Petrographic and Chemical Study
of a
Diabase Dike
in
Gatineau Park, Quebec

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Abstract

Swarms of diabase dikes have been reported in all Provinces of the Precambrian Shield. One of these is the Buckingham swarm which extends into the region of the Gatineau Park. A fresh exposure of one of these dikes was sampled to study its petrographic and chemical characteristics and any variations which might reflect the nature of its formation.

The physical and chemical characteristics of the dike compare closely to those of Hawaiian tholeiitic basalts, and the sub-ophitic texture of this dike resembles that of typical diabase dikes. The dike appears to be a member of a swarm of diabase dikes of probable Ordovician age, and are located in the Grenville province of the Canadian Shield.

Some variations in composition exist across the dike.

(a) Mafic minerals decrease in quantity inward while plagioclase increases inward.

(b) Grain size graphs plot in the shape of a bell curve, rather than parabolic.

(c) The characteristic sub-ophitic texture is replaced by porphyritic texture in the contact samples.

(d) An content of plagioclase decreases inward.

(e) Silica content of bulk rocks decreases outward.

(f) Rock compositions appear to have erratic variation in the zones near the contacts.

The observed variation in texture and chemical composition within the study dike may be attributed to a combination of factors including; contamination, secondary alteration, and some form of differentiation.

Acknowledgements

The author wishes to thank Dr. Ralph Kretz for his patient guidance and helpful advice, Dr. D.D.Hogarth for his helpful advice and criticism, the Ontario Research Council for providing funds for the preparation of materials and chemical analyses, and the Geological Survey of Canada for the use of Laboratory and library facilities.

Contents

Figures

Tables

Plates

Introduction

Swarms of vertical diabase dikes are common in many parts of the Canadian Precambrian Shield, as in other parts of the world. When the present study was begun in 1967, only meagre information was available on the chemical composition of these rocks and their minerals, and on variation in texture and composition within individual dikes. Such information may lead to an understanding of the crystallization of basaltic magma in dike-like bodies, and may reveal whether or not minor differentiation or contamination occurred during emplacement and crystallization. The present study provides some data on a single dike from the Grenville province of the Canadian Shield.

Geological Setting

The diabase dike selected for study lies in the southern part of Gatineau Park, 12.8 km northwest of Ottawa. The geology of this area was studied in detail by Hogarth (1970) who mapped three easterly-trending diabase dikes, cutting a complex of gneiss, marble, and granitic-syenitic rocks, as shown in fig. 1. Similar dikes were reported from adjacent areas by Wilson (1920), Beland (1954, 1955), Hogarth (1962) and Sabourin (1965).

The width of diabase dikes in Gatineau Park and adjacent area ranges from a few centimetres to tens of metres, and some can be traced on the ground for a distance of several kilometres. They are tabular in shape and dip steeply or vertically.

The age of some easterly-trending diabase dikes in and near Gatineau Park has been determined, as indicated in table 1 where the dikes are referred to as the Buckingham swarm. A whole-rock K/Ar age determination on the central dike shown in fig. 1 (which is the dike studied here) gave 488 ± 45 m.y., while hornblende from a xenolith of amphibolite in the south margin of the dike gave a K/Ar age of 972 ± 40 m.y. (Wanless, et al., 1971). Although an Ordovician age was obtained for the dikes, no occurrence of diabase cutting Ordovician sedimentary rocks has yet been found.

Field Observations

The dike that was selected for study (fig. 1) is well exposed in a road cut on the east side of the Gatineau Parkway, .4 kilometres south of MacKenzie King Estate parking lot. The road cut crosses the dike nearly at right-angles, showing the dike to be 23.8 metres thick.

The fresh dike rock is a dense, blackish coloured, very hard, strong rock, but the weathered surface appears to be one half centimetre of very soft, light brown material. The texture of the rock appears to be mainly massive crystalline with some ophitic patterns present. At the contacts the rock is extremely fine grained, and this grain size increases gradually inward for about three or four metres from the respective north and south walls. Beyond these points there is apparently no further systematic increase of size with distance.

The central portion is a fairly uniform, medium-grained aggregate of crystals, with some patches of more coarse-grained material, which are not clearly part of a zone. In these patches, crystals of plagioclase and pyroxene are easily observed and are 5 to 10 mm in diameter. A few patches show spherical clusters of feldspar grains, 2 cm in diameter. Magnetite, and in some places minor pyrite, were observed with the aid of a hand lens.

The selvage zone appears to be nearly 2.5 cm wide and is quite weathered, especially at the south contact. Brunet (1966) described this zone and noted that the outer 1/8 inch is light coloured, due to leaching, and the remainder is darker than the dike rock a few inches inward.

Considerable fracturing and weathering were observed at the south contact, where fractures evidently allowed dike material to enter the wall rock and surround portions of it. Elsewhere, xenoliths of country rock were found in the dike (Brunet, 1966; Wanless, et al, 1971).

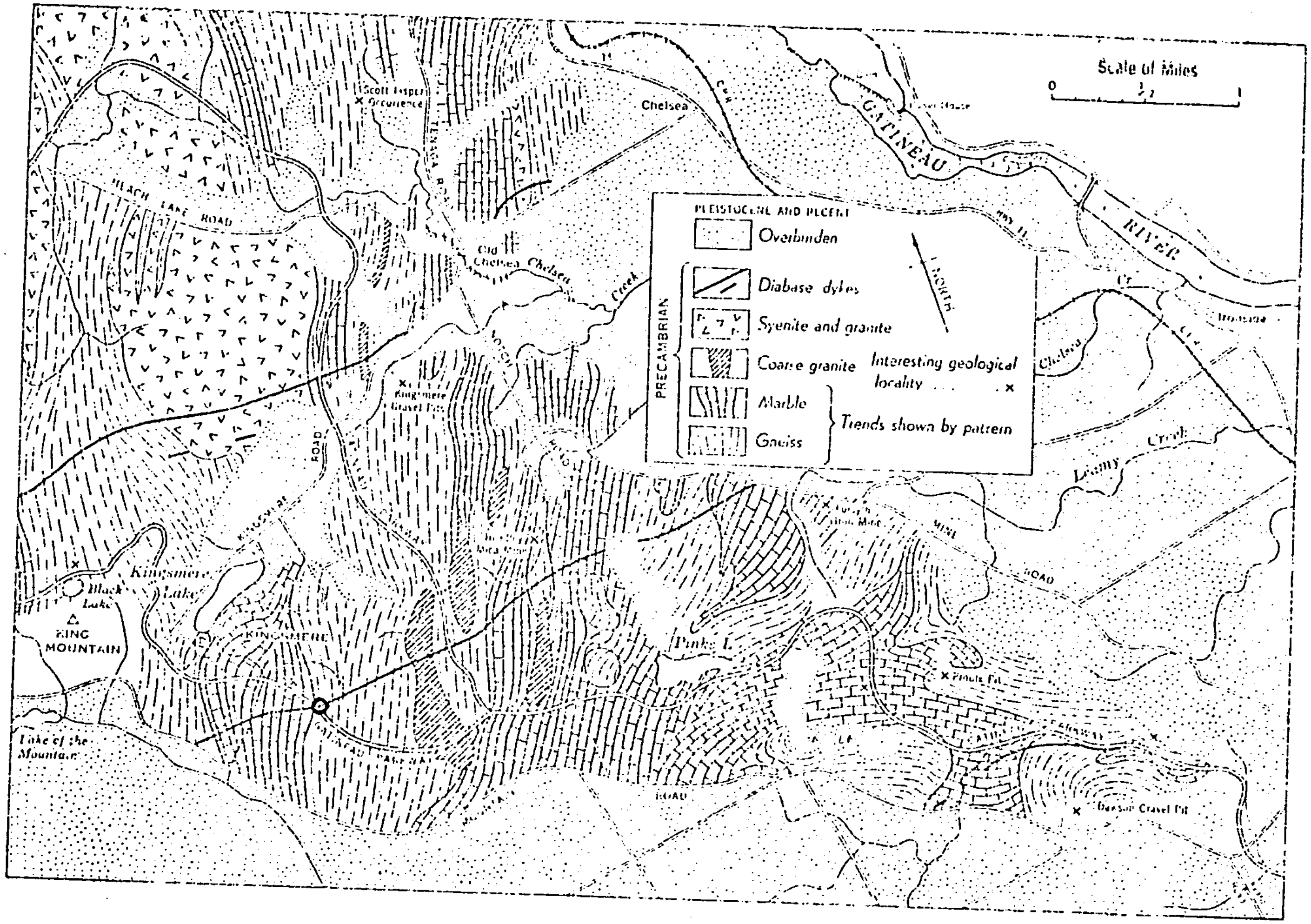


Fig. 1 Geology of the southern part of the Gatineau Park, by Hogarth (1962)

O - Location of sampling.

Table 2

GEOCHRONOLOGY OF THE OTTAWA REGION

Era	Period	Sedimentary Rocks	Igneous and Metamorphic Rocks	Age(m.y.)	δ^2	n^3
Cenozoic	Neogene	Pleistocene & Recent unconsolidated sediments				
Mesozoic	Triassic		Blackburn carbonatites	190^4		1
Palaeozoic	Pennsylvanian		Buckingham peridotite	275		1
	Ordovician	Queenston Fm. (red shale) Russell Fm. (grey shale & dolomite) Carlsbad Fm. (grey shale) Billings Fm. (black & brown shale) Eastview Fm. (limestone) Ottawa Fm. (limestone) St. Martin Fm. (limestone) Rockcliffe Fm. (shale & sandstone) Oxford Fm. (dolomite) March Fm. (dolomite & sandstone)	Diabase dykes (Buckingham swarm)	446	41.6	5
	Cambrian or Ordovician	Nepean Fm. (sandstone)				
	Cambrian		Onslow syenite dyke Buckingham latite	575	14.7	3
Helikian			Meach Lake carbonatite	920	48.9	4
			Pinks Lake peridotite Kingsmere diorite dyke Wakefield monzonite Kingsmere amphibolite Wakefield pegmatites Buckingham lamprophyre complex Old Chelsea metapyroxenites	1008	51.4	11

1. K/Ar ages compiled from records of the Geological Survey of Canada, McGill University, Carleton University and the University of Ottawa
2. Standard deviation.
3. Number of determinations.
4. Maximum age. Possible contamination of sample with Precambrian biotite.

TABLE 1 -- Geochronology of the Ottawa Region

From the Geology of the National Capital Area Gu
International Geological Congress. (Baird, ed.

Methods of Investigation

The dike was sampled along its fresh exposure in the road cut on the east side of the Parkway at places shown in fig. 2. The specimens were broken from the face along a horizon about 1.5 metres above the base of the exposure across the dike width of 23.8 m. The choice of sample locations was determined by obvious changes in grain size of the crystals of the rock which otherwise did not show any physical change. Since the greatest amount of change appeared within the first three to four metres inward from the contact, the majority of the specimens was taken in these zones. The large middle portion of the dike appeared more uniform in texture, and only one sample was selected from the central portion between the two samples that marked the lateral extremes of this middle portion of the dike. A total of nine specimens was collected and labelled (fig. 2) N2b to N2j respectively from the north contact to the south contact. Because of irregular mixing of host rock with the diabase dike at the south contact, as noted above, specimen N2j was selected 0.3 metres inside of this contact.

Each sample was large enough to allow a thin section to be cut, a bulk rock sample to be crushed for wet chemical analysis, and a larger bulk to be ground finely and processed for mineral separation. Only three of the specimens were selected for mineral chemical analysis.

The thin sections were used for petrographic observations which include grain size measurements, estimates of mineral composition, and observation of textural characteristics. Some of the optical properties of the minerals were determined, and identification of minerals was made with the aid of additional methods. Grains of the minerals were removed from some thin sections in order to check identification by X-ray diffraction and to measure some refractive indices. Microscope stage traverses were made on each thin section for modal composition and for average grain size. The point count traverses were made

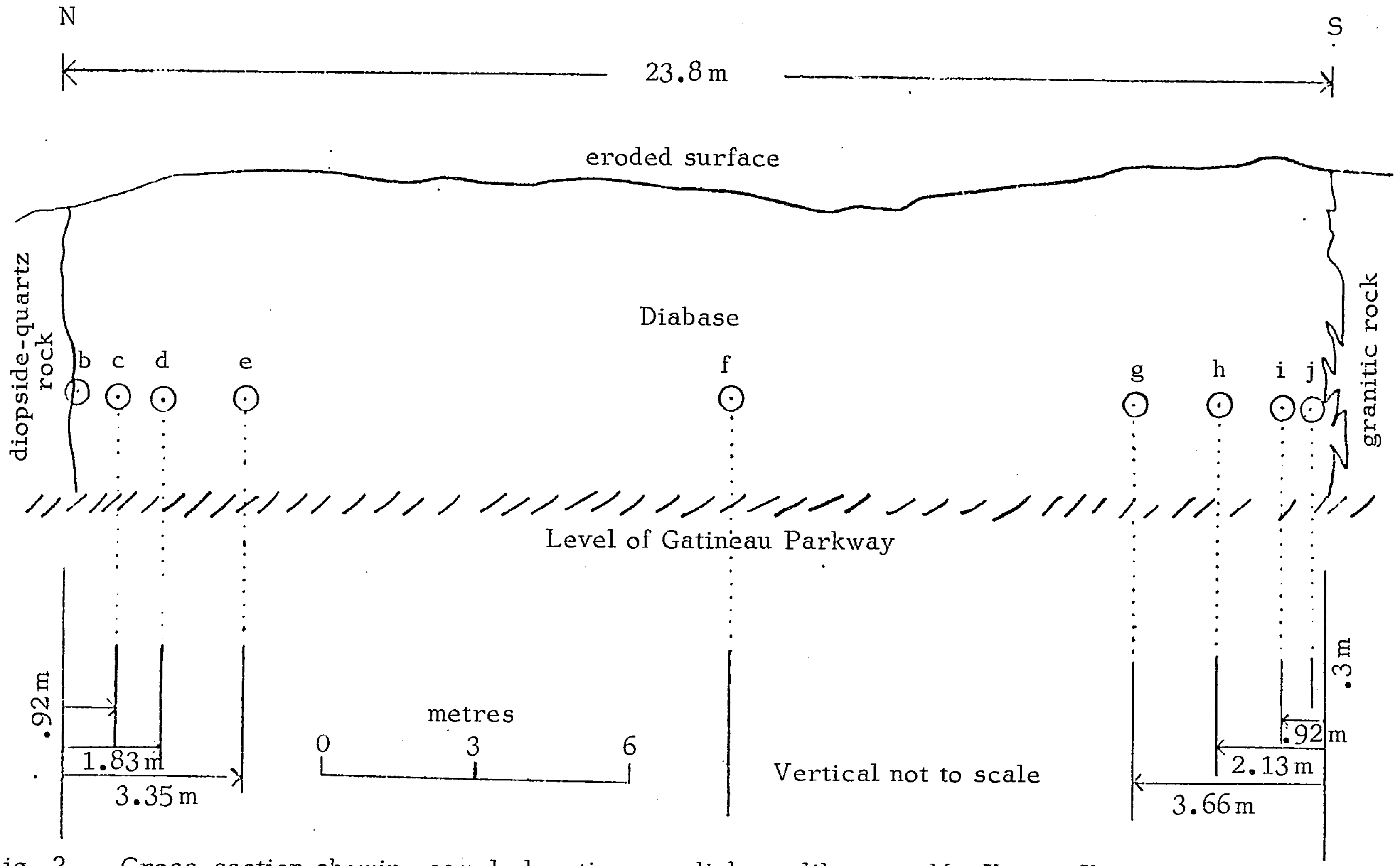


Fig. 2 Cross-section showing sample locations on diabase dike near MacKenzie King Estate Parking Lot, Gatineau Parkway.

in the range of six thousand points per thin section, the averages were calculated, and the results plotted for each mineral, showing comparison of location with composition. For the grain size averages the traverses involved the measurement of one hundred grains of each mineral per thin section, recording both the long axis dimension and the short axis dimension. The microscopic units were converted to millimetres and averaged. The averages in millimetres were plotted against the lateral location of the sample. These data refer to the apparent size of crystals as seen in thin section.

The nine rock samples were analysed chemically in duplicate by Technical Services Laboratories, Toronto. For the weight percentages of the oxides both larger and smaller values of the duplicate determinations were plotted against the lateral distribution in the dike. The average of the duplicate determinations was calculated for each result, and the mol-percent was calculated from these averages. A second set of graphs was then plotted to show the variation in mol-percent of oxides over the lateral traverse of the dike. These graphs allowed observation of variations within the rock, and they allowed comparison with both mineral analyses and petrographic observations. In addition, comparisons were made with rock analyses from other areas of the world by plotting oxide proportions on ternary diagrams such as the AFM diagram.

Studies of variations in the chemical composition of minerals were confined to samples N2c, N2d and N2e which represent one of the zones of obvious change in crystal size. Plagioclase feldspar and pyroxene which make up 85% of the rock were separated from each sample and sent to Technical Services Laboratories in Toronto for wet chemical analysis.

The three samples were ground down to a mesh size of - 230 + 325, and passed through the Frantz magnetic separator. Several trials were made with various combinations of amperage, tilt angle and slope angle until concentrates of plagioclase and pyroxene appeared to have less than 1% contaminants when viewed under a binocular microscope. Table 2 shows a typical flow chart that was successful in concentrating the two minerals from the ground rock samples.

The wet analyses were made in duplicate, and again the larger and smaller values were plotted against the lateral distribution of the specimens. Observations of variations were made, and comparison with the other types of examinations were made. Both the weight percent graphs and the mol-percent graphs were plotted similarly to the rock analyses. The values were calculated into ion proportions and fitted into general formulas. Ionic ratios for certain elements for each mineral were calculated and plotted on ternary diagrams in order to determine the position in its isomorphic series.

Sample N2c
Mesh size + 230 - 325

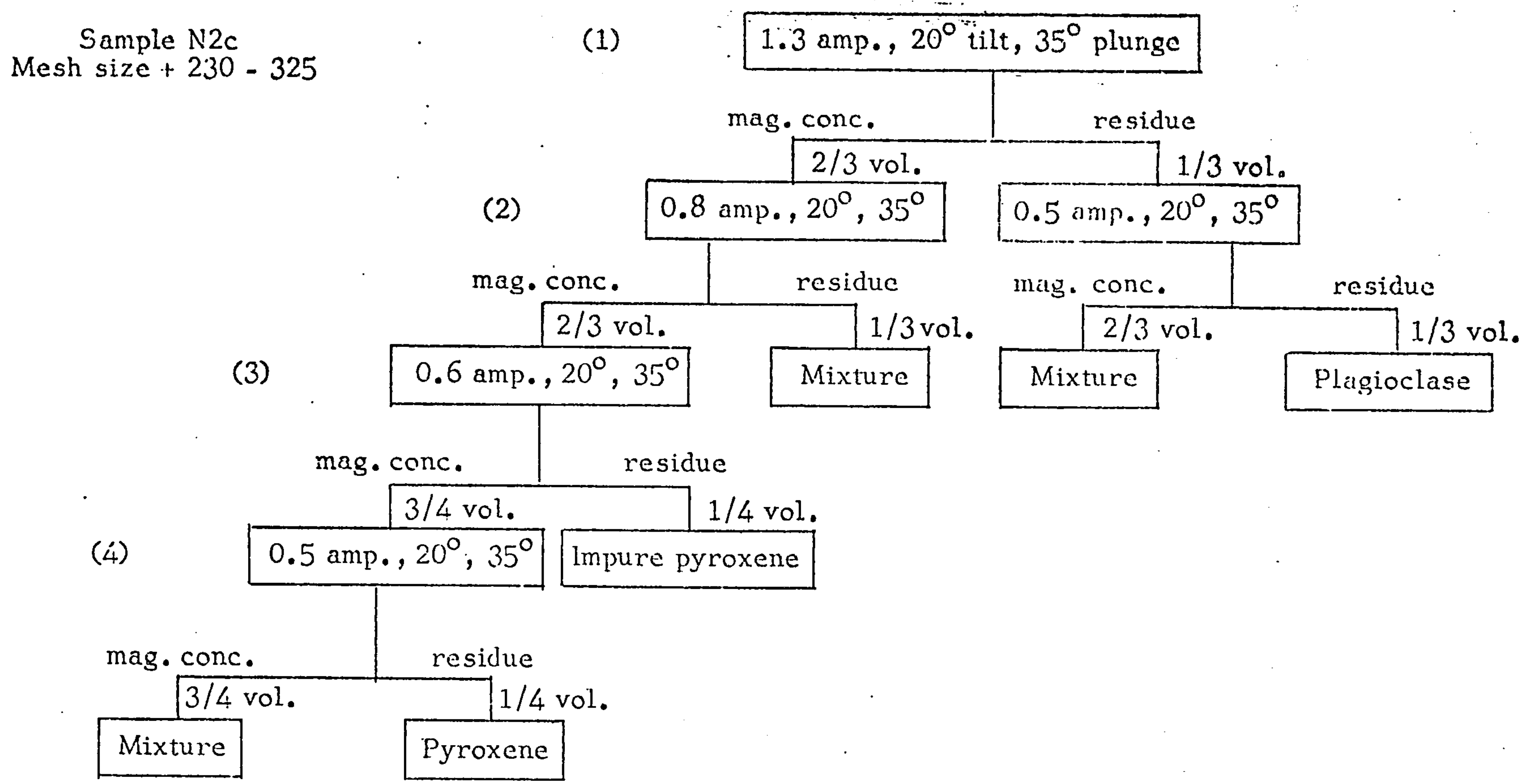


Table 2 A typical flow-sheet for magnetic separation of minerals from the diabase dike.

Petrography

The nine thin sections generally reveal a consistent texture and set of minerals, with some variations in quantity and grain size. The major components are plagioclase feldspar and pyroxene which, if grouped with their alteration material, account for ninety-three percent of the rock. Most of the alteration material is composed of brown hornblende, associated with the pyroxene, and sericite + carbonate material, associated with, or as inclusions in, the feldspar crystals. The opaque mineral, which averages about six percent of the rock, is usually magnetite with some ilmenite inclusions. A micrographic intergrowth of quartz and potassium feldspar occupies a little less than two percent of the rock (plate 1).

Minerals

Plagioclase, which makes up nearly half of the rock, appears as rectangular laths and tapering "spear-shaped" grains. These "spear-shaped" crystals are actually "step-down" crystal faces on grains of feldspar that have grown while being surrounded by growing pyroxene crystals (plates 2 and 3).

The plagioclase is characterized by elongated prismatic shape and by albite and Carlsbad twinning which is noticeable under crossed nicols. The maximum extinction angles of the albite twins were measured and the compositions of the crystals were estimated using the Michel-Lévy method (fig. 3). These range from An62 to An70, which is in the labradorite range.

In most thin sections, some alteration of feldspar occurs as very-fine grained mats of sericitic-type material. It was observed along cleavage traces in most sections. In thin section (N2j) selected from near the contact, a very large feldspar grain has altered and displays some zoning (plate 4). In some fields of view, the sericite alteration appears to be associated with the micropegmatite intergrowth.

scale 0.0 0.5 1.0 mm.

Plate 1

Specimen N2e, crossed nicols, showing micropegmatite intergrowth.

