THE NIPISSING DIABASE

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ABSTRACT

Undulating sheets of Nipissing tholeiitic diabase that intruded Archean and Proterozoic rocks throughout the Cobalt-Gowganda region were subsequently eroded, leaving the lower parts of the sheets as isolated diabase basins. Differentiation of the magmas resulted in a concentration of olvine- and hypersthene-bearing diabase in the depressed parts of the intrusions, and a concentration of the less refractory components in the elevated parts. Mineralogical and chemical studies of two diabase sheets intersected in a vertical hole in Henwood township, near Cobalt, confirm that the development of the different rock varieties in the sheets was brought about by differentiation. Chemical trends and cryptic zonation of the feldspars systematically change and suggest that in basin-shaped intrusions there was a lateral transfer of magmatic components. The early crystallization of calcic feldspars and magnesium-rich pyroxenes was followed by later amphiboles and soda-rich feldspars. Plagioclase rim compositions became progressively more sodic with fractionation, and show no compositional gap between the feldspars of ordinary and granophyric Nipissing diabases.

INTRODUCTION

The Nipissing diabase was named by Miller (1911) to denote the massive tholeiitic intrusions of Precambrian age which occur at Cobalt, the type area. These form part of an extensive diabase province of about 175,000 square miles which extends from Lake Timiskaming southward to the Great Lakes area and westward to Lake of the Woods. The diabase occurs as dykes and sills ranging in thickness from less than a hundred feet to more than a thousand feet. In the Cobalt-Gowganda region thick sill-like sheets predominate.

Microscopic studies of the Nipissing diabase date back to the discovery of the silver deposits at Cobalt. The earlier workers, such as Bowen (1909, 1910), Hore (1910), and Collins (1910, 1913) realized that the diabase consisted of a variety of rock types, and directed their efforts toward unravelling the relationship between diabase differentiates and the late-stage granophyres and cross-cutting aplites.

Because of the constancy of the Nipissing diabase-silver ore association, no study of the nature and origin of the silver-cobalt ores would be complete without a detailed examination of the differentiation of the diabase. The necessity for such studies is applicable regardless of whether the diabase or some alternative is advocated as the source of the ore-forming fluids. Unfortunately, time limitations in the present work have not permitted an examination of all of the features of the diabase in the detail that is desirable and warranted. Attention has been focused primarily on feldspar mineralogy and some hydrous differentiates in order to determine the nature of granophyre and aplite development, and to ascertain whether there is any relationship between the mineral assemblages occurring in ore veins and those produced at the terminal stages of diabase fractionation.

GENERAL FEATURES OF THE DIABASE

Field characteristics

Outcrops of the Nipissing diabase in the Cobalt-Gowganda region form large arcuate to circular patterns derived by erosion of an undulating sheet or sheets, or funnel-shaped intrusions (Figs. 7, 8). This type of surface expression for extensive diabase intrusions is not unusual, but is also found in Tasmania, South Africa (Karroo), and in other parts of the world.

The prolonged mining activity in the Cobalt area has provided much information on the subsurface configuration of the diabase. The dips of the intrusions are for the most part gentle. There are few places where the diabases parallel the bedding of the relatively flat-lying Huronian sediments, and few where the Archean-Proterozoic unconformity has acted as the intrusive plane. Rather, the cross-sections show that most sheets follow planes which transect the bedding and unconformity even though intrusion dips may be gentle for relatively long distances. In other words, the diabase occurs in saucer-shaped bodies whose contacts are not precisely controlled by stratigraphic features. The writer prefers "sheets" to "sill", and uses the plural to indicate that more than one intrusion makes up what has ben called the "Nipissing diabase sill".

At Cobalt, the bottom contact of the diabase was used by Thomson (1957) to outline the basins and arches shown in Figure 8. The diabase in this area has a maximum thickness of about 1,100 feet (335 m). Some typical features are evident around the New Lake basin. For example, the western side has an almost vertical dip and in places thins to a width of less than 200 feet (61 m) ; such narrowing with steepened dips is common. A second feature is the Schumann Lake arch with northeasterly-trending axis along the southern rim of the basin. The diabase along the south part of the arch dips southward beneath the cover rocks ; that to the north dips toward the centre of the New Lake basin. The existence of the arch suggests that some of the diabase basins may have been part of a single undulating sheet. Although most of the diabase along the Kerr Lake arch has been removed by erosion, its continuity along the western edge suggests that the New Lake and Peterson Lake basins are part of a continuous sheet. The feeder or feeders for the sheet may lie in the New Lake basin and in the Cross Lake fault, the latter source having been suggested by Lovell & Caine (1970). Another feeder probably occurs in the Nicol Lake basin (Fig. 8). The circular outline and inward dips of the diabase here suggest the presence of a cone-shaped intrusion. Possible cone shapes are also suggested wherever the diabase has been injected into a homogeneous medium, particularly the massive Lorrain granite. Merging sheets from multiple sources are a possibility, but an unconfirmed one.

Examination of the diabase underground and in surface exposures shows that fracturing has controlled the shapes of the sheets. Sharply-defined, step-like contacts transect bedding in some cases. Each step may be only a few cm high, but at some localities steep dips prevail for a few meters, thus giving rise to undulations called "rolls". Permissive intrusive conditions are evident from the lack of structural disturbance of the enclosing rocks (Fig. 14) even where strongly discordant relationships

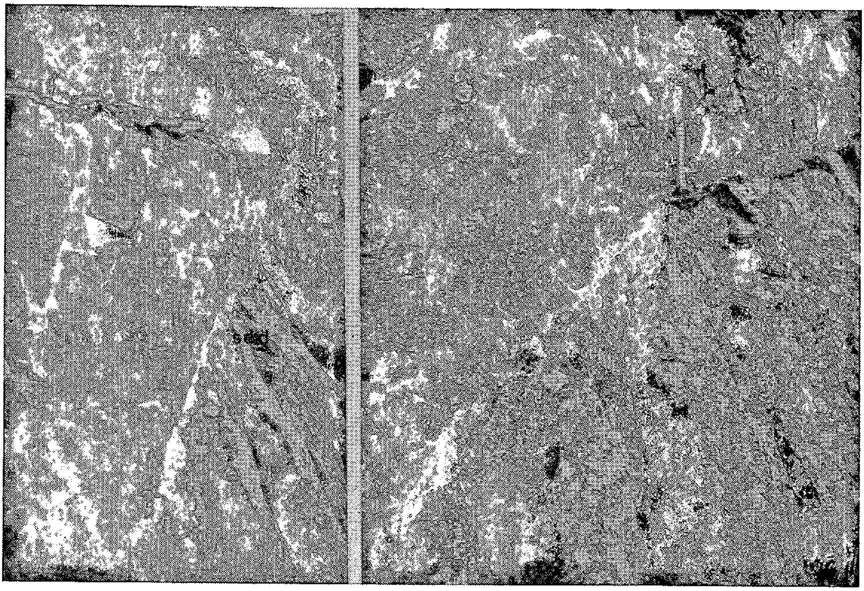

FIG. 14. Steep intrusive contact of Nipissing diabase and Cobalt sediments, lot 11, conc. II, Bucke tp., Cobalt. The photograph on the right shows the undisturbed, nearly horizontal bedding of the sediment in the foreground. The geological pick is on the intrusive contact in both photographs.

are present. If sharp rolls indicate an upward movement along steeply-dipping features, then they also indicate the direction of diabase movement. In this connection, it should be mentioned that the diabase has not been folded. The post-diabase tectonic event at about 1700 m.y. which has been shown isotopically to have occurred north of Lake Huron does not seem to extend into the Cobalt area. Indications from radiogenic isotopes (Fairbairn *et al.* 1969) are that the diabase in the Cobalt-Gowganda region has not been metamorphically disturbed since its intrusion.

Joints

Columnar jointing is well-developed in most places and seemingly in all phases of the diabase. In a few places the baked Proterozoic sediments adjacent to the diabase show well-developed jointing continuous with that in the intrusion. The highest topographic points in the region usually have the most pronounced relief because the columnar joints form cliff faces. This feature is particularly prominent along the shore of Lake Timiskaming where the eastern edge of the North Lorrain basin has almost vertical, continuous columns more than 150 feet (46 m) high.

The columnar joints are usually developed normal to the diabase sheet contacts, with a less prominent joint set occurring parallel to the contacts. Either set may therefore be used to derive the configuration of an intrusion.

A less common but interesting phenomenon is the presence of concentric joints. In cross section they are arcuate to almost completely circular and have their long axes normal to the contacts of the diabase sheets. Concentric joints noted by Moore (1956) at Gowganda were subsequently described in detail by Eakins (1961). Both writers attributed the jointing to cooling effects, but Hester (1967) proposed an elegant tectonic origin. The present writer has observed concentric jointing at Gowganda, Elk Lake, Cobalt, and South Lorrain, and it has been reported in diabase and volcanics in several other places in the world (*eg.* Hill 1965; Stevenson 1968; Goryainov & Pesterev 1969). Such a widespread occurrence makes a tectonic origin unlikely. Moreover, the most perfectly-developed concentric joints seen by this writer occur in a steeply-dipping quartz diabase dyke that cuts the Nipissing diabase in the Castle-Trethewey mine at Gowganda. The column axes are normal to the dyke walls; this is considered to be conclusive proof of the cooling origin of the joints.

Contact effects

The diabase is generally free of small inclusions, but there are exceptions. At Elk Lake, for example, MacKean (1968) noted local contact brecciation in James township, and in the same area the present writer has seen inch-sized metasedimentary inclusions in coarse-grained diabase several hundred feet from known contacts.

Alteration of the country rocks adjacent to the diabase is largely dependent on the rock type present. Extensive development of chlorite spotting, particularly in Proterozoic sediments, is described in a later paper (p. 305). Thomson (1961) reports a local alteration and recrystallization of Cobalt sediments on the Kerr Lake arch ; for many years the rock here was referred to as being a granitic dyke. Biotite is present in some sediments adjacent to the contact. MacKean (1968) noted local development of chlorite spotting and bleaching in sediments in the Elk Lake area. Similar effects at Gowganda were described by Collins (1913), who also pointed out that only argillaceous sediments were appreciably affected. Some quartzites are fused and blackened for a few inches out from the contact, but granites are unaffected. Todd (1926) mentions that recrystallization and reddish coloration occur as contact alteration effects in arenites in the Matabitchewan area to the west of South Lorrain.

The upper contacts of flat-lying sheets are generally the most altered. In the Anima-Nipissing area to the west of Cobalt, Todd (1927) mentioned that, in the field, the upper contact of the diabase at one locality appeared to be gradational with the overlying Lorrain quartzites. Bowen (1910) and Bastin (1935) described local occurrences of "adinole" (albitized argillaceous sediments) near the upper contacts of Nipissing sheets at Gowganda. Bowen proposed that both the granophyre and adinole formed by hydrothermal alteration at the contact. Even where adinole is intensively developed, demarcation of the diabase-sediment contact to within a few centimeters is generally readily possible. For most of the region, assimilation seems to have played a negligible role in the diversification of the diabase magma.

DIABASE VARIETIES

Introduction

The first extensive and systematic petrographical study of complete cross-sections of the diabase basins and arches was that of Hriskevich (1952, 1968), who provided the key to understanding the evolution and distribution of the diverse rock types comprising the diabase. He showed that the proportion of acidic and basic differentiates in a sheet is substantially affected by the configuration of the intrusion ; basins contain a greater proportion of basic rocks whereas the arches have a higher proportion of salic material.

The availability of drill core from a 7,662 foot vertical drill hole provided a unique opportunity to carry out further petrological studies of the diabase. The hole was drilled in Henwood township, approximately 20 miles northwest of Cobalt, and is thus within the belt of silver showings that extend westward to beyond Gowganda. In addition to having a complete section, further studies were prompted by the knowledge that the hole passed through two sheets of diabase, one above the other. This is the only locality where two thick sheets occur in sequence.

Throughout the Cobalt-Gowganda region the Nipissing diabase can be subdivided megascopically into the following principal rock types: quartz diabase, hypersthene diabase, varied-texture diabase, pegmatitic diabase, granophyre, and aplite. Their typical distribution within a sheet is schematically shown in Figure 15.

Quartz diabase

The upper and lower contacts of the Nipissing diabase generally show well-defined chill zones. For 5 to 10 mm from the contact the diabase is greenish and aphanitic, but this rapidly gives way to black, and then dark grey fine-grained quartz diabase which becomes progressively coarser towards the central part of a sheet. In a 1000 foot thick sheet, the quartz diabase zones may be 50 to 150 feet thick, the lower zone generally being thicker than the upper.

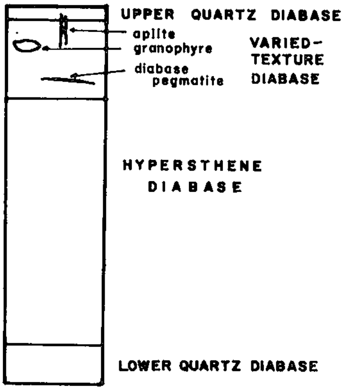

FIG. 15 Schematic illustration of the occurrence of the principal rock types comprising differentiated Nipissing diabase.

