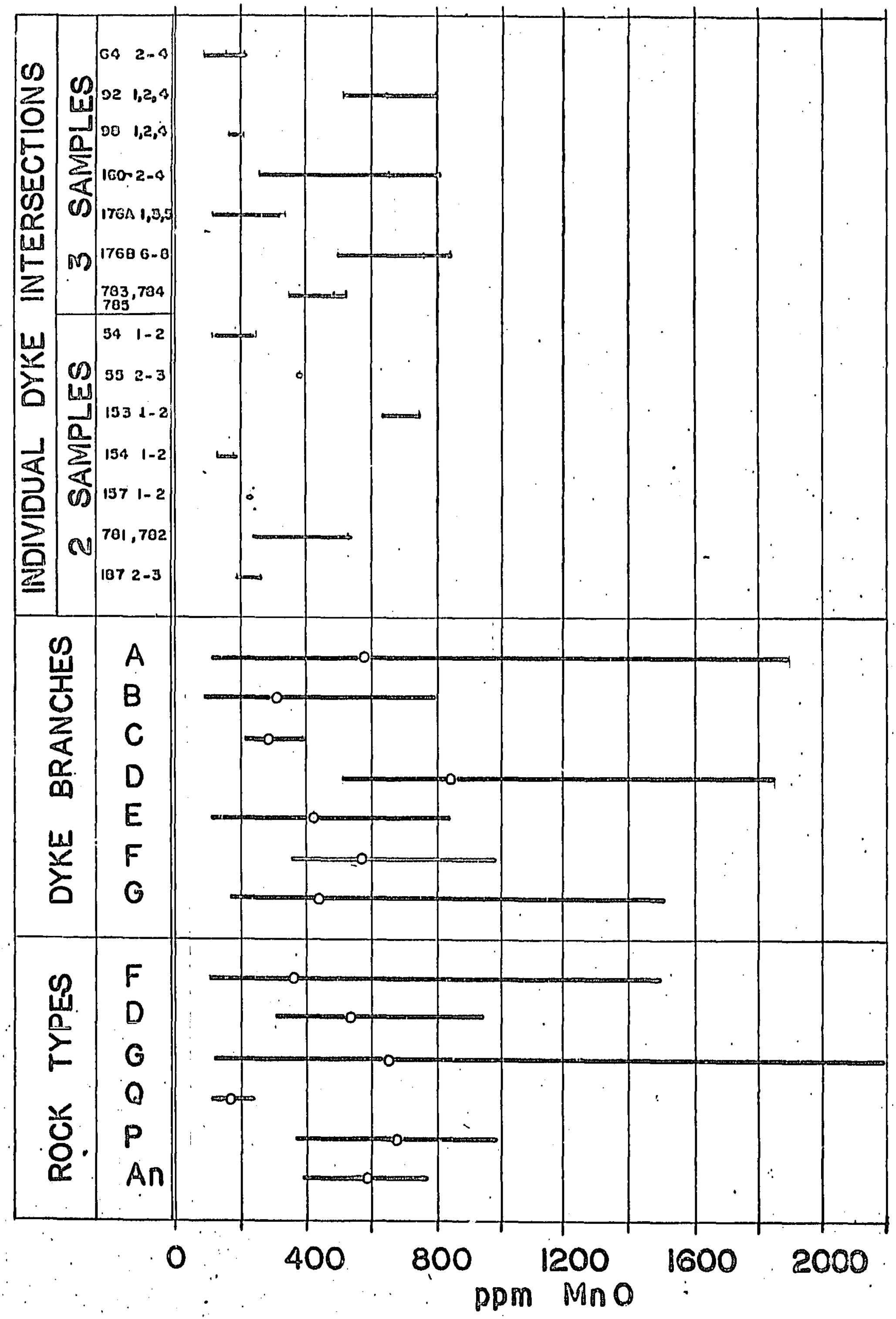


PLATE 28. Range Chart, showing distribution of MnO

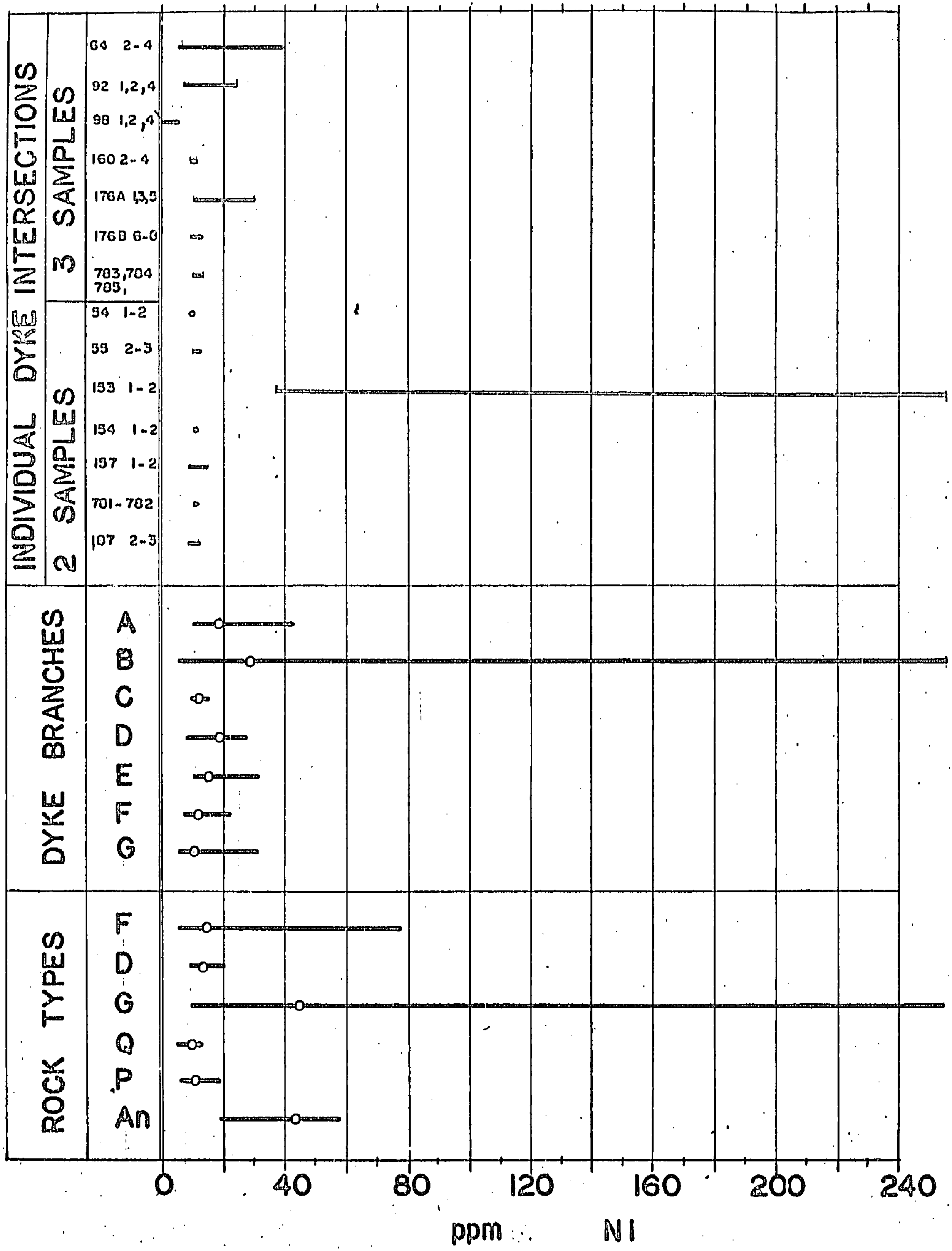