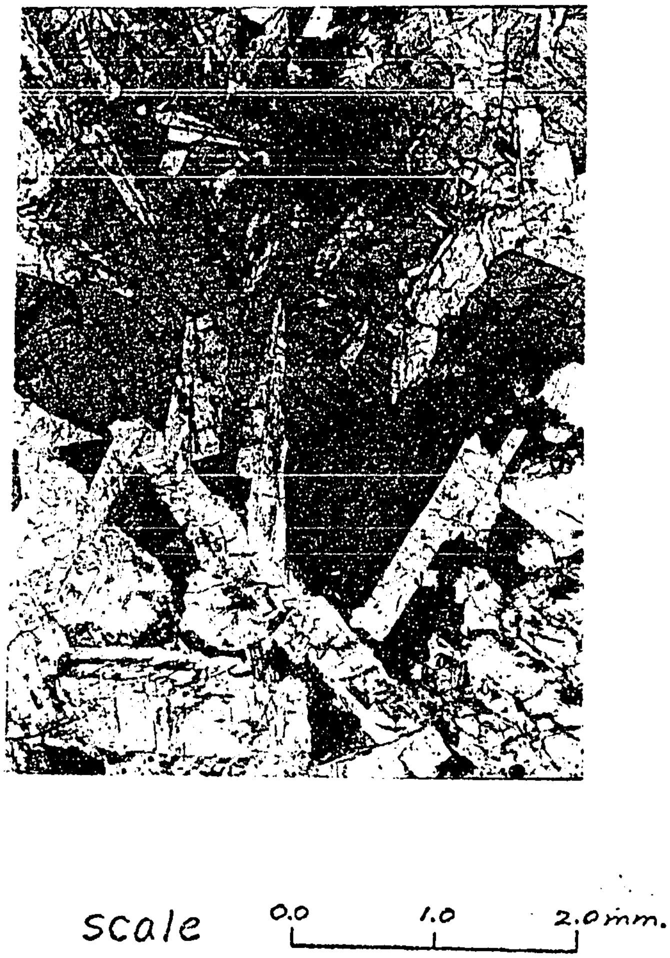


Plate 2

Specimen N2f, plane light, showing ophitic texture with spears or wedges of plagioclase in pyroxene grains.

scale 0.0 0.5 1.0 mm.

Plate 3

Specimen N2f, plane light, showing enlarged view of plagioclase wedge. Note steps formed along the contacts.

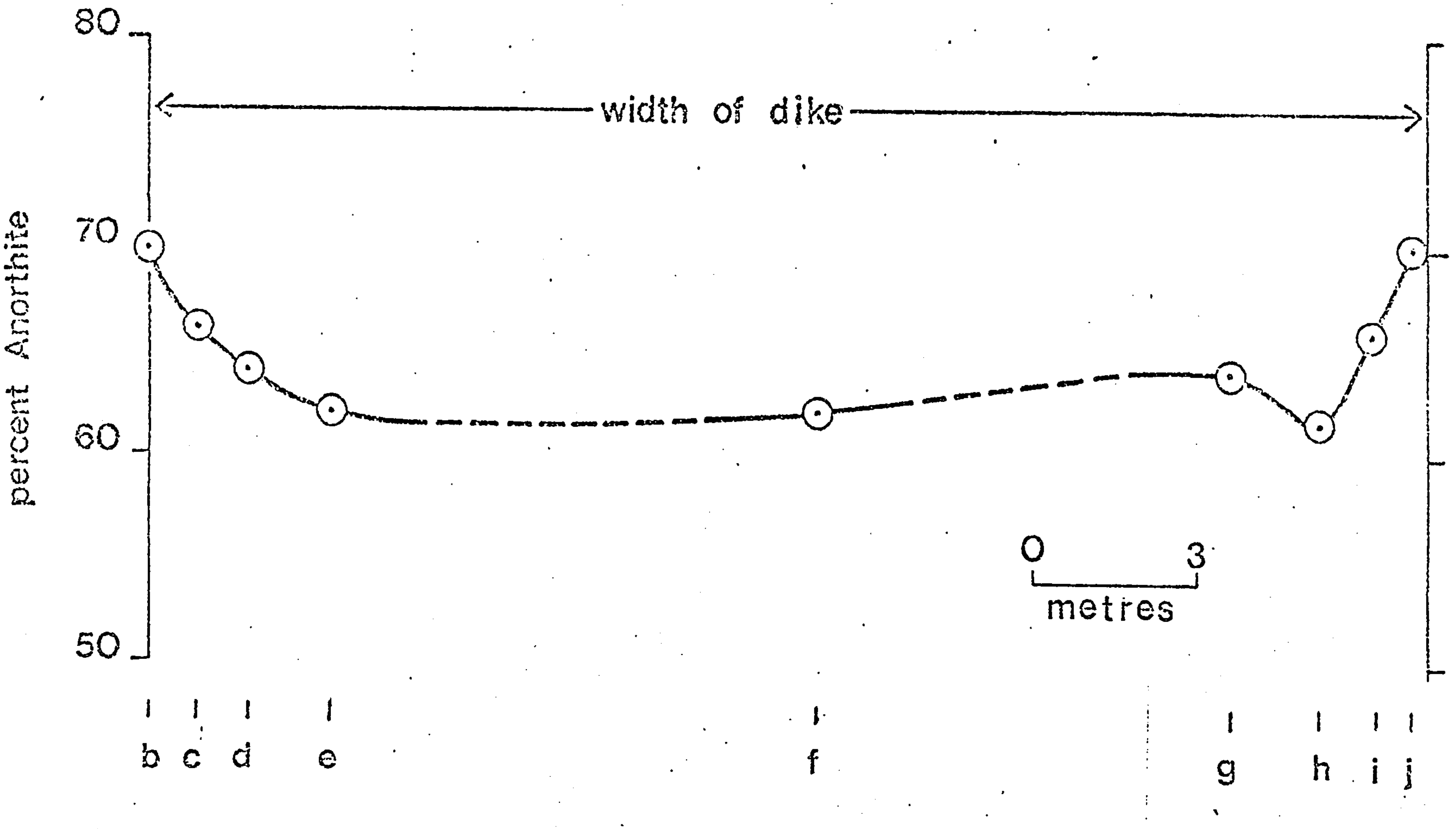


Fig. 3 Plagioclase Composition. (Michel-Lévy method)

scale 0.0 1.0 2.0mm.

Plate 4

Specimen N2j, plane light, showing non-ophitic texture of a contact sample. Note large "trapped" feldspar grain with zoning emphasized by some alteration in the middle portion. A small portion of a large trapped pyroxene grain may be seen at the top margin.

The other major mineral component of the dike is pyroxene, which appears colourless with some grains tinted slightly greenish in thin sections. Under crossed nicols high-order interference colours are brilliantly displayed, and often reveal that clusters of smaller pyroxenes have intergrown to form the larger masses of pyroxene which were observed in plane light. Optical examination of the pyroxene grains suggests a clinopyroxene, either diopside or augite. The brown hornblende alteration and lack of metamorphism in the rock suggests that the pyroxene is augite; some grains reveal a 2V of 40°, which agrees with augite or sub-calcic augite. Pigeonite and orthopyroxene in small amounts has been noted by Dr. D.D.Hogarth.

The pyroxene crystals in sections at the margins of the dike show much opaque alteration (probably hematite), while the inner group of specimens reveals a significant amount of brown hornblende alteration on the pyroxene cleavage traces. Two specimens, N2g and N2h, did not reveal very much hornblende alteration.

The black opaque mineral, which occupies an average of 6 percent of the dike rock, is magnetic, and under reflected light appears to be magnetite, with small amounts of inclusions of another opaque material. X-ray diffraction analysis of the mixture revealed strong magnetite lines and weak ilmenite lines.

The micrographic intergrowth of potassium feldspar and quartz, which shall be called micropegmatite, may be observed under high power objectives. It is mainly intergranular, but in some locations it appeared to be associated with sericite alteration of feldspars (plate 1). It averages just under two percent of the dike material.

The average figure of seven percent has been estimated for alteration materials, most of which are too fine grained to be identified. Although this material has been grouped together, it appears to be composed of several different phases which could have altered from various minerals. Brown hornblende has been recognized in many thin sections, and it is definitely associated with pyroxene and may be primary. The amount of hornblende appears to be greater in the northern half of the dike than in the southern half. Mats of very fine grained material including sericite, chlorite and carbonate were observed in most specimens, but the thin sections of rock from near the contacts contained the most significant amounts of these mats. In specimen N2j one unusually large grain of plagioclase feldspar was partly covered with a sericite type mat that helped to emphasize the zoning in this feldspar grain (plate 4). Generally this type of alteration occurs more in the north half of the dike than in the south half. Specimens at, or quite near, the contacts possess a great amount of alteration that is brownish and opaque. Some of this seems to be hematite as well as the magnetite. Carbonate masses appear mainly in the contact specimens. One very large grain has altered completely to a very fine grained carbonate mixed with other fine grained material. The grain appears to be an alteration of an earlier crystal of either olivine or pyroxene (plate 5). Brunet (1966) has reported carbonate alteration of olivine grains along the contact.

Texture

From thin section observations the texture appears to be a randomly oriented aggregate of plagioclase and pyroxene crystals, which are best described as sub-ophitic. Although the average grain size varies across the dike, the variation in grain size within each thin section can be 12 X the minimum. Predominantly the plagioclase crystals are inter-grown with pyroxene crystals with the same general size range, but accompanying this are "wedge-shaped", smaller sized plagioclase crystals which appear to be surrounded by pyroxene grains (plates 2 and 6). This textural feature is present in all thin sections at least to some extent, but is only slightly developed in thin sections which represent contact or very near contact dike rock.

Plate 5

Specimen N2j, plane light, showing contact dike rock with a large altered grain that may have been an earlier formed pyroxene grain.

Plate 6

Specimen N2e, crossed nicols, showing typical sub-ophitic texture in a rock of medium grain size.

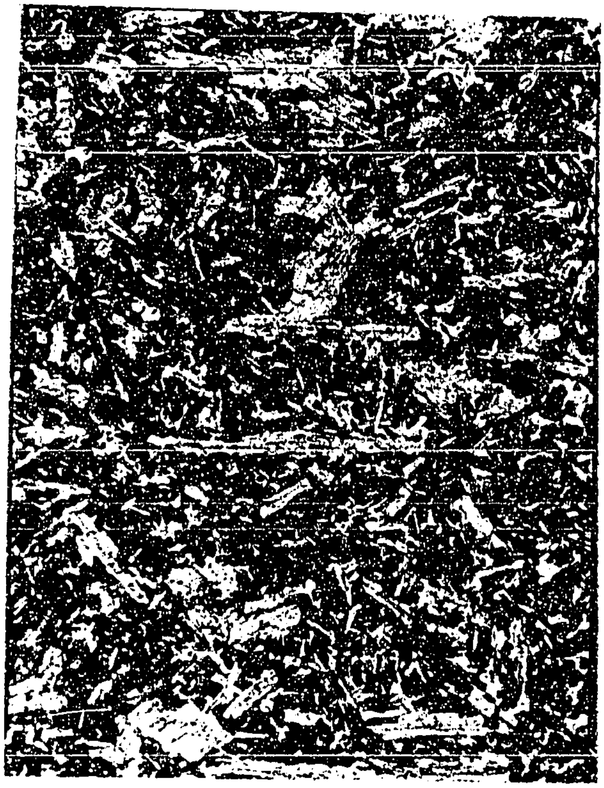


Plate 7

Specimen N2b, plane light, showing porphyritic texture developed in the dike at its contact. Note preferred orientation of feldspar laths.

Plate 8

Specimen N2g, plane light, showing typical texture of medium grained dike rock with very little alteration of grains. Note large range in crystal size of feldspar.

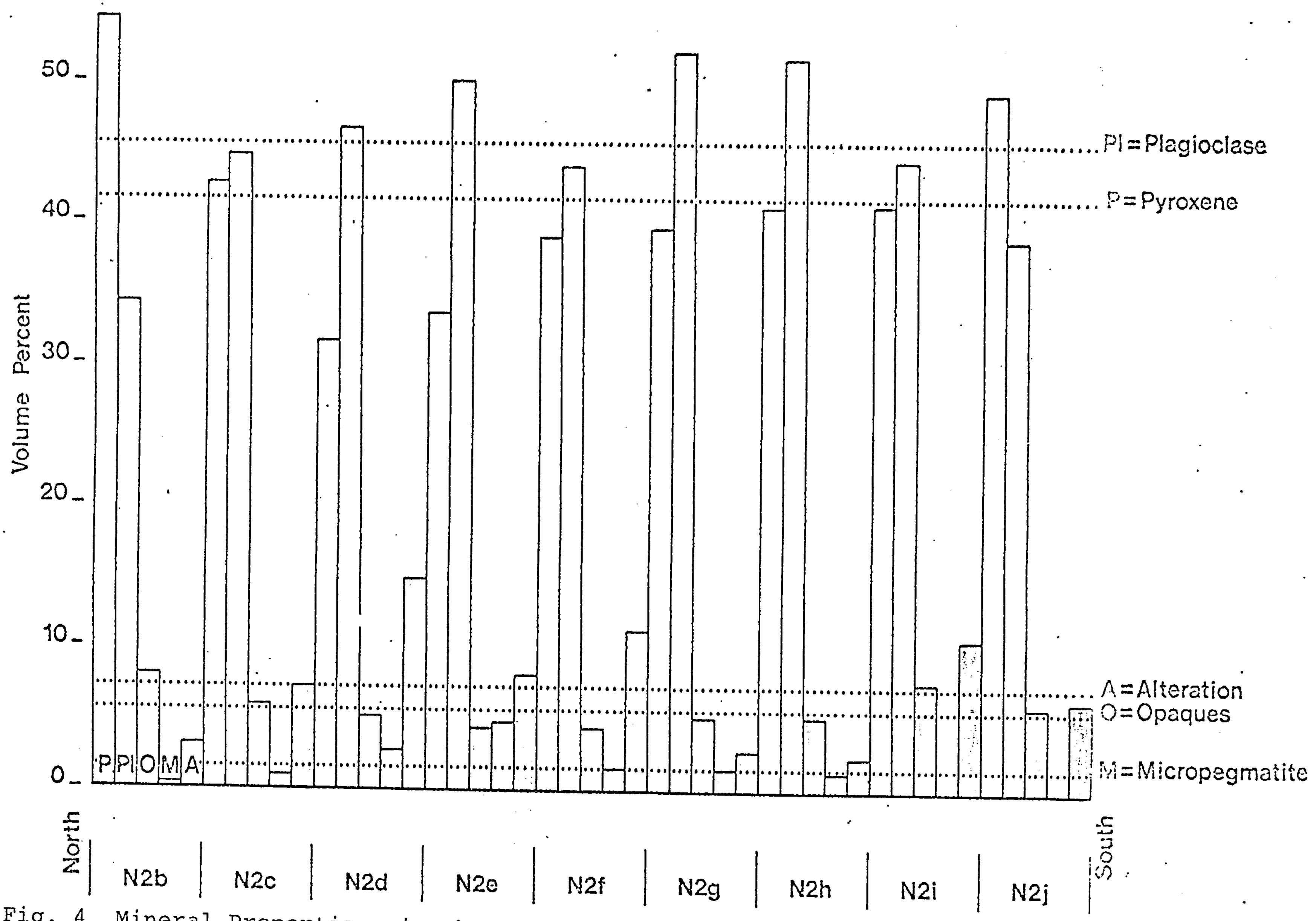


Fig. 4 Mineral Proportions in the Diabase Dike. Average of nine samples shown by dotted line.

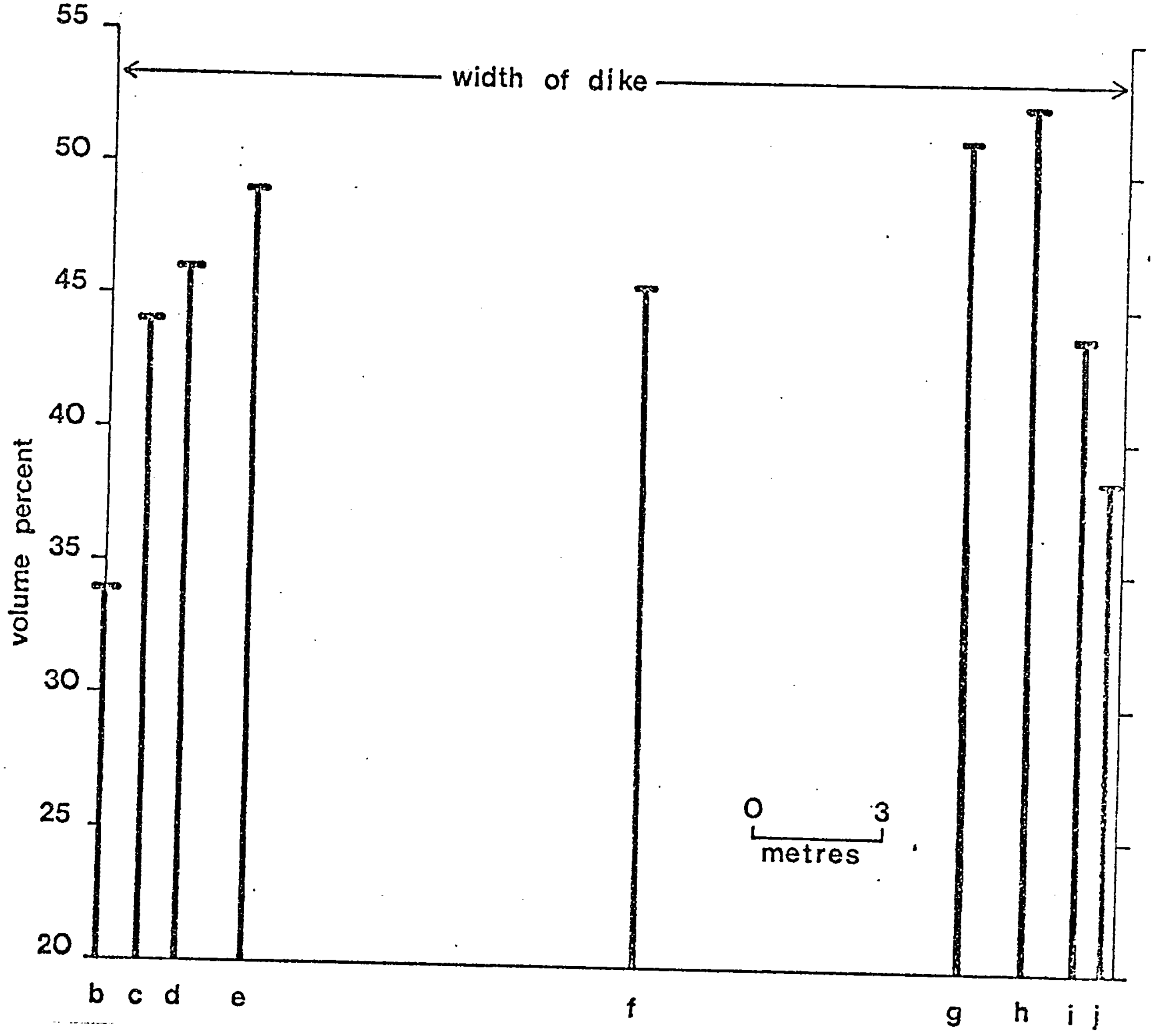


Fig. 5 Modal Percentage of Plagioclase Feldspar.

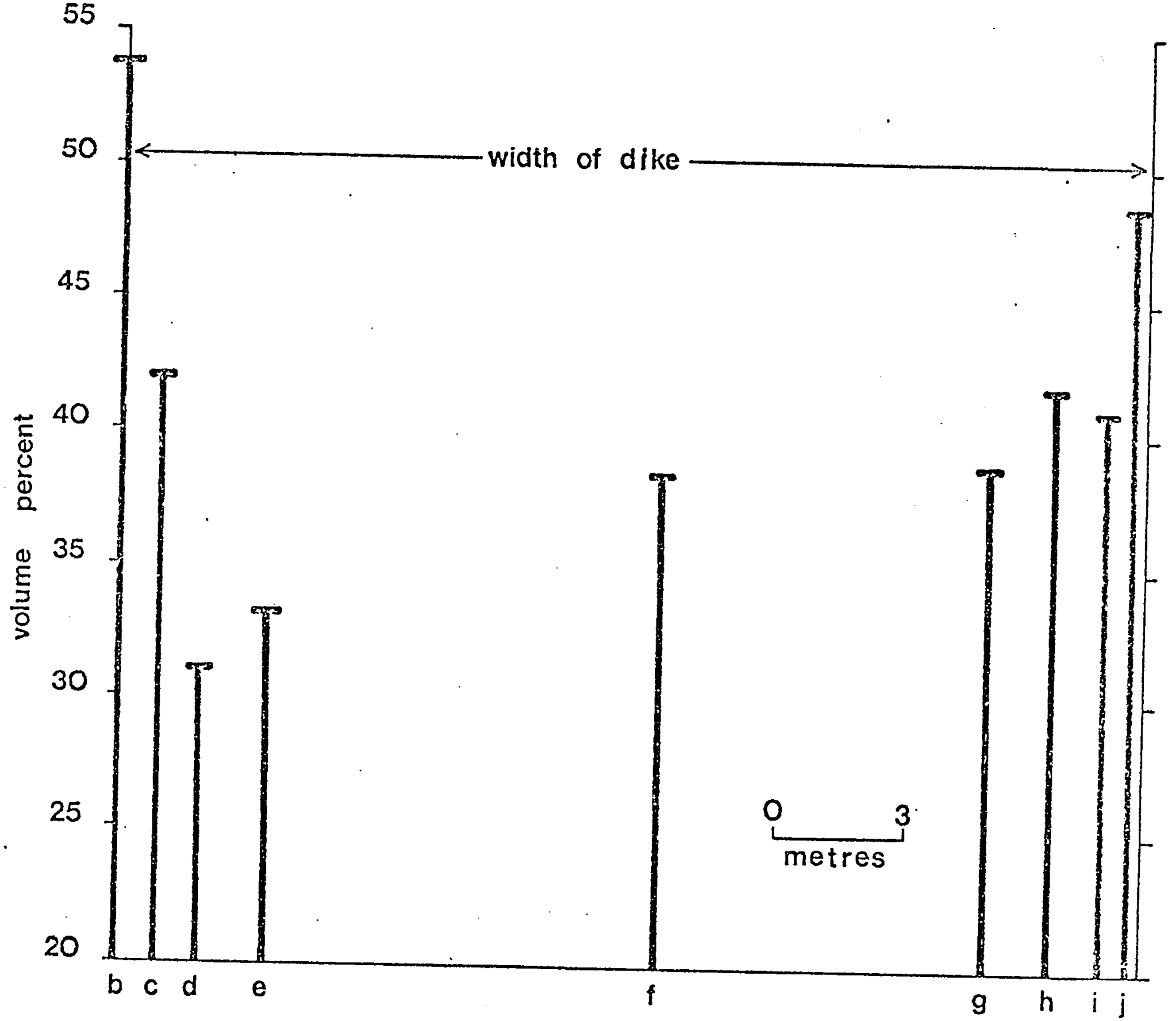


Fig. 6 Percentage of Pyroxene.

The two contact specimens display some differences in texture to those of the inner portion of the dike. The two contact thin sections appear to have some microphenocrysts of plagioclase and pyroxene in a very much finer grained matrix composed of plagioclase, pyroxene, opaque material and masses of alteration material. This porphyritic texture is especially well developed in N2b (plate 7). This thin section also displayed a weak orientation to tabular feldspar crystals; the orientation position was not determined but is probably parallel to the walls as stated by Brunet (1966). A further complication of this porphyritic texture is caused by the presence of a few very large grains which are altered as shown in plates 4 and 5.

In the thin sections two size ranges of plagioclase crystals predominate. Those plagioclase grains that appear enclosed in pyroxene grains are consistently smaller than the plagioclase grains that appear free of the pyroxene. The pointed "wedge-shaped" plagioclase crystals, which are only partly included within pyroxene, display an irregular blocky surface rather than a smooth plane of a true wedge (plates 2 and 3). The longer terraces parallel the cleavage directions of the plagioclase while the shorter rises, which form an obtuse angle rather than a right angle, appear to be conforming to parting or cleavage direction in the pyroxene grains similarly to crystal intergrowths described by Kretz (1966).

