THE OVOID ANORTHOSITIC GABBRO
AT
BERNIC LAKE, MANITOBA

A thesis submitted to the Faculty of Graduate Studies
University of Manitoba
in partial fulfillment of the requirements
for the degree Master of Science

by

William Douglas Bond
February, 1973

Abstract

Sedimentary and volcanic rocks of the Bird River Area have been intruded by peridotite and gabbroic magmas of various compositions, including anorthosite. At several localities the anorthosite displays a unique texture, with distinct elliptical and/or spherical ovoids averaging 6 inches across uniformly distributed within a massive gabbroic groundmass. This texture is exposed in sills along the shores of Bernic Lake, Manitoba, and also as concordant layers near the base of the gabbroic portion of the Bird River Sill.

Structural observations both in the field and in thin section indicate the ovoids are pretectonic. Compositional observations indicate the ovoids are igneous in origin and are poly-crystalline aggregates of plagioclase feldspar that originated by the accumulation of phenocrysts. These aggregates were intruded as a crystal-mush magma that became concentrated in narrow sills through a flow differentiation mechanism.

The ovoid anorthositic matrix at Bernic Lake is similar in texture, mineralogy and chemical composition to a gabbroic body thought to be intrusive into the Bird River Sill and a genetic relation is suggested.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

General Statement

Sedimentary and volcanic rocks of the Bird River area in southeastern Manitoba have been intruded by a variety of magmas, both before and after deformation. These magmas include the Bird River Sill, a layered sequence of peridotite and gabbros, including anorthosite. In several localities within the Bird River Sill the anorthosite has an unusual texture, characterized by plagioclase crystals that form distinct ellipses and/or balls in a gabbroic matrix. This "ovoid" texture is also found in sills along the shores of Bernic Lake (Figure 1), 4 miles south-east of the Bird River Sill.

Davies was the first to record the presence of the ovoid anorthositic gabbro at Bernic Lake; he described it as "remarkable on account of the occurrence of round spheres of anorthosite set in a gabbro matrix" (1955, page 16).

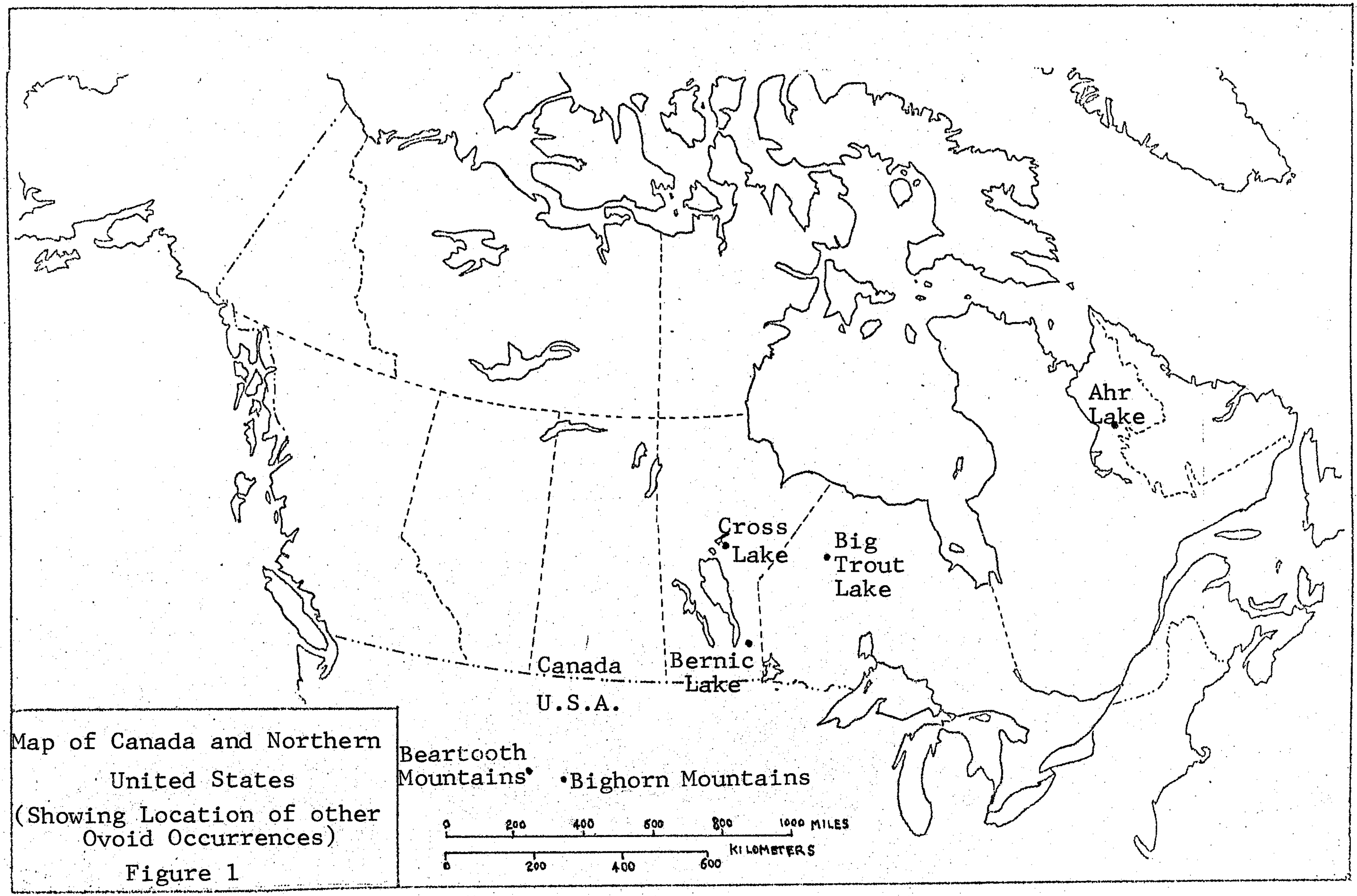
Ovoid texture was described by Frarey (1952), Fahrig (1955), and in more detail by Baragar (1960, 1967), who found the texture to occur widely in the basic rocks of the Labrador Trough in and around the Ahr Lake region (Figure 1).