The chill zones contain microphenocrysts of augite, abundant altered glomeroporphyritic plagioclase, and sparse equidimensional grains of a completely altered mineral, possibly olivine. The phenocrysts generally make up less than 5 per cent of a chill zone, with about 80 per cent of the grains being plagioclase laths less than 2 mm in length. Flow texture is restricted to phenocrysts within a millimeter of the contact. The groundmass consists of plagioclase laths, commonly in radial growths, with minute intergranular grains of augite. Within a few cm from the contact the grain size, though still fine, rapidly coarsens and the texture becomes diabasic. The only mineral clearly identifiable in most hand specimens is plagioclase. Prismatic mafic minerals up to 2 mm in length in the coarser portions of the quartz diabase are generally augite, but in some places, particularly in the upper quartz diabase, abundant amphibole is present.

Chilled contact zones generally attract attention because they possibly represent the composition of original magma, save perhaps for the loss of some volatiles. It was hoped that an examination of chilled diabases might tell whether distinct injections of magma formed the various diabase basins. An extensive suite of chilled diabase was collected for this purpose. The possibility of defining lateral variations in the more extensive sheets proved untenable because insufficient unaltered diabase could be obtained to give meaningful results. There seems to be no recognizable megascopic properties for satisfactorily discriminating between highly altered and relatively unaltered chill zones. Seemingly fresh aphanitic chills collected underground in many cases proved to be completely albitized. Because of this, and because the diabase rapidly changes in grain size within inches from the contact, a proper comparison of chill zones from basin to basin would require a very extensive and meticulous study. Some representative results obtained from *x*-ray diffractometer analyses of feldspar compositions of several chilled diabase samples are given in Table 4. The results, which are based on mean peak positions obtained from ground whole rocks, show that the average composition of the matrix feldspar in most of the diabases is about An 55. Several samples also show that some chill zones have been totally altered to albite. The albitized chills are characterized in thin section by their low birefringence and the absence of primary mafic minerals. Plagioclase phenocrysts in the altered zones have in many cases retained their shapes and zoning, though complete pseudomorphism by albite and chlorite is always present.

The change from completely albitized to "unaltered" chilled diabase is transitional. It is marked initially by the gradual appearance of relict clinopyroxene, and eventually by sericitization rather than albitization of the primary plagioclases, particularly the phenocrysts. Chemical analyses

TABLE 4. X-RAY DIFFRACTOMETER COMPOSITIONS (wt. % An) OF PLAGIOCLASE IN CHILLED NIPISSING DIABASE.

Area	*Locality*	*No.*	*Position*	*Mean An*
South Lorrain	Keeley mine, claim HR 19	69L–1	less than 20 cm from upper contact with Keewatin	52 ± 5
Cobalt, Nicol L. basin	Eastern edge of Nicol L. basin	68–143	8 cm from upper contact with Lorrain granite	50 ± 5
	500 m NW of 68-143	68–149	15 cm from basal contact with granite	55 ± 5
Cobalt, Peterson L. basin	Belmont property, lot 2, conc. IV, Coleman tp.	68–9	absolute basal chill * with Cobalt sediments	0–5
Cobalt, Peterson L. basin	Nipissing RL 407, lot 5, conc. V, Coleman tp., 300 m west of 407 shaft	69–385B	absolute basal chill with Cobalt sediments	0–5
		69–385T	20 cm above 69–385B	0–5
Cobalt, Peterson L. basin	Silver Summit property, lot 5, conc. IV, Coleman tp., 60 m north of shaft 7	69–46B	absolute basal chill with Cobalt sediments	64 ± 5
		69–46M	12 cm above 69–46B	52 ± 5
		69–46T	25 cm above 69–46B	52 ± 5
Cobalt	SW corner of lot 11, conc. II, Bucke tp.	68–1	absolute basal chill with Cobalt sediments	5 ± 2
		68–2	20 cm above 68–1	55 ± 5
		68–7	2 cm above 68–1	55 ± 5
		69S–19	absolute chill, 10 m from 68–1 along contact	2–5
Elk Lake	North ½, lot 2, conc. VI, James tp.	69E–16	basal chill with Cobalt seds.	52 ± 5
Gowganda, Miller L. basin	Lower Bonsall mine	68–332	abs. basal chill with Keewatin	2 ± 5
	Siscoe mine, 350 level near shaft 6	69G–19	abs. top chill with Keewatin	52 ± 5
	about 200 m south of Lower Bonsall shaft	69G–20	abs. basal chill with Keewatin in drill core	52 ± 5
	near Tonopah (Walsh) shaft	69G–104	abs. top chill with Keewatin in drill core	0–5
	approx. 65 m from 69G–104	69G–107	abs. top chill with Keewatin in drill core	60 ± 5

* The term "absolute chill" is used for chilled diabase less than 3 cm from the contact.

of some representative contact diabases are given in Table 5. The results indicate that the zone of albitization at the bottom contact generally penetrates less than a meter into the diabase. Albitization is erratic in that it may persist for tens of meters, but does not continue for hundreds of meters along the strike of the contact. There seems to be no correlation between albitization and the dip of the diabase contact, nor with the type of country rock, be it Proterozoic sediments or Archean volcanics.

In Table 4 the samples from the bottom contact in Bucke township are representative of the rapid transition from an albitized chill to unaffected diabase at approximately 30 cm from the contact. The sample from Nipissing RL407 is representative of the transitional alteration stage in which the feldspars are completely albitized but relict clinopyroxenes

TABLE 5. CHEMICAL ANALYSES OF NIPISSING DIABASE AT INTRUSIVE CONTACTS, COBALT AREA.

Location[1]	Bucke Township			Nipissing RL407	Silver Summit Property			Colonial Mine	
No. (JF–)	68–2	68–6	68-7	69–385T	69–46B	69–46M	69–46T	116*	69C–30
Type	absolute chill	30 cm from contact	2 meters from contact	20 cm from contact	absolute chill	12 cm from contact	37 cm from contact	chill	2 m from top contact
SiO_2	55.3	52.6	52.0	51.6	52.8	51.9	52.3	51.98	47.9
Al_2O_3	16.8	14.6	14.2	15.9	14.8	14.9	15.0	14.69	15.2
Fe_2O_3	3.3	2.2	2.3	2.0	2.3	1.9	0.5	0.85	2.3
FeO	6.3	7.2	7.4	7.6	7.4	7.5	9.2	8.70	8.7
MgO	7.4	7.6	7.5	7.6	7.5	7.6	7.5	7.50	9.2
CaO	0.4	10.3	10.5	4.0	10.7	10.6	10.8	11.46	2.1
Na_2O	5.0	1.6	1.6	4.5	2.0	1.5	1.4	1.83	3.9
K_2O	0.1	1.0	1.0	0.3	1.1	0.9	0.8	0.51	0.4
$H_2O\pm$	5.0	1.8	1.9	4.0	1.9	1.9	1.6	1.43	5.9
TiO_2	0.8	0.6	0.6	0.7	0.6	0.6	0.6	0.62	0.8
P_2O_5	0.05	0.06	0.02	0.06	0.06	0.06	0.05	0.06	0.07
MnO	0.06	0.15	0.16	0.12	0.17	0.17	0.18	0.18	0.17
CO_2	<0.1	0.1	<0.1	0.3	0.1	0.2	0.2	0.04	1.0
Total	100.5	99.9	99.2	98.7	101.4	99.7	100.1	99.85	97.6
Fe as FeO	9.3	9.2	9.5	9.4	9.5	9.2	9.6	9.5	10.8

Analyses by Analytical Chemistry Section, GSC.

[1] See Table 4 for location details.

* After Hriskevich (1952).

are abundant and only partly chloritized. The sample is about 20 cm from the contact, with the underlying absolute chill being similar to the Bucke township chill. The Silver Summit suite may be considered as normal chilled Nipissing diabase, which in this case is about 700 meters from the RL407 sample. Both are from the bottom contact of the sheet forming the Peterson Lake diabase basin. The Colonial mine samples are also from the Peterson Lake basin, but are in this case from near the top of the sheet. Sample 116 appears to be normal chilled diabase, but the other, despite its proximity to the contact, is medium grained and lacks the texture of chilled diabase. Its principal constituents are albite laths, averaging about 0.5 mm in length, intergrown with chlorite pseudomorphs of similar size. Judging from the preservation of zoning and indications of twinning, the pseudomorphs appear to have been formed predominantly from clinopyroxene. Fine-grained carbonate is disseminated throughout the section, which also contains sphene and a few grains of quartz, micropegmatite, and biotite shreds at the edges of some of the chlorite pseudomorphs. The rock is clearly not an albitized chilled diabase even though there are similarities in that water and sodium are relatively high and calcium correspondingly low.

It can be seen from Table 5 that the most drastic chemical change in the altered chills is the pronounced depletion of calcium. Most of the chemical changes can be accounted for by eliminating the primary calcic feldspars and augitic clinopyroxenes, and replacing them with albite and chlorite. Total iron in the samples remains reasonably static, but even in non-albitized rocks such as the Silver Summit samples it is apparent that detectable oxidation has occurred. The brownish turbidity so common to chilled diabase is undoubtedly largely a manifestation of iron oxidation.

The disappearance of calcium from the albitized chill zones is a problem clearly warranting more study. Alkali analyses of country rocks near the contacts would be an interesting check for possible metasomatism, particularly where fused contacts are reported. The works of Butler (1961) and Woodward (1968) might be cited here as examples where alkali metasomatism has been detected by detailed studies of country rocks adjacent to diabase and gabbroic intrusions. In the Cobalt-Gowganda region, the pre-Nipissing rocks are typically soda-rich, and in view of the narrow width of the albitized zones, one might suspect that the alteration involved an absorption of soda from the country rocks. There are, however, several other lines of evidence which suggest that the albitized zones are areas of deuteric alteration. The restricted width of the alteration is not particularly significant, and is in fact very similar to the deuteric zone along the Australian diabase-picrite intrusion described by Wilshire (1960, 1967). Among the arguments favouring the concept of deuteric alteration along contacts in the Cobalt area is the lack of correlation of albitization with the type of country rock at the contact; the inference is that if metasomatism had occurred, it should perhaps have shown some sensitivity to the rocks constituting the source for the ions involved in the metasomatic exchange. This insensitivity also appears in the converse case where albitization is erratic despite the presence of a relatively uniform country rock, particularly where a sheet is locally conformable with Huronian sediments. That an egress rather than absorption of sodium occurred at the diabase contacts is indicated by the local development of albite metasomatism in adjacent sediments as was described by Bowen (1910).

The progression toward increasingly hydrated phases in diabase differentiates is readily recognized, but the nature of volatiles in the diabase magma is difficult to ascertain from chilled zones. Carbonate grains are commonly present in thin sections of chill zones, and evenly-distributed, minute specks of calcite (confirmed by microprobe) have been noted in more than one "unaltered" chill. Carbonate grains have also been found in Lorrain granite at the diabase contact, but are absent in a single thin section of the pluton away from the contact. Although it is not known whether this association is extensive, there is nevertheless at least a tentative indication that carbon dioxide expulsion from the diabase magma may have occurred.

Table 6. Microprobe Partial Analyses of Clinopyroxene Phenocrysts in the Absolute Chill Zones of Nipissing Diabase.

	Miller Lake Basin, Gowganda				*Nicol Lake Basin, Cobalt*
	JF68–332		JF69–103	JF69–107	JF68-149
Wt. %	(a)	(b)			
CaO	18.6	21.3	18.7	20.2	12.9
FeO	7.0	7.1	6.7	6.6	11.9
MgO	19.1	15.8	15.5	16.8	17.9

Analyst: A.G. Plant

Notes

JF68–332: Bottom contact of sheet, Lower Bonsall mine. Analysis (a) made on three phenocrysts; (b) on one.

JF69–103: Upper contact in drill core, Tonopah (Walsh) property.

JF69–107: Upper contact in drill core, approximately 120 m from JF69–103.

JF68–149: Eastern side of basin, 15 cm from bottom contact.

There is a remote possibility that the compositions of plagioclase and clinopyroxene phenocrysts in the chilled margins can be used to distinguish between diabase sheets formed from different injections of magma. Although the feldspar phenocrysts are generally highly altered, the clinopyroxene phenocrysts are better-preserved. Microprobe analyses of grains from four samples, of which three are from the Miller Lake basin at Gowganda, are given in Table 6. The results indicate that phenocrysts in a single sheet and within a single sample are of variable composition. It is possible, however, that the variation may be confined within a limited compositional range.

Hypersthene diabase

Dark grey basal quartz diabase is gradational upwards into hypersthene diabase characterized by the presence of brownish orthopyroxene grains averaging 3-5 mm, and reaching a maximum of 8-10 mm in length. The orthopyroxene is distinctive in hand specimens and contrasts well with the finer-grained, lighter-coloured feldspars and blackish clinopyroxenes. In the lower parts of diabase basins the hypersthene diabase may be olivine-bearing. Neither olivine nor the persistently-present interstitial quartz is readily identifiable in most hand specimens.

Hypersthene diabase is the most abundant rock type in basins throughout the Cobalt-Gowganda region. Where the sheets are not steeply-dipping, the hypersthene diabase zone forms about two-thirds of the lower basin portion of the sheets. The zone between the hypersthene diabase and the upper quartz diabase consists of varied-texture and granophyric diabase. On the rims of basins these increase in thickness at the expense of hypersthene diabase.