Variation in Mineral Proportions

Modal analyses were obtained for the specimens that were collected at intervals across the dike, and the results are presented in figs. 4, 5 and 6.

The modal amount of plagioclase, including alteration products, shows some variation across the dike, as is indicated in fig. 5. The lowest values of plagioclase content occur in the contact specimens. At these points the plagioclase represents less than forty percent of the rock. Inward about a metre from each contact the content rises to forty-four percent and generally rises, further inward, to values of forty-eight percent to fifty-three percent. The amount of plagioclase is greater in the southern half of the dike than in the northern half (fig. 5).

The distribution of pyroxene and alteration products in the dike appears to be complementary to the plagioclase distribution (fig. 6). The pyroxene is most abundant in the specimens selected at the contacts and within one metre of the wall. From these points inward the pyroxene is less abundant than the average for the dike. N2b has the highest pyroxene content of the nine specimens. This may be because "b" is the only sample taken right at the contact, while its counter location on the south side, N2j, was selected from 0.3 metres inward (fig. 2).

The distribution of the magnetite in the dike is quite uniform. The two specimens nearest each contact are enriched in magnetite and the amount diminishes inward to the middle of the dike (fig. 4)

The distribution of micropegmatite follows the trend of plagioclase in that it is lowest and absent at the contacts and becomes progressively greater toward the middle part of the dike. However, whereas the plagioclase was higher in amount in the southern half of the dike, micropegmatite is higher in the northern half (fig. 4).

Variation in Crystal Size

The result of crystal size measurements are presented in figs. 7 and 8. The mean size of plagioclase increases sharply in the marginal zones and apparently reaches a maximum in the central part of the dike. The mean size of pyroxene crystals also increases sharply in the marginal zones, but then it appears to decrease and be somewhat less in the centre of the dike than in the regions that lie about four metres from the contacts. However this is based on one sample.

In the graph of grain size, the long-axis dimension of pyroxene and the plagioclase appears to overlap both near the contact and at the centre of the dike.

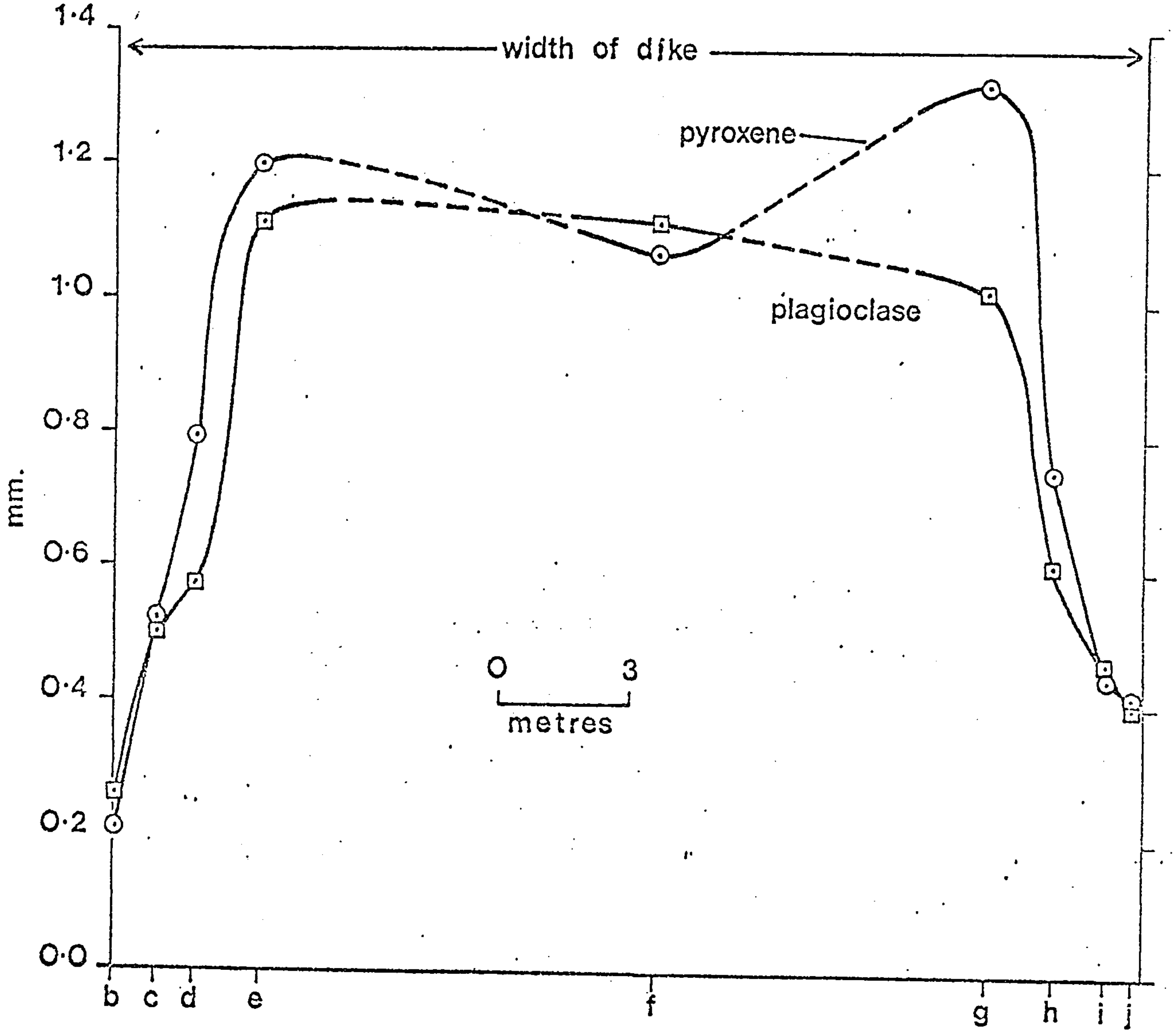


Fig. 7 Variation in mean grain dimension (long axis) across the diabase dike.

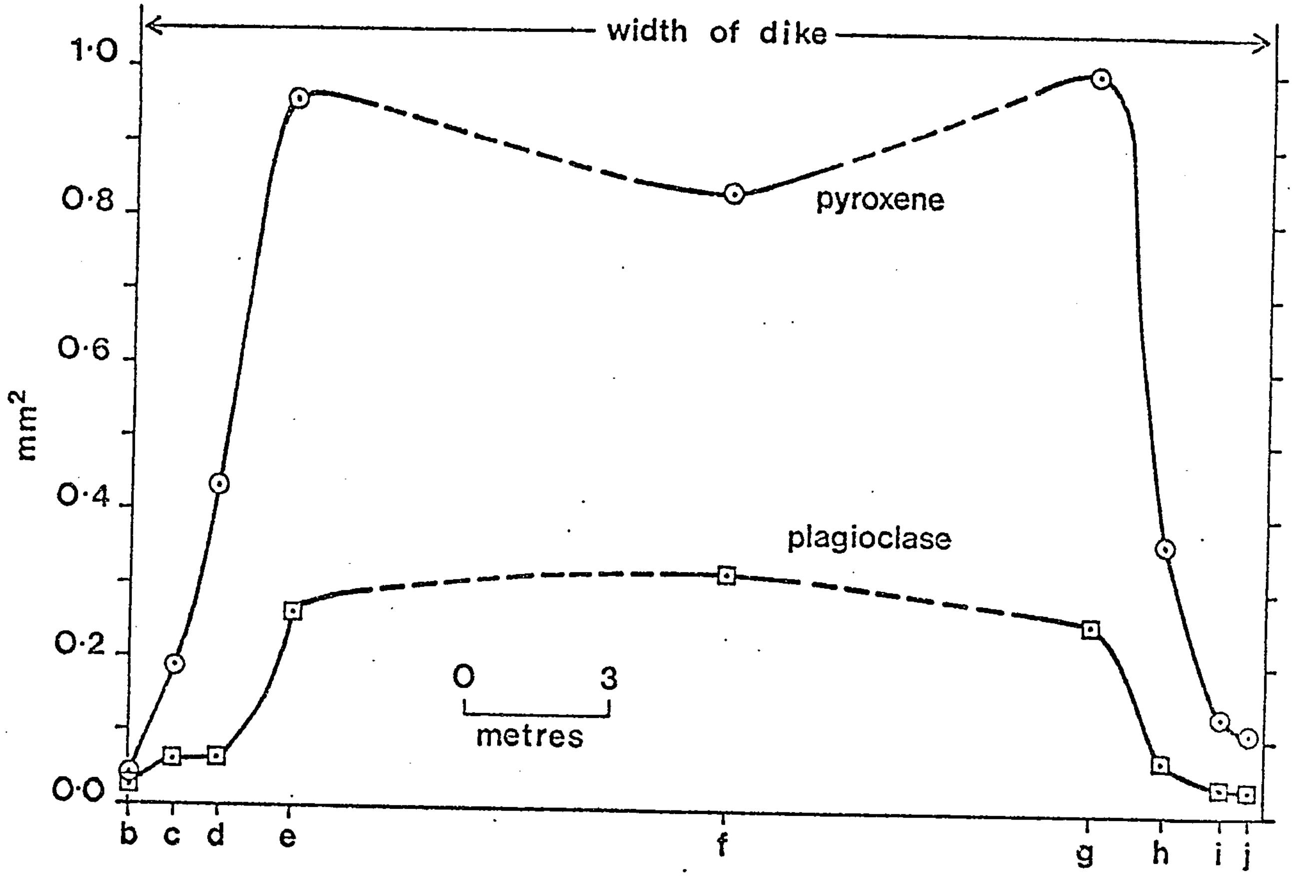


Fig. 8 Variation in average area of crystals as seen in thin section.

By calculating the products of the respective long axis and short axis, the area of crystals as seen in thin section were obtained and are plotted in fig. 8, giving a different range for each mineral, but the individual patterns remained similar.

Variation in Rock Composition

Chemical analyses of the nine specimens that were collected at intervals across the dike are listed in table 3 and the results are presented graphically in figs. 9 to 20. The unweighted average composition of the central and marginal portions of the dike, and of the dike as a whole, are listed in table 4, and are represented, in part, in fig. 21. The norms are listed in tables 5 and 6.

In attempting to determine whether or not two adjacent samples of rock have different concentrations of an element such as Ca, consideration must be given to the precision of the analyses. In a group of analyses, if we denoted d (CaO) as the difference between duplicate determinations of CaO, the maximum d (CaO) could be taken as a rough indication of precision. Then in adjacent samples, if the mean of the duplicate determinations in one was greater or less than the mean in the adjacent sample by an amount that exceeded d_{max}(CaO), then one could say that a difference exists in the CaO content of the two samples.

When the chemical analyses of the nine rock specimens are compared, only a small amount of variation is noted. Some variations are apparently erratic.

SiO_2

Fig. 9 shows a constant amount of silica across the middle portion of the dike. The downward trend at the north contact agrees with some of the petrographic observations. Thus the low amount of plagioclase and the higher amount of pyroxene, and the composition of plagioclase both indicate that less silica would be present in the margins. The higher amount of opaque minerals also may contribute to this. If mol-percentages are plotted, the variation of silica across the

Table 3

Mean of Duplicate weight-percent Analyses for Rocks

Sample No.	N2b	N2c	N2d	N2e	N2f	N2g	N2h	N2i	N2j
SiO_2	46.07	47.27	49.61	48.32	48.39	48.5	47.34	48.30	48.28
Al_2O_3	15.55	14.80	11.55	15.53	14.97	14.34	16.19	13.54	13.29
Fe_2O_3	2.31	3.69	4.00	4.45	3.37	3.41	3.10	3.31	3.32
FeO	11.42	11.16	9.79	8.11	10.68	10.13	11.03	10.13	10.16
CaO	11.27	10.77	11.72	12.32	11.32	11.39	11.57	11.65	11.92
MgO	6.20	5.88	6.27	5.09	4.46	5.99	4.52	6.18	6.01
MnO	0.11	0.14	0.10	0.12	0.11	0.15	0.11	0.12	0.11
TiO_2	1.63	1.66	1.75	1.35	1.70	1.70	1.61	1.63	1.58
Na_2O	2.29	2.15	2.32	2.19	2.22	2.36	2.12	2.14	2.06
K_2O	0.34	0.31	0.28	0.25	0.41	0.31	0.30	0.34	0.39
CO_2	0.93	0.19	0.21	0.36	0.14	0.26	0.39	0.28	0.20
H_2O^+	0.78	0.70	0.90	0.56	0.82	0.30	0.34	0.65	0.81
Total	98.90	98.72	98.50	98.65	98.59	98.84	98.62	98.27	98.02

Legend for chemical analyses graphs

●	duplicate analyses
x	mean of duplicate analyses
I	max. difference between duplicate analyses. d_{max}

Horizontal axis represents 23.8 m
from northwall on the left to
southwall on the right.

Letters b to j refer to sample locations.

Fig. 9 SiO_2

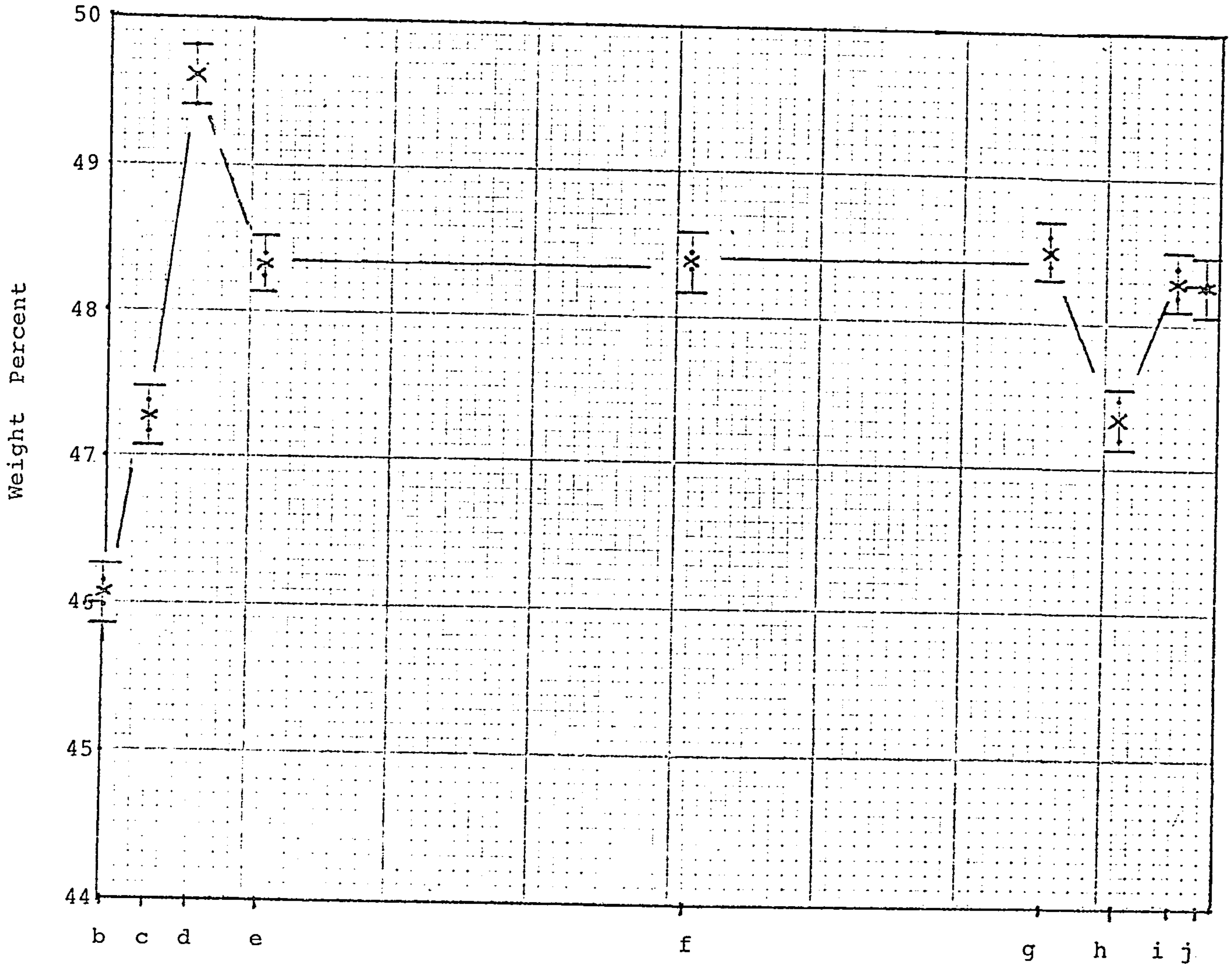
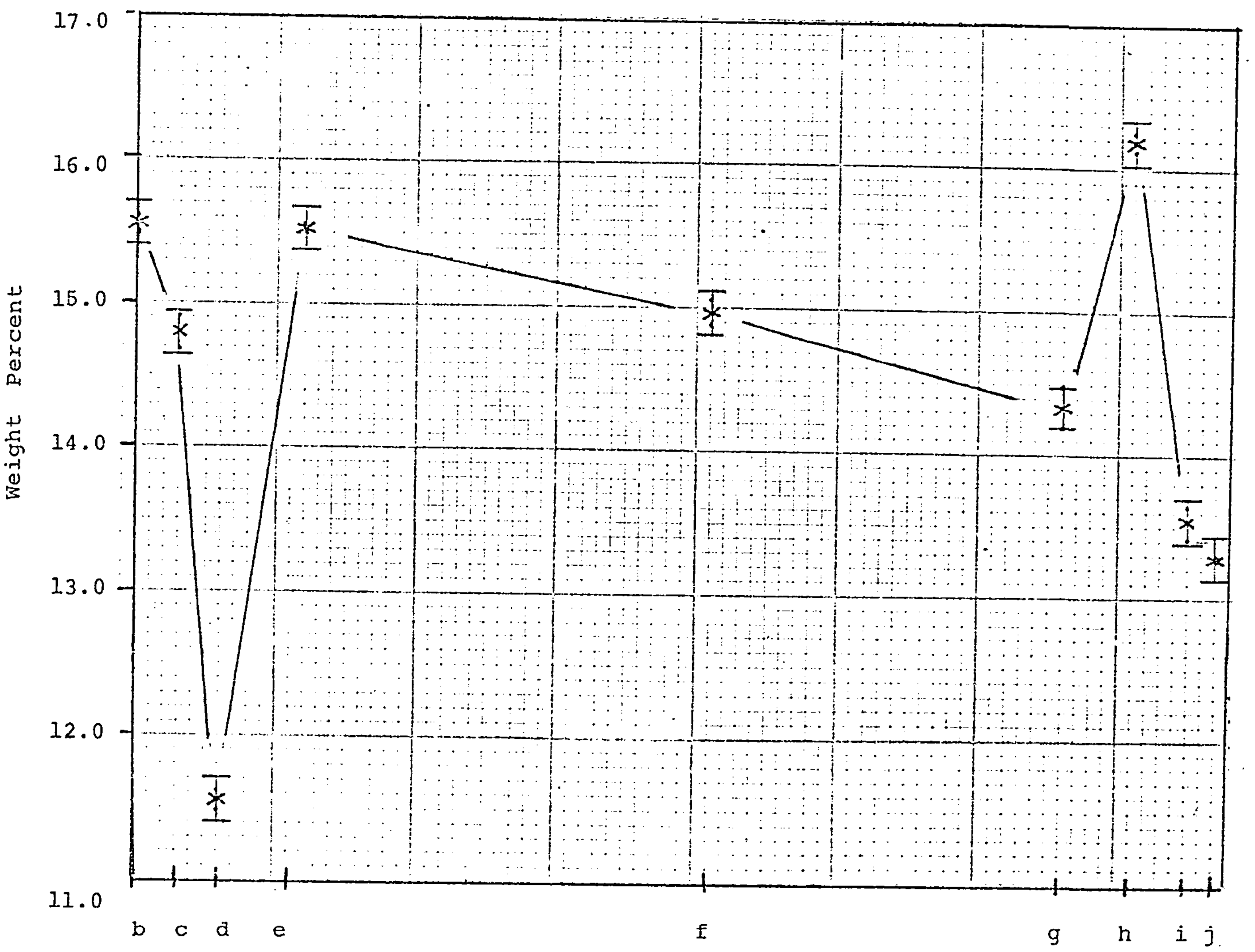