PLATE 29. Range Chart, showing distribution of Ni

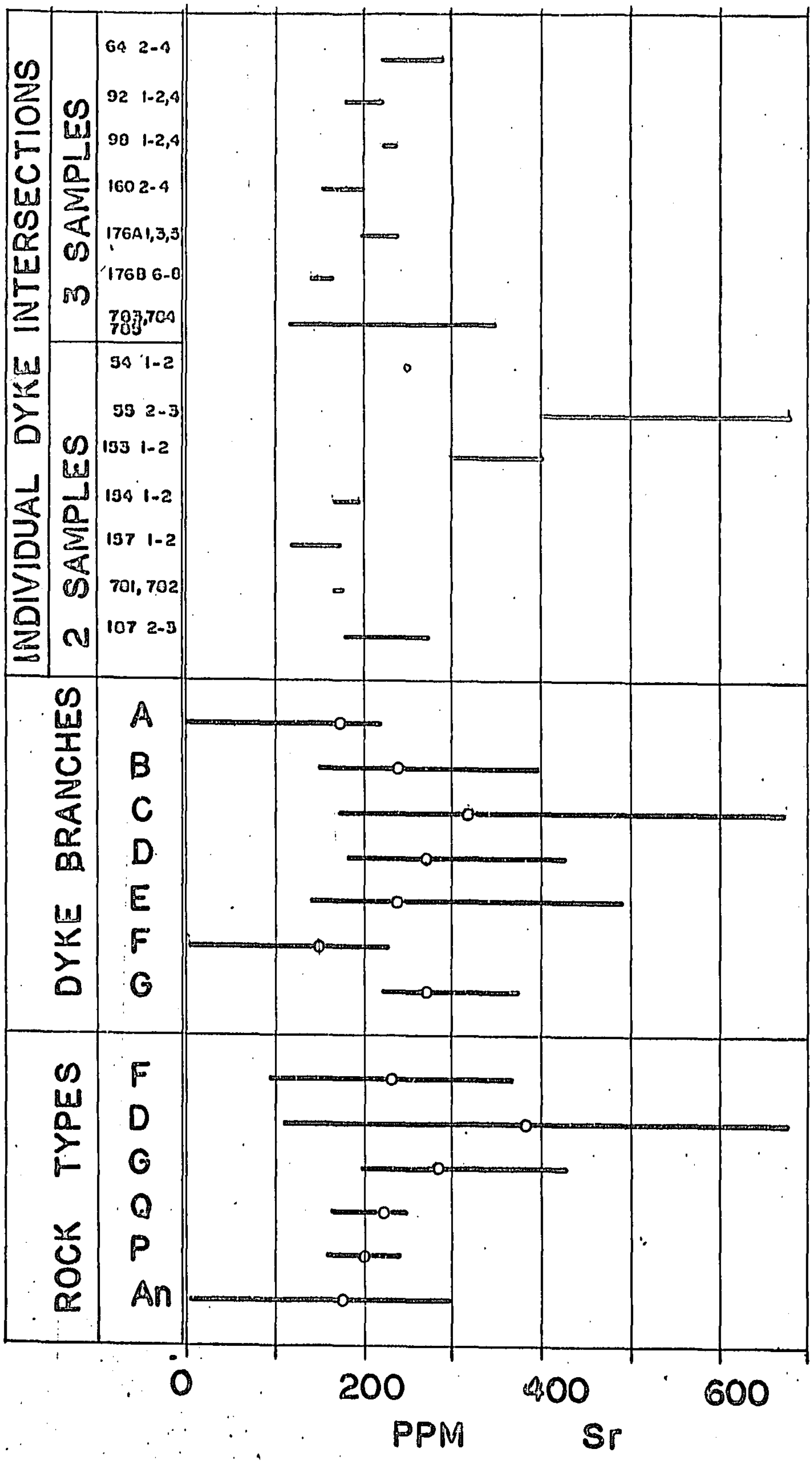