The various terms used to describe this texture have included "glomeroporphyritic", "leopard rock", "anorthositic", "blotchy" and "mottled". Rousell (1965) first used the term "ovoid" in describing an occurrence at Cross Lake, Manitoba (Figure 1). Prinz (1964) described the texture in the dike swarms near the Beartooth Mountains (Figure 1), associated with the Stillwater complex in Montana. Leopard rocks very similar in appearance to the subject of this thesis were described by Hudec (1964) at Big Trout Lake (Figure 1) and by Heimlich and Manzer (1973) in the Bighorn Mountains (Figure 1). Trueman (1971) described the ovoid texture in the Bird River Sill, Chrome Property section (Figure 2).

It is the aim of this study to describe this ovoid texture at Bernic Lake, both chemically and structurally and to consider the relationship between the anorthositic magma here and the more mafic magma that formed the Bird River Sill.

Present Work and Acknowledgments

Field work, involving detailed mapping and sampling of the ovoid anorthositic gabbro, was conducted during the fall of 1970. Twenty-five samples were obtained and thin sections were cut from these. Chip samples of the ovoids



Map of Canada and Northern United States (Showing Location of other Ovoid Occurrences)

Figure 1

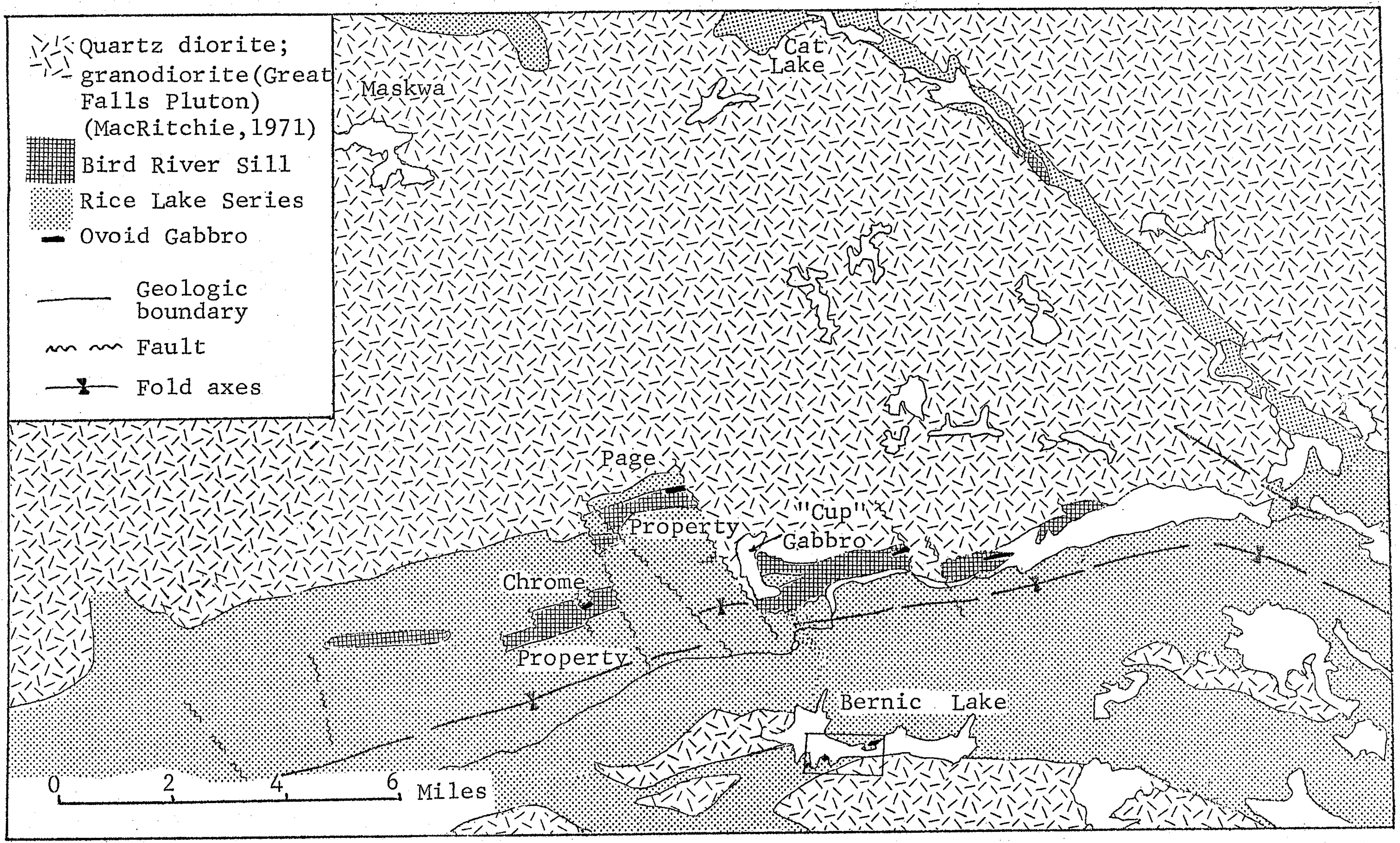


FIGURE 2: General Geology of the Bird River Area (after Davies et al, 1962 with modifications by Trueman, 1971). Outlined area at Bernic Lake is location of Figure 3.

were taken across and along the length of the sill for petrographic analysis.

The study of the ovoid anorthositic gabbro was first proposed by Dr. A.C. Turnock. The field work was supported by a grant to Dr. Turnock from the Geological Survey of Canada, Department of Energy, Mines and Resources. The writer would like to thank Dr. Turnock for his helpful suggestions and assistance concerning the direction which the thesis should take, both in and out of the field.

The writer especially wishes to thank Mr. D.L. Trueman for his valuable assistance in the field and for many stimulating discussions. Dr. Peter Cerny is also to be acknowledged for his suggestions and criticism. The writer wishes to express his gratitude to Miss I. Berta, Mr. J. Macek and Mr. K. Ramlal for their technical assistance. Special thanks are also bestowed upon Bob Crouse, geologist at the Tanco Mine, for the hospitality and courtesies extended to the writer.

REGIONAL GEOLOGY

Regional mapping by Springer (1949, 1950) and, in more detail, by Davies (1952, 1955) established the distribution of the main rock types. Karop-Møller and Brummer (1971), Trueman (1971) and Trueman and Macek (1971) have mapped the Bird River Sill in great detail.