Fig. 10 Al_2O_3



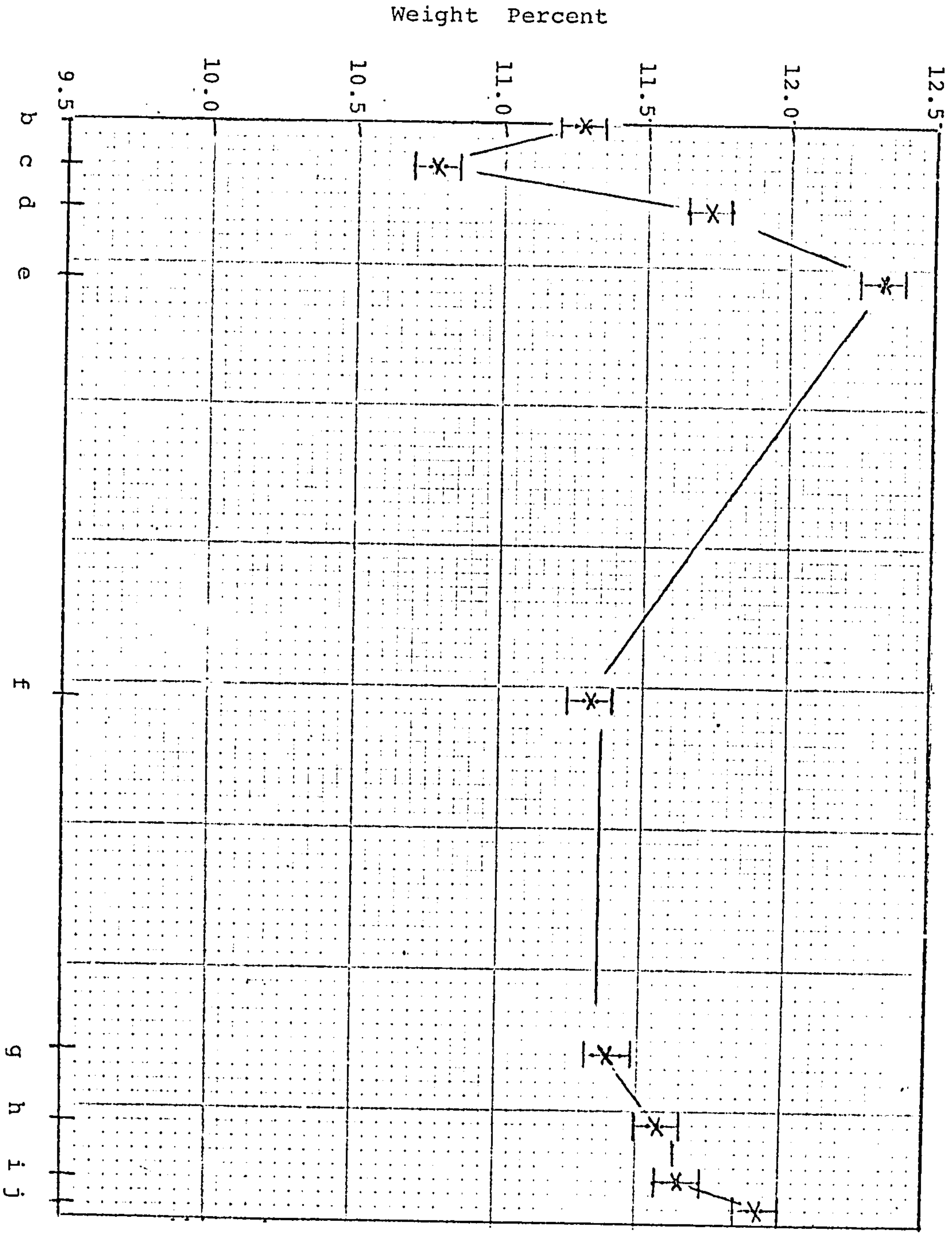


Fig. 11 CaO

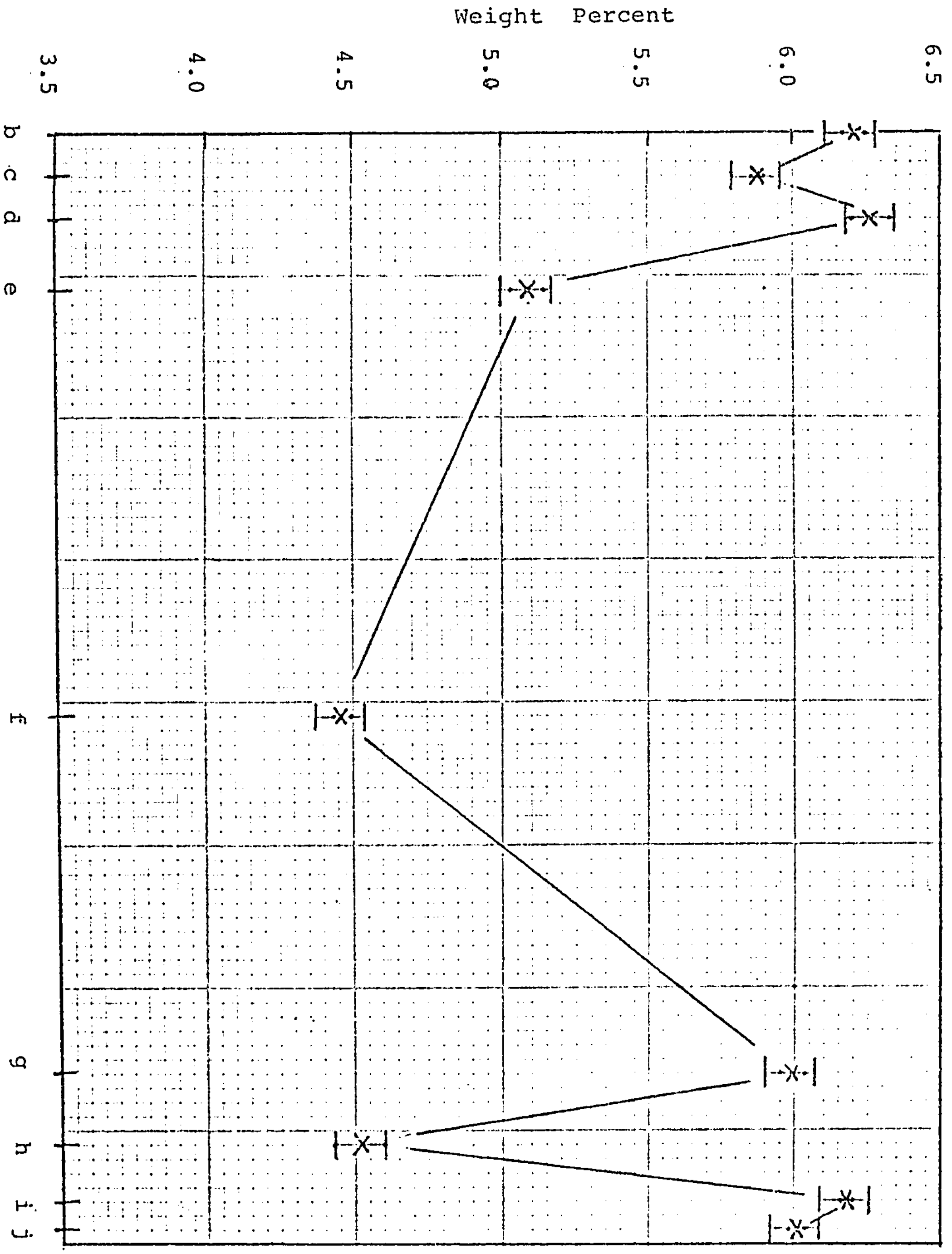


Fig. 12 MgO

Fig. 13 Na_2O

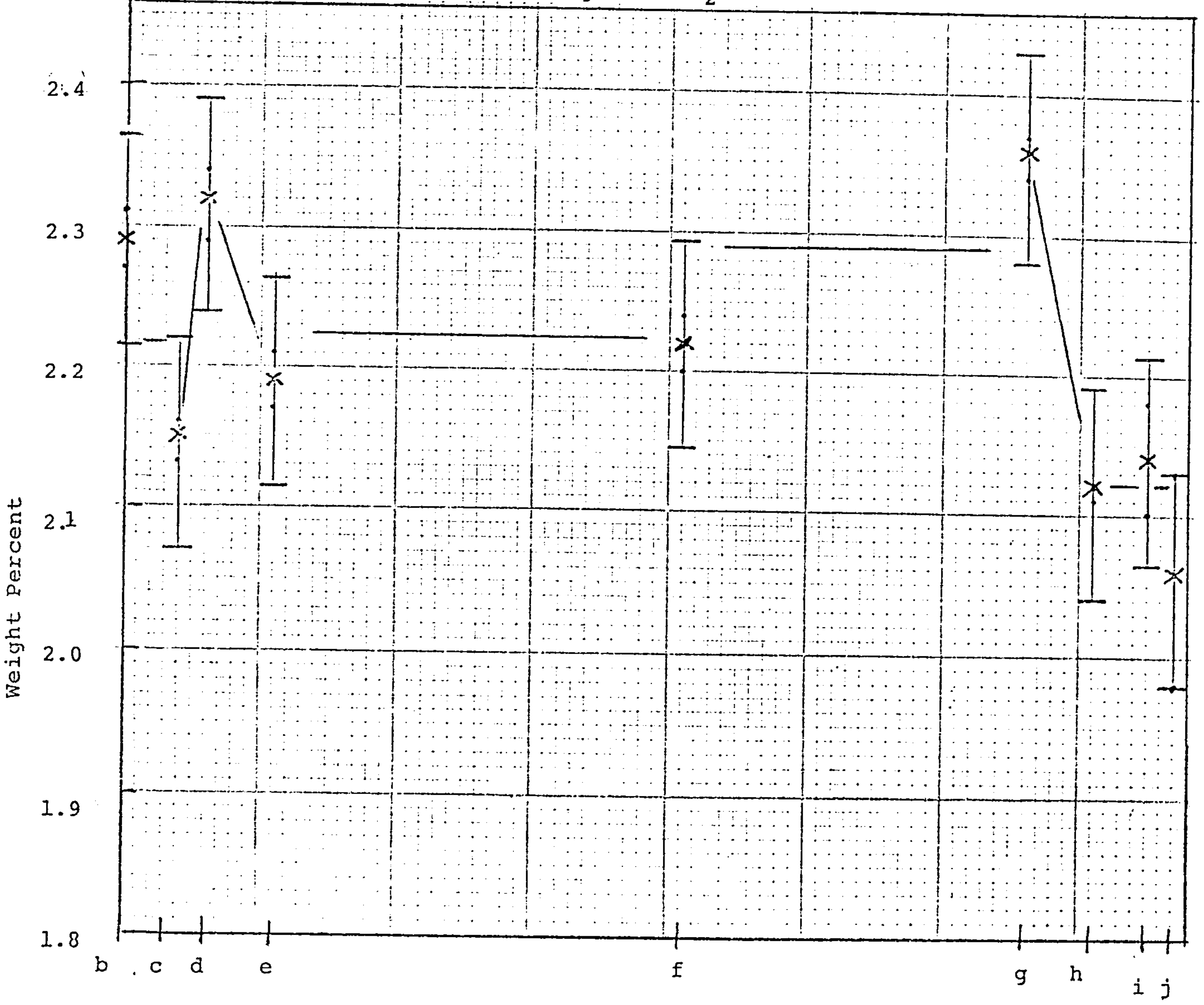


Fig.14 K_2O

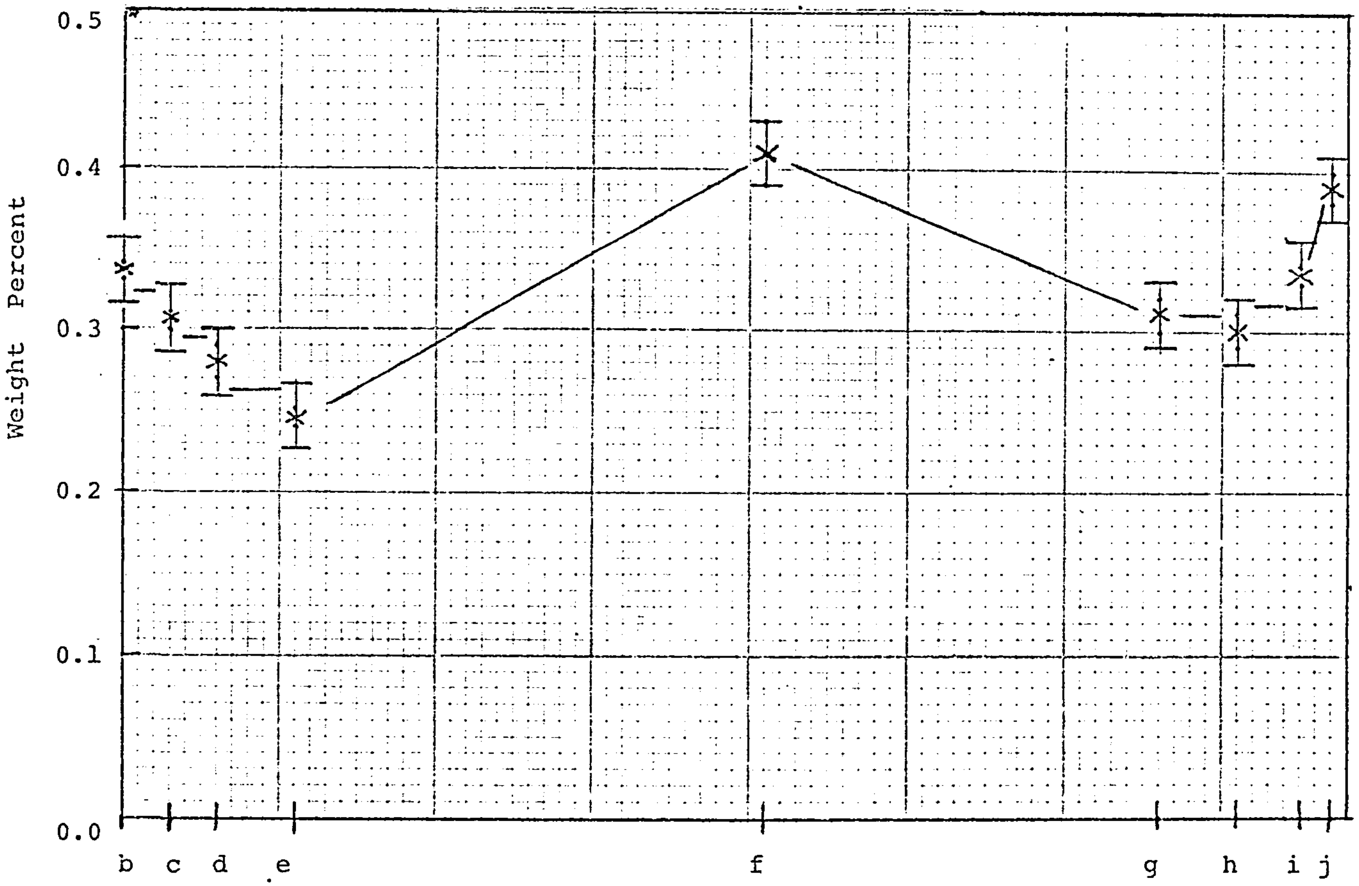


Fig. 15 FeO

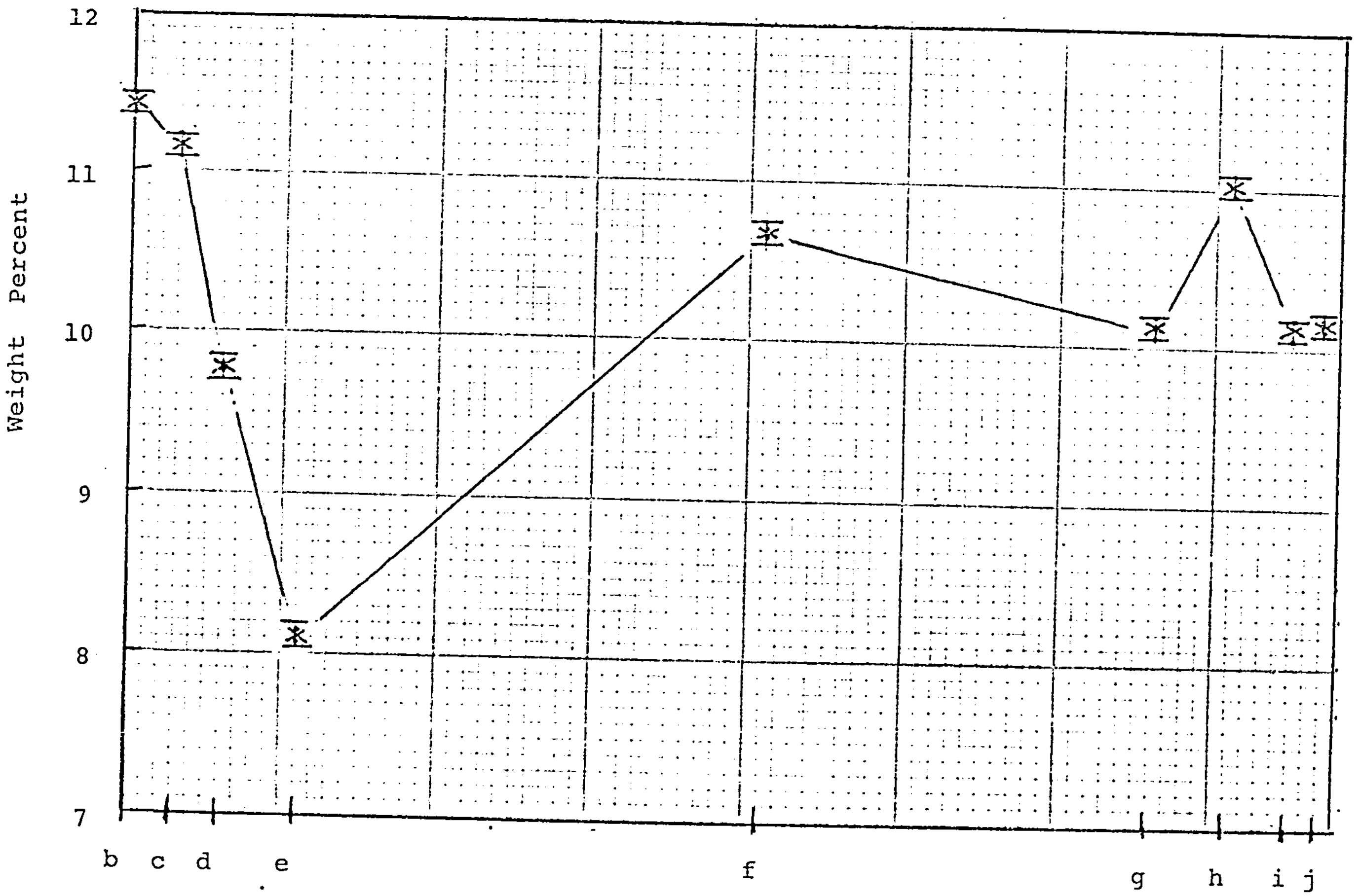


Fig. 16 MnO

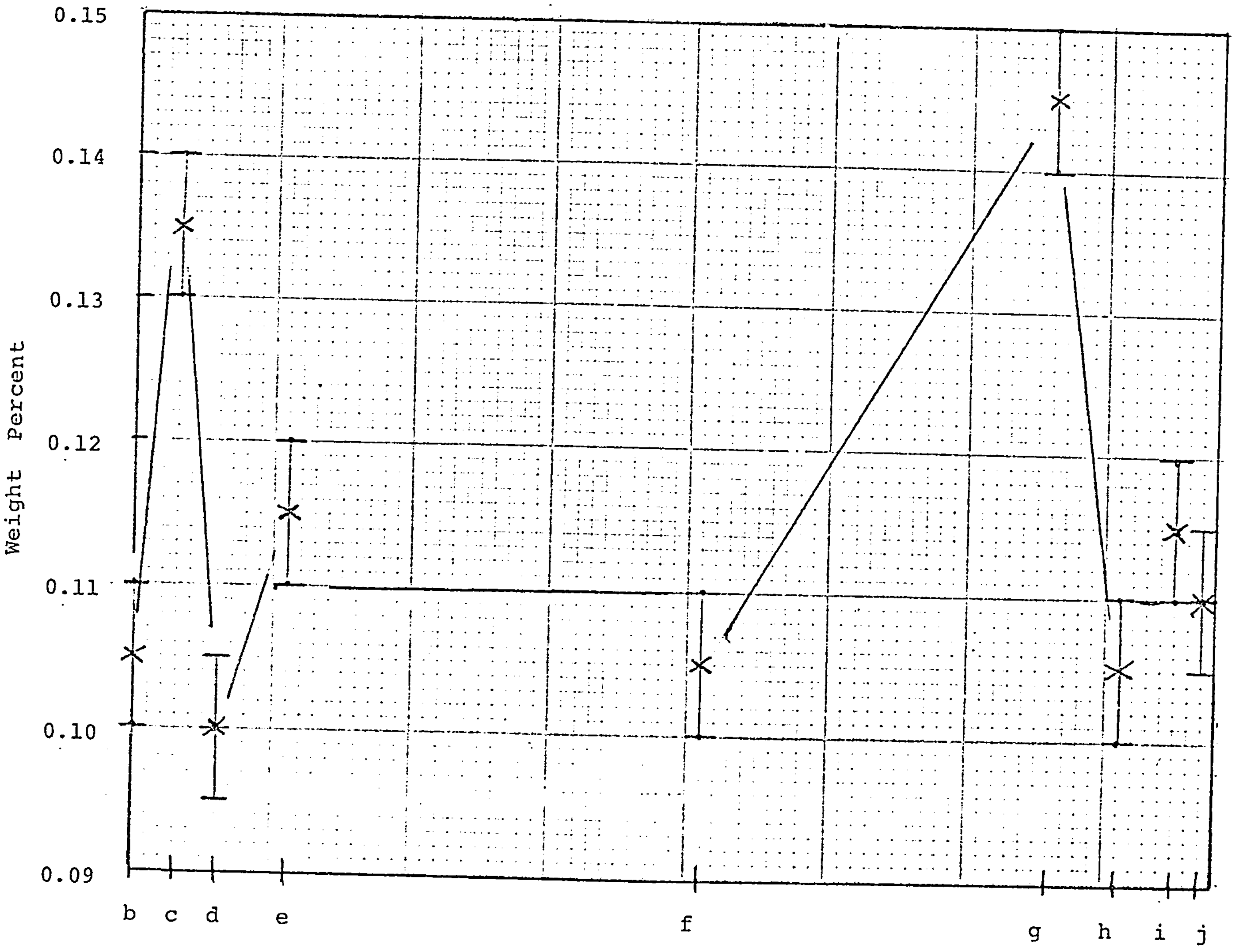
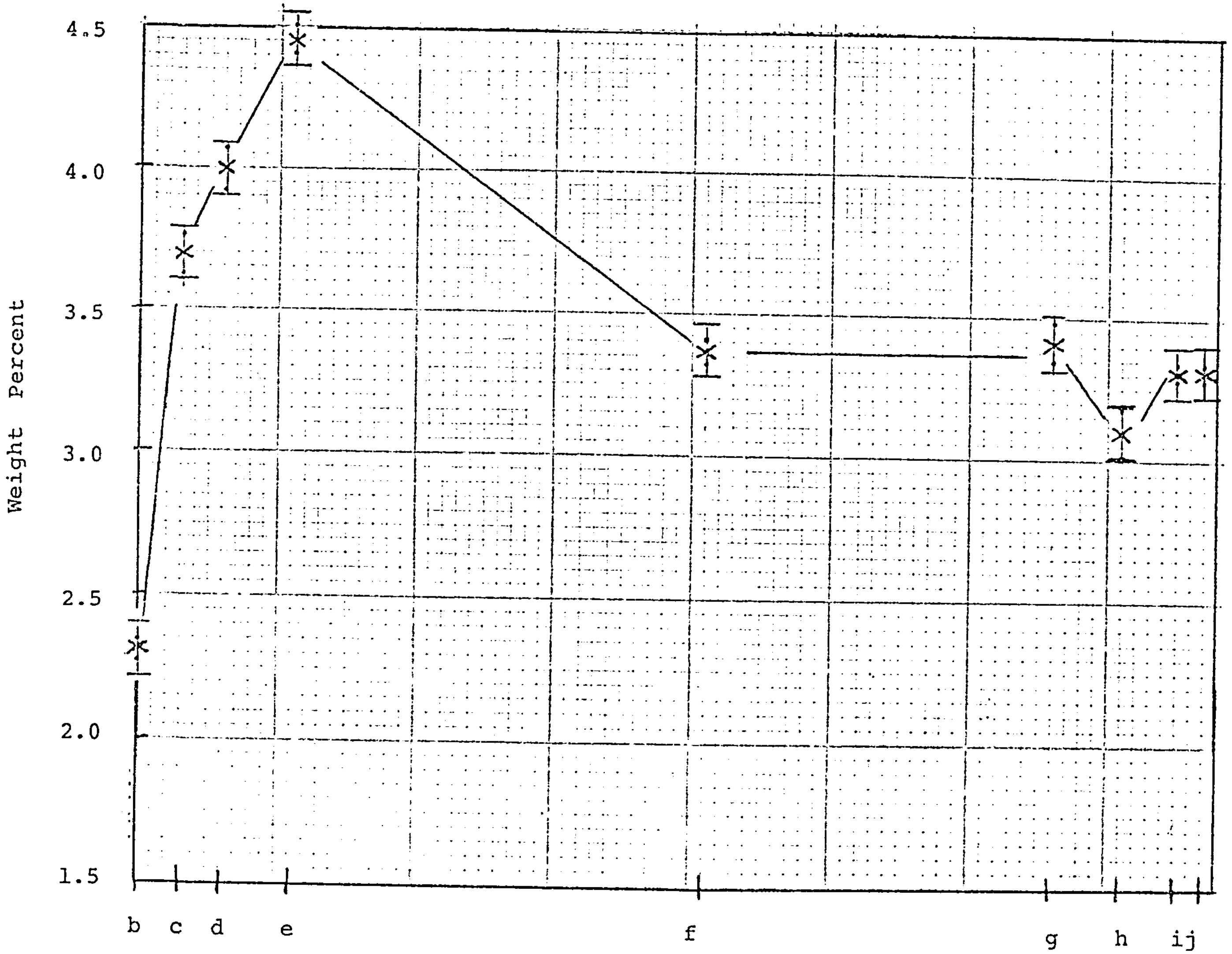