PLATE 30. Range Chart, showing distribution of Sr

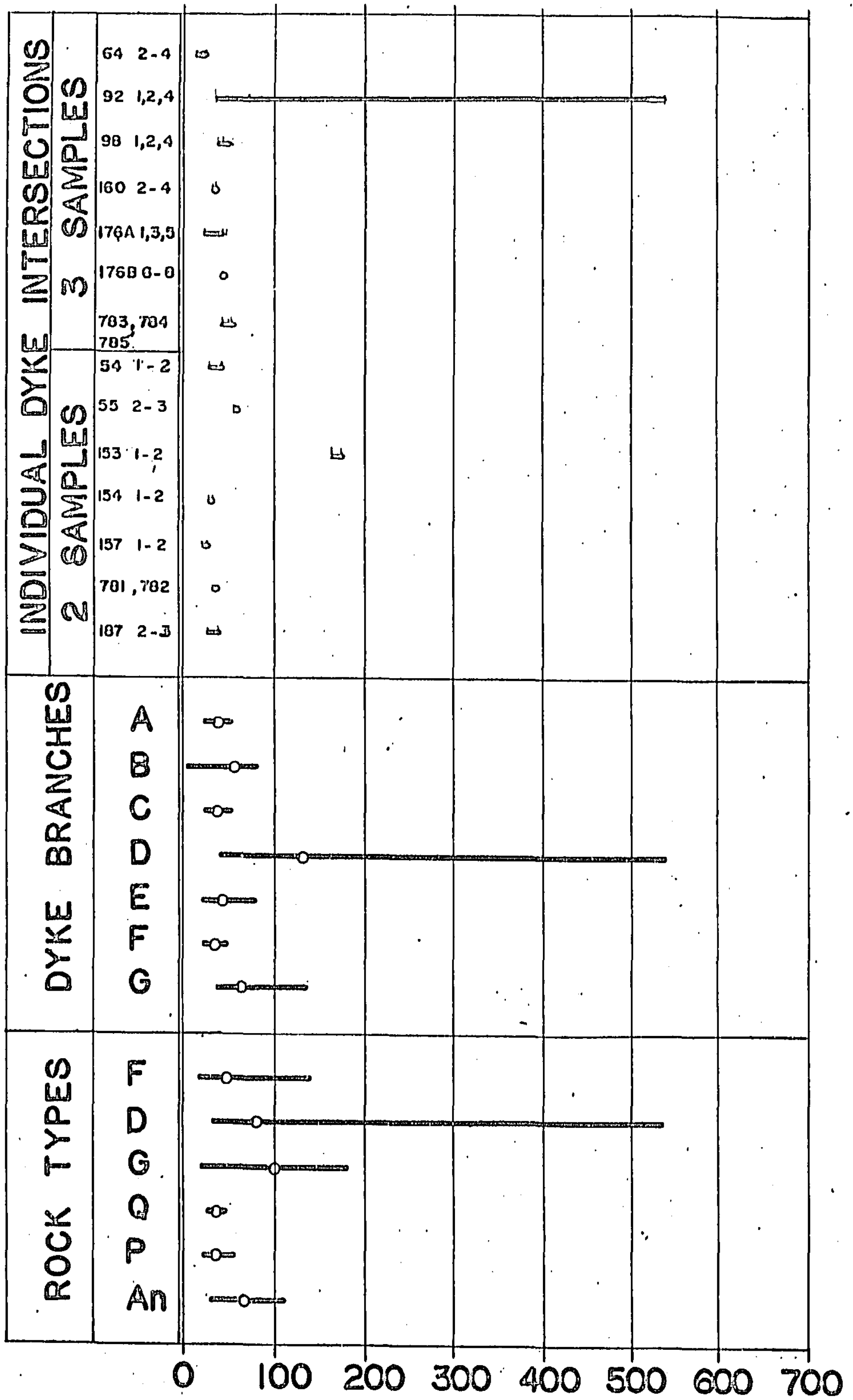


PLATE 31. Range Chart, showing