Rock Types

Regional and detailed mapping has established that all the consolidated rocks are of Precambrian (Archean) age and may be divided into two main categories: the "Rice Lake Group" and later intrusive rocks. Table 1 shows the sequence of rock types and Figure 2 their distribution.

The Rice Lake Group is composed of conformable metavolcanic and metasedimentary rocks and is the oldest unit in the area. The metavolcanics are mostly mafic to intermediate flows in which pillow structures are common. The metasediments overlie the metavolcanics and include fine to medium-grained greywackes, arkoses and conglomerate (Davies, 1955). Metagabbro, present as thin sills, is confined entirely to the metavolcanics and may be older than the metasediments (Trueman, 1971). These

TABLE I

TABLE OF LITHOLOGIC UNITS IN THE BIRD RIVER AREA

		RECENT and PLEISTOCENE		Boulder till, sand, gravel, clay
				UNCONFORMITY
PRECAMBRIAN	ARCHEAN	INTRUSIVE ROCKS		Quartz diorite - granodiorite
				INTRUSIVE CONTACT
			BIRD RIVER SILL	Porphyritic gabbro Hornblende gabbro Anorthositic gabbro, anorthosite, gabbro Pyroxenite Serpentinized peridotite with interlayered chromitite and chromiferous peridotite Marginal gabbro
				INTRUSIVE CONTACT
				Metagabbro
				INTRUSIVE CONTACT
		RICE LAKE GROUP		Metasediments: Greywacke, crystal tuff, polymict conglomerate; derived schists Metavolcanics: Basalt, porphyritic andesite, pillowed lavas; derived schists

(After Trueman, 1971)

rocks have been deformed by folding and faulting, and metamorphosed at low grade conditions.

During the initial stages of orogenesis, the Bird River Sill was intruded along the contact between the metavolcanics and metasediments of the Rice Lake Group. Differentiation of the intrusion took place in situ, through gravity settling, and gave rise to the layered sequence of the Bird River Sill (Table 1). Major orogenesis followed; the Bird River Sill and the Rice Lake Group were deformed with low-grade metamorphic alteration, and there was penecontemporaneous intrusion of quartz diorite-granodiorite, gabbro and ultramafic rocks (Karup-Møller and Brummer, 1971).

Structure

The major structural feature in the area is the easterly plunging syncline-anticline complex formed by the Rice Lake Group and the Bird River Sill. Faulting is fairly common and on the Chrome property within the Bird River Sill (Figure 2), Trueman (1971) has recognized four different sets of faults. These faults are not apparent, however, in the monotonous sequence of the Rice Lake Group.

Metamorphism

The Rice Lake Group and the Bird River Sill have been metamorphosed to greenschist facies rank and the metamorphic grade increases to the lower amphibolite facies at Bernic Lake (Butrenchuk, 1970).

Economic Geology

Ni-Cu sulphides are associated with the peridotites and gabbros of the Bird River Sill. Their relationship to the sill remains obscure (Karup-Møller and Brummer, 1971). Chromite occurs as thin continuous layers within the Bird River Sill.

A tantalum-lithium-cesium-bearing pegmatite intrudes the Rice Lake Group at Bernic Lake and is presently being mined for tantalum.

STRUCTURE

General Statement

The geological setting of the ovoid anorthositic gabbro at Bernic Lake is summarized in Figure 3. Well exposed on the shores of Bernic Lake, it forms a narrow band of low to moderate relief that can be traced discontinuously over a strike length of approximately 7,000 feet. The strike of this band varies from N60°E in outcrop D (Figure 3) to N85°E in outcrops A, B, and C and dips from vertical to 80°N. Structurally, the ovoid anorthositic gabbro is concordant with the surrounding, near vertical easterly trending pillowed volcanics. Its absence or termination may be by faulting or by wedging out.

The sill consists of an inner ovoid anorthositic gabbro approximately 30 feet in width, flanked by outer margins of ordinary gabbro; the total width of the sill is approximately 100 feet. The ovoid gabbro grades abruptly into ordinary gabbro, which is distinguished from the former only by the lack of anorthositic ovoids. Shearing is locally present along the contact between the two types of gabbro. The marginal gabbro zones grade imperceptibly into the surrounding lavas by a decrease in grain size.