Fig. 17 Fe_2O_3



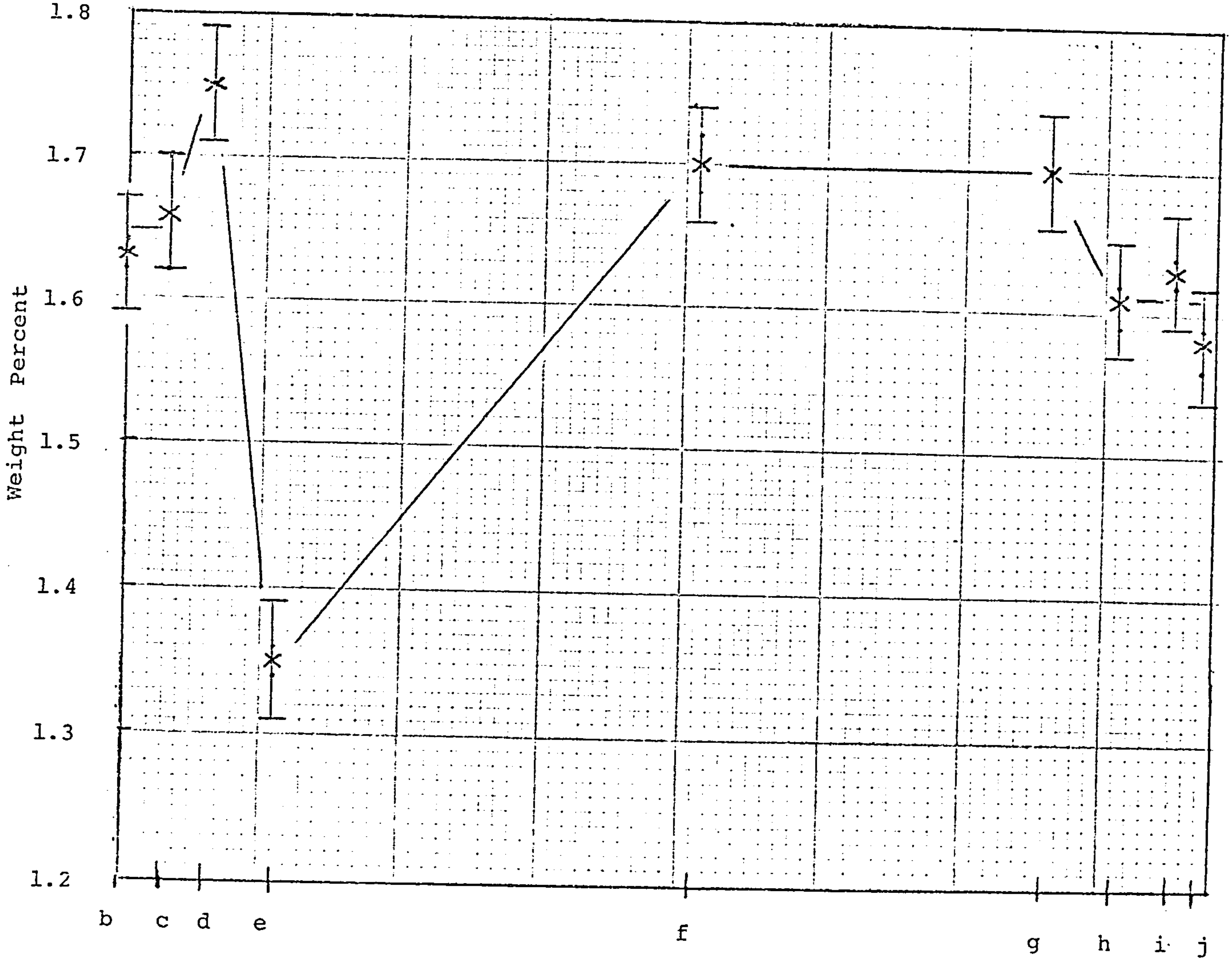


Fig.18 TiO_2

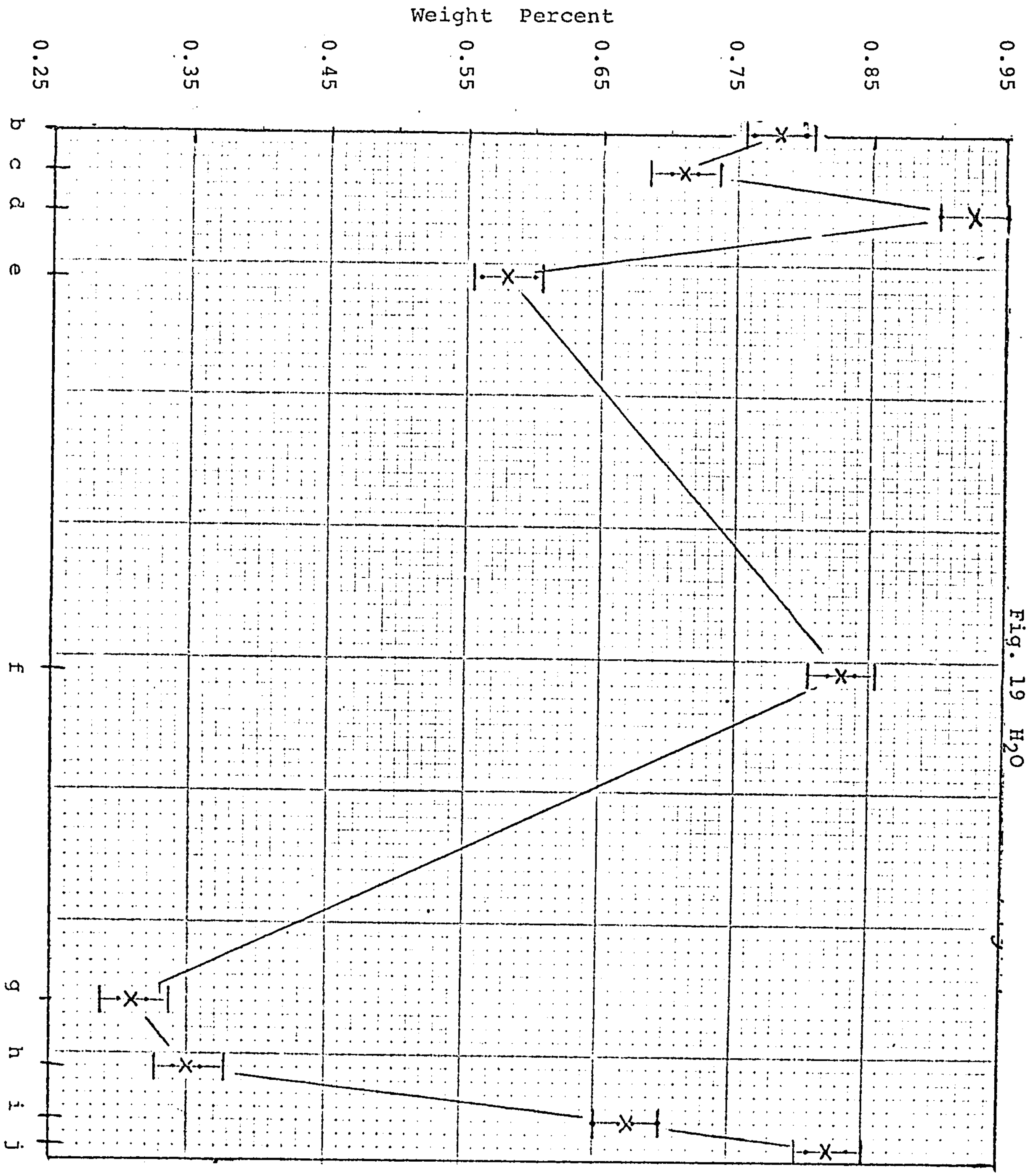


Fig. 19 H_2O

Fig. 20 CO_2

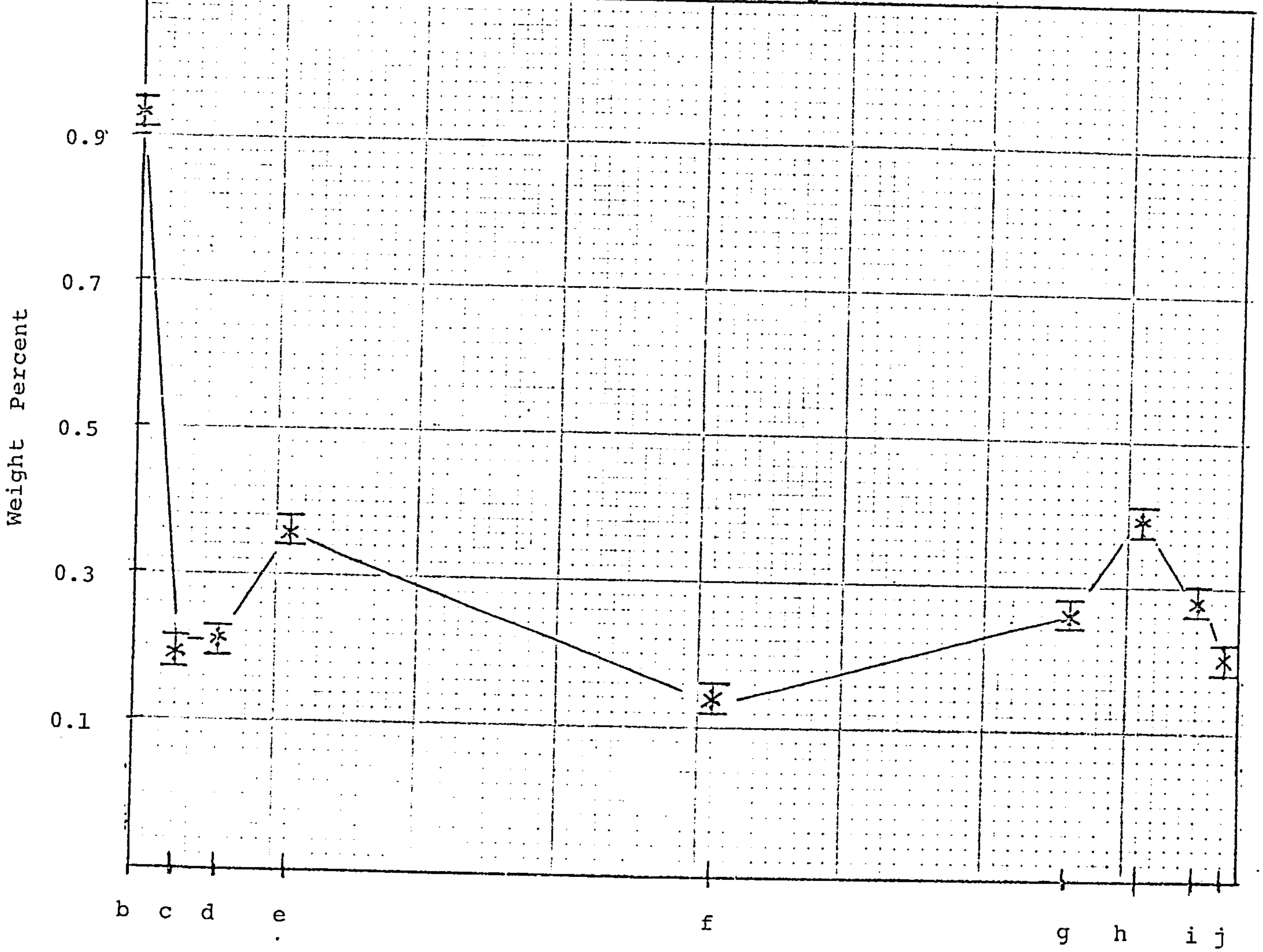


Table 4

Average Weight-percent of Rock Analyses

Oxides	3 Central Specimens N2e, N2f & N2g	6 Margin Specimens N2b, c, d and h, i, j	All 9 Specimens
SiO_2	48.40	47.81	48.01
Al_2O_3	14.95	14.15	14.55
Fe_2O_3	3.74	3.28	3.44
FeO	9.64	10.61	10.35
CaO	11.67	11.48	11.55
MgO	5.18	5.84	5.62
MnO	0.13	0.12	0.12
TiO_2	1.58	1.64	1.62
Na_2O	2.26	2.18	2.21
K_2O	0.32	0.32	0.33
CO_2	0.25	0.37	0.33
H_2O^+	0.56	0.70	0.65
TOTALS	98.34	97.79	98.35

Table 5

Norms for Gatineau Diabase Dike Samples

	N2b	N2c	N2d	N2e	N2f	N2g	N2h	N2i	N2j
Kf	2.2	2.08	1.9	1.68	3.0	2.05	2.0	2.26	2.58
Ab	23.3	21.86	23.47	21.99	22.45	23.72	21.38	21.68	20.93
An	35.26	33.73	22.84	35.61	33.41	30.88	37.89	29.73	29.31
di- -he	21.0	20.05	32.02	24.60	22.39	24.23	19.91	26.66	28.25
en- -hy	2.5	15.69	18.31	15.63	18.43	13.96	14.17	16.29	16.34
O1	15.74	6.58	-	-	0.56	5.15	4.65	3.38	2.58
Qz	-	-	1.51	0.48	-	-	-		

(Simplified form from Bayly, 1968)

Table 6

Norms For Average of Analyses of Gatineau Dike

	3 central specimens N2e, N2f & N2g	6 margin specimens N2b,c,d, and h,i,j	all 9 specimens
Kf	2.12	2.14	2.19
Ab	22.72	22.12	22.30
An	33.21	31.45	32.37
di- -he	23.74	24.72	24.11
en- -hy	16.96	14.36	14.56
Ol	1.28	5.23	4.47
Qz	-	-	-

(Simplified form from Bayly, 1968)

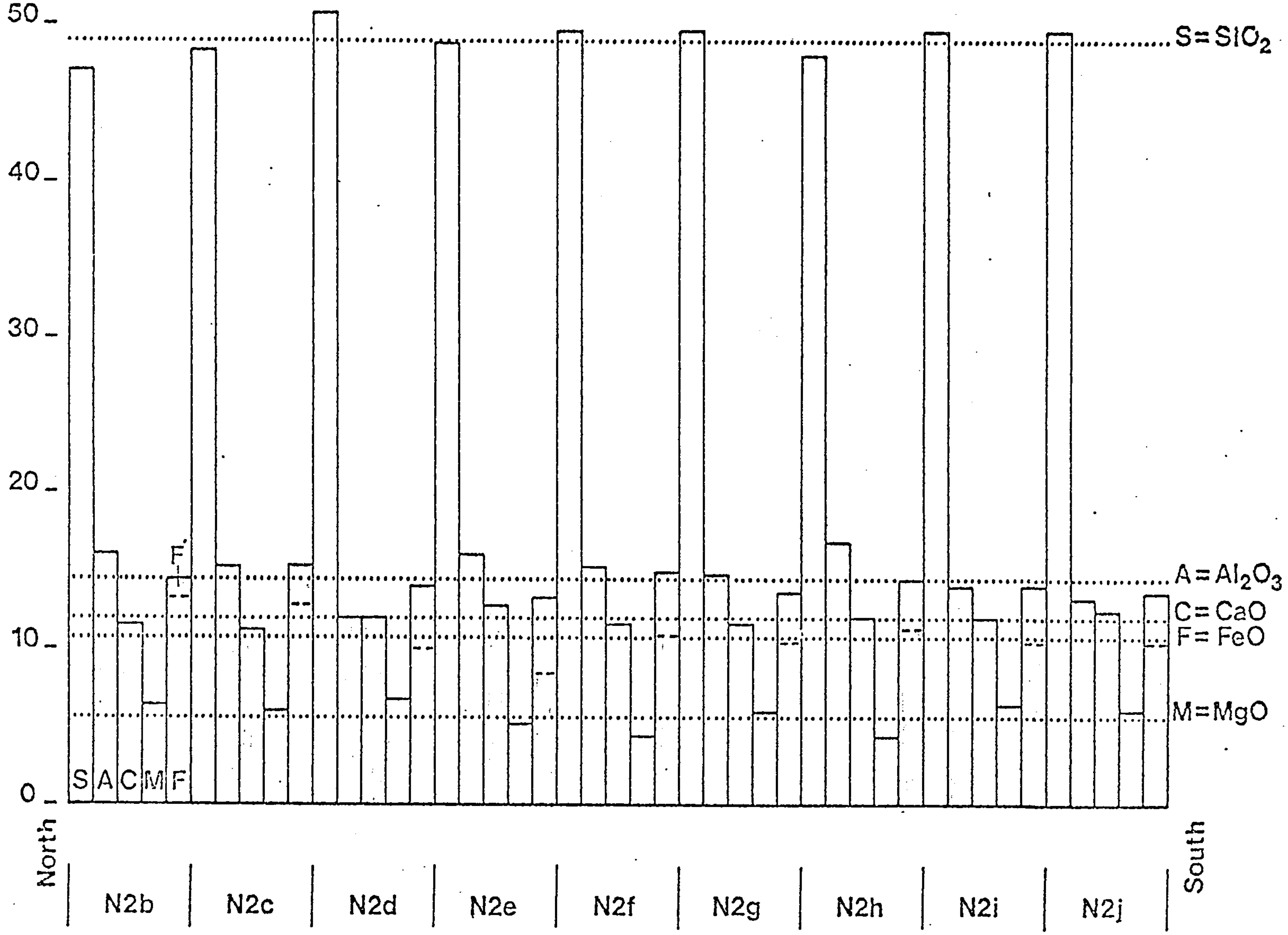


Figure 21. %-wt. of Oxides in Dike. Average of nine analyses shown by dotted line.

dike is more apparent to petrographic evidence.

Al_2O_3

The analyses plotted an irregular pattern across the dike (fig. 10). An interesting phenomenon is the corresponding high values of silica with low values of alumina, and vice versa, at N2d and N2h. The ions of aluminium and silicon may to some extent substitute for each other in silicate minerals.

CaO

Calcium oxide is an important cation of both the major minerals of the dike, which allows it more freedom in its location throughout the dike than some of the other oxides. Near the south side of the dike the amount of variation is more regular than at the north side.

MgO

The magnesium is almost entirely contained in pyroxene. The rock analysis graph shows magnesia highest at the contacts, and low values in the middle part of the dike (fig. 12), which is to be expected when comparison is made to the relatively high pyroxene content in the margins. The low pyroxene modal count for N2d may be due to much hornblende alteration being counted separately from the pyroxene. Hornblende alteration was highest in quantity at this point.

Na_2O

Considering the proposed guidelines concerning precision, soda does not necessarily vary much across the dike (fig. 13). A notable drop in value occurs near the south side.

K_2O

Potash represents a very small amount of the chemical content of the rock samples. Considering precision, only a small amount of variation can be detected from fig. 14. The high potash value at the centre agrees with the description of many other diabase dikes (Archbold, 1962, and Walker, 1957), and it agrees with the modal observations that micropegmatite is concentrated near the middle of the dike.

FeO

The ferrous oxide represents more than ten percent of the dike rock composition, and it records the largest amount of variation (fig. 15). The distribution of ferrous iron was measured in pyroxenes from three samples, but the amount used by opaque minerals and alteration material is not known. The low value at N2e might be attributed to the lesser amount of opaque mineral and the above average amount of alteration material. On the other hand the high value at N2h may be due to the freshness of that sample.

MnO

The manganese content in the dike is small and some variation was found across the dike (fig. 16).

Fe_2O_3

Ferric iron shows the most variation at the north half of the dike (fig. 17), and considering precision, very little variation occurs in the south half of the dike. The variation trends in ferric iron appear to be complementary to the trends in ferrous iron (fig. 15) especially in the north contact zone. The anomalous trends of N2e and N2h for ferrous iron are reversed for the ferric graph, and suggests that secondary oxidation has occurred.

The lower amount of total iron (ferrous plus ferric) at the south contact zone is reflected by the lower modal count for opaque mineral in this same zone. The combined iron concentration would appear to support modal information on opaque minerals, pyroxene and alteration material, combined.

TiO_2

Similarly to ferric iron, the titanium shows the most fluctuation in the north half of the dike (fig. 18). Ilmenite has been detected in some of the magnetite from the opaque material, and this may account for most of the distribution of titanium.

H_2O^+

Water of crystallization represents a very small amount of the dike's composition, and values vary irregularly across the dike (fig. 19). The highest value, N2d, corresponds to the large amount of hornblende observed in this specimen.

CO_2

Carbon dioxide represents less than one half of a percent, except for the north contact where it is nearly one percent. Carbon dioxide varies erratically across the dike (fig. 20).

Variation in Mineral Composition

The above data on mineral proportions and rock composition indicate that the greatest variation in the composition of the dike may occur in the 3 to 4 metre wide marginal zones, particularly that adjacent to the north contact. Hence pyroxene and plagioclase were separated from specimens N2c, N2d, and N2e for chemical analysis. These specimens were obtained at intervals within the north margin; the specimen N2b, from the north contact was not used for mineral analysis because of its very fine grain size. The analyses are listed in tables 7 and 8, and are presented graphically in figs. 22 to 25.

A rough estimate of the precision of the mineral analyses is obtained from the maximum difference between duplicate determinations (d_{max}) for each of the element oxides determined. These d_{max} values are then used to estimate whether or not differences exist in the chemical composition of the three pyroxene and the three plagioclase samples (figs. 22 to 25).

Plagioclase

The three main components of plagioclase, silica, alumina and lime show a consistent variation from N2c to N2e (fig. 22), and this variation supports the estimate in plagioclase composition, based on extinction angles. The silica is essentially constant, but may increase slightly, while alumina and calcium decrease from c to e (from contact toward the centre). The decrease in Ca from c to e should be accompanied by an increase in Na. Hence the plagioclase at c (fig. 22) is apparently too high in Na_2O by about 0.5 weight percent and may be in error.

The chemical analyses consistently show values of MgO and Fe_2O_3 that are much too large, when compared to other plagioclase analyses, and these determinations are considered to be in error. The reported Fe^{+3}/Fe^{+2} values are much higher than in pyroxene, and it therefore seems unlikely that pyroxene impurity could account for the anomalous results.