distribution of V

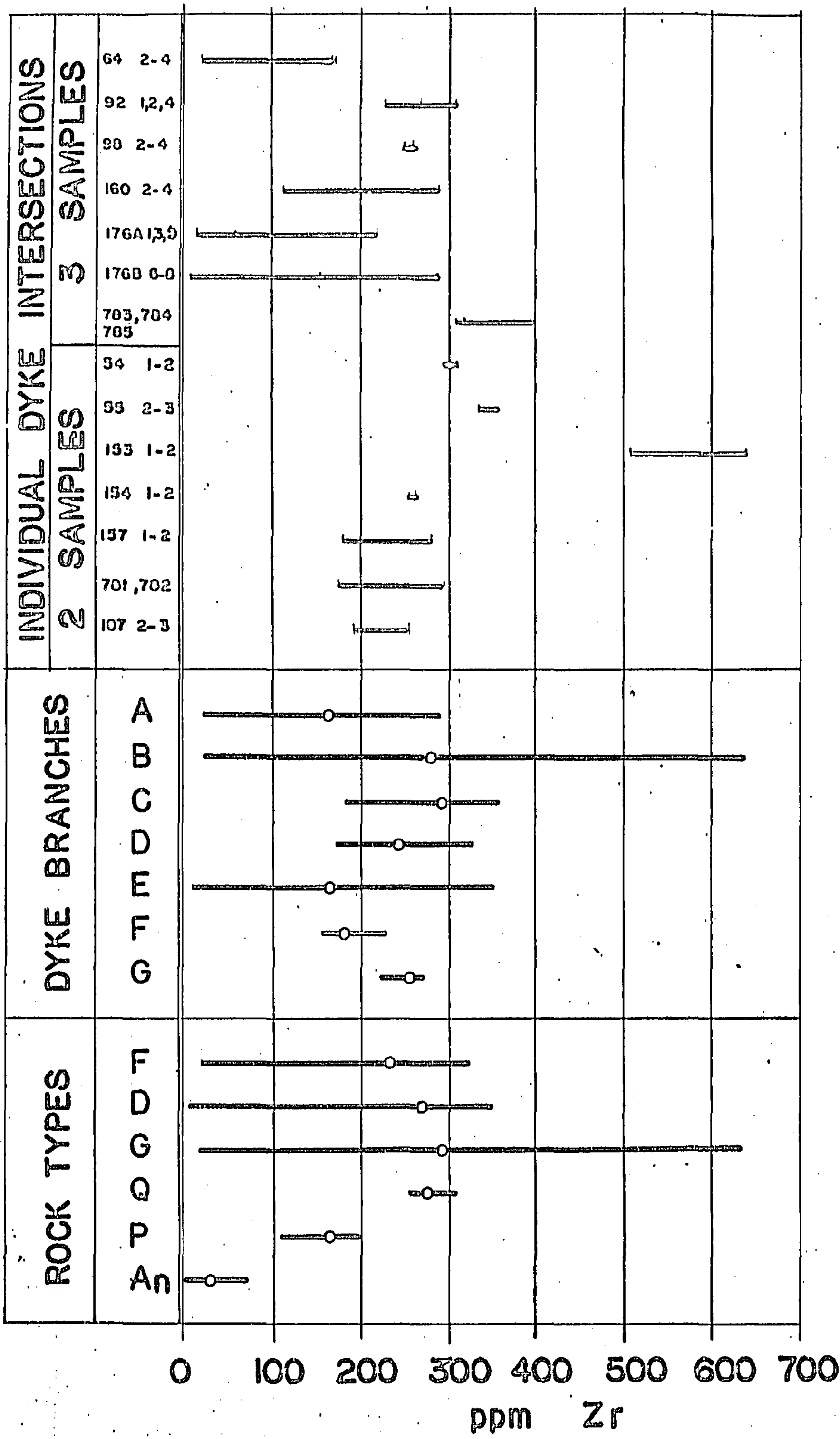


PLATE 32. Range Chart, showing distribution of Zr.