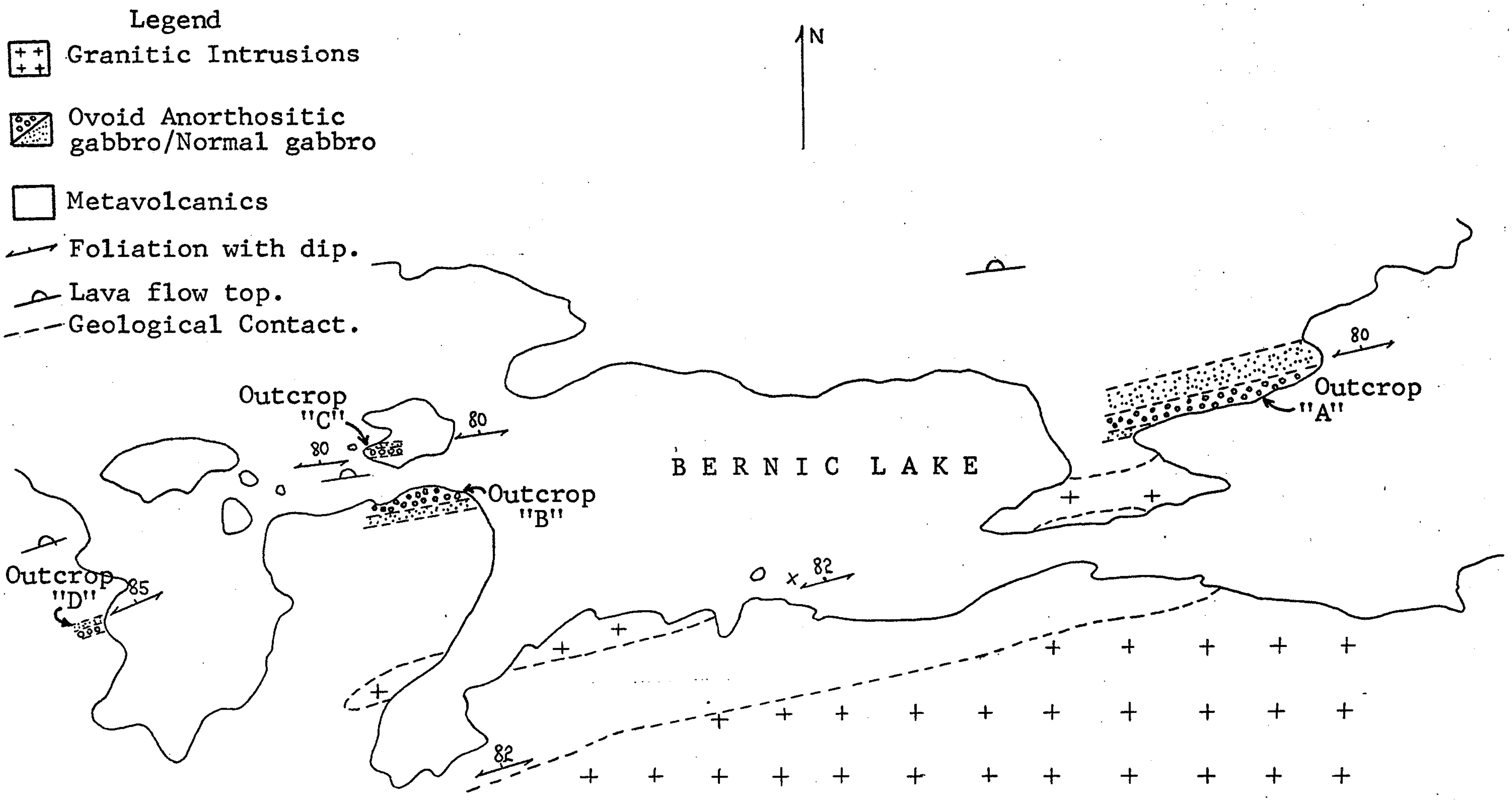


FIGURE 3: Geology of the Ovoid Gabbro at Bernic Lake (see Figure 2 for location of Figure 3)

Nature of Constituents

The ovoids at Bernic Lake are distinct zones of anorthosite in the form of balls (spheres) and/or ellipses, ranging in size from 1 inch to a maximum of 10 inches, and averaging 6-8 inches (Figure 4a, 4b). These ovoids are polycrystalline aggregates of coarse-grained plagioclase in a massive, finer-grained gabbroic host. In some localities the anorthositic ovoids have jagged to lobate edges (Figure 5b), and these ovoids tend to be smaller than the more perfectly formed ovoids. The more ellipsoidal ovoids have a maximum axis ratio of 2:1 or 3:1. The margins of the anorthositic ovoids are remarkably sharp (Figure 5a), except rarely, where the smaller, more jagged ovoids exhibit gradational contacts (Figures 5b, 6a, 7).

The matrix consists of roughly equal proportions of randomly oriented laths of plagioclase (1-2mm) and prisms of hornblende.

Distribution of Ovoids

The spacing of the ovoids within the gabbroic host is very regular (Figure 4a); only rarely do two or more occur in close proximity (Figure 6a) and they are invariably separated by thin portions of gabbro. No size sorting, or

FIGURE 4a: Ovoid anorthositic gabbro at Bernic Lake showing the size and distribution of ovoids. (From Outcrop A, Figure 3).

FIGURE 4b: Ovoid anorthositic gabbro at Bernic Lake. Note the faulted ovoid near the top right-hand corner. (From Outcrop A, Figure 3).

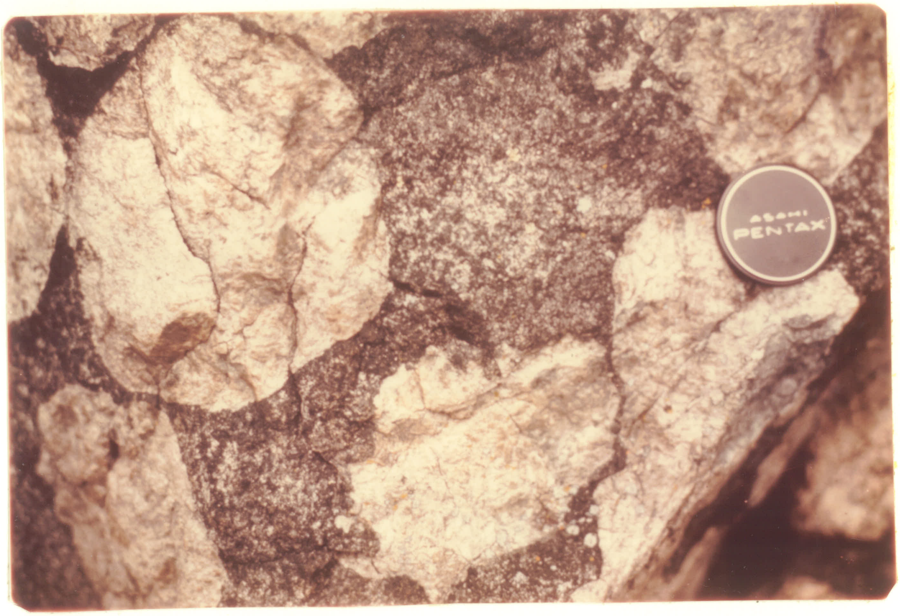


FIGURE 5a: Ovoid anorthositic gabbro at Bernic Lake showing the sharp contacts between the matrix and the ovoid. Note also the concentration of the plagioclase of the matrix near the center of the picture and the rotational form of the lower ovoid. (Closer view of part of Figure 4b).

FIGURE 5b: Ovoid anorthositic gabbro at Bernic Lake showing a smaller, more jagged zone of anorthosite characterized by a more diffuse contact. (From outcrop A, Figure 3).

FIGURE 6a: Ovoid anorthositic gabbro at Bernic Lake showing two very closely spaced ovoids with foliated amphibole in between. (From outcrop A, Figure 3).

FIGURE 6b: Ovoid anorthositic gabbro at Bernic Lake showing irregular distribution of ovoids. (From outcrop D, Figure 3).