Table 7

Mean Duplicate Weight Percent Analysis of
Separated Plagioclase

(K_2O, P_2O_5 and CO_2 not determined)

Sample No.	N2c	N2d	N2e
SiO_2	52.07	52.11	52.19
Al_2O_3	28.46	28.35	28.10
Fe_2O_3	2.22	2.41	2.38
FeO	0.36	0.35	0.36
CaO	11.35	11.24	11.16
MgO	2.28	2.86	2.87
MnO	0.02	0.02	0.02
Na_2O	3.41	3.00	3.05
TiO_2	0.11	0.09	0.10
H_2O^+	0.30	0.31	0.32
Totals	100.58	100.74	100.55

Table 8

Mean Duplicate Weight Percent Analysis of Separated Pyroxene

(K_2O, P_2O_5 and CO_2 not determined)

Sample No.	N2c	N2d	N2e
SiO_2	48.13	48.19	48.02
Al_2O_3	5.79	5.20	5.09
Fe_2O_3	6.61	6.41	6.48
FeO	11.33	11.23	11.46
CaO	14.49	14.60	14.36
MgO	12.41	12.19	12.43
MnO	0.29	0.29	0.28
Na_2O	0.59	0.59	0.59
TiO_2	0.31	0.31	0.30
H_2O^+	0.60	1.19	1.31
Totals	100.55	100.2	100.32

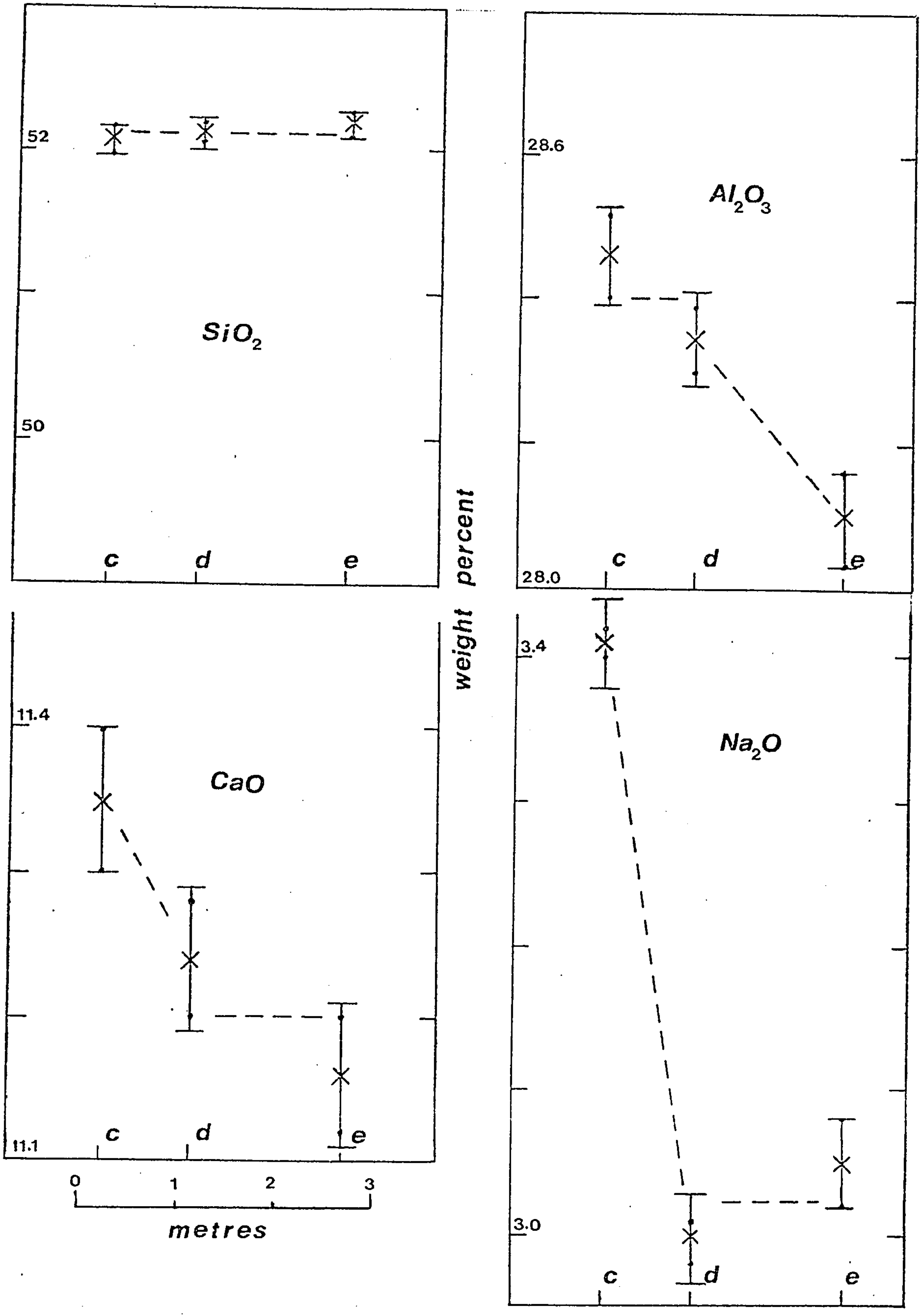


Fig. 22. Chemical analyses of plagioclase.

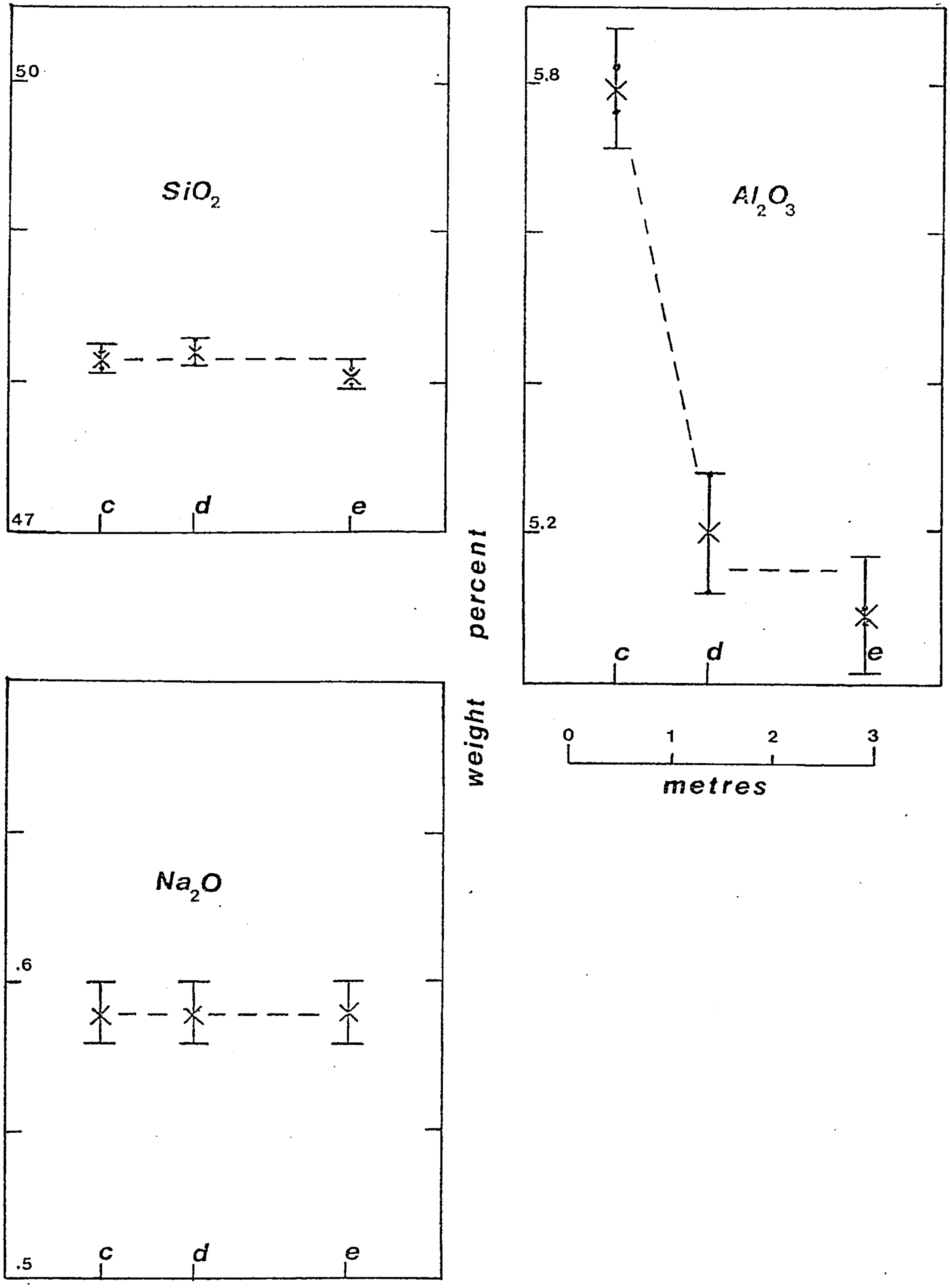


Fig. 23. Chemical analyses of pyroxene

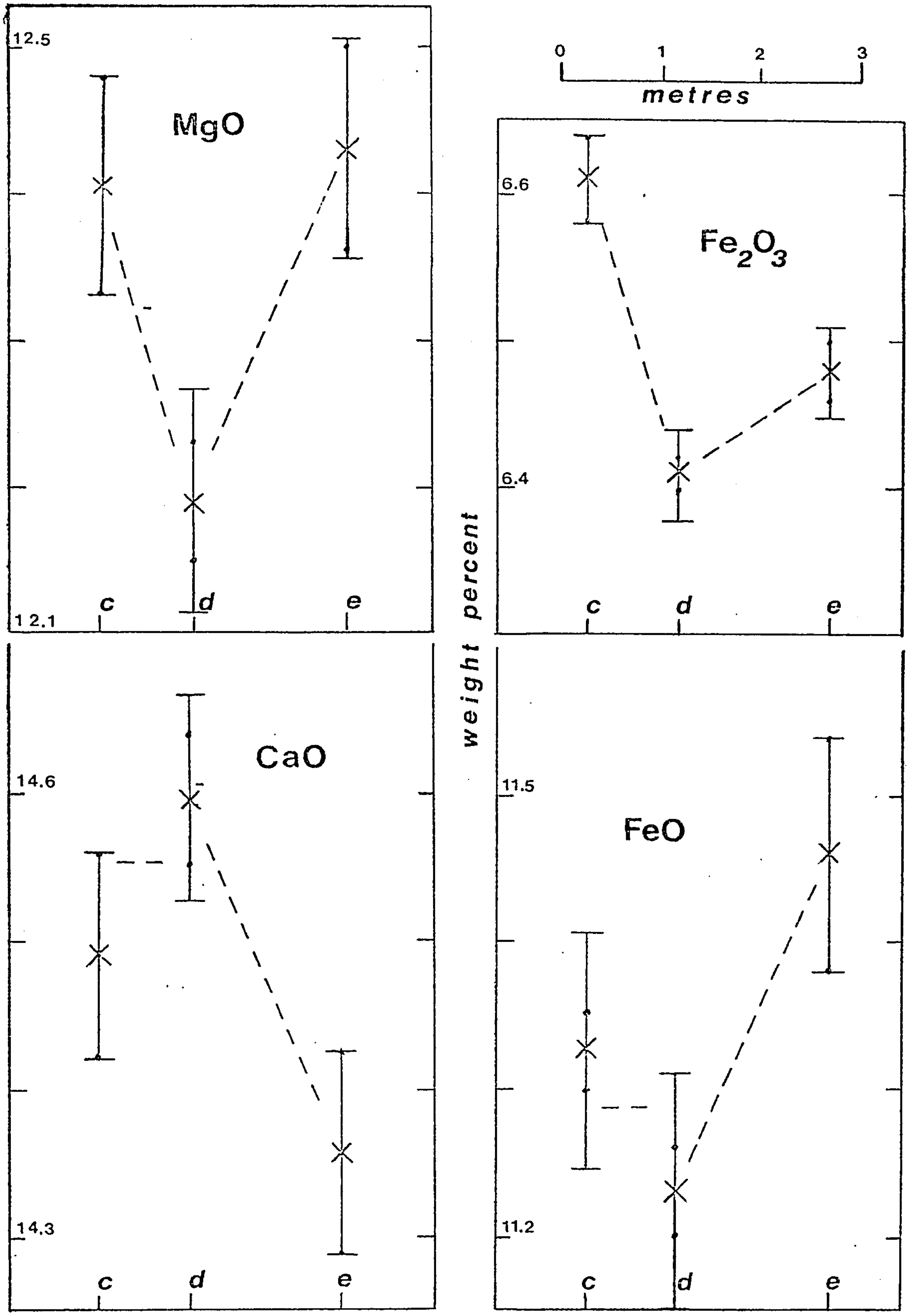


Fig. 24. Chemical analyses of pyroxene

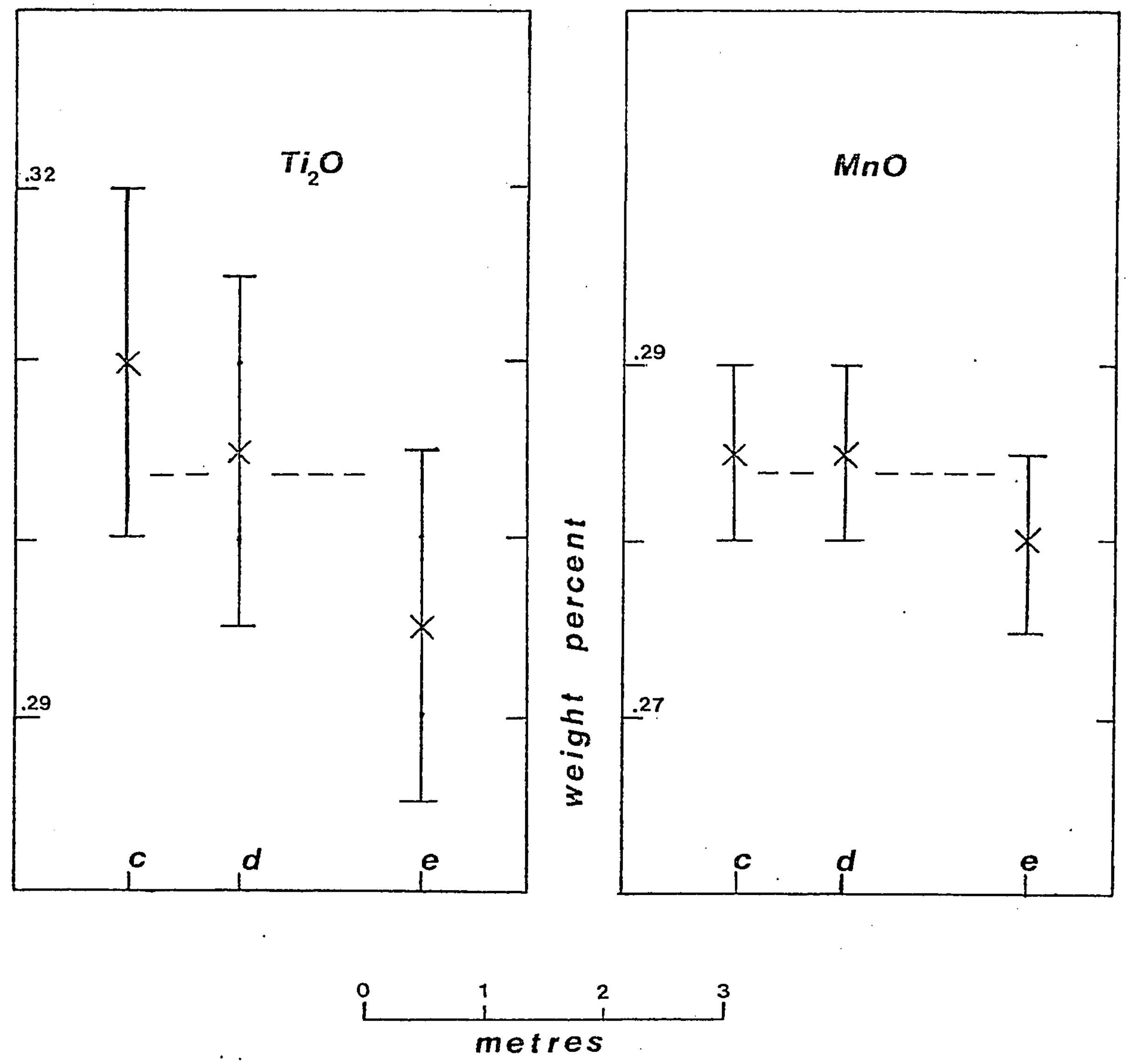


Fig. 25. Chemical analyses of pyroxene

Formulas were calculated for the 3 plagioclase samples, uncorrected for Fe^{+3} and Mg, according to the method used by Deer, Howie and Zussman (1966), and these are listed in table 9. A sample calculation is given in the Appendix.

Technical Service Laboratories were unable to obtain potash values from the samples of plagioclase and pyroxene, and for purposes of mole proportions and formula calculations the potash value from the respective rock analysis was adjusted and substituted without consideration to the amount needed for micropegmatite.

The calculated anorthite content of the minerals is higher than that obtained by extinction angle measurements (fig. 3). This may be due to error in the Na analyses. Although some error may be present in the chemical analyses, the trends for Ca and Al shown in fig. 22 are considered to be real.

Norm calculations for the corresponding rocks gave a range in An content of normative plagioclase of An_{49} to An_{62}, with an average of An_{60}. These values are lower than those obtained directly, as noted above.

Pyroxene

The pyroxene analyses show very little variation, and the variation is apparently more irregular than that found in the plagioclase analyses. Silica is apparently constant while alumina may decrease slightly in the inward direction (fig. 23), calcium apparently drops in value from d to e, and magnesium plots an irregular pattern (fig. 24); ferrous iron increases from d to e (fig. 24), and ferric iron shows an irregular pattern with a high value at c (fig. 24). Both alumina and ferric iron have higher values at c, but these are not by very large amounts.

Formulas for the three pyroxene samples were calculated by the method used by Deer, Howie, and Zussman (1966) and are listed in table 10. A sample calculation is given in the Appendix. Water determinations were disregarded in these calculations. The resulting formulas give atomic ratios which are fairly close to

Table 9

Formulas for plagioclase*

	N2c	N2d	N2e
Si	9.53)	9.52)	9.54)
Al	6.14)	6.11)	6.05)
Ti	0.01) 15.99	0.01) 15.93	0.01) 15.93
Fe^{+3}	0.31)	0.29)	0.33)
Fe^{+2}	0.06)	0.05)	0.55)
Ca	2.23)	2.20)	2.19)
Mg	0.62) 3.59	0.78) 3.63	0.78) 4.12
Mn	0.00)	0.00)	0.00)
Na	0.61)	0.53)	0.54)
K**	0.07)	0.07)	0.06)
Or	2.5	2.4	2.1
Ab	20.8	19.0	19.4
An	76.7	78.6	78.5

* Based on 32 oxygen ions:

$(Na\ Si,\ Ca\ Al)_4\ Al_4\ Si_8\ O_{32}$

or $(Ca,\ Na,\ K,\ Fe^{2})_4\ (Si,\ Al,\ Ti,\ Fe^{3})_{16}\ O_{32}$

** Potassium content estimated from rock analyses

Table 10

Formulas for pyroxene*

	N2c			N2d			N2e		
Si	1.82	2.0		1.84	2.0		1.84	2.00	
Al^{iv}	0.18			0.16			0.16		
Al^{vi}	0.08	1.35	1.96	0.07	1.33	1.95	0.07	1.36	1.97
Ti	0.01			0.01			0.01		
Fe^{+3}	0.19			0.19			0.19		
Fe^{+2}	0.36			0.36			0.37		
Mn	0.01			0.01			0.01		
Mg	0.70			0.69			0.71		
Ca	0.59	0.61		0.60	0.62		0.59	0.61	
Na	0.02			0.02			0.02		

* Based on 6 oxygen ions:

$$(Ca, Mg, Fe, Al)_2 (Al, Si)_2 O_6$$

the ideal whole numbers, which would tend to substantiate the accuracy of the pyroxene analyses.

The mol proportions of lime, magnesia, and total iron oxides, plotted on a ternary diagram (fig. 26) fall in the range of sub-calcic augite, confirming the identification based on optical properties. The presence of small amounts of orthopyroxene and pigeonite impurity would have the effect of shifting the points slightly toward the base of the triangle.

The chemical analysis of pyroxene N2d produces a molecular ratio Wo34, En40, Fs26, while the ratio obtained from the norm of the corresponding rock is Wo32, En36, Fs32.

Table 11 compares one of the augite chemical analyses with analyses of augites from Scotland and New Zealand. The Gatineau pyroxene is relatively high in Fe^{+3} and low in Ti, while the Ca content is slightly lower compared with most of the other analyses. Otherwise, all of the clinopyroxenes listed in table 11 are comparable.

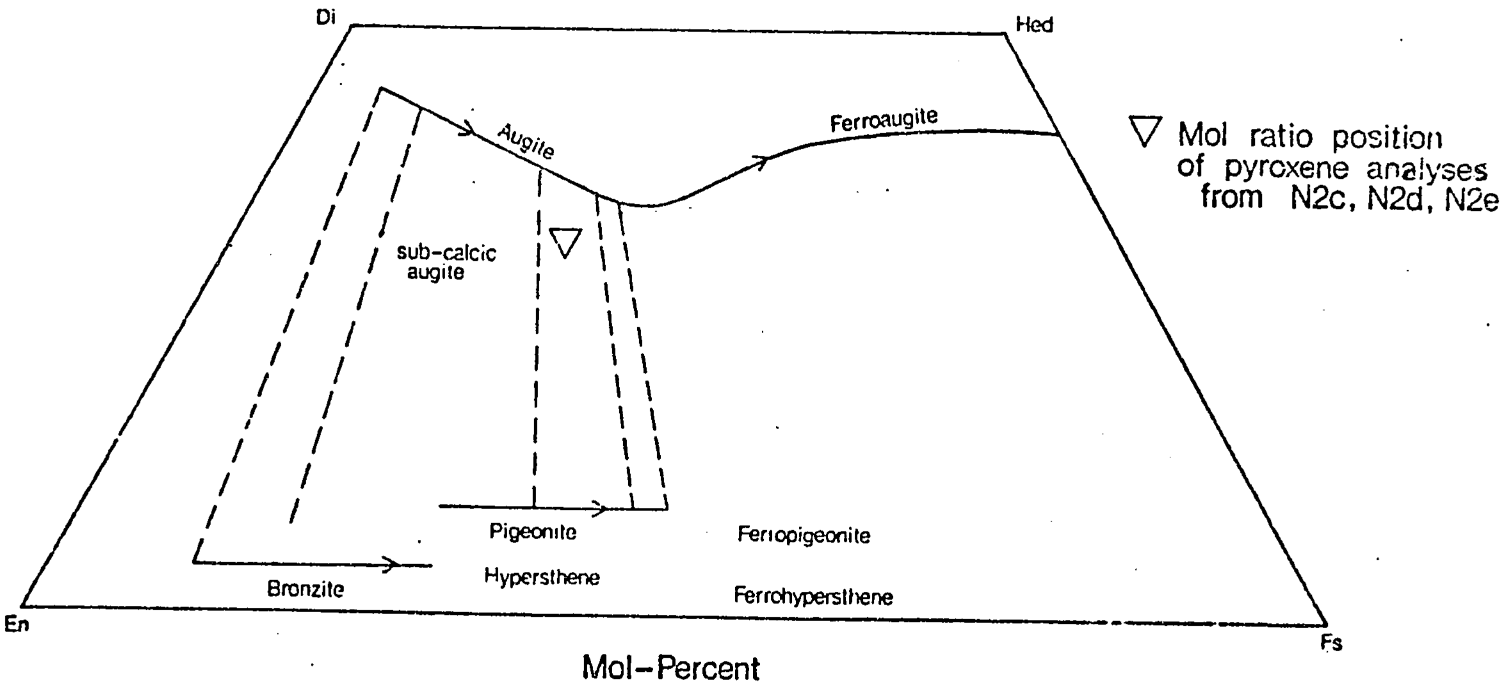


Fig. 26 Pyroxenes plotted in relation to pyroxene compositions in the Skaergaard intrusion (Deer, Howie and Zussman, 1966, P.127.)

Table 11

Chemical Analyses of Clinopyroxenes

	I	II	III	IV	V	VI
SiO_2	48.1	50.8	47.89	47.04	47.96	48.19
Al_2O_3	2.21	1.46	3.35	6.80	7.75	5.20
Fe_2O_3	17.5	16.2	1.26	2.67	1.58	6.41
FeO			14.74	11.64	12.27	11.23
CaO	15.2	16.0	16.86	17.82	13.60	14.60
MgO	12.8	13.7	14.66	11.20	12.60	12.19
MnO	0.43	0.38	0.42	0.33	0.33	0.29
Na_2O	0.28	0.28	0.28	0.78	1.12	0.59
TiO_2	1.46	0.98	0.77	1.61	1.49	0.31

I Calcium rich clinopyroxene, tholeiitic dolerite, Moeraki, New Zealand, Nakamura 1973, table 1, No. 103, p. 219.

II Clinopyroxene, tholeiitic dolerite, Moeraki, New Zealand, Nakamura, 1973, table 1, No. A-1086, p. 219.

III Augite from Centre #1 dolerite ring dikes of Ardnamurchan, Scotland, Gribble, 1974, table 6, No. 107, p. 82.

IV Augite from Centre #2 dolerite ring dikes of Ardnamurchan, Scotland, Gribble, 1974, table 6, No. 114, p. 82.

V Augite from Centre #3 dolerite ring dikes of Ardnamurchan, Scotland, Gribble, 1974, table 6, No. 129, p. 82.

VI Augite from sample N2d, Gatineau diabase dike.

Interpretation and Discussion

Petrography

The recently prepared geological map of Canada (Douglas, 1968) shows that the orientation of swarms of diabase dikes varies from place to place, and the age determinations of Fahrig, et al. (1965) indicate that different dike swarms may differ greatly in age, as shown in fig. 27. However, little work has been done to compare the petrography of different dike swarms, the most comprehensive study of this kind being that of Archbold (1962).