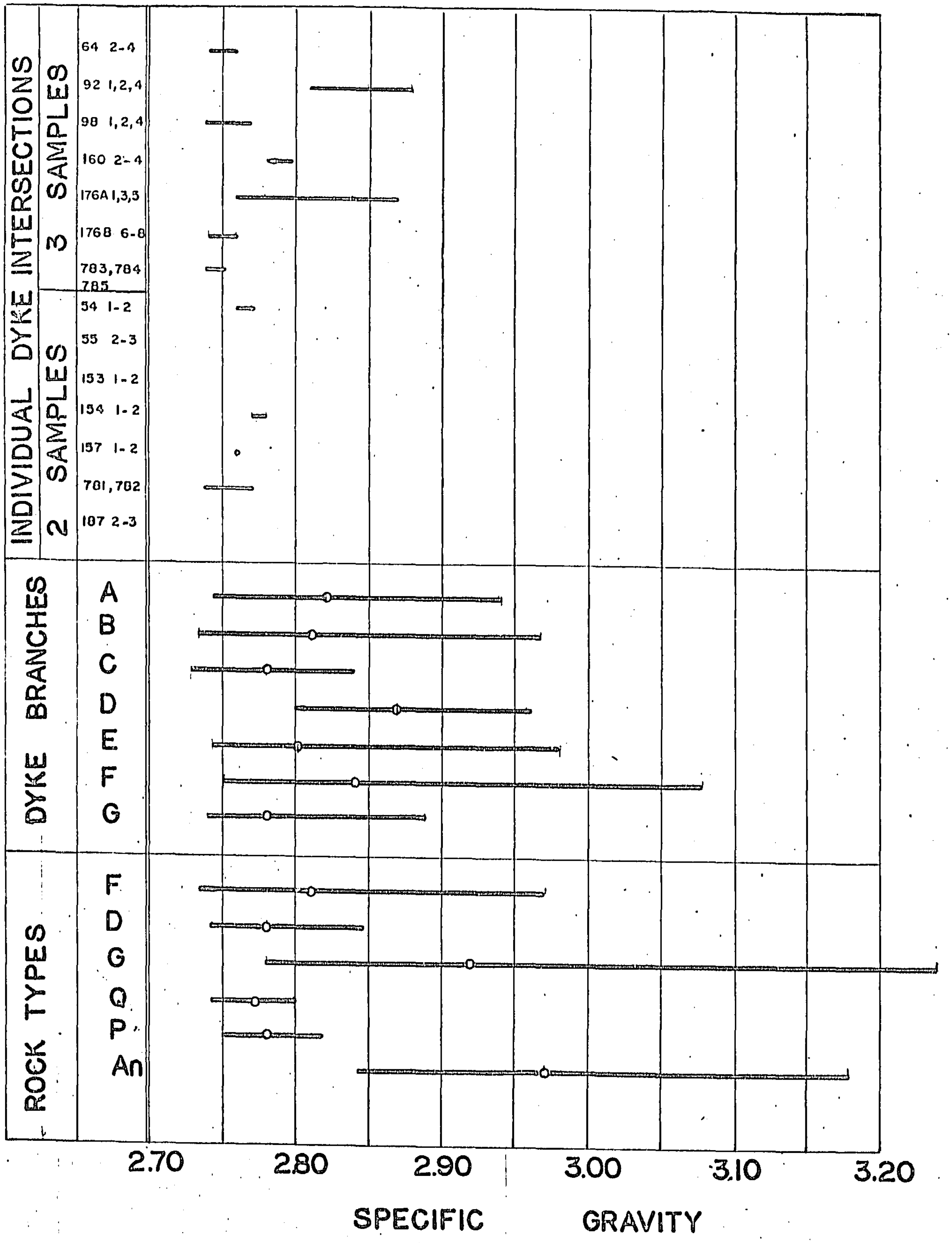


PLATE 33. Range Chart, showing distribution of Specific Gravity.