Varied-texture diabase

The hypersthene diabase is gradational upwards to diabase having a variable texture and grain size. The term "varied-texture diabase" (Hriskevich 1952) is a useful field name to describe rocks of this type. Varied-texture diabase consists of diabase phases having contrasting grain sizes and textures which may be completely gradational (Fig. 16C), or rather abrupt. The rock may be fine, medium, or coarse-grained, the significant aspect being the presence of contrasting grain sizes.

Hriskevich (1968) defined varied-texture diabase as follows : "The varied-texture diabase consists of irregular patches of coarser-grained diabase with gradational boundaries, occurring in finer-grained diabase of apparently the same composition." The present writer has removed the

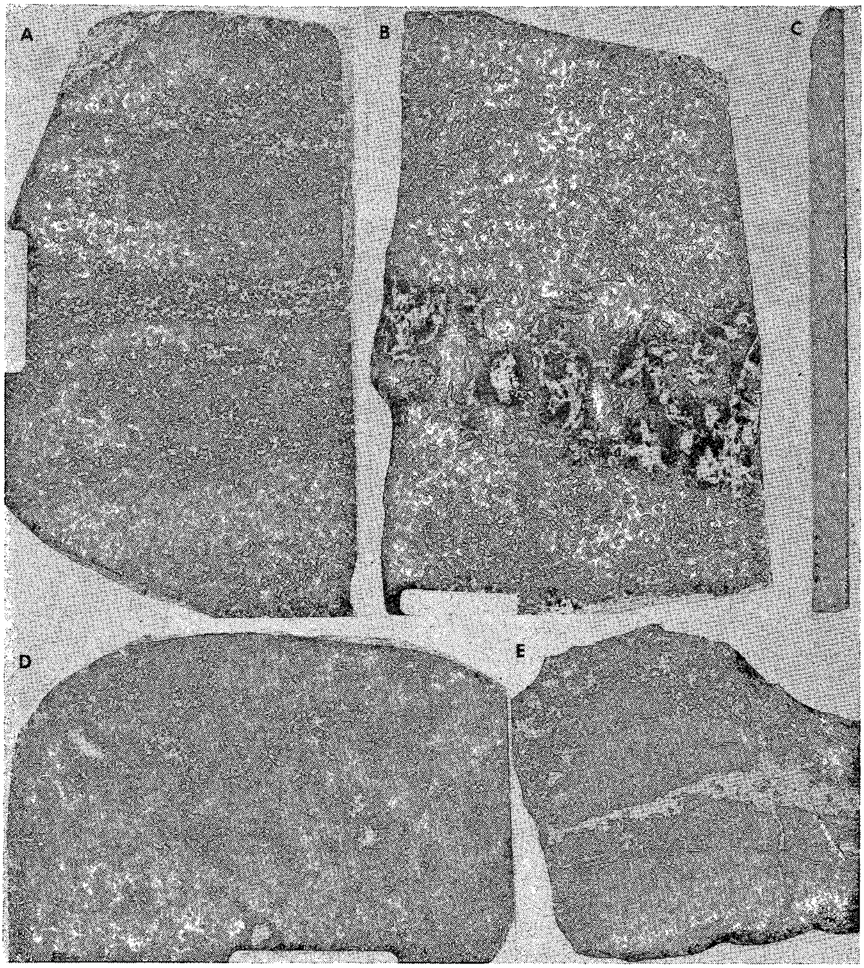

FIG. 16. (A) Layering in hypersthene diabase, Miller Lake, Gowganda. The large, dark grey, somewhat rounded grains are orthopyroxene. This specimen shows the best banding seen in this study. (B) Diabase pegmatite dyke, Siscoe mine, Miller Lake. (C) Varied-texture diabase from the Lower sheet, Henwood township; core length 51 cm or approximately 20 ins. (D) Pinkish granophyre with miarolitic calcite (white), Silverclaim Lake, Mickle tp., Elk Lake. (E) Varied-texture diabase, Coleroy property, Miller Lake, showing coarse-grained, pinkish granophyric diabase (top and bottom) in contact with dark "normal" diabase. Horizontal and vertical light pink aplite stringers merge with the granophyric diabase without discontinuity (specimen width 30 cm or 12 in).

compositional restriction and expanded the term to include all diabase having schlieren, irregular patches, large pockets, or numerous veinlets of granophyre or diabase pegmatite (defined below) having a relatively finer-grained host or associate. Defined this way, varied-texture diabase occurs as a mappable field unit in the upper parts of all differentiated sheets.

Diabase pegmatite

Diabase pegmatite is characterized by its coarse grain size (Fig. 16B). The rock occurs as irregular schlieren, as large pockets with rounded margins, and as dykes in finer-grained diabase. The contacts are generally sharp, but not chilled. The mineralogy is similar to that of diabase, but orthopyroxene is absent and the texture is granitic rather than diabasic. Walker (1953) showed that diabase pegmatites are slightly more acidic than the associated normal diabase.

Diabase pegmatite is not abundant and is largely restricted to the zone of varied-texture diabase. Some pegmatitic dykes extend into the hypersthene diabase, but a trend to fewer and smaller dykes with increasing distance from the varied-texture zone is readily apparent.

Granophyre

Granophyric diabases contain abundant fine-grained intergrowths of quartz and alkali feldspar. Such rocks are generally pink and contain amphibole, biotite, or chlorite as the principal mafic minerals. Clinopyroxene may be present, but is invariably extensively replaced by the above minerals.

Barker (1970) has discussed the terminology used to designate quartz-feldspar intergrowths and restricts the term "granophyre" to material having a "granite" composition. The intergrowths found in the present study fall within Barker's compositional fields for myrmekite and graphic granite. However, intergrowths reported by Bowen (1910) and Phemister (1937) for rocks from the Cobalt-Gowganda region correspond to true granophyres. In view of this ambiguity, the term micropegmatite will be used to designate the fine-grained mineralogical intergrowths, and granophyre (or granophyric) will be used as a rock term.

Nearly all Nipissing diabase contains small amounts of interstitial micropegmatite, but only in the upper parts of the sheets is it abundant. Such granophyric diabase is gradational to true granophyre in which the mafic minerals decrease and the rock takes on a pink granitic appearance.

The alkali feldspar in Nipissing granophyres examined in this study is albite containing hematitic dust which imparts the pinkish colour. In rocks having a granitic appearance, the micropegmatite grains may be coarse, but subordinate in quantity to hypidiomorphic quartz and albite. Most granophyre contains some carbonate, either along grain boundaries or in commonly present miarolitic cavities (Fig. 16D).

Granophyre normally forms part of the zone of varied-texture diabase, usually occurring within it as irregular masses. The proportion of granophyre present in a sheet is in part dependent on the shape of the intrusion : minimal granophyre development occurs in deep basins, but the abundance increases towards the arch positions.

Aplite

Aplite dykes may occur anywhere in a sheet, but are most common within the diabase. The dykes are generally less than 30 cm wide and 50 meters long. Most are pink and largely devoid of mafic constituents ; a few are grey and contain minor amounts of actinolite. Equigranular, hypidiomorphic quartz and albite are the principal constituents.

Aplite dykes may occur anywhere in a sheet, but are most common in the upper parts. The dyke contacts may be sharp or gradational, but nowhere are they chilled. In some places the dykes contain vugs lined with dolomite, calcite, and arsenides. These are described in detail by Sampson & Hriskevich (1957).

Diabase in Henwood Township

Introduction

The general geological features of Henwood township, as mapped by Thompson (1966) are shown in Figure 7. Outcrops are generally sparse, but most of the area is underlain by quartzites and arkoses of the Lorrain Formation of the Cobalt Group. Nipissing diabase is present in the northern and western parts of the township as a great arc which is the inner fringe of a diabase basin.

Beginning in 1953, several drill holes were put down in the central part of the township in a search for economic silver deposits. The holes and the unusual circumstances which led to their being drilled are described in detail by Thomson (1966, 1968). Only two of the holes need be mentioned here. The first, designated by Thomson as the "Stone-Eplett No. 3", was drilled at -65° for 4050 feet and was completed in 1958. The second, designated the "Eplett" hole, is a vertical boring collared about 800 feet northeast of the Stone-Eplett No. 3. Begun in 1966, it reached a depth of 7,662 feet before being abandoned in 1969 without having reached the Archean basement.

Drill core logs for the Stone-Eplett and part of the Eplett cores are given by Thomson (1966, 1968). The Stone-Eplett hole intersected the Nipissing diabase from footages 1935 to 2761, equivalent to a vertical thickness of 749 feet. The vertical Eplett hole intersected the sheet from footages 1670 to 2493, giving a thickness of 823 feet. It is not known whether the different thicknesses found are geological, but Thomson (1968) has suggested that mislabelling of the Stone-Eplett (inclined hole) core boxes may have occurred.

Below the 823 foot thick diabase, the vertical Eplett hole intersected approximately 3000 feet of Huronian sediments, and then passed through a second diabase sheet (called the Lower diabase sheet) having a thickness of 772 feet. Proterozoic sediments, which are unlike those found anywhere else in the Cobalt-Gowganda region, extend from the Lower sheet to the hole bottom.

The sediments intersected in the Eplett drill hole are described by Thomson (1966, 1968). The Lorrain Formation is present to footage 1,158; it is almost exclusively reddish brown to pale greenish grey arkose. Below this, 2032 feet of Firstbrook sediments (the upper member of the Gowganda Formation) were intersected. The Firstbrook, almost exclusively argillite, is characterized by its fine-grained, conspicuously bedded nature. The beds range from reddish brown to grey to green, with colour alternations being typical.

According to Thomson (1968), the contact between the Firstbrook argillite and the underlying Coleman Member of the Gowganda Formation is distinct in the drill core. The Coleman Member is pebble-bearing, but with variable rock types such as arkose, argillite, quartzite, and conglomerate making up its 830-foot thickness.

Throughout much of the Cobalt area, relatively flat-lying Gowganda sediments unconformably overly steeply-dipping, predominantly metavolcanic rocks of Archean age. In the Henwood vertical drill hole, however, the Gowganda Formation is underlain by 756 feet of uniformly bedded, grey-green argillite which was called Eplett Formation A by Thomson (1968). Eplett Formation A is in turn underlain by more than a thousand feet of greywacke, argillite, arkose, quartzite, and conglomerate collectively designated Eplett Formation B. Rocks having thickness equivalent to the Eplett formation are not known in the Cobalt area, but as Thomson has pointed out, it appears that successively lower formations of the Cobalt Group overly the Archean in a northwesterly direction from Cobalt.

The development of a topographic low in the Henwood township area during the early Proterozoic may have been the result of regional graben faulting. Prominent, extensive, northwest-trending lineaments in the area mark the sites of major faults. Where movement along these faults is known, the effect has been to displace the northeast side downwards. Thus, the depression in which the Proterozoic sediment accumulated in the vicinity of Henwood township may well have originated or been accentuated by faulting.

The Upper diabase sheet

As mentioned previously, the presence in Henwood township of two diabase sheets, one above the other, is the first known occurrence of such a phenomenon in the Cobalt area. The occurrence is of considerable importance for it raises the possibility that, if there is a genetic association between Nipissing diabase and the silver ore deposits, then such deposits may occur only with a particular phase of diabase intrusion. The assumption has been made (Thomson 1968) that both sheets are Nipissing, primarily because of their habit and lithology.

The thickness of the Upper sheet as intersected in the Eplett drill hole is 823 feet (251 m). The proportions of the diabase varieties comprising the sheet are given in Table 7. At the upper contact an aphanitic chill zone is absent and fine-grained quartz diabase abuts laminated Firstbrook sediments. At the contact the flat-lying sediments have been folded so that vertical dips prevail for at least half a meter. At footage 1671 a 15 cm length of core shows the diabase in an undulatory vertical contact with sediments. The diabase is medium-grained and mafic-rich, with a 6 cm-wide black, biotite-rich zone at the contact. The roof quartz diabase is relatively thin, and passes almost immediately into varied-texture diabase. The lower part of the varied-texture zone contains abundant pegmatitic

TABLE 7. PROPORTIONS OF DIABASE VARIETIES IN THE HENWOOD INTRUSIONS INTERSECTED BY THE EPLETT VERTICAL DRILL HOLE.

	UPPER SHEET		LOWER SHEET	
	Footage	Thickness	Footage	Thickness
Quartz diabase	1670–1685	15 ft.	6181–6273	92 ft.
Varied-texture zone	1685–1866	181	6273–6450	177
Hypersthene diabase	1866–2397	531	6450–6800	350
Basal quartz diabase	2397–2493	96	6800–6903	103
		823		722

material, and is gradational downwards into rather uniformly dark grey, medium-grained hypersthene diabase. Diffuse banding similar to that shown in Figure 16A is visible in some of the hypersthene diabase. It is nowhere prominent, but is best developed in the upper half of the hypersthene zone.