FIGURE 7: Ovoid anorthositic gabbro at Bernic Lake. The area shown is immediately below the ordinary gabbro. Note that the ovoids are fairly competent in highly sheared areas. Note also that the ovoids are in zones that appear similar to bedding. Several of the ovoids seem to be breaking up along the margins which are less sharp than normal. (From outcrop A, Figure 3).

structures that could be interpreted as being due to settling, were observed, although the size of the ovoids changes along strike, but with no apparent trend. The ovoids form 50 to 80 per cent of the rock. Where the ovoids are smaller, they appear to be more tightly packed, with a lesser volume of intervening matrix. In Figure 4a, the ovoids occupy approximately 77% of the outcrop.

At a few localities the ovoids are not regularly distributed throughout the rock. These areas are characterized either by a lack of or a concentration of ovoids. There occur small irregular patches within the ovoid zone that contain no ovoids (Figure 4b, 6b). Locally lenses, less than 4 feet wide (Figure 7), are devoid of the anorthositic ovoids; these are parallel to subparallel to the trend of the sill and are continuous for up to 50 feet along strike. Adjacent to these lenses that contain no ovoids, there are linear zones that contain concentrations of ovoids, that further accentuate the layering noted above (Figure 7). Figure 8 is a sketch of a plan view of outcrop "D"; it shows a zone of ovoids within the marginal gabbro parallel to the shear contact between the two types of gabbro.

Shearing is localized, and it is concentrated in the matrix whereas the more competent ovoids are only slightly stretched (Figure 7). The sheared matrix is locally slightly foliated.

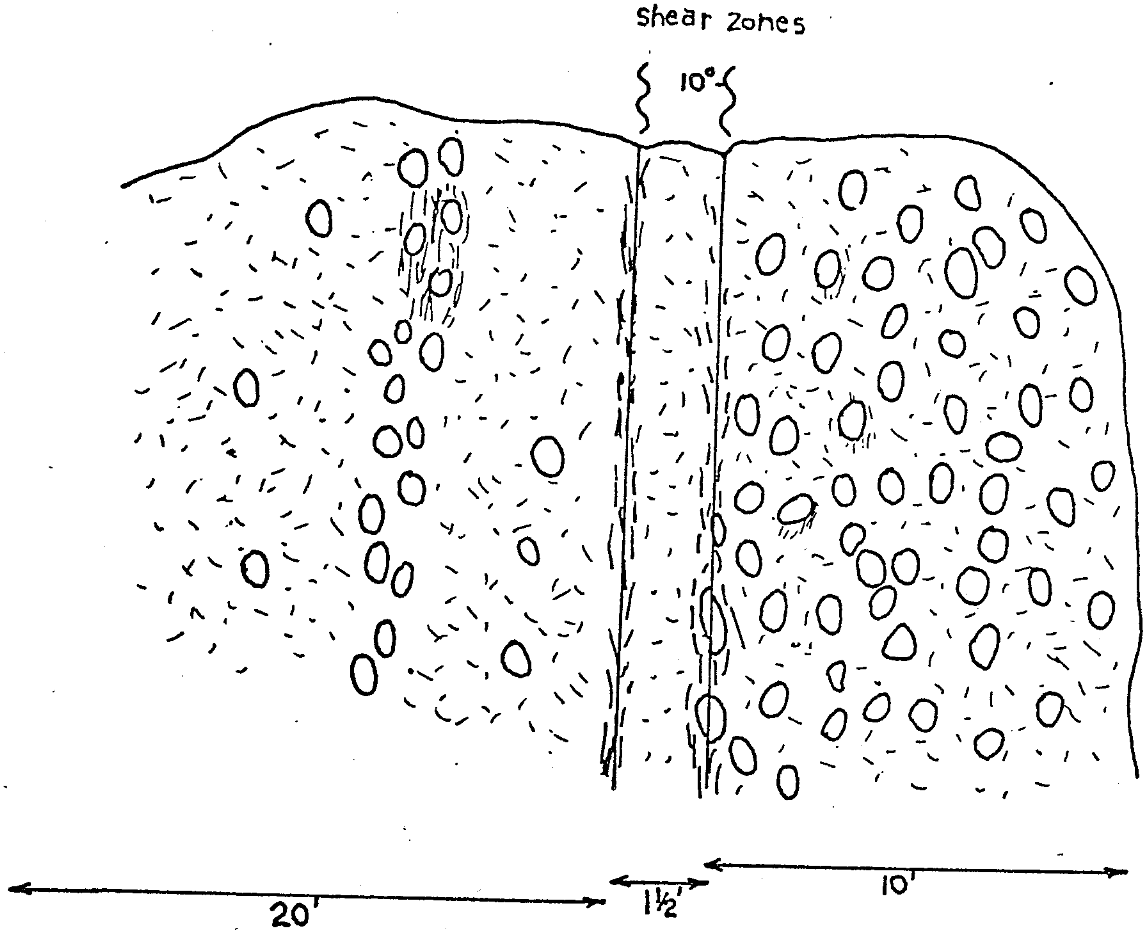


FIGURE 8: Plan view of outcrop "D" showing the ovoid anorthositic gabbro (right) in shear contact with ordinary gabbro to the left. An ovoid-rich zone occurs in the gabbro with a trend parallel to the overall trend of the ovoids sill and resembles bedding or flow layering.

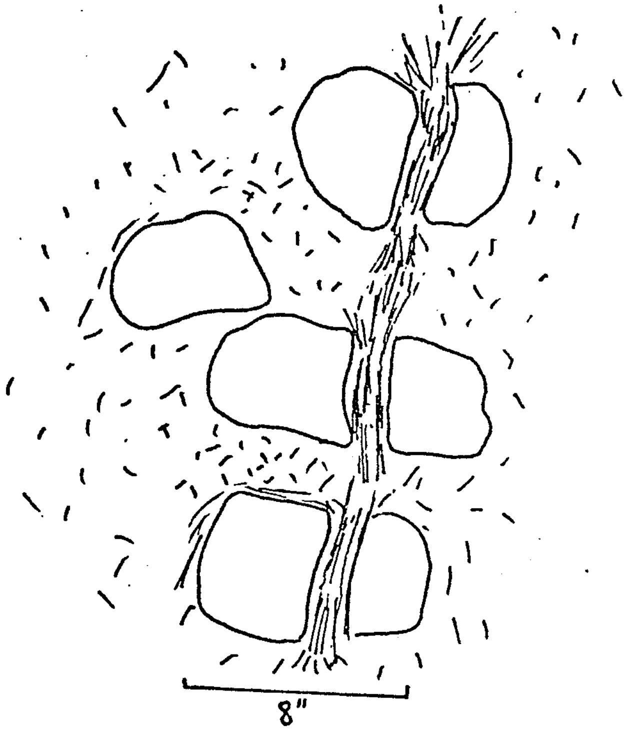


FIGURE 9: Sketch showing three ovoids displaced along a common fracture that was subsequently invaded by matrix material. (From outcrop A, Figure 3).