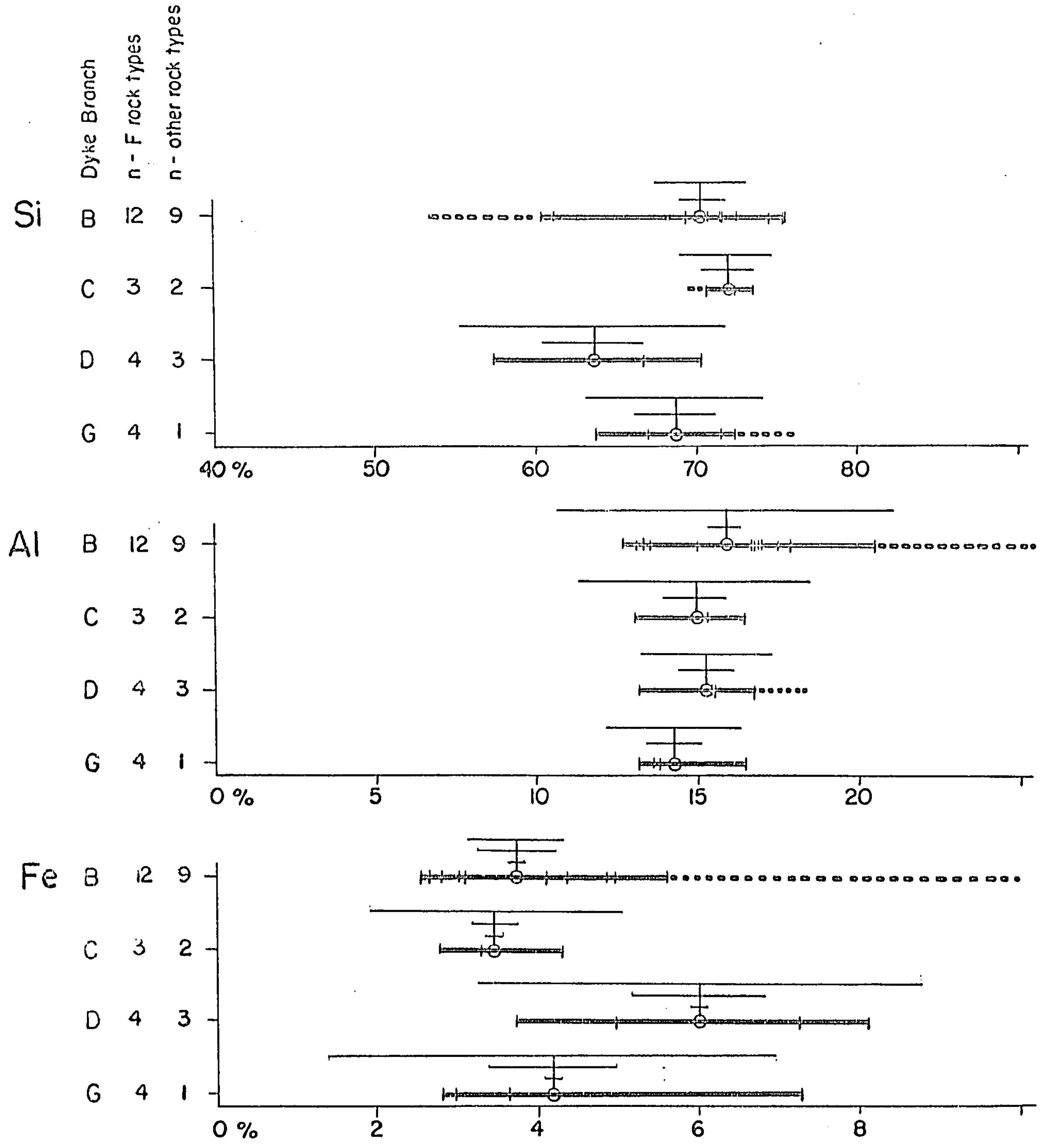


Plate 34 a.

Range charts for concentrations of elements in samples taken from four different dyke branches, showing the "F" rock types separately by heavy solid lines.

The contribution of analytical error to the variation in chemical composition is indicated by light solid lines.

See Explanations on Plate 34 d.