The basal quartz diabase zone is relatively well-defined and shows a pronounced decrease in grain size from medium to fine about 3 meters from the contact. The quartz diabase zone is megascopically separable simply on the basis of its being much lighter-coloured than the hypersthene diabase. The bottom contact of the sheet is flat-lying and shows aphanitic greenish chilling. Both diabase and bands of laminated sediments are present in the last 30 cm of the contact zone. The sediments are either inclusions, or the diabase is present as chilled apophyses of the sheet. The latter is more likely because the sedimentary bedding is still horizontal.

The Lower sheet

The Lower sheet is 722 feet (220 m) thick. The proportions of diabase varieties comprising the sheet are given in Table 7. The thicknesses differ from those in the Upper sheet, but both intrusions are similar in appearance. Thomson (1968) reports that the core of the Lower sheet roof contact was destroyed in drilling, and that the bottom contact is not sufficiently distinct to give reliable information on its attitude.

The Flank section

The somewhat irregular, elliptically-shaped diabase exposed in Henwood and surrounding townships can reasonably be assumed to be the surface continuation of the Upper diabase sheet. As discussed by Thomson (1966), the few attitudes available indicate that the western half of the ellipse dips eastward from 30° to almost 90°.

For the present study, the diabase was sampled in Cane and Henwood townships by traversing southward along their common boundary. This line of cross-section is referred to as the "Flank" section as it constitutes a part of the western rim of the Henwood diabase basin. The precise attitudes of the contacts in the traversed area are not known, hence sample positioning is rather poor. However, neither the thickness of the diabase sheet nor the sequence and proportions of diabase varieties are abnormal. For convenience, the thickness has been assumed to be the same as that of the Upper sheet in the Eplett drill hole.

The bottom contact of the sheet in the Flank section is not exposed. The first specimen collected is a medium-grained hypersthene-bearing diabase approximately 50 meters from the nearest exposure of the underlying Lorrain arkose. The normal upward progression to the varied-texture variety was then followed. Although the roof contact was not found, very fine-grained quartz diabase, such as occurs within less than 4 meters of the contact, was obtained.

MINERALOGY

Plagioclase

Plagioclase throughout most of the sheets occurs in lath-shaped grains with normal and normal-oscillatory zoning. The calcic cores usually make up half to three quarters of the individual grains, with most of the composition change occurring in the remainder, or rim portion of a grain. Although alteration is not restricted to the cores, it is usually most severe in, and commonly largely confined to, this portion of a grain. The replacement minerals are usually sericite, or turbid epidote-rich aggregates referred to as saussurite.

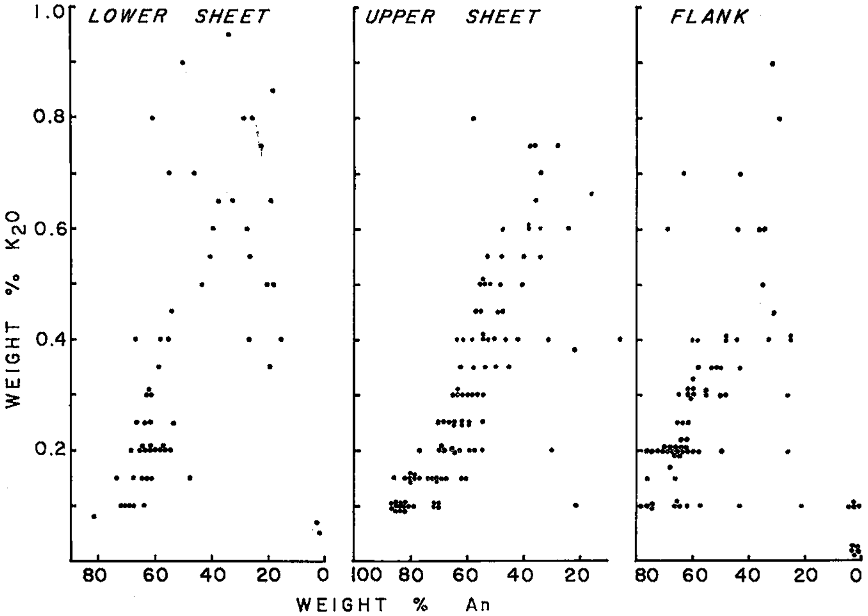

FIG. 17. Microprobe analyses of plagioclase grains in the Henwood township diabases. The change from calcic to intermediate compositions is marked by increasing K in solid solution. The horizontal linearity of groups of data results from rounding off the analytical K_2O values. Approximately 100 grains are represented, with nearly all being zoned.

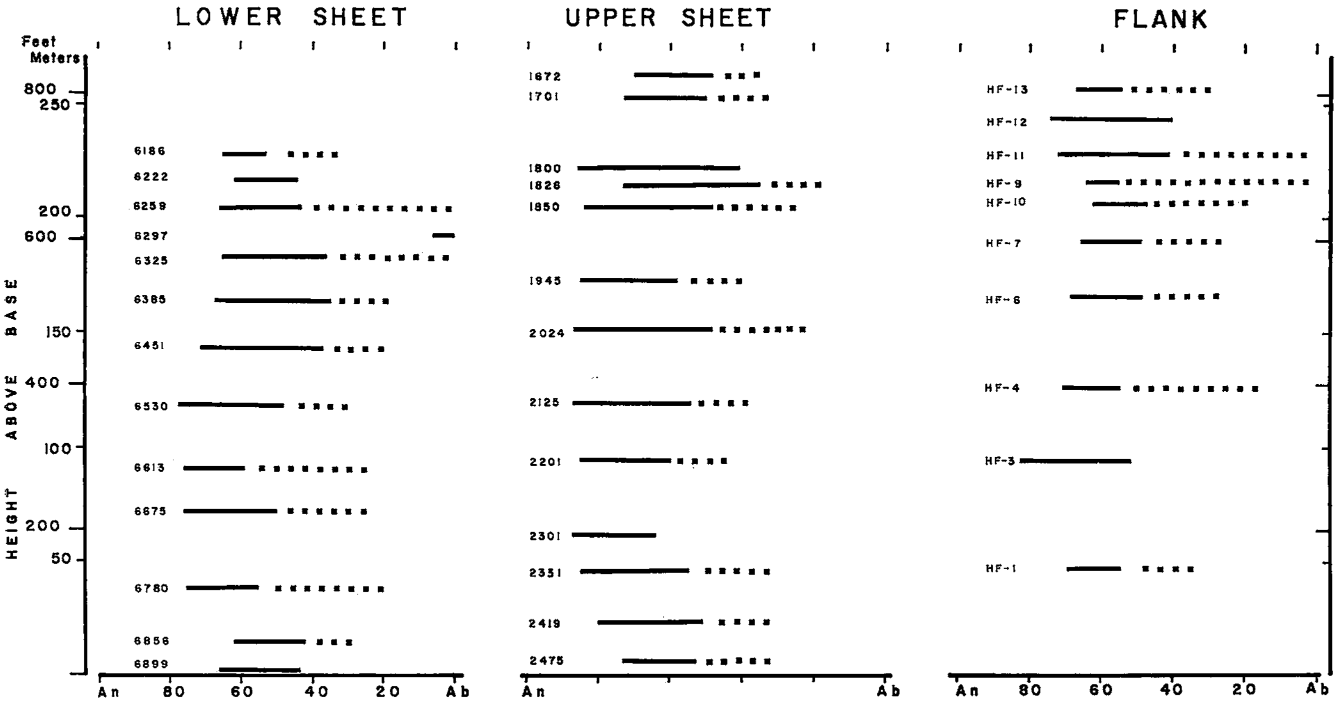

FIG. 18. Variation in plagioclase compositions (wt. % An) versus height above the basal contact of the Henwood diabase intrusions. Solid lines represent the composition range from the cores to the edges of several grains in each section; the dashed lines show the extension of zoning at the extreme outer margins of the grains (see Fig. 19). Sample numbers for the Lower and Upper sheets correspond to footages in the Eplett vertical drill hole.

X-ray powder diffraction studies of the plagioclase indicate that it has the so-called "low" structural state. The compositional results obtained by microprobe analyses are shown in Figures 17 and 18. The principal standards used were synthetic glasses prepared by D. H. Lindsley (Ribbe & Smith 1966). K_2O in all the Henwood samples is relatively low in calcium-rich plagioclases and in micropegmatitic intergrowths (Fig. 17).

The results shown in Figure 18 are a summary of microprobe analyses of approximately 200 feldspar grains. In the Lower sheet, for example, 14 polished thin sections were used, and a number of optically-selected grains, usually about 5, were analysed in each section. The anorthite contents of the core and rim were determined in each grain, and the range of compositions found within each section plotted as a solid line in Figure 18. Because the largest part of most grains consists of calcium-rich material, the average bulk composition of all the feldspar in a specimen, if plotted as a point, would fall on the anorthite-rich half of the solid line.

Plagioclase grains adjacent to interstitial quartz and micropegmatite in many cases have considerably more sodic compositions than the main

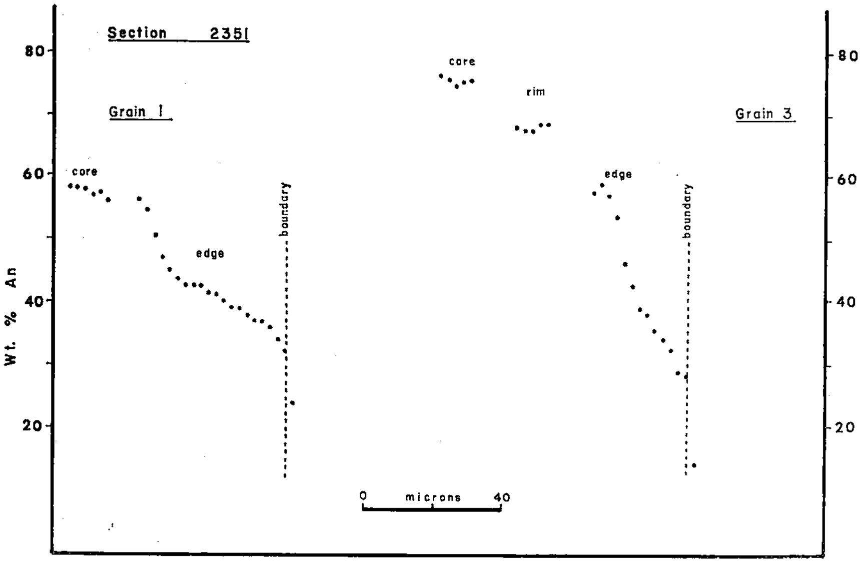

FIG. 19. Zoned plagioclase grains in the Henwood Upper sheet. The "core" forming most of grain 1 (left) gives way to a relatively broad, more sodic edge at the grain boundary. The calcic "core" forming most of grain 3 gives way to a narrow "rim" of less calcic composition, and this in turn gives way to a much more sodic "edge" at the grain boundary. Only a small portion of the cores are shown. (In Figure 18 the core and rim compositions are shown as solid lines, and edges as dashed lines).

mass of feldspar grains. This trait is probably analogous to the zoning adjacent to mesostasis as noted by Muir (1954) in the Beaver Bay diabase, Minnesota. The character and occurrence of such material suggests that it represents continued growth of the crystals in salic-rich interstices. In the Henwood diabases the sodic zones are usually less than 0.03 mm wide; beyond this width there is a rapid progressive rise in calcium content toward the cores. Microprobe analyses indicate that compositions of the soda-rich margins show the same differentiation trends as the main feldspar mass. For convenience, the normal zoned plagioclase is referred to as having "cores" and "rims" whereas the soda-rich material is categorized as the "edge" (Fig. 19). The amount of edge material present in a sample constitutes less than one per cent of the total feldspar volume.

The compositional range of the feldspar edges in each thin section are plotted as dashed lines in Figure 18. The demarcation of "rims" versus "edges" was fairly easy in the Lower sheet plagioclases, but proved to be more difficult in the sections of the Upper sheet and Flank because the rim and edge compositions gradually merge in the higher parts of the sheets.

In all 3 diabase cross-sections the maximum albite contents of the edge portions of plagioclase grains are somewhat erratic, but an over-all trend toward soda enrichment is evident. The fluctuation may be due to an insufficient number of analyses, but it appears also to reflect the physical nature of the plagioclase. For example, the feldspar in samples 6222 in the Lower sheet and HF-12 in the Flank section both have extensively altered edges from which compositions could not be obtained. Albite is present in small amounts in 6222, but is not at the edges of zoned grains. In sample 2301 the soda-rich growth is absent or very rare.

The final sample worthy of specific mention is 1826. The rock is a coarse-grained varied-texture diabase representative of the most differentiated rock type occurring in the Upper sheet. The plagioclase core compositions reach a maximum of An 73, this value being noticeably lower than those in the main mass of the sheet. The previously-mentioned problem of separating plagioclase rims and edges is most acute in this portion of the sheet. This problem, however, is clearly of only minor concern in evaluating the over-all trend of plagioclase differentiation which is briefly summarized further below.

In the Lower sheet the normal zoned plagioclases making up the bulk of the rock have cores ranging in composition from An 77 to An 62, and rims ranging from about An 59 to An 35. The lowermost part of the hypersthene diabase zone is readily distinguished by the marked shift to plagioclase compositions considerably more calcic than those in the basal quartz diabase. The upward succession in the hypersthene diabase zone is characterized by the appearance of progressively more sodic cores and rims, the trend eventually culminating in the appearance of a completely albitized rock at footage 6297, approximately 600 feet above the base of the sheet. The rock here is not granophyric, but consists of amphibole, epidote, and coarse albite.