Orientation of the Ovoids

Flow lamination in the matrix or of the plagioclase crystals within the ovoids is not apparent. Furthermore, the elliptical ovoids generally show no direction of preferred orientation except, rarely on vertically jointed surfaces, a subparallel, near-vertical alignment was observed (Figure 10). The elliptical ovoids also locally form a subparallel alignment along shear zones (Figure 7).

The orientation of elongate ovoids was measured. The apparent lineation of the ovoids and the corresponding attitude of the plane of exposure were measured on numerous non-parallel surfaces (Appendix I). Care was taken to choose only those ovoids characterized by a length to width ratio of 2:1 or more. Figures 11a, 12a and 13a are stereonet plots of the apparent plunge of the ovoids and the corresponding poles to the attitude of the exposed surface plane joined along a great circle. Should there be a common orientation of the ovoids, the great circles will pass through a common point representing the common plunge. Figures 11b, 12b and 13b are stereonet plots of the points of intersection of the various great circles represented in Figures 11a, 12a and 13a respectively. Figures 11c, 12c and 13c are contoured equal area plots of these points of intersection. There is, in fact, a rough

FIGURE 10: Photograph of a near vertical surface of the ovoid anorthositic gabbro at Bernic Lake showing a rough common orientation of the ovoids. (From outcrop A, Figure 3).

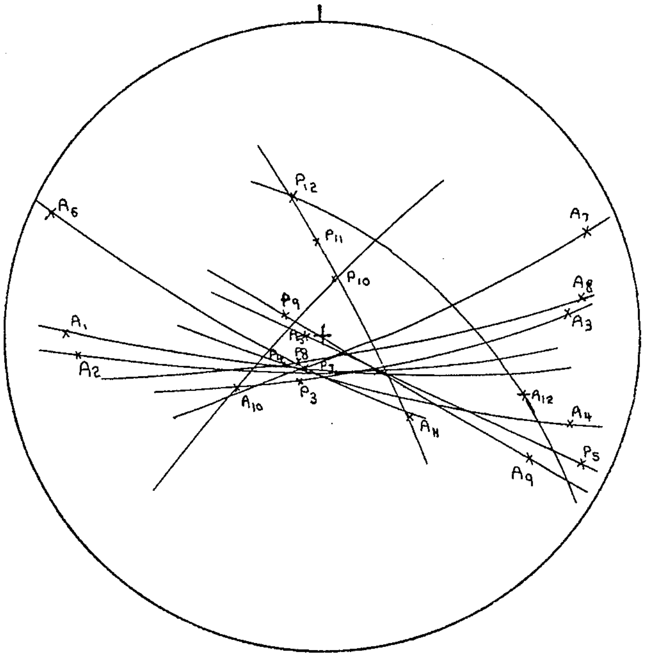


FIGURE 11a: Stereonet plot of great circles connecting apparent lineations (A) of the ovoids and the poles to the attitude of the corresponding outcrop surfaces (P). "A" outcrop.

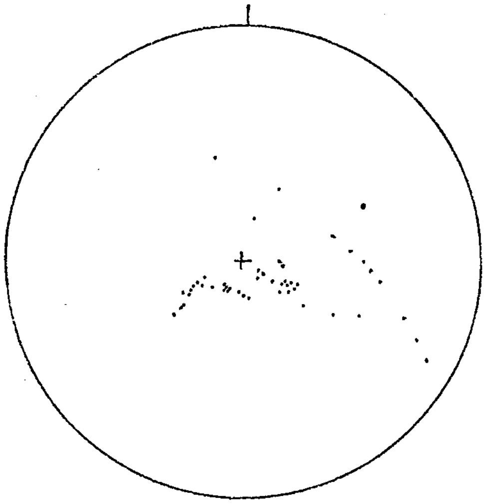


FIGURE 11b: Stereonet plot of the points of intersection (lineations) of the great circles shown in Figure 11a. 55 points.

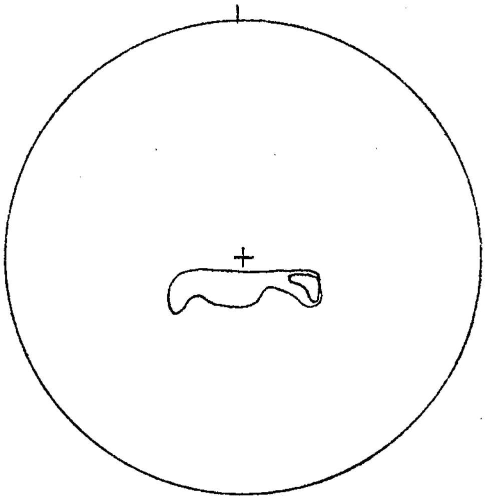


FIGURE 11c: Contoured equal area plot of the lineations in Figure 11b. Contours at 10 and 15 per cent.