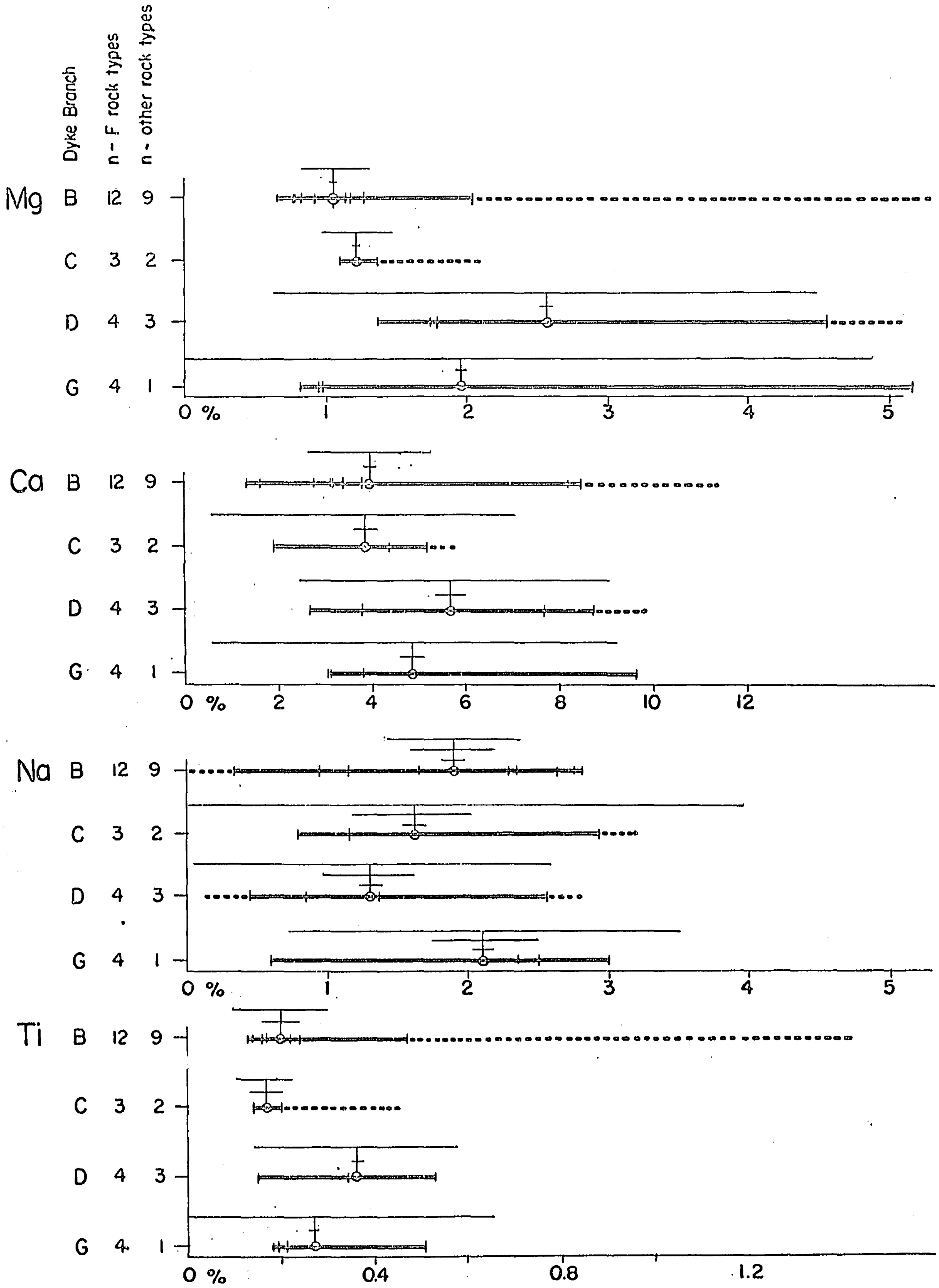

Dyke Branch
n - F rock types
n - other rock types
Mg
B 12 9
C 3 2
D 4 3
G 4 1
0 %
1
2
3
4
5
Ca
B 12 9
C 3 2
D 4 3
G 4 1
0 %
2
4
6
8
10
12
Na
B 12 9
C 3 2
D 4 3
G 4 1
0 %
1
2
3
4
5
Ti
B 12 9
C 3 2
D 4 3
G 4 1
0 %
0.4
0.8
1.2

Plate 34 b.

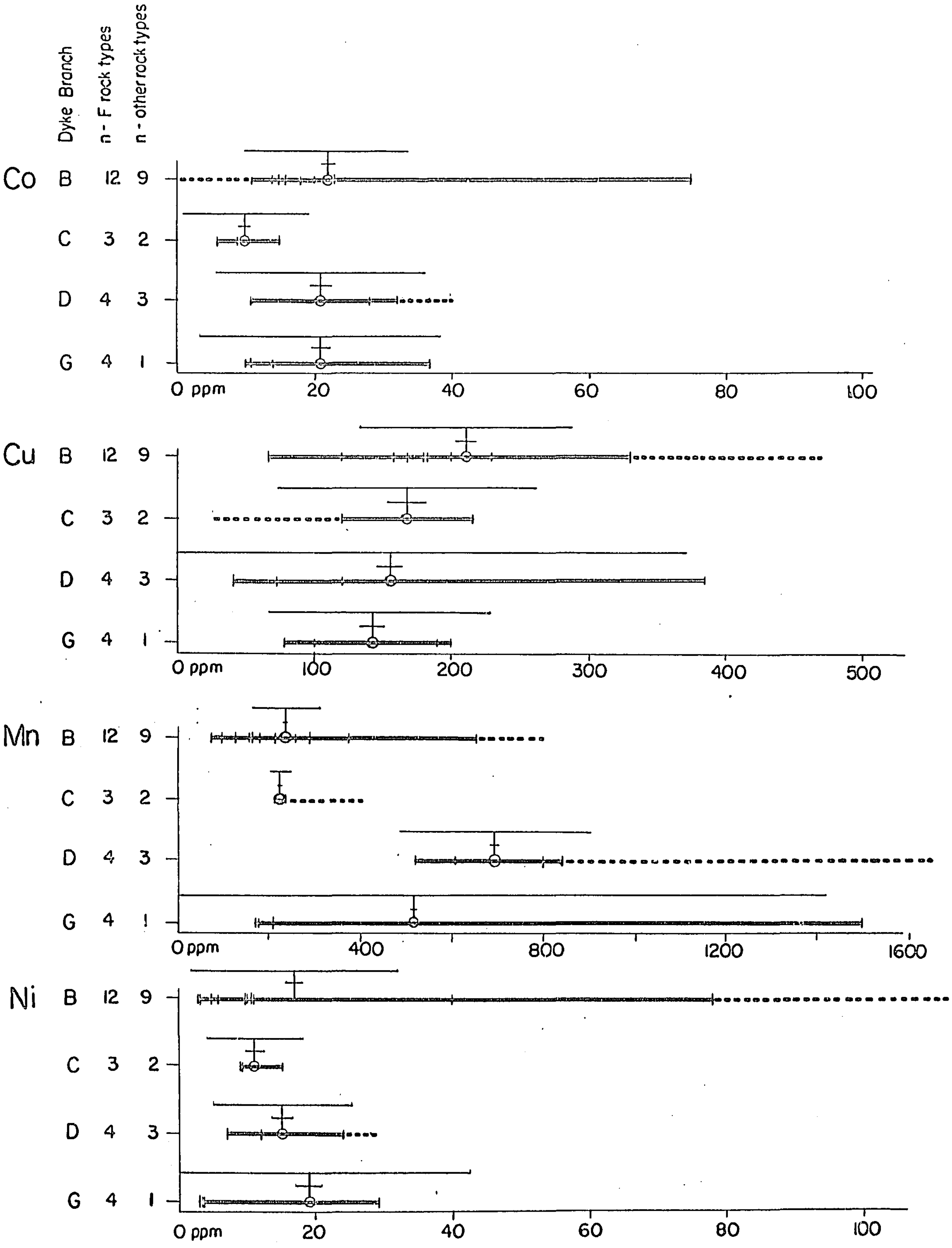
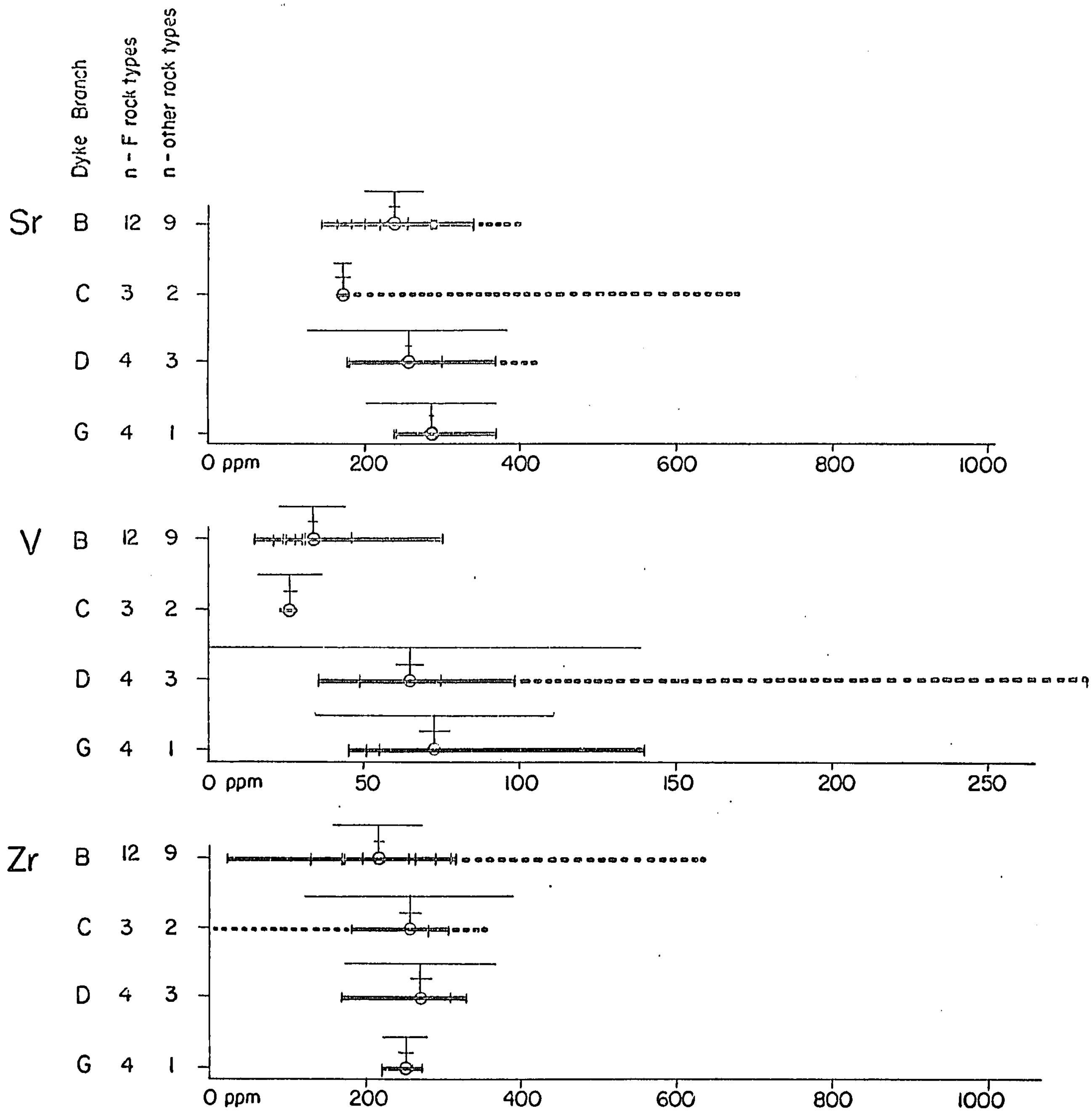
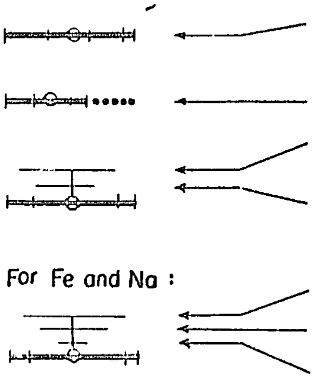

Dyke Branch
n - F rock types
n - other rock types
Co
B 12 9
C 3 2
D 4 3
G 4 1
0 ppm
20
40
60
80
100
Cu
B 12 9
C 3 2
D 4 3
G 4 1
0 ppm
100
200
300
400
500
Mn
B 12 9
C 3 2
D 4 3
G 4 1
0 ppm
400
800
1200
1600
Ni
B 12 9
C 3 2
D 4 3
G 4 1
0 ppm
20
40
60
80
100

Plate 34 c.



EXPLANATIONS :



Range chart for "F" rock types, showing mean value, (circle), and values of individual samples, (vertical lines).

Range chart for all rock types.

Confidence limits of the mean = $2\frac{ts}{\sqrt{n}}$, where t = Student's t, s = standard deviation, and n = number of samples.

Analytical confidence limits of the mean = $\frac{\bar{x}C}{\sqrt{n}}2$, where $\bar{x}$ = mean value, C = relative deviation, (Table 5), and n = number of samples.

For Fe and Na :

Confidence limits of the mean.

Mean deviation for n samples.

Mean deviation, (Table 6).

Plate 34 d.