Plagioclase compositions in the roof quartz diabase of the Lower sheet are similar to those of the basal unit : both are characterized by intermediate compositions with a relatively restricted range of zoning.

Cores and rims of the plagioclases in the Upper diabase sheet are slightly different from those of the Lower sheet both in compositional range and in the trend of variation with height : (a) the analyses indicate that the quartz diabase units in the Upper sheet contain plagioclase cores of An 70-73 whereas those in the Lower sheet are less than An 70 ; (b) in the main mass of the Upper sheet nearly all cores are more calcic than An 80 whereas in the Lower sheet the core compositions do not reach An 80 ; (c) the Lower sheet shows a well-defined trend of progressive soda-enrichment with height ; this feature is considerably obscured in the Upper sheet because calcic cores persist to the roof quartz diabase. In the cross-section of the diabase Flank the plagioclase cores reach An 82 near the base of the sheet and show a marked trend to soda enrichment toward the top.

Little detailed discussion of the plagioclase in the Flank cross-section is necessary. Core and edge compositions are on the whole considerably more sodic than those in the Upper sheet. The data are in harmony with the concept that the Upper sheet and Flank are a single contiguous sheet having a basin or saucer shape. The drill-intersected "Upper sheet" is the depressed, central part of the saucer, and the "Flank" section is the rim of the saucer.

Pyroxenes

Only the pyroxenes in the Upper sheet and Flank section have been worked on in moderate detail. Examination of thin sections of the Lower sheet indicates, however, that the principal pyroxene types described below are also present in this intrusion.

The pyroxenes in the Upper diabase basin may be roughly grouped into the following categories : (a) orthopyroxene, (b) high-calcium clinopyroxenes, most of which fall within the compositional field of augites (c) low-calcium clinopyroxene referred to as pigeonite, and (d) orthopyroxenes with exsolution lamellae of calcic clinopyroxene. The last commonly occur as twinned crystals showing the well-known, characteristic herringbone structure indicative of inversion from original clinopyroxene. Pyroxenes of this type were referred to by Hriskevich (1952) as "inverted pigeonites" and for convenience this term has been retained in the present study.

The character of the pyroxenes in the Henwood diabase basin is similar to that described by Hriskevich (1952, 1968) in the diabase at Cobalt, and need not be repeated in the same detail here. In the Upper sheet of the Henwood basin, anhedral augite and pigeonite in the basal quartz diabase are joined by very turbid inverted pigeonite at about 10 meters above the contact. Exsolved clinopyroxene in the inverted pigeonite does not occur as well-defined lamellae, but is present instead as extremely fine blebs and rods, commonly in trains parallel to (001). A few relatively large, extensively altered orthopyroxene grains are also present; most are mantled by extremely turbid material which appears to be altered inverted pigeonite. Augite is commonly enclosed by inverted pigeonite, and vice versa. With increasing distance from the contact, orthopyroxene becomes more abundant and both pigeonite and inverted pigeonite decline. At 50 meters above the contact, the principal pyroxenes are augite and very large, stubby orthopyroxene grains which are characteristic of the hypersthene diabase zone. Some augite occurs in elongate grains, commonly twinned on (100), up to 1 mm in length, but most is irregular and roughly equidimensional with an average diameter of 0.3 to 0.4 mm. In contrast, the orthopyroxene averages about 4 mm in length. The grains typically have a relatively narrow, gradationally higher-birefringent, iron-rich rim. Individual grains of inverted pigeonite never completely disappear in the hypersthene diabase zone, but they are sufficiently uncommon that they do not appear in every thin section. On the other hand, all orthopyroxene grains have small spots, worm-like blebs, and short lamellae of calcic clinopyroxene which occur near the orthopyroxene rims. The calcic material is usually developed in patches, though come complete mantling does occur. Where lamellae are well-developed, it is evident in a few cases that they were exsolved along (001) in an originally monoclinic host occasionally twinned on (100). Thus, the presence of inverted pigeonite rims approximately coincides with the decrease of individual isolated grains of inverted pigeonite. Towards the middle of the hypersthene diabase zone the bleb-free orthopyroxene cores become smaller, and exsolution commonly extends from the rim to the centre of some grains. Near the top of the hypersthene diabase zone the bleb-free cores fluctuate in size, and as the varied-texture zone is approached individual grains of inverted pigeonite reappear in quantity. The transition from hypersthene diabase to varied-texture diabase is especially rapid above footage 1900, where orthopyroxene markedly decreases and inverted pigeonite increases. By footage 1866 orthopyroxene occurs only sporadically and is absent in some thin sections. Coarse-grained varied-texture diabase is present at footage 1847. Augite and inverted pigeonite are the predominant pyroxenes, but amphibole becomes abundant and much of the pyroxene is heavily altered. This situation prevails through most of the Flank section of the diabase basin. The bottom part, however, does contain orthopyroxene mantled by inverted pigeonite.

In summary, the Henwood diabase basin contains readily-perceived variations in pyroxene mineralogy. Augite in chilled diabase gives way to augite plus pigeonite as the quartz diabase coarsens in grain size. Individual pigeonite grains have a relatively restricted range of occurrence, rapidly giving way to augite plus orthopyroxene in the hypersthene diabase zone. At the top of the hypersthene diabase zone, orthopyroxene in turn markedly decreases to the point where only a few scattered grains are present in the varied-texture zone. Inverted pigeonite occurs in almost all phases of the diabase, but in the hypersthene zone is almost exclusively present as rims around orthopyroxene. The predominant pyroxenes in each of the phases of the diabase may be summarized as follows:

1. chilled diabase	augite
2. quartz diabase	augite, pigeonite, inverted pigeonite
3. hypersthene diabase	augite, orthopyroxene
4. varied-texture diabase	augite, inverted pigeonite

Orthopyroxene and clinopyroxene grains throughout the diabase basin are zoned, and in all cases the outer, or rim, portions of the grains are enriched in iron relative to the cores. The compositions given below were obtained by microprobe analyses for MgO, CaO, and total iron as FeO; the calculated atomic Ca-Mg-Fe percentages have been arbitrarily expressed in terms of Wo, En and Fs. Manganese and titanium in the

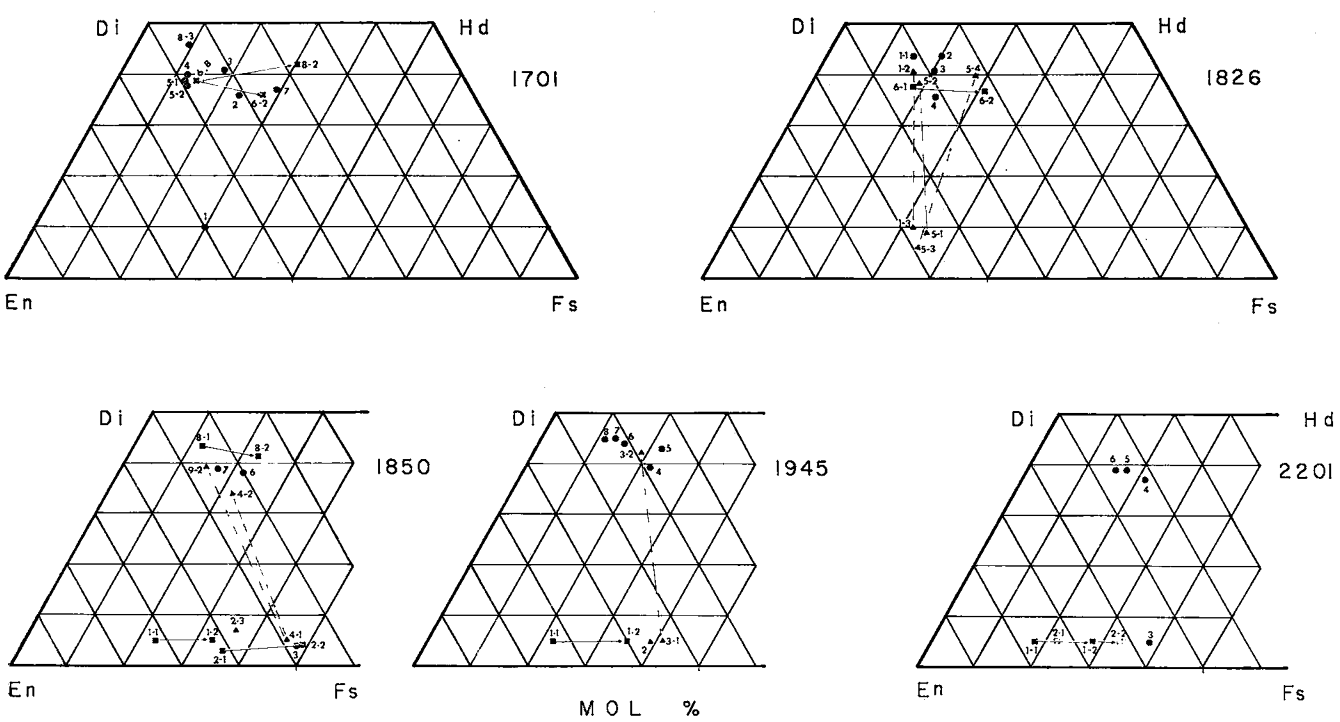

FIG. 20. Microprobe compositions of pyroxenes in the Henwood Upper sheet. Each quadrilateral contains the analyses from a single thin section. Sample 1701 : upper quartz diabase; 1826 and 1850 : varied-texture zone; 1945 and 2201 : hypersthene diabase. Solid lines show zoned grains, with arrows pointing toward the rims. In grains with calcium-rich exsolution, the host and exsolved phases are shown as triangles joined by dashed lines. Other symbols are used only for graphical clarity.

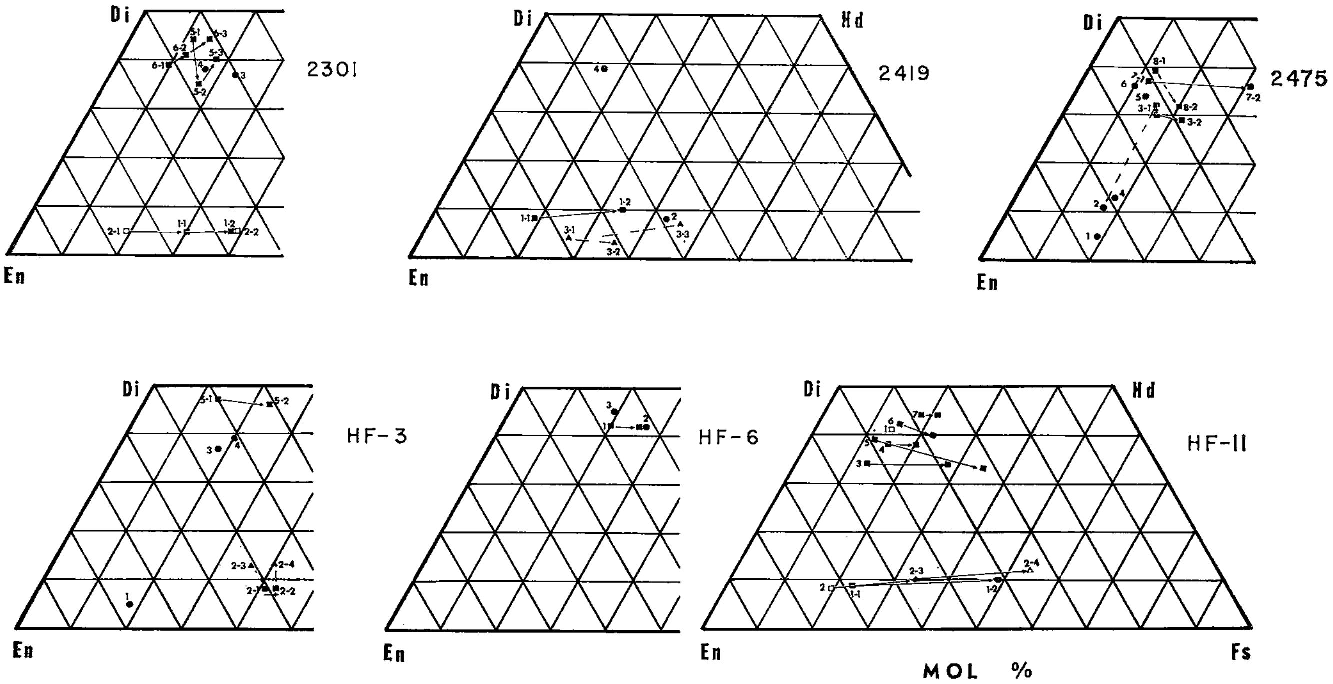

FIG. 21. Microprobe compositions of pyroxenes in the Henwood Upper sheet and Flank. Sample 2301 : hypersthene diabase; 2419 and 2475 : basal quartz diabase; HF-3 : transitional hypersthene diabase of the Flank section; HF-6 and HF-11 : varied-texture diabase. Symbols are as given in Figure 20.