Archbold describes the dikes that occur in a large area including portions of north eastern Ontario and north western Quebec and his results are summarized in tables 12 and 13. These dikes are located in the Southern and Superior Provinces, and are older than those found in the Grenville province.

Petrographically, most of the dikes studied by Archbold do not resemble the Gatineau dike very closely. The Noranda group appears to have the most characteristics in common with the Gatineau dike (table 13).

Chemical Composition

The chemical composition of the Gatineau dike, expressed in terms of the mol proportions of magnesium oxide, iron oxides, and alkali oxides is shown in the AFM diagram of fig. 28. The data points fall well within the zone of tholeiitic basalts of Hawaiian variety (Kuno, 1968). Two of the samples (N2f and N2h), when compared with the others, have about 5 mol percent less MgO and about 5 mol percent more iron oxides, while the alkali content is about the same.

The chemical composition of diabase dikes from different parts of the Canadian Shield, mainly in Ontario and Western Quebec has been determined by Fahrig, et al. (1965) and some of their results are listed in table 14, which also lists the composition of the margins of the Gatineau dike. Compared with these

Fig. 27

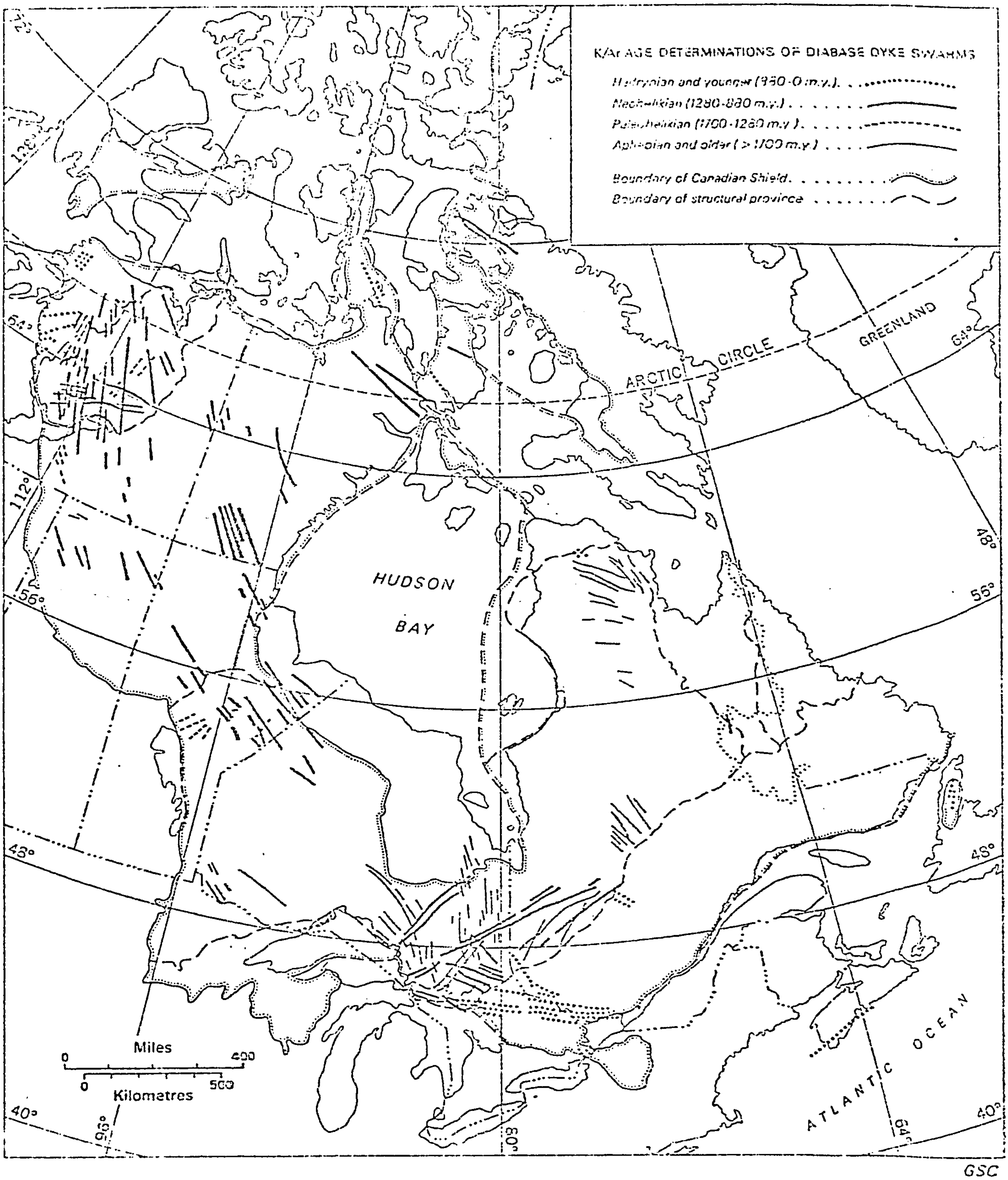


FIGURE IV-30. Diabase dyke swarms of the Canadian Shield (by W. F. Fahrig).

From Douglas (1968)

Table 12

Summary of the various groups of diabase dikes in eastern Ontario and western Quebec,(Archbold, 1962)

Ontario	Quebec
Dikes intruding the Huronian sediments	
Sudbury group.- Northwesterly trending, prophyritic and non-porphyritic dikes of olivine diabase.	
Northerly trending dikes of quartz diabase in the Cobalt area. Northeasterly trending, quartz diabase dikes at Gowganda and Matachewan, Ontario. Age relative to Sudbury dikes is uncertain.	*Noranda group*.- Northerly and northeasterly trending dikes of quartz diabase in the Noranda area. (Minor northwesterly trending dikes)
Dikes intruding the Algoman granites but not the Huronian sediments	
Porcupine-Mattagami group. - Northeasterly trending dikes of quartz diabase and olivine diabase. (Also extended into Quebec)	*Porcupine-Mattagami, Quebec northeast, and Quebec north-northeast groups*. - Olivine diabase and quartz diabase.
Matachewan group. - Northerly trending, porphyritic dikes of quartz diabase.	*Matachewan group*. - Minor representatives in Quebec around Lake Clericy and Opasatica Lake; probably includes Abana dike and dikes along Turgeon River.

	Gross texture	Plagioclase composition	Pyroxene	Quartz and olivine	Accessories	Remarks
Sudbury dikes	Porphyritic and non-porphyritic Plagioclase phenocrysts are fresh	Ab 39-50	Intermediate to calcic augite	10 to 20% fresh olivine, Fo 20-53 No quartz	Up to 2% apatite in well developed grains Magnetite-ilmenite Sulfides rare	Relatively unaltered
Matachewan dikes (includes Abono dike)	Porphyritic; plagioclase phenocrysts are highly altered.	Ab 33-49	Augite with very rare pigeonite	Up to 10% quartz	Magnetite-ilmenite, minor apatite and sphene Sulfides are common.	
Porcupine-Mattagami, Quebec Northeast, Quebec North-northeast dikes	Non-porphyritic	Ab 34-50 in quartz-bearing dikes. Ab 27-44 in olivine-bearing dikes	Augite or endiopside with lesser amounts of hypersthene and pigeonite Exsolved clinopyroxene is common in the hypersthene.	Up to 15% quartz or 10% olivine Olivine is generally altered in central part of dikes and may occur in chilled edges of quartz-bearing dikes. Quartz may occur in central part of olivine-bearing dikes.	Magnetite-ilmenite, minor apatite, very rare garnet Sulfides and sphene largely confined to quartz-bearing dikes	Olivine-bearing dikes are less altered than quartz-bearing dikes
Noranda dikes	Non-porphyritic	Ab 35-51	Intermediate augite	Up to 15% quartz. Rare olivine in edges of dikes.	Magnetite-ilmenite, minor apatite Sulfides are common	More altered in the area south of the Horne Creek fault

Table 13

Summary of petrographic characteristics of the various groups of dikes (Archbold, 1962)

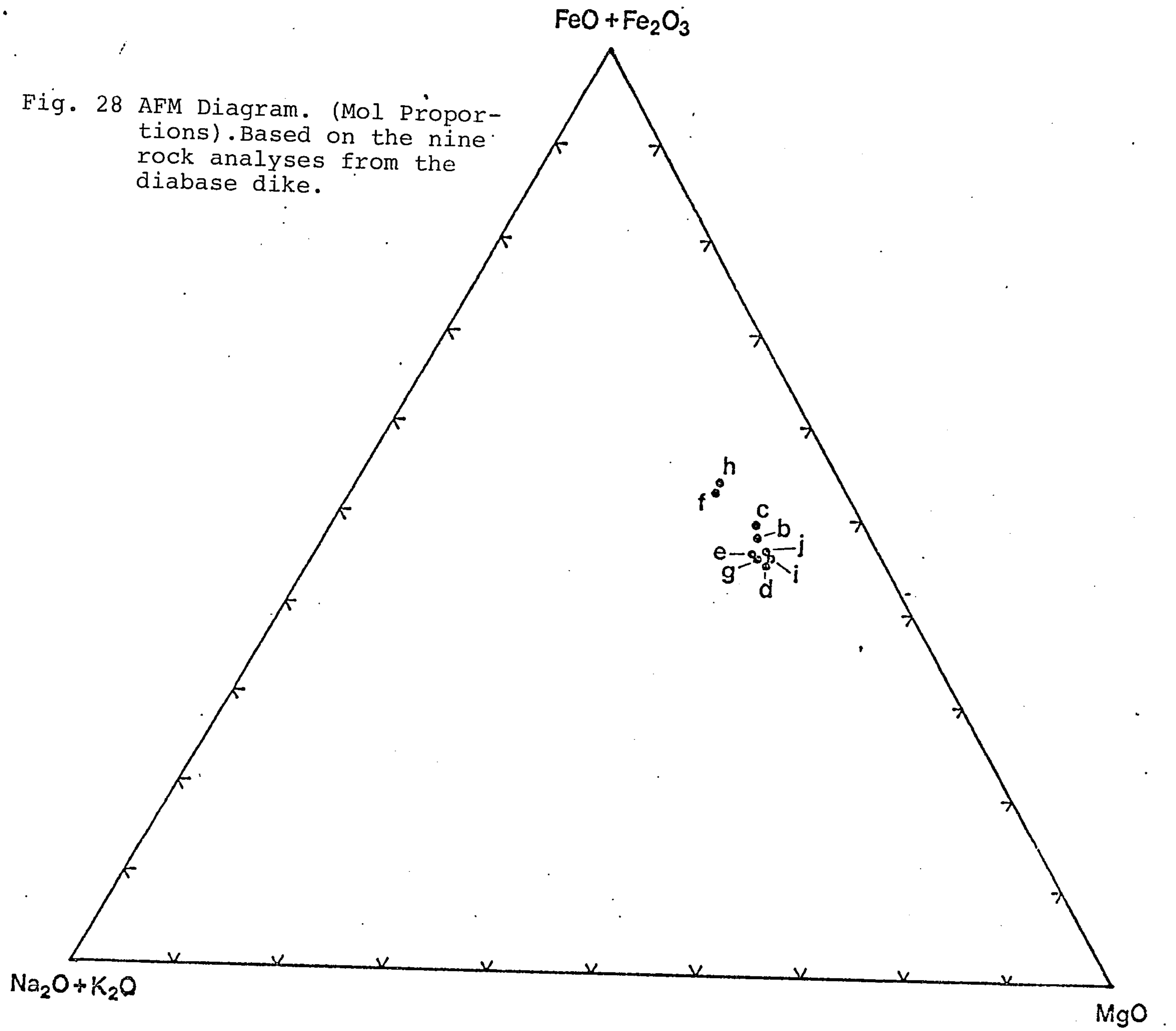


Fig. 28 AFM Diagram. (Mol Proportions).Based on the nine rock analyses from the diabase dike.

Table 14

The chemical composition of Canadian Shield diabase dikes and of comparable rocks, Fahrig et al. (1965). The average of the 6 marginal samples of the Gatineau dike is included.

	Mackenzie 1	Sudbury 2	Matachewan 3	Marathon 4	Abitibi 5	Av. Tholeitte 6	Continental 7	Alkalic Basalt 8	Gatineau Margins 9
SiO_2	47.7	45.9	50.5	50.5	49.6	51.9	50.6	47.1	47.8
Al_2O_3	11.9	15.1	13.9	12.7	13.9	15.1	15.4	15.8	14.15
Fe_2O_3	3.4	2.9	4.0	3.5	2.4	1.3	4.4	4.0	3.28
FeO	12.7	12.1	10.8	10.3	9.9	9.0	6.9	8.3	10.61
CaO	9.8	8.5	9.6	9.5	10.3	10.0	8.7	9.4	11.48
MgO	4.7	4.2	4.8	4.7	6.8	6.6	7.5	7.4	5.84
Na_2O	2.8	3.5	3.0	2.8	2.6	2.1	3.0	3.1	2.18
K_2O	0.7	1.2	1.0	1.0	0.8	0.9	1.4	1.3	0.32
TiO_2	2.5	3.1	1.4	1.6	1.4	1.3	1.5	2.9	1.64
MnO	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.12
CO_2	0.1	0.1	0.1	0.1	0.1				0.37
H_2O^+	1.2	1.7	1.4	2.0		0.9			0.7
	97.7	98.8	100.7	99.0	98.0	100.0	100.0	100.0	97.79

Legend for table 14 Canadian Shield diabase dikes. From Fahrig, et al. (1965)

No. 1. Average of 20 analyses of samples from margins of 20 Mackenzie dikes.

2. Average of 10 analyses of samples from margins of 10 Sudbury dikes.

3. Average of 8 analyses of samples from margins of 8 Matachewan dikes.

4. Average of 4 analyses of samples from margins of 4 Marathon dikes.

5. Average of 10 analyses of samples from margins of 10 Abitibi dikes.

6. Average composition of various tholeiite quarzite diabase occurrences as given by Turner and Verhoogen (1960, p. 215, table 16, column 9).

7. Newer volcanic series, Victoria, Australia; 27 olivine basalts (A.B.Edwards, The Tertiary volcanic rocks of central Victoria. Geol. Soc. London Quart. J., vol. 94, p. 309, Nos. 11, 12, 1938).

8. Carboniferous of Scotland; average olivine basalt (27 analyses). (S.I.Tomkeieff. Petrochemistry of the Scottish Carboniferous - Permian igneous rocks. Bull. volcanologique, ser. 2, tome 1, table 1, No. 13, 1957).

9. Average of 6 analyses of 6 samples taken from the margins of the Gatineau dike. Three from each margin.

dikes, the Gatineau dike is evidently slightly richer in CaO and poorer in K_2O and Na_2O.

Fig. 29 shows a plot of the alkali and silica percentages of the analyses listed in table 14, and fig. 30 contains these as well as some additional data. The Gatineau dike falls in the tholeiitic field of these figures, and does not support the presumed trend of increasing alkali content for younger dikes (Douglas, 1968).

The chemical composition of some diabase dikes from Greenland was recently determined by Rivalenti (1974). The analyses and norms are listed in table 15, where comparison may be made with the Gatineau dike. The norms calculated from the averages listed in this table all contain olivine.

Chemical analyses of diabase and dolerite from other parts of the world have been presented in numerous reports. Such data from Eastern North America have been obtained by Weigand and Ragland (1970), from North Carolina by Ragland, et al. (1968), from the Wyoming-Montana area by Prinz (1964) and Condie, et al. (1969), from Finland and Sweden by Laitakara (1969) and Boyd (1972) and from the Ukraine by Sviridov (1968). An examination of all of these data as well as those from Canada and Greenland shows that the composition of diabase in diabase dikes is variable to an extent that is comparable to the variation that is found in basaltic and gabbroic rocks. This variation is reflected in the mineral content, which for some of the above areas is shown in table 16. With regard to both mineral content and chemical composition, the Gatineau dike falls within the tholeiitic portion of the composition range.

Internal Variation in Composition

A variation in chemical composition within a diabase dike may conceivably develop as a result of various processes, in addition to fractional crystallization, some of which are: 1) chemical exchange with the wall rocks, 2) flow differentiation, causing first formed crystals to migrate toward the centre of the dike, 3) variation in the composition of the melt with time during

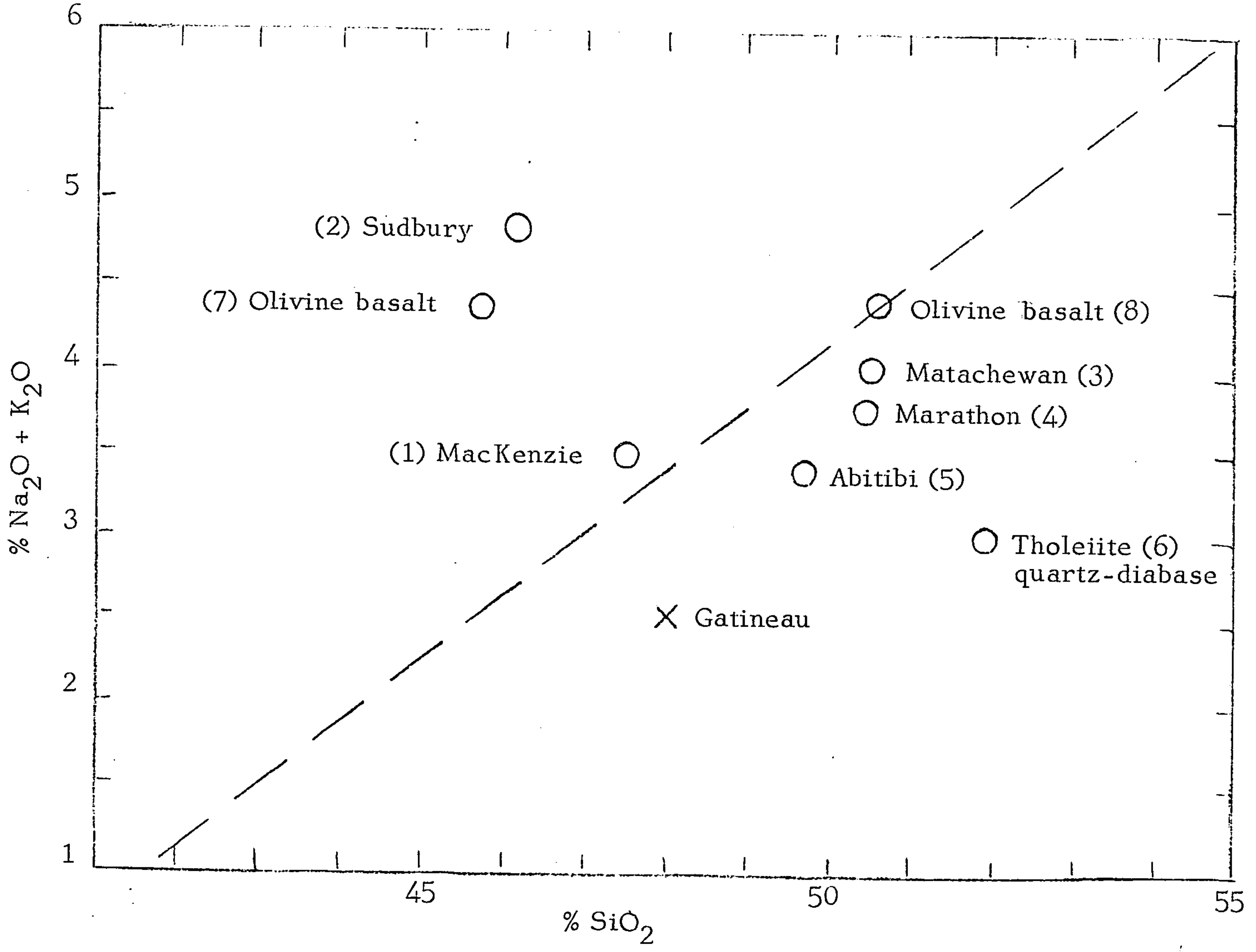
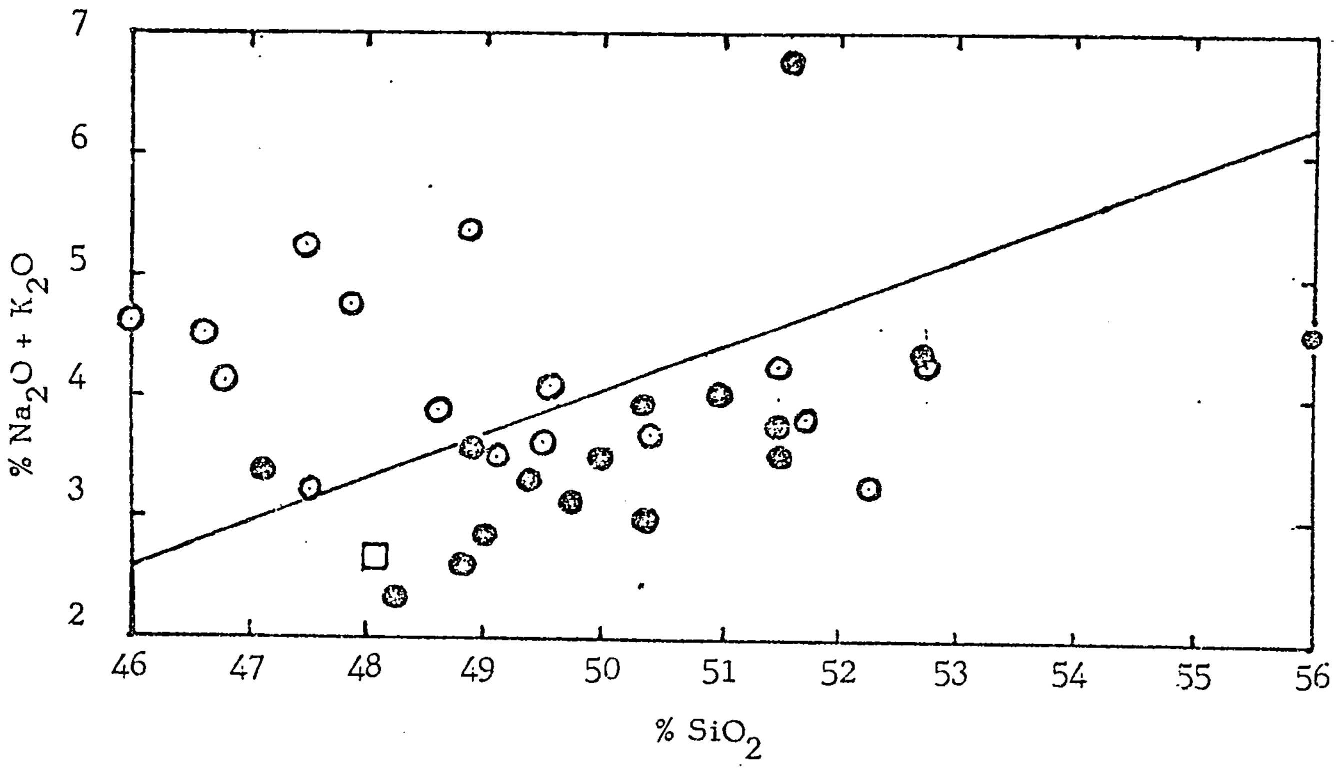


Fig. 29 Alkali-silica diagram of Canadian Shield diabase dike swarms and comparable rock types from table III, Fahrig et al. (1965). The diagonal broken line is from MacDonald and Katsura (1964) and is used to separate rocks with tholeiitic mineral composition (lower right) from rock with alkalic mineral composition (upper left).