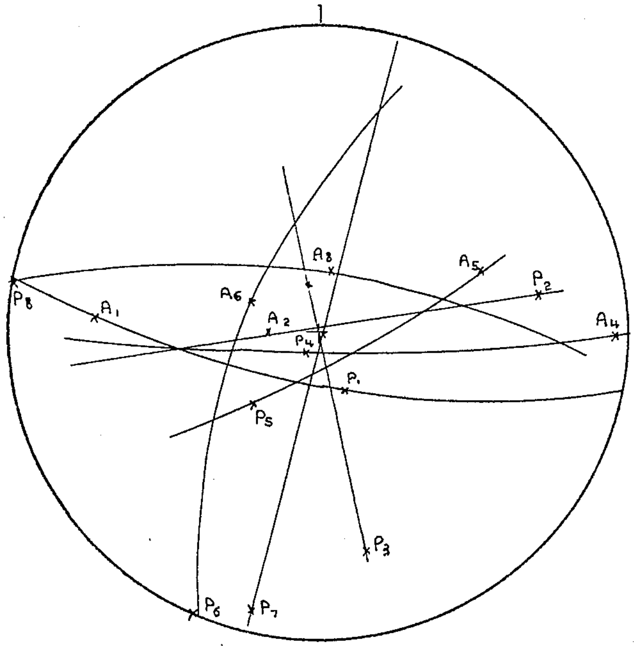


FIGURE 12a: Stereonet plot of great circles connecting apparent lineations (A) of the ovoids and the poles to the attitude of the corresponding outcrop surfaces (P). "B" outcrop.

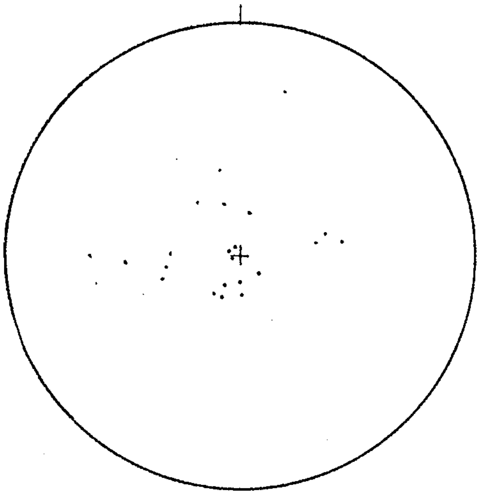


FIGURE 12b: Stereonet plot of the points of intersection (lineations) of the great circles shown in Figure 12a. 22 points.

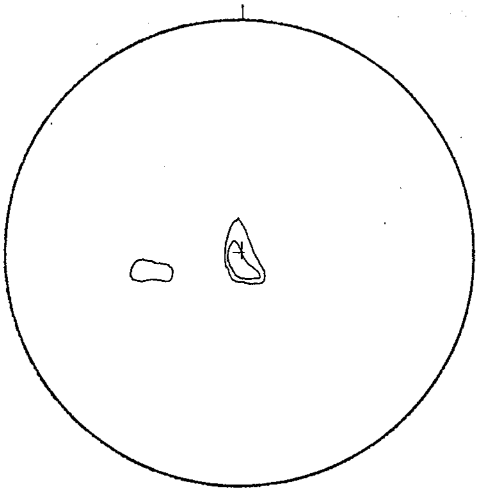


FIGURE 12c: Contoured equal area plot of the lineations in Figure 12b. Contours at 10 and 15 per cent.

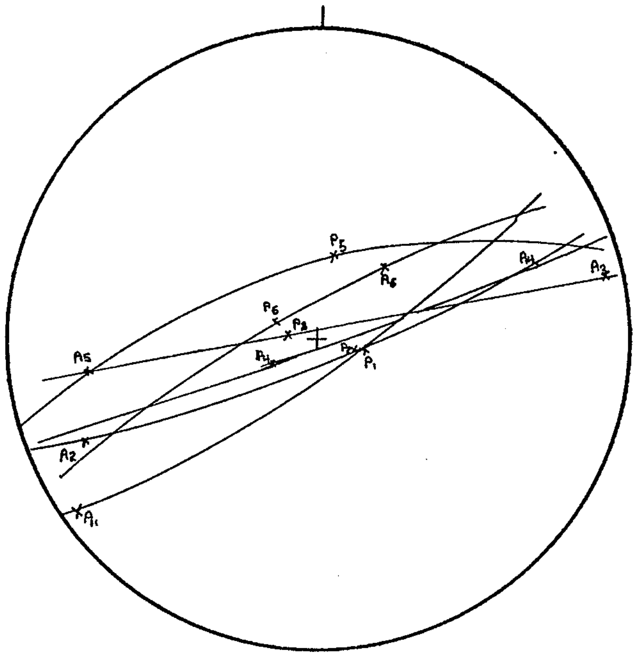


FIGURE 13a: Stereonet plot of great circles connecting apparent lineations (A) of the ovoids and the poles to the attitude of the corresponding outcrop surfaces (P). "C" and "D" outcrops.

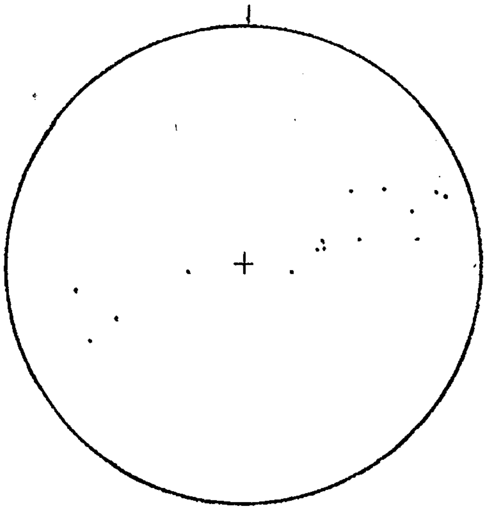


FIGURE 13b: Stereonet plot of the points of intersection (lineations) of the great circles shown in Figure 13a. 16 points.

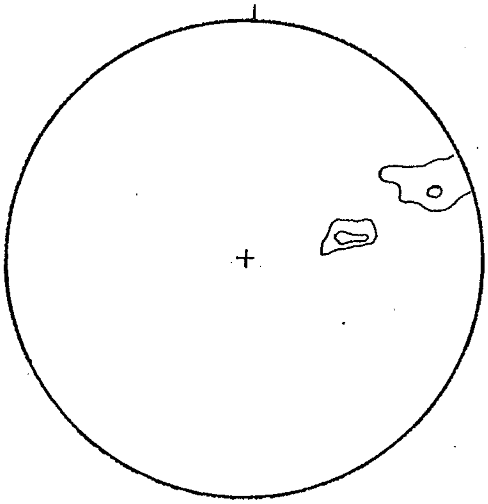


FIGURE 13c: Contoured equal area plot of the lineations in Figure 13b. Contours at 15 and 20 per cent.

preferred orientation - a near vertical plunge to the ovoids. Also, there appears to be a small difference in the position of the direction of the maximum intersection from the various exposures.