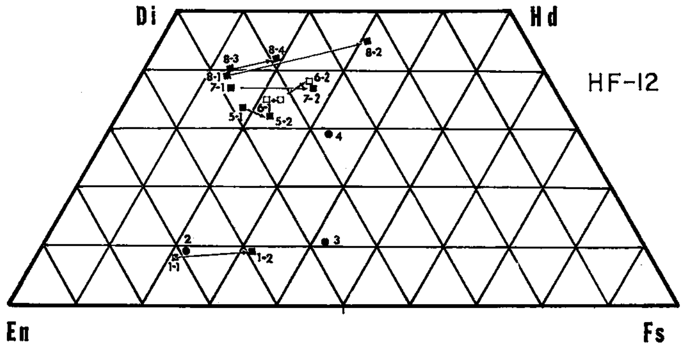

FIG. 22. Microprobe compositions of pyroxenes in the roof quartz diabase of the Henwood Flank. Solid lines with arrows show composition variations from cores to rims. Grains 1, 2 and 3 are pigeonites.

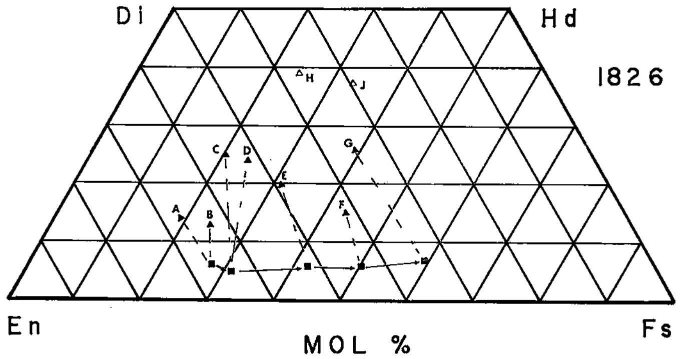

FIG. 23. Zoned inverted pigeonite in section 1826 from the lower part of the varied-texture zone in the Henwood Upper sheet. Squares denote the zoned orthopyroxene host and triangles the adjacent exsolution lamellae. The lamellae may be more calcium-rich than shown, but their thinness has prevented their complete resolution. The most calcium-rich lamellae found in the grain are shown as open triangles H and J.

pyroxenes were found to be sufficiently low that they were not readily amenable to rapid accurate analysis. Aluminum is important, but its determination was sacrificed for Ca, Mg, and Fe on the three available spectrometers. Alumina analyses on 16 pyroxenes showed that the orthopyroxenes generally contain less than 1% Al_2O_3, with the range extending from 0.7 to 1.2. Co-existing augites contain more aluminum, the range extending form 1.8 to 3.1% Al_2O_3.

The compositions of the pyroxene in the Upper sheet and Flank are shown in Figures 20, 21, and 22. The calcium content of the large, stubby orthopyroxene grains is fairly constantly Wo 5, with cores reaching a maximum of En 77 and rims extending

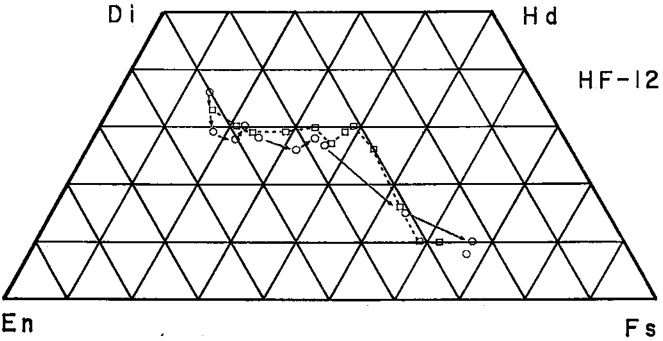

FIG. 24. Composition ranges of two grains of zoned clinopyroxene from section HF-12 (roof quartz diabase of the Henwood Flank). One grain is shown as open circles and the other as open squares.

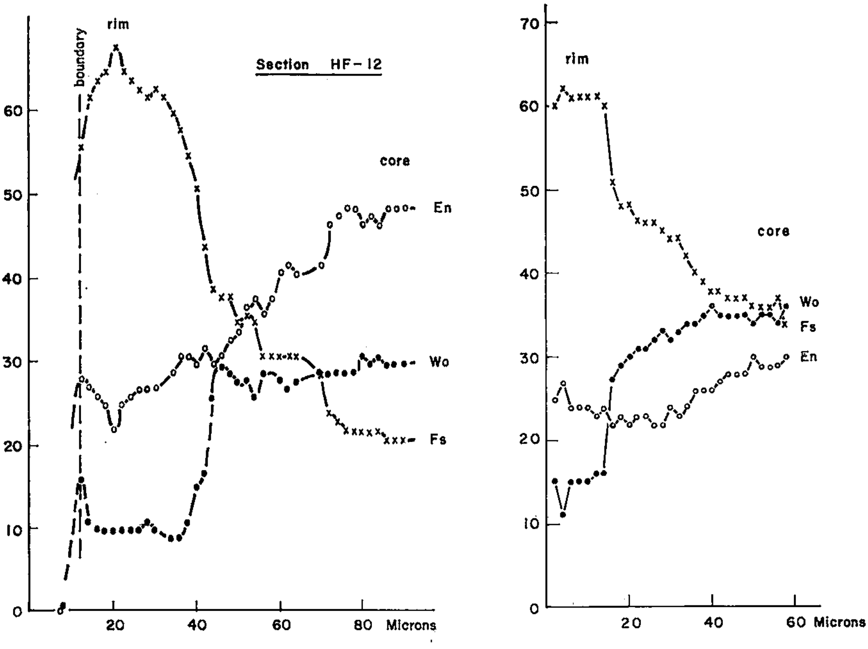

FIG. 25. Microprobe traverses showing the composition variation (atomic %, vertical scale) in two zoned grains of clinopyroxene in section HF-12. In both cases a rapid changes occurs from about Wo 15 to Wo 25.

to En 54 in the lower part of the sheet. In the varied-texture zone, orthopyroxene cores are not quite as magnesium-rich (Fig. 20), and rims are mantled by inverted pigeonite. Also in this zone, small amounts of iron-rich, higher-birefringent orthopyroxene occur around a few grains of inverted pigeonite. These are the most iron-rich orthopyroxenes found in the Upper sheet, with the compositions extending to Wo 4 En 47 (Fig. 20, points 2-2 and 3, footage 1850).

The inverted pigeonites in the Henwood diabase basin are not very suitable for composition determinations because of the fine-grained nature of the exsolved phases and the presence of extensive alteration. It is clear, however, that inverted pigeonites are no exception to the general rule that all pyroxenes in the diabase basin are compositionally zoned. Microprobe analyses indicate that iron enrichment occurs at grain rims and is accompanied by a slight increase in calcium (Fig. 23, and HF-11 in Fig. 21).

Compositions of zoned high-calcium clinopyroxene are considerably erratic in detail, but the over-all pattern is also always toward more iron-rich rims. There are, however, concomitant diverging trends toward either the hedenbergite or the ferrosilite corners of the pyroxene quadrilateral. Zoned high-calcium clinopyroxenes whose compositions project toward the hedenbergite corner are most readily seen in Figure 22. In the same thin section, a few grains have augite cores ultimately leading to a ferropigeonite rim (Fig. 24). The problem of whether there is a continuous gradation between the rim and core of such material has been discussed by Carmichael (1967), who suggested that the grain be moved in steps equivalent to the diameter of the electron beam ($\sim 1\ \mu m$) in order to determine whether the calcium counts consistently indicated compositions intermediate between the common values of augite and pigeonite in the rock. The analytical profiles of two grains from section HF-12 are shown in Figure 25. In both cases the compositional change in the sub-calcic field is extremely rapid. This may be an indication of a discontinuity even though the zoning from augite to ferropigeonite is apparently complete. It may be recalled, however, that only MgO, FeO, and CaO have been determined for almost all pyroxenes, and all interpretations are limited by this fact. Complete microprobe analyses for the rim and core portions of a grain representative of strongly zoned clinopyroxene in sample HF-12 are given in Table 8. The

TABLE 8. MICROPROBE ANALYSES OF ZONED CLINOPYROXENE GRAIN IN HF-12 FROM THE FLANK SECTION OF THE HENWOOD DIABASE BASIN.

Wt. %	*Core*	*Rim*	6(O)	*Core*		*Rim*	
SiO_2	51.2	45.9	Si	1.917	2.001	1.933	1.953
TiO_2	0.2	0.2	Al	0.084		0.020	
Al_2O_3	1.9	0.4	Ti	0.006	2.035	0.006	2.099
FeO*	9.9	39.3	Fe^{2+}	0.310		1.384	
MnO	0.2	0.5	Mn	0.006		0.018	
MgO	18.9	7.8	Mg	1.055		0.490	
CaO	16.4	4.4	Ca	0.658		0.199	
Na_2O	0.0	0.0	K			0.002	
K_2O	0.01	0.03					
	98.7	98.5					

Analyst: G.R. Lachance
* Total Fe as FeO

augite core has a composition of Wo 33 En 52, whereas that of the ferropigeonite rim is Wo 10 En 24. As in the Skaergaard pyroxenes (Brown 1967), augite is enriched in Al_2O_3 relative to the pigeonite.

The iron-rich trend of the inverted pigeonite and uninverted ferropigeonite, though exceptional, is not unique. Compositions equivalent to the Henwood trend were obtained from a micropegmatite vein in the Hawaiian Makoauki lava lake (Evans & Moore 1968), and in the Beaver Bay gabbro complex (Konda 1970). Inverted pigeonite more ferriferous than found here has recently been reported by Atkins (1969) from the Bushveld intrusion. Two additional occurrences were discussed by Lindsley & Munoz (1969), who pointed out that silica activity is important in stabilizing the iron-rich, low-calcium pyroxenes. One of the strongly zoned Henwood grains shows this relationship particularly well. The grain is a tapering needle, with only the thickest part showing the complete range in composition from an augite core to ferropigeonite rims on both sides of the needle. Only this part of the needle is in contact with, and completely surrounded by quartz.

Amphibole

Amphibole is present in all parts of the diabase except the albitized chills where chloritization is complete. Most of the amphibole in the lower parts of sheets is secondary greenish "uralite" which has replaced the edges of pyroxene grains. Replacement is generally greater in basal quartz diabase than in the overlying hypersthene diabase where uralitization is erratic but tends to be low. Both uralite and primary amphibole increase above the hypersthene diabase zone and reach peak abundances in the most salic differentiates. Thus amphibole rather than pyroxene is the principal mafic constituent in the upper part of the Henwood Flank.

Primary amphibole is negligible in hypersthene diabase. The mineral first appears in this zone as small fibrous radiating aggregates associated with interstitial quartz and gradually increases upwards in size and abundance. A bluish tint is common and becomes more intense in salic rocks. In pegmatitic and granophyric diabases, strongly pleochroic brownish and bluish-green amphiboles are present. Microprobe analyses of representative material from the Henwood Upper sheet are given in Table 9. Compositions are highly variable, but all are characterized by extreme iron enrichment.

Opaque minerals

All varieties of the diabase contain minor amounts of evenly-distributed opaques. They are most abundant in pegmatitic and some granophyric diabases, where concentrations amounting to several per cent are locally attained. The predominant phases in all rocks are ilmenite and titanomagnetite with exsolution lamellae of ilmenite.

The opaque constituents of the Henwood diabases have not been studied in detail, but some general comments on the Henwood diabase basin are possible. Except in very coarse salic rocks, the opaques amount to less than 1 per cent in the rocks. In the basal quartz diabase, both ilmenite and titanomagnetite with ilmenite exsolution lamellae are present. The grains are anhedral and average less than 0.1 mm in diameter. The amount of opaque material decreases from an estimated 1 per cent in the quartz diabase to about half this in the hypersthene diabase. The opaques most commonly occur at the edges of pyroxene grains and have biotite at the edges. Magnetite-ilmenite intergrowths are apparently missing, but magnetite with titanomagnetite lamellae was found in one section. Quantitatively, however, virtually all of the opaque material in the hypersthene zone is ilmenite. In the varied-texture and roof quartz diabases ilmenite and the exsolution intergrowths are again both present and their abundance increases to 1 per cent or slightly more. As was the case in quartz diabase (but not the hypersthene variety), the titanomagnetite hosts have been partly replaced, but the ilmenite grids have been largely unaffected. Ilmenite occurs both as isolated grains and as partial rims on the exsolution intergrowths. In some cases the gridwork and rim are in optical continuity. Throughout the main mass on the Flank section, ilmenite occurs as discrete grains, rims, and exsolution lamellae. The host titanomagnetite, which contains up to 10 per cent TiO_2, is again largely replaced in the salic rocks below the roof quartz diabase. Where alteration is severe, ilmenite has been replaced by titanium oxides and sphene.

TABLE 9. MICROPROBE ANALYSES OF PRIMARY AMPHIBOLES IN SECTION 1826 HENWOOD UPPER SHEET, AND SECONDARY AMPHIBOLES IN HF-6, HENWOOD FLANK.