Fig. 30



Ratio of alkali and silica content of diabase dikes from the Canadian Shield: Paleohelikian and older (solid circles); Neohelikian and younger (open circles). The diagonal line separates rocks with tholeiitic mineral composition (lower right field) from rocks with alkalic mineral compositions (according to G.A. MacDonald and T. Katsura). ☐ Gatineau Dike

From Douglas (1968)

Table 15

Chemical analyses and norms of dolerites, near Fiskenaesset, Greenland, compared to Gatineau dike.

	I	II	III	IV
SiO_2	49.83	48.19	48.56	48.01
TiO_2	0.63	1.42	1.53	1.62
Al_2O_3	16.50	14.83	13.33	14.55
Fe_2O_3	1.57	2.61	2.29	3.44
FeO	7.36	11.10	12.18	10.35
MnO	0.17	0.23	0.23	0.12
MgO	8.52	5.59	5.60	5.62
CaO	11.22	10.45	10.63	11.55
Na_2O	2.22	2.73	2.65	2.21
K_2O	0.28	0.61	0.36	0.33

	I	II	III	IV
Or	1.65	3.6	2.13	2.19
Ab	18.78	23.09	22.41	22.30
An	34.23	26.41	23.42	32.37
Cpx	16.9	20.17	23.55	24.11
Opx	19.56	10.94	16.15	14.56
Ol	3.58	6.83	3.42	4.47

I Average olivine normative MD 1 (samples 1, 3, 4 & 5), Rivalenti, 1975, table 2, p. 728.

II Average MD 2 (samples 7 and 8), Rivalenti, 1975, table 2, p. 728.

III Olivine normative MD 3 (sample 9, 10, 13, 15, 30 & 33), Rivalenti, 1975, table 2, p. 728.

IV Average of 9 samples across the Gatineau diabase dike.

Table 16

Comparison of Modal Compositions of Doleritic Rocks of North America

	Montana - Wyoming, U.S.A. Condie, Barsky and Mueller (1970)			North Carolina, U.S.A. Ragland (1968)	Eastern North Amer. Weigand & Ragland (1970)	Gatineau Diabase Dike	
	Wind River	Bighorn	Beartooth			Range 9 Samples	Average 9 samples
Plagioclase An	50-70% 50-60	50-60% 45-60	50-70% 50-60	50% Labradorite	40-60% 50-70	34-54% 62-70	45%
Clinopyroxene Augite other	10-30% mainly some pigeonite	20-40% mainly some pigeonite	10-40% mainly some pigeonite	25-30% some pigeonite	0-20% some pigeonite	34-54% mainly some pigeonite	42%
Orthopyroxene	0-3%	0-tr	0-5%	rare	some	some	
Olivine	tr	0-2%	tr-2%	10-20%	0-10%	tr	
Hornblende	0-5%	5-25%	0-5%			2-14%	7%
Alteration	tr-3%	tr-11%	tr-11%		0-5%		
Opaque	2-5%	1-5%	1-8%	minor	some reported as minor	4-8%	5%
Quartz	tr	0-1%	0-3%				
Micropegmatite				tr	some reported as minor	0-4%	1.5%

emplacement, and 4) secondary alteration, for example oxidation in the marginal zones.

Figs. 9 to 20 show that apparently significant variation in composition exists within the Gatineau dike with respect to all major elements. Although considerable "erratic" variation was found in the concentration-distance profiles, the central part of the Gatineau dike is evidently slightly richer in Si and Ti than the margins, and poorer in Mg. The Fe^{+2} and K concentrations, from edge to centre, first decrease and then increase, while the Fe^{+3} concentration first increases and then decreases. This trend for Fe^{+2} and Fe^{+3} is best developed in the north half of the dike. Concentrations of the remaining elements (Al, Mn, Ca, Na) appear to vary erratically. The trends are summarized in table 17, where they may be compared with results obtained elsewhere.

With regard to mineral content (figs. 5 and 6), the amount of plagioclase in the marginal 3-4 metres of the Gatineau dike increases from contact inward, while the pyroxene content decreases. The central part of the dike, in so far as it is represented by a single sample, appears to contain plagioclase and pyroxene contents that approximate the average of a marginal zone.

These variations can, to a very limited extent, be correlated with the observed variation in rock composition. Thus the decrease in Fe^{+2} content of the rock, measured inward from the north contact, may be correlated with a decrease in pyroxene, which is the major iron-bearing mineral present. The absence of other correlations of this kind may be the result of spurious variations in the concentration of opaque minerals and alteration products. For example, thin sections from the north margin (N2d) show substantial amounts of hornblende which was not counted as pyroxene although in some cases it formed part of the pyroxene grain. This tends to lower the pyroxene count which at N2d is exceptionally low (fig. 6).

Table 17

Internal variation in chemical composition in vertical diabase dikes

	Ross & Heimlich (1972) Wyoming	Boyd (1972) Finland		Fratta & Shaw (1972) Lake of the Woods, Ont.	This Study Gatineau Park, Quebec
		V	F		
SiO_2				↑	↑
TiO_2				↓	↑
Al_2O_3	↑			↑	
Fe_2O_3	↑	↑	↑	↓	⤵
FeO	↑	↓	↓	↓	⤴
MgO			↑	↓	↓
CaO	↓		↑	↓	
Na_2O				↑	
K_2O	↑		↓	↑	⤴

V	Vehkajarvi dike
F	Fiskartorp dike
↑	increase from contact inward
↓	decrease from contact inward
⤵	increase followed by decrease
⤴	decrease followed by increase
blank	apparent erratic variation

N2d and N2e have the lowest pyroxene, the highest hornblende, exceptional amounts of micropegmatite and the highest ferric iron content. These are the two most oxidized specimens, and the magnetite norms were not calculated. Consequently the norm calculations of these samples have not reflected the low amount of pyroxene, and they have shown to be quartz-normative (table 5).

Very few studies of modal variation in diabase dikes have been carried out elsewhere. In some dikes in Eastern Ontario and Western Quebec, Archbold (1962) observed an increase in quartz and plagioclase content and a decrease in pyroxene and olivine content from the margins inward, giving trends for pyroxene and plagioclase similar to those in the Gatineau dike. Similar trends were observed by Ross and Heimlich (1972) in diabase dikes of Wyoming. On the other hand, Ragland, et al. (1968) found no significant modal variation across vertical dikes in North Carolina. However, samples were collected at equal intervals across these dikes and modal variation in the marginal zone may have passed undetected.

With regard to the chemical composition of plagioclase and pyroxene in the north margin of the Gatineau dike, the main conclusion to be drawn from the analyses is that the composition of pyroxene shows little or no variation, and that of plagioclase becomes slightly more sodic from the contact inward. A trend of this kind was also observed, on the basis of extinction angle measurements, in diabase dikes that were studied by Archbold (1962), Ross and Heimlich (1972) and Rivalenti (1975).

Some possible processes which separately, or in co-operation, might be responsible for the observed variation within the Gatineau dike will now be considered.

Diabase magma moving upward through opening fractures may gain or lose some material by exchange with the wall rock, and if the magma does not subsequently become homogenized, variation in composition may be preserved on crystallization. That such "contamination" is possible has been known for some time and was recently demonstrated by Fratta and Shaw (1974), who found a higher concentration of potassium in a diabase dike where it was in contact with granite than where it was in contact with basic volcanic rock.

At the present level of exposure, the Gatineau dike on its north side is in contact with diopside-quartz rock and on its south side with granitic rock. The lowest Si content in the dike was found at the north contact and this may possibly reflect a slight loss of silica to the wall rock, where it would be consumed to form calc-silicates. Although some Ca and Mg may have entered the dike at this point, the analysis is not especially high in these elements. On the south contact, potassium contamination might be expected, and the sample obtained near this contact is indeed relatively rich in this element. However, the silica and sodium contents are not anomalously high.

Evidence for a loss of elements from the dike might possibly be found in the wall rocks. In a microscopic examination of wall rocks of adjacent diabase dikes in Gatineau Park, including the dike under study, Brunet (1966) found abundant fracturing and secondary alteration, but no conclusive evidence that material had migrated from the dikes into the surrounding rocks.

The possibility that differentiation may take place in a sill or dike, by the inward migration of early-formed crystals during flow of the magma was suggested by Baragar (1960) and was discussed in detail by Bhattacharji (1967) and Komar (1972). Evidence that this process has operated in some ultrabasic dikes in Scotland was presented by Gibb (1968) who reported an increase in olivine content from margin to centre within these dikes.

The Gatineau dike shows a slight increase in plagioclase content from its contact inward for a short distance, and the model of flow differentiation might be applied, provided evidence existed for early crystallization of plagioclase. However, both plagioclase and pyroxene exist as small phenocrysts at the contact, and during the initial stage of crystallization, both minerals evidently crystallized together.

The possibility exists that some of the observed internal variation in the Gatineau dike may be attributed to non-uniform post-crystallization alteration. Thus samples N2d and N2e, which contain relatively large amounts of unidentified fine-grained material are exceptionally erratic in composition, and may have been more affected by the introduction, and possibly the removal, of material to bring about hydration and oxidation reactions.

Secondary alteration might be expected to produce variation in the relatively mobile elements or compounds, such as CO_2, H_2O, and possibly K and Si, and it may account in part for the observed variation in these substances. Oxidation may possibly account in part for the opposite trends in Fe^{+2} and Fe^{+3} (table 17). But it is unlikely that secondary alteration would noticably affect the concentration of the relatively immobile elements such as Ti and Mg, for which significant variation was found. Also, in view of the relatively small amount of alteration in most samples, at least some of the recorded variation in plagioclase and pyroxene content is considered to be the result of primary rather than secondary processes.

The possibility of a variation in the composition of the melt that has produced the diabase should be considered. Depending on the mechanics of emplacement, the wall rocks may exert a certain amount of "drag" so that when the melt finally comes to rest, the central part of the dike material, as seen in horizontal section, would have arrived at a later time than the margins. If some variation in composition existed in the "magma chamber" from which the dike was trapped, this might show up as a variation in composition from the margin to the centre in the solidified dike. This may account to some extent for the observed variation in the Gatineau dike.

Finally, attention may be drawn to the observed variation in plagioclase and pyroxene content (fig. 5 and 6) and the fact that the average amount of their minerals in the margin zones is about equal to the amounts in the central portion of the dike. This distribution would result if the dike was initially homogeneous and some migration of ions occurred away from and toward the contact, within the marginal zones. It is possible that a process of this kind, the cause for which is not yet understood, occurred in the marginal zones, where extreme thermal gradients existed during crystallization.

Temperature of Crystallization

The low Ca content of the pyroxene in the Gatineau dike may be indicative of a particular temperature of crystallization. Although the geothermometer developed by Ross and Huebner (1975) for co-existing pyroxenes cannot be applied directly, a minimum temperature of just above 1100°C is indicated for the Gatineau dike.

Brunet (1966) noted the presence of sanidine up to 3 feet from diabase dikes in Gatineau Park. If the microcline-sanidine inversion temperature is about 700°C, and if the country rock was cold when the dike was emplaced, the heat flow equations of Jaeger (1957) would indicate a melt temperature of at least 1400°C which is reasonably higher than minimum. However, if the country rock was at about 400°C a melt temperature of 1100°C would produce a temperature of 700°C in the wall rock near the contact.

Crystal Size

Compared with the small-magnitude variations in chemical and modal composition in the Gatineau dike, as discussed above, a very great variation exists in grain size, particularly in the marginal zones. Thus the range in average grain size as shown in fig. 7 is from about 0.2 mm to about 1.2 mm.

Although the fine-grained margins of diabase dikes are frequently cited as examples of the effect of cooling rate on crystal size in igneous rocks, very few measurements have been carried out to examine the size-distance profile in detail. Until recently, the only important study of this kind was carried out by Winkler (1949) on the Cleveland dike, in England. Some data were also obtained by Archbold (1962) for Ontario-Quebec dikes and by Gray (1970) for one dike from Grenville township (Quebec) and one from Baffin Island.

There is no doubt that the crystal size in diabase dikes is governed to a large extent by cooling rate. Winkler (1949) calculated the cooling rate at different points in a dike, by use of heat flow equations (Jaeger, 1968) and experimentally determined relationships between rate of cooling and grain size. Thus he was able to predict crystal size-distance profiles for dikes of different thickness. It is interesting to note that some of the resulting curves do not rise smoothly from dike edge to centre, as might be expected, but they rise to a maximum at some distance from the contact and then decline somewhat toward the centre of the dike. Such a size-distance profile was found in the Cleveland dike, with respect to pyroxene, as shown in fig. 31, where comparison may be made with results of the present study.

The grain size of the Cleveland dike is much smaller than that of the Gatineau dike, despite the fact that its width (16.8 m) is not much less than that of the Gatineau dike (23.8 m). The reason for this may be that the former dike reached higher and cooler levels in the crust and crystallized at a more rapid rate.

Apart from the difference in grain size, the size-distance profiles in the two dikes are similar as shown in fig. 31.

Diabase dikes and basalt flows

In some volcanic regions, dike swarms similar to those found in the Canadian

Legend to fig. 31

Comparison of grain size in the Gatineau dike (present study) and the Cleveland dike (Winkler, 1949).

N - north half of Gatineau dike
S - south half of Gatineau dike
C - Cleveland dike

g - mean grain dimension (long axis) in mm., Gatineau
c - mean grain dimension in mm., Cleveland dike.

The Gatineau dike is 23.8 m thick, the Cleveland dike is 16.8 m thick.

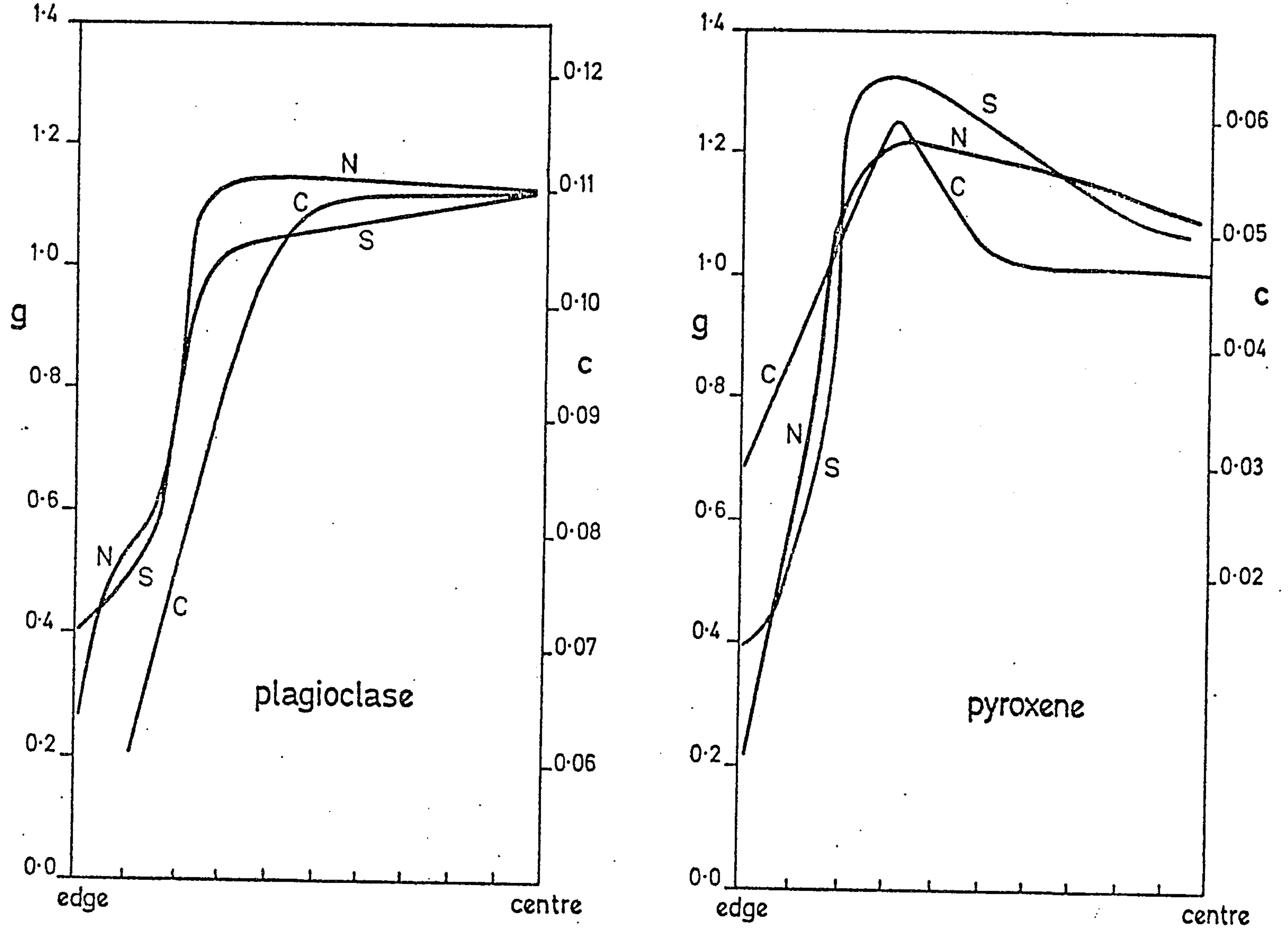

1·4
1·2
1·0
g
0·8
0·6
0·4
0·2
0·0
edge
centre
0·12
0·11
0·10
c
0·09
0·08
0·07
0·06
N
C
S
N
S
C
plagioclase
1·4
1·2
1·0
g
0·8
0·6
0·4
0·2
0·0
edge
centre
0·06
0·05
c
0·04
0·03
0·02
S
N
C
C
N
S
pyroxene

Fig. 31

Shield occur as feeder dikes to basalt flows (Frankel, 1968; Clifford, 1968). Occurences in North America include those described by Ragland, et al. (1968), Prinz (1964) and Foster (1958). However, there is no evidence that the diabase dikes in the Gatineau province ever acted as vents to large discharges of basaltic lava. It is possible, however, that some basalt was extruded and was completely removed by erosion.

If the Gatineau dike was the site of a channel leading to a surface vent, and if large discharges of basalt passed through this channel, then a more intense development of metamorphism than that found by Brunet (1966) would be expected.

Some Comparisons with Other Occurrences of Diabase

Extensive work has been done on the dike swarms in the Montana-Wyoming mountain region of U.S.A. by Prinz (1964), Condie, et al. (1970) and Ross and Heimlich (1972). Prinz classified the dike swarms into 3 groups of dolerites, each of which composes a variety of compositions and textures, and the Gatineau dike is similar to some of them (table 16). Texture varies within many dikes and from one dike to another, but ophitic or sub-ophitic texture is dominant in most swarms. Ophitic texture is relict in the metadolerite dikes which make up the oldest swarm in the area. The second type, and second youngest, the late Precambrian dolerites, are less like the Gatineau dike in composition in that pigeonite and bronzite are major pyroxene components, coexisting with augite. The grain size and texture are similar. The third type, the Tertiary (?) dolerites, have similar texture but are high in altered olivine grains.

In the Bald Mountain area of Wyoming, Ross and Heimlich (1972) studied Precambrian dolerite dikes that are fine to medium grained with sub-ophitic texture common near the margins, grading to ophitic inward, and in some dikes a coarser interior is hypidiomorphic-granular. Chill contact may be microporphyritic, which is similar to the Gatineau dike. Plagioclase and clinopyroxene compose 90% of the Bald Mountain dikes. Augite predominates over pigeonite. The fresh appearance of these minerals, as observed in the Gatineau dike, is usually present but not consistently.

Weigand and Ragland (1970) reported on over one hundred Mesozoic dolerite dikes of eastern North America. The Gatineau dike appears to be similar to parts of these dikes in composition and texture.

Ragland, et al. (1968) described ten dolerite dikes in North Carolina. The texture of some of these dikes appears to be similar to the Gatineau dike especially when lower olivine values are encountered. The generally high olivine content of these dikes is in contrast to the composition of the Gatineau dike.

Baragar (1960) used grain size as the criterion for the term gabbro to describe the differentiated zones in the igneous sill studied in the Labrador Trough near Ahr Lake. In some layers of the sill the texture and composition is similar to many dolerite dikes, and the Gatineau dike resembles the description of some samples from the lower middle zones of the sill.

The composition and texture of the Gatineau dike is well represented in part of each of these study areas, but none of the areas have dikes with the same age as the Gatineau dike.

Conclusion

The Gatineau dike is a member of one of the relatively young ($<$880 my.) diabase dike swarms of the Canadian Shield. It consists principally of plagioclase and sub-calcic augite, and mineralogically and chemically may be classed as tholeiitic diabase.

A small amount of variation was found in the chemical composition and modal composition within the dike, and in the chemical composition of plagioclase and pyroxene in one of the marginal zones. These variations are thought to be the result of a number of processes, including contamination, secondary alteration, and some form of differentiation.

The form of the crystal size-distance profiles in the dike is in agreement with calculations based on experiments with basalt melts and heat-flow theory.

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Appendix 1

General Formula Calculation

Pyroxene N2d

Oxides	Wt-%	Mol Proportions	Atomic prop'ns for each mol	No. Cations for 6 oxygen	No. Ions in Formula
SiO_2	48.19	0.8018	X2 = 1.6036	X2.2971 = 3.6836	÷2 = 1.8418
Al_2O_3	5.20	0.0510	X3 = 0.1530	X2.2971 = 0.3515	$X\frac{2}{3}$ = 0.2343
Fe_2O_3	6.41	0.0401	X3 = 0.1203	X2.2971 = 0.2783	$X\frac{2}{3}$ = 0.1855
FeO	11.23	0.1562	0.1562	X2.2971 = 0.3588	0.3588
CaO	14.60	0.2602	0.2602	X2.2971 = 0.5977	0.5977
MgO	12.19	0.3024	0.3024	X2.2971 = 0.6946	0.6946
MnO	0.29	0.0040	0.0040	X2.2971 = 0.0092	0.0092
Na_2O	0.59	0.0095	$X\frac{1}{2}$ = 0.0047	X2.2971 = 0.0107	X2 = 0.0214
TiO_2	0.31	0.0038	X2 0.0076	X2.2971 = 0.0175	÷2 = 0.0088
Totals	99.01	1.6290	2.6120	$\frac{6}{2.612}$ = 2.2971	

(Fe^3, Fe^2, Mn) - 26.30%
Ca - 34.11%
Mg - 39.64%
100.05

Appendix 2

General Formula Calculation

Plagioclase N2d

Oxides	Wt-%	Mol Proportions	Atomic prop'ns of oxygen for each mol	No. cations for 32 oxygen	Ions in formula
SiO_2	52.11	0.8671	X2 = 1.7342	X10.9815 = 19.0441	÷2 = 9.5221
Al_2O_3	28.35	0.2780	X3 = 0.8340	X10.9815 = 9.1586	$X\frac{2}{3}$ = 6.1057
Fe_2O_3	2.41	0.0134	X3 = 0.0402	X10.9815 = 0.4415	$X\frac{2}{3}$ = 0.2943
FeO	0.35	0.0048	0.0048	X10.9815 = 0.0527	X1 = 0.0527
CaO	11.24	0.2004	0.2004	X10.9815 = 2.2007	X1 = 2.2007
MgO	2.86	0.0709	0.0709	X10.9815 = 0.7786	X1 = 0.7786
MnO	0.02	0.0002	0.0002	X10.9815 = 0.0022	X1 = 0.0022
Na_2O	3.00	0.0484	X½ = 0.0242	X10.9815 = 0.2658	X2 = 0.5316
TiO_2	0.09	0.0010	X2 = 0.0020	X10.9815 = 0.0220	÷2 = 0.0110
*K_2O	0.58	0.0062	X½ = 0.0031	X10.9815 = 0.034	X2 = 0.0680
Totals	100.74	1.4904	2.914	$\frac{32}{2.914}$ = 10.9815	

*K_2O estimated from N2d rock analysis

Or	Ab	An
2.43%	18.98%	78.59%