			1826	HF-6	
Wt. %	blue		brown	alteration rim on clinopyroxene	
				outer rim	inner (adjacent to cpx.)
SiO_2	35.8	45.5	42.3		
TiO_2	0.1	0.1	1.6–1.9		
Al_2O_3	13.4	6.1	10.0–8.8		
FeO*	32.3	27.7	26.7	25.7–28.6	22.5
MgO	1.0	4.2	6.6–4.9	9.4– 8.8	12.4
CaO	10.8	11.1	10.2	11.6– 9.7	11.3
Na_2O	0.3	0.3	1.4–1.4		
K_2O	3.9	1.9	1.1–1.3		
Sum	97.6	96.6			

Analyst: G.R. Lachance

* Total Fe as FeO

Most diabase contains only a few minute grains of sulphides, of which pyrite and chalcopyrite are identifiable. They are least abundant in hypersthene diabase and usually occur along grain boundaries or at the edges of altered silicate grains. Sulphide inclusions in oxides are relatively rare.

Other minerals

Quartz and micropegmatitic intergrowths of quartz and albite are present in all phases of the diabase, but their combined abundance is less than 1 per cent in the hypersthene zone. There is a marked increase with diabase fractionation, with abundances of 5 to 6 per cent being reached in salic rocks exclusive of granophyres. The usual occurrence of both quartz and micropegmatite is interstitial.

Olivine is abundant in some diabases in the region but is very rare in the Henwood intrusions. Only a few grains have been found in basal quartz diabase within 1 to 3 meters of the contact of the Lower sheet. Their average size is about 1mm in diameter, and all except one grain have been completely altered. The preservation of the remnant grain, which has a composition of Fo 73, may have been due to the shielding effect of its orthopyroxene mantle.

Brown biotite is a minor constituent of all phases of the diabase. The mineral is for the most part associated with opaque iron oxides, but it also occurs in the upper parts of sheets as ragged partial alteration rims on amphiboles. Near the top of the Henwood Upper sheet relatively coarse flakes up to 0.5mm in diameter are intergrown with amphibole. The presence of both minerals attests to relatively hydrous conditions during the late stages of crystallization.

Although very small in total volume, large numbers of garnet grains averaging about 0.02mm in diameter are present in the salic parts of the diabase. They are associated with interstitial quartz and are usually clustered around its grain boundaries. Microprobe analyses indicate that the garnet is andradite ($a = 13.051 \pm 0.005$ Å) with 5 to 6 weight per cent Al_2O_3. Although andradite has been noted in the basal quartz diabase of the Henwood Lower sheet, the predominant occurrence in the Henwood and other intrusions is in the varied-texture zone.

Small needles of apatite are present in all phases of the diabase, but are most abundant in pegmatitic and granophyric varieties. The amount of P_2O_5 in the rock analyses adequately reflects apatite abundances and confirms that the smallest quantities of the mineral occur in hypersthene diabase. The Henwood Lower sheet contains slightly more P_2O_5 than the Henwood diabase basin.

Chlorite occurs in small amounts in all types of diabase, usually as an alteration mineral replacing pyroxenes and amphiboles. However, in salic differentiates, particularly granophyres, the mineral also occurs as scattered grains in plagioclase and is abundant as fine-grained aggregates along grain boundaries and in interstices. Chlorite of this kind typically occurs in partly radiating sheaves which are not replacements of earlier-formed minerals.

Stilpnomelane is present in some granophyric diabases. It is abundant at some localities but, unlike chlorite, does not occur everywhere. The mineral is very dark brown and typically occurs as compact intergrowths of partly radiating fibres, most of which are concentrated in interstices and along grain boundaries.

Several other minerals are present in very small amounts in granophyric diabase. Dark brown needles of allanite have been seen in a few specimens and sphene in small amounts is common. Miarolitic cavities in granophyres commonly contain epidote and calcite. In many cases the distinction between primary and secondary minerals is difficult. Among the latter, however, is the widespread alteration of plagioclase to fine-grained sericite and epidote. Orthopyroxene is in some cases altered to minerals of the serpentine group and is also replaced by talc. Prehnite, although relatively uncommon, is extensively developed in one part of the Henwood Flank. The outcrops, which are described by Thomson (1966), are about 2 miles north of the traversed Flank section and are close to the bottom contact of the sheet.

Differentiation Trends

General features

There may have been small mineralogical and chemical variations in the magma, but is seems probable that in most intrusions the diversification in rock types is due largely to differentiation after emplacement. That most of the crystallization occurred after emplacement is indicated by the low percentage of phenocrysts in chilled margins and the progressive change in grain size and mineralogy near the contacts. The general lack of flow texture in the chilled margins throughout the region also suggests that the diabase magma was largely liquid when intruded. In most sheets throughout the region, the major part of differentiation in the early stages was brought about by the separation of magnesium-rich pyroxenes and, in some cases, magnesium-rich olivine. Consolidation in most sheets apparently occurred mainly from the bottom toward the top. This is indicated by the occurrence of basic rocks in the lower parts of intrusions, and the upward zonation toward less refractory and more hydrous minerals. Similarly, the basal quartz diabases are generally thicker than the upper, which again suggests that cooling was slower at the top. Dissipation of heat equally from both contacts would lead to a symmetrical development of rock types if there was no crystal settling, but the general presence of the afore-mentioned asymmetry implies that unequal thermal gradients existed; crystallization and heat transfer were predominantly upward from the base. However, not all sheets, nor all parts of an extensive sheet, would be expected to have identical thermal gradients. Thus the diabase on the western side of Miller Lake at Gowganda is more symmetrical than most sheets in that there are zones of hypersthene diabase near both the top and bottom of the intrusion. The zones are unequally developed and the arrangement is still asymmetrical, but the arrangement is distinctive because in most intrusions an upper hypersthene zone is absent. Such differences also raise the possibility (not yet demonstrated) that composite intrusions may be present at some localities. Similarly, there is not yet unequivocal proof that the magma in any diabase basin in the region was laterally uniform and hence rapidly emplaced. The differences in the compositions of clinopyroxene phenocrysts in chilled diabases from Miller Lake (Table 6) indicate either a lack of equilibrium with their enclosing magma or a lack of rapid emplacement.

Differentiation of the Henwood sheets

The Henwood sheet and Flank section respectively correspond to the depressed portion and elevated rim of a single basin-shaped diabase sheet. The configuration of the underlying Lower sheet must be deduced from the solitary drill hole which completely penetrated the intrusion.

The results of chemical analyses of 18 specimens of drill core from the Henwood township Lower sheet, and of 32 specimens from the Upper sheet and Flank are shown in Figures 26 and 27.* Aplites and granophyres are not represented in the chemical analyses nor in the previously-given data on plagioclases and pyroxenes. The chemical analyses reflect the combined effects of pyrogenic and deutric crystallization, whereas the mineralogical results were largely restricted to primary magmatic phases.

That the development of the different rock varieties which make up the Henwood diabase basin and Lower sheet was brought about by differentiation is indicated by the systematic variations in the profiles

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* Chemical data, norms, and modes of the Henwood diabases, and brief descriptions of the pyroxenes shown in Figures 20 to 24 are given in Geological Survey of Canada Open File Report No. 69.

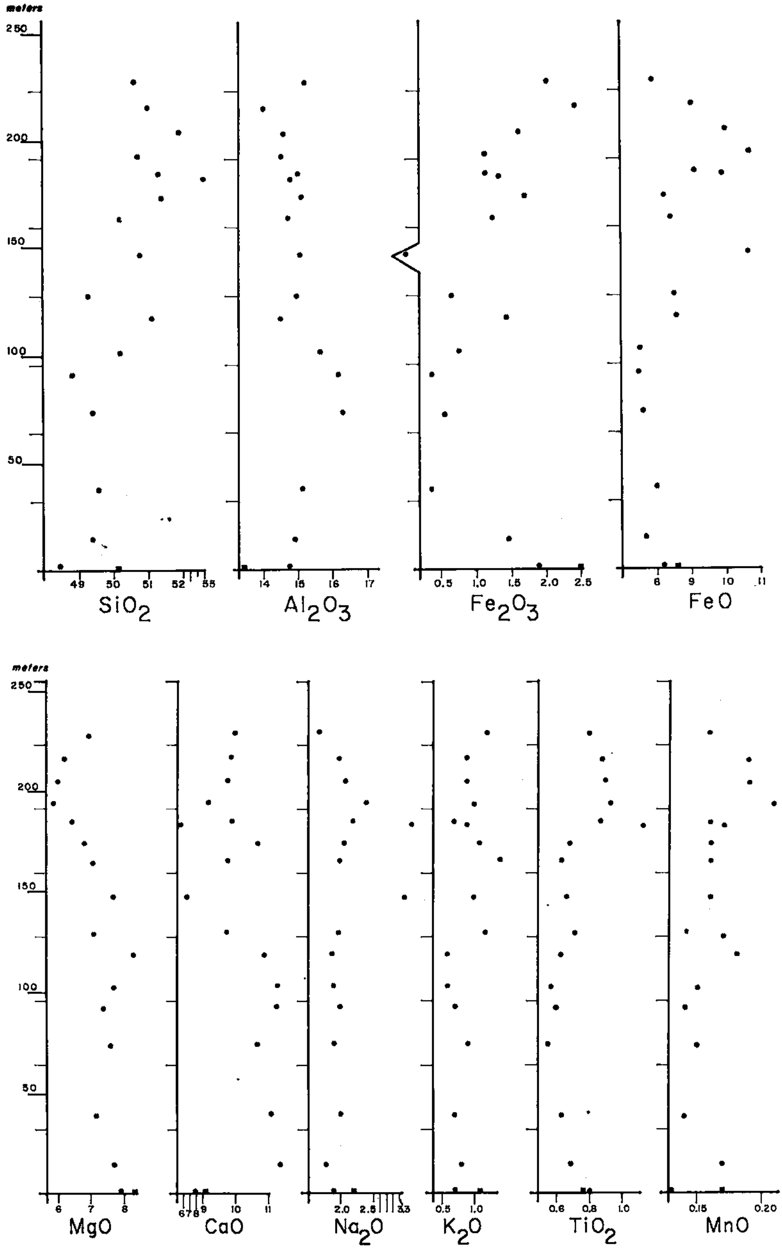

FIG. 26. Variation in weight per cent of the major oxides with height above the bottom contact of the Henwood Lower sheet. Solid squares are albitized chilled diabase at the contact. (Subsidiary vertical scale in hundreds of feet).

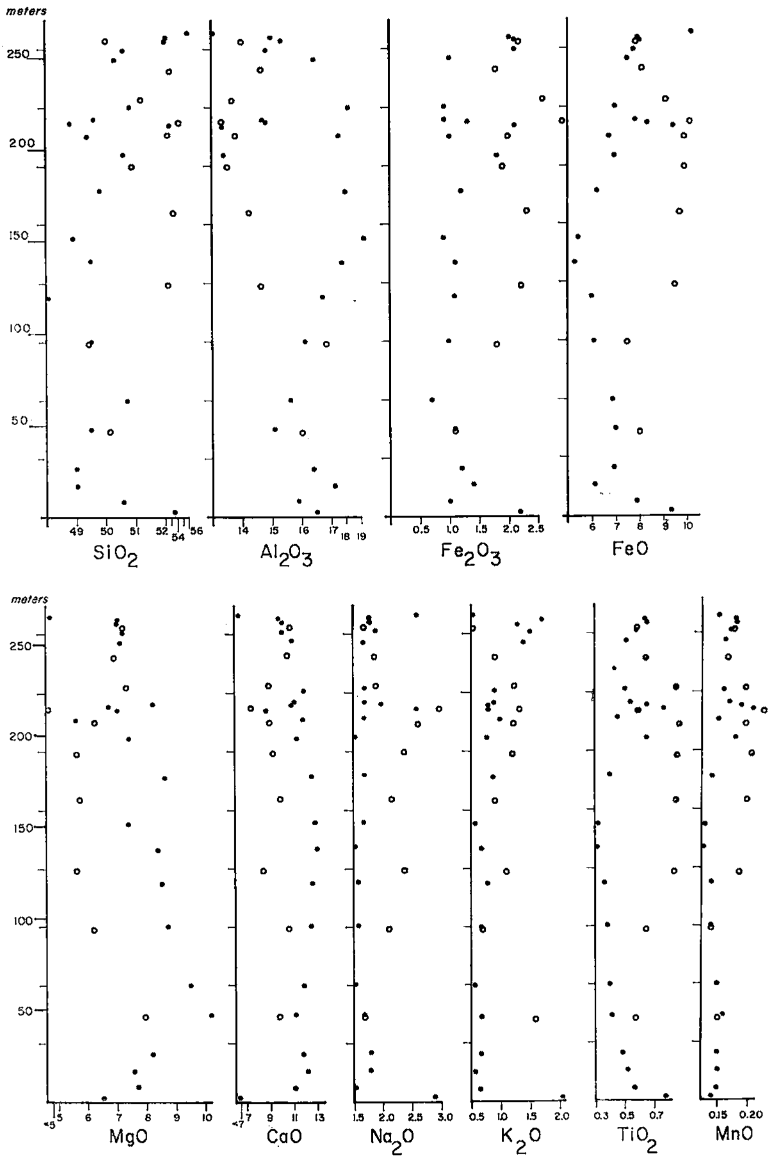

FIG. 27. Variation in weight per cent of the major oxides with height above the bottom contact of the Henwood diabase basin (the Upper sheet is shown as solid dots and the Flank as open circles; the subsidiary vertical scale is in hundreds of feet).

of the oxides, the progression in mineralogical changes, and the cryptic zonation of plagioclase compositions. Plots of the oxides versus the mafic index, 100 $(FeO+Fe_2O_3)$ / $(FeO+Fe_2O_3+MgO)$, which is a measure of the degree of differentiation, have the normal trends found in similarly-fractionated diabasic bodies and are therefore not shown. The felsic index, 100 (Na_2O+K_2O) / (Na_2O+K_2O+CaO), also increases with differentiation.

Solidification in both Henwood intrusions began from the bottom, as indicated by the relatively thick zones of hypersthene diabase in the Lower and Upper sheets. Because MgO is present largely in pyroxenes, its variation with height above the bottom contacts shows the initial differentiation trends particularly well. Thus in both the Henwood Lower and Upper sheets maximum MgO enrichment occurs in the lower part of the hypersthene diabase zone and is followed by a progressive decrease upward in the sheets. Of particular interest is the continuation of this decrease and the over-all lower total MgO in the Flank section of the diabase basin. As there is every indication that total MgO in the Flank is lower than total MgO in the depressed part of the basin, there was apparently a lateral movement of magnesium-enriched material from the elevated to the depressed part of the sheet. This transfer is evident in Figure 27, where MgO values for the Flank section (open circles) fall to the left of those for the depressed part of the basin (solid dots). Similar left side distributions (corresponding to lower weight percentages) are evident for CaO and most of the Al_2O_3. The equivalent mineralogical expressions are the decreases in calcic plagioclases and magnesium-rich pyroxene in the Flank. The role of fractional crystallization is therefore readily apparent, but some fundamental differences occurred in the mechanism of differentiation of the two Henwood sheets. These differences are not evident in the profiles of the oxides in the Lower and Upper sheets ; the similarity of the oxide trends might in fact suggest that the two sheets have the same shape. In the Lower sheet, however, the cryptic variation in plagioclase compositions (Fig. 18) shows that crystallization of the most calcium-rich cores occurred in only the lower half of the sheet. This is markedly different from the persistence of calcic cores through almost the whole of the Upper sheet. It is clear, however, that the persistence was achieved at the expense of calcic compositions in the Flank. In other words, there was apparently a descent of calcium-rich material into the depressed part of the basin represented by the Upper sheet. As no such transfer seems to have occurred in the Lower sheet, the simplest explanation is to assume that the intrusion is a relatively flat-lying sill. Differentiation therefore occurred through a vertical solidification and migration of material, with enrichment in Mg, Al, and Ca in the bottom half of the sill, and Fe, Si, and alkalies in the top half. In the overlying diabase basin the equivalent compensation was achieved by an updip transfer of material to the Flank, thus involving lateral as well as vertical migration.

Chemical and mineralogical data of the fine-grained contact rocks are not sufficiently precise to indicate whether fractionation occurred during emplacement. However, compositions from near the top of the Flank section suggest that some transfer may have been accomplished in the very early stages of cooling. Certainly the prevalence of soda-rich cores in the main central part of the Flank section is a good indication that the composition of the magma had changed before the crystallization of these plagioclases had begun. Hriskevich (1952, 1968) invoked gravitational settling of olivine and orthopyroxene with some differential lateral movements as a method of achieving the appropriate mineral distribution in such circumstances. The major problem is that the movement of crystallized solids should result in flow layering. Diffuse banding of the type shown in Figure 16A is present in some of the intrusions, and in the Henwood Upper sheet it is largely confined to the upper half of the hypersthene diabase zone. As banding of this type must originate by a fluctuation in the conditions of crystallization, convection may have been operative. However, this need not have involved solid phases to a major extent as the chief requirement is a slow circulation in which the partly differentiated salic magma of the basin migrates updip. Thus in the initial stages of differentiation in the basin, calcic feldspars and magnesium-rich pyroxenes crystallized. In the hypersthene diabase zone, fractionation of augite and low-calcium pyroxene could account for the observed chemical changes. As crystallization progressed the amount of magnesium available in the magma progressively decreased and pyroxenes became more iron-rich. Throughout most of the crystallization history, however, the liquid in the pore spaces was impoverished in calcium and magnesium so that iron-rich rims were formed. Feldspar compositions similarly show that the pore liquids became progressively more sodic as crystallization progressed. Thus the composition of the remaining magma was continually being modified by magma mixing and diffusion exchanges with the residual (pore) liquids. The gradual accumulation of Si, Na, K, Ti, Mn, total iron, and volatiles is evident from their enrichment in the rocks of the Flank section. The ultimate derivation of albite-rich rocks is readily seen in Figure 18. In all 3 cross-sections of the diabases, plagioclase rim compositions become progressively more sodic until albitic compositions are attained in the most fractionated parts of the sheets. The demontration of this progression is significant because it shows that there is no compositional gap between the feldspars of ordinary and granophyric diabases. Hriskevich (1952), Ernst (1960), McDougall (1962, 1964), Hawkes (1966), Wilshire (1967), and others have discussed the origin of granophyres and felsic associates and have demonstrated their derivation by fractionation without invoking assimilation. The field and petrological characteristics of the Nipissing diabase likewise indicate that assimilation was negligible. In cases where granophyres occur in structural highs near the roof contact, there was probably an egress of volatiles and alkalis to form the adinole described by Bowen (1910). A rather interesting feature of some granophyres is that relatively coarse micropegmatite is locally associated with patches of much finer-grained quartz and albite having an equigranular, hypidiomorphic texture. This unusual feature is also characteristic of some aplites in which a micropegmatite layer on the diabase walls gives way to finer hypidiomorphic quartz and albite which form the main central part of the dyke. In the case of granophyric masses, rapid cooling to form the finer phase is unlikely. However, a decrease in pressure accompanied by a rapid loss of volatiles could produce the diminished grain size. Fracturing, or additional dilation along existing fractures, would be an appropriate mechanism for achieving the necessary pressure reduction.

LATE STAGE EFFECTS

The cessation of crystallization of pyrogenic minerals in one part of an intrusion does not necessarily isolate that segment; it is still susceptible to modification by the progressively decreasing magmatic residuum. Among the first of the late-stage magmatic effects was the crystallization of diabase pegmatite. This material for the most part occurs in pods and schlieren which forms as integral part of the varied-texture zone. The pegmatites are compositionally not far removed from ordinary diabase, though their coarse grain size is indicative of crystallization in a volatile-rich environment. Most pegmatitic material apparently crystallized *in situ,* but a quantitatively minor feature is the occasional appearance of sharply-defined dykes, without chilled contacts, which cut hypersthene diabase. These significantly demonstrate that the host diabase was hot, but sufficiently coherent to withstand fracturing at a time when magmatic crystallization had not yet advanced to the ultimate stage of alkali-enrichment. Probably a somewhat later stage of fracturing is represented by the appearance of contraction dykelets. A photograph of these is shown in Miller (1913, p. 203), and easily accessible examples can be seen near the top of the diabase sheet at the Colonial property, Cobalt. Most of the dykelets consist of masses of amphibole (Table 10), containing small rounded grains of andradite (Table 11) and coarse altered magnetite-ilmenite intergrowths in which only the ilmenite gridwork remains. More common at the Colonial and other properties is the occurrence of centi-

TABLE 10. MICROPROBE ANALYSES OF AMPHIBOLES FROM COBALT AND GOWGANDA.

	Contraction dykelet[1]		Joint filling[2]				Ore vein[3]	
	JF68–103		JF69–36				JF69G–63	
Wt. %			green		colorless			
SiO_2	54.7		52.8		56.5		54.3	
TiO_2	0.25		0.4		0.5		0.4	
Al_2O_3	1.5		3.4		2.1		2.5	
FeO*	14.5		17.5		10.6		11.5	
MgO	15.0		11.9		17.3		16.5	
CaO	11.8		11.7		11.2		11.9	
Na_2O	0.9		0.8		1.2		1.4	
K_2O	0.15		0.2		0.2		0.2	
Sum	98.8		98.7		99.6		98.7	
On the basis of 23(O) :								
Si	7.838	8.000	7.685	8.000	7.856	8.000	7.706	8.000
Al	0.162		0.315		0.144		0.294	
Al	0.091	5.060	0.267	5.024	0.200	5.071	0.124	5.023
Ti	0.027		0.044		0.053		0.043	
Fe	1.738		2.131		1.232		1.365	
Mg	3.204		2.582		3.586		3.491	
Ca	1.812	2.090	1.824	2.087	1.668	2.027	1.810	2.231
Na	0.250		0.226		0.324		0.385	
K	0.028		0.037		0.035		0.036	
			Total range at random positions : MgO 9.3–17.6 ; FeO 20.4–10.1 wt. %				Range in FeO : 9–13 wt. %	

Analyst : A.G. Plant

* Total iron as FeO

[1] Dykelet, 2 cm wide, near the top of the diabase at the Colonial property, Cobalt.

[2] Joint filling in varied-texture zone, Colonial property, Cobalt. The colorless material is concentrated near the grain rims.

[3] In hypersthene diabase, Capitol shaft, Miller Lake, Gowganda.

meter-wide fillings along vertical joints. The fillings, which extend almost to the bottom of the varied-texture zone, consist of relatively coarse grains (~ 1mm diameter) of ilmenite and albite, with variable amounts of carbonate, sphene, chlorite, and amphibole (Table 10). The diabase bordering the joints is partly altered to albite, which is gradational outward into sericitic replacement of the primary plagioclases. Post-magmatic albitization and sericitization are not restricted to fractures, but are important alteration effects throughout the diabase sheets. In all cases the hypersthene diabase is least affected, and alteration intensity generally increases with differentiation. The Henwood intrusions are no exception; water, CO_2, and alkalis are enriched in the uppermost rocks. This enrichment reflects both the pyrogenic and the autometamorphic processes, each of which is a part of the total fractionation system.

In the Henwood Flank section, pink albite occurs as coatings about a millimeter thick along vertical joints near the top and bottom of the sheet. Several centimeter-wide aplite dykes cut the diabase near the top of the Flank section, and in the drill core an irregular pink aplite dyke was intersected 4 meters below the top contact of the Lower sheet. The derivation of aplites by diabase fractionation presents no problems, but the origin of aplites has nevertheless been a matter of controversy. Part of the difficulty has been the indiscriminant use of the term for any linear or dyke-like body containing pink feldspar. Sampson & Hriskevich (1957) concluded that aplites were magmatic in origin, whereas Bastin (1935, 1939) had contended that the aplites were zones of hydrothermal alteration following fractures. The present writer agrees with the conclusions of Sampson & Hriskevich, but at the same time would point out that there

TABLE 11. MICROPROBE ANALYSIS OF ANDRADITE IN A CONTRACTION DYKELET, COLONIAL PROPERTY, COBALT (JF68–103).

SiO_2	37.0	On the basis of 24(O):		
TiO_2	0.3	Si		6.00
Al_2O_3	7.7	Ti	0.037	
Fe as Fe_2O_3	20.0	Al	1.472	3.949
MnO	0.15	Fe^{3+}	2.440	
MgO	0.6	Mn	0.020	
CaO	33.9	Mg	0.145	6.056
	——	Ca	5.891	
	99.65			

Analyst: A.G. Plant

are pink feldspathic borders along some fractures that are alteration zones megascopically resembling aplites. There is little difficulty in recognizing well-defined examples of both types, but there are also gradations between the extremes. This strongly suggests that there is a close relationship between the dykes and alteration zones. The richness in volatiles of some aplites had been commented upon by Sampson & Hriskevich, and this factor was undoubtedly critically significant in regulating the gradation. Bastin also recognized the similarities of the linear zones of hydrothermal alteration, the aplites, and the masses of albite-rich rock which form an integral part of the sheets. Because of the evidence of widespread activity of volatiles in these rocks, he proposed that all had evolved by hydrothermal alteration of ordinary diabase. His reason for rejecting the Nipissing diabase as the source of these solutions was that the "... diabase sills were not only completely crystallized but also considerably fractured and in places faulted prior to the hydrothermal development of "aplite", "red rock", and ores. It is unlikely, therefore, that the sills themselves were the source of the hydrothermal solutions." (Bastin 1935, p. 734). There is, however, no evidence that the diabase was "completely crystallized" as stated by Bastin. On the contrary, the presence of diabase pegmatite dykes, contraction dykelets, joint fillings, and the local to pervasive deuteric alteration effects all indicate that the intrusions were sufficiently solid to sustain fracturing (or faulting) long before the primary and secondary minerals comprising the total system had ceased to form. Bastin sought a deep-lying magma to provide the source of the hydrothermal fluids, but the geological relationships of the Henwood intrusions demonstrate particularly well that such a hypothesis is untenable. There is little need to repeat that the volatile and soda-rich products are the end result of diabase fractionation. Bastin did not attempt to explain why hydrothermal fluids from a later and completely extraneous source would throughout the region bypass the more susceptible refractory mineral zones and selectively seek out only those portions of the Nipissing diabase in which the pyrogenic minerals coincidentally show the greatest degree of magmatic differentiation.