The margin of the ovoids is extremely sharp signifying little or no alteration or resorption by post-consolidation metamorphism and their shapes are interpreted to be of igneous origin. Therefore, any preferred orientation of the elongate ovoids is probably due to igneous flow. It is not known whether the intrusion was pre-tectonic or post-tectonic although, the fact that the surrounding lavas are dipping from vertical to 85N while the ovoids have a rough steep plunge slightly to the south might indicate the intrusion did take place post-tectonically.

Fracturing and Faulting of the Ovoids

Small-scale fracturing and faulting commonly occur within the ovoids. The fracturing does not seem to be preferentially located along crystal boundaries or twins within the ovoids but rather cuts across grain boundaries. These fractures and microfaults do not continue into the recrystallized matrix (Figure 4b). Many of the small faults have components of rotation, as evidenced by the different amount of offset from one edge of the ovoid to the opposite edge. In thin section, twins show progressively increasing amounts of displacement along the faults.

Figure 9 shows three ovoids which have been broken apart along the same line and then invaded by mafic material of the matrix. If this is pre-metamorphic it indicates that the matrix material had partly crystallized and was semi-competent when the fracturing took place. On the other hand, it cannot be discounted that this may be due to recrystallization and is a post-metamorphic feature.

Thin sections may be cut by microfaults or the faults may be restricted to small portions of a single crystal (Figure 16a). The fractures commonly have cataclastic textures showing varying degrees of granulation (Figures 16a, 17b). Rarely the plagioclase crystals are broken up along the margins of the ovoids and are incorporated as rafts within the matrix.

Interstitial Material

A few ovoids contain interstitial gabbro similar to that of the matrix, in the form of veinlets or small pods that may or may not be connected to the outer margins and the matrix (Figure 14a).

FIGURE 14a: Ovoid anorthositic gabbro showing interstitial gabbroic matrix. Some crystals of plagioclase are evident in the large ovoid. (From outcrop A, Figure 3).

FIGURE 14b: Ordinary gabbro flanking the ovoid anorthositic gabbro at Bernic Lake with leucocratic zones of feldspar. In thin section these zones are composed of anhedral masses of clinozoisite. (From outcrop C, Figure 3).

More rarely the ovoids show a spiralling effect on their outer margin (Figure 5a); i.e. they show marginal outlines that suggest they have been rotated prior to or during consolidation. This form may be attributed to corrosion by the matrix, to plastic deformation prior to consolidation, or to partial resorption of the ovoid plagioclase.

Matrix

The matrix is massive and gabbroic in composition. Although it is recrystallized and foliation is weak to absent, some of the hornblende crystals are foliated in areas of intense shearing or between two closely spaced ovoids (Figure 6a). Rarely the foliation wraps around the ovoids. For the most part, feldspar and hornblende are present in equal amounts but locally they are concentrated in monomineralic patches; especially around the margins of the ovoids where hornblende concentrations occur, while close by, plagioclase is concentrated into vaguely-defined, loosely-packed patches in the matrix (Figure 5a).

Marginal Gabbro

The central ovoid-rich portion of the sill is flanked by normal gabbro. The marginal gabbro is more extensively recrystallized, richer in dark green to black hornblende, and massive to foliated; foliation in the margins is more pronounced than in the central (ovoid) portion of the sill. In places the margins contain rather nebulous zones where feldspar has accumulated (Figure 14b). The thickness of the gabbroic flanks is not uniform and in places the marginal gabbro is almost absent. At outcrop "C" there is a zone of ovoids sparsely concentrated along a shear zone flanked by gabbro. South of the shear zone there is approximately 5 feet of massive gabbro that grades abruptly into sheared pillow volcanics.

COMPOSITION

Mineralogy

The plagioclase within the ovoids is the only remaining primary mineral. Matrix plagioclase, amphibole, zoisite, epidote, chlorite, sericite and minor quartz are secondary, having been derived from the primary minerals during metamorphism. Some of the chlorite in the matrix is replacing amphibole and indicates retrograde metamorphism.

Plagioclase

Plagioclase is the most abundant mineral comprising at least 98 per cent of the ovoids and 40 to 50 per cent of the groundmass. In the field, the plagioclase appears unaltered and weathers white to grey. Within the ovoids, the plagioclase crystals are randomly oriented, tightly packed, roughly equi-dimensional subhedral crystals 2 to 5 cm. long. Matrix plagioclase forms small (1 to 2mm.) randomly oriented, lath-shaped crystals.

In thin section, the boundaries of the ovoid plagioclase crystals are characterized by generally straight surfaces. Commonly, both the edges of the plagioclase crystals and the margins of the ovoids are markedly affected by corrosion. Along the margins of the ovoids, rafts of plagioclase, apparently mechanically separated from the main ovoid, appear to be floating in the matrix (Figures 15, 18).

Plagioclase in the ovoids is weakly to moderately sericitized; the alteration often increases in intensity near fractures or crystal boundaries.

Twinning is common in the plagioclase of both the ovoids and of the matrix. Twinning is considered to be primary if growth took place during precipitation, and secondary if it was formed by post crystalline deformation (Barth, 1969). Barth (1969) and Spry (1969), have stated that, in general, simple twins (e.g. Carlsbad, Baveno, and Manebach) tend to be primary whereas more complex polysynthetic twins, (e.g.: Albite and Pericline) tend to be secondary. The criteria for distinguishing between primary and secondary twinning in this study is given by Vance (1961).

The ovoid plagioclase exhibits complex, polysynthetic albite and pericline twinning; the twinning is characterized by many thin wedge-shaped lamellae (Figure 16a, 16b). The form of the twinning is variable, and in places is absent, due possibly to low grade metamorphism (Spry, 1969). Where two sets of twins are present there are obvious age relations. Figure 17a shows earlier twinning displaced along later,

FIGURE 15: Photomicrograph showing an ovoid margin (upper left corner) with a plate of fractured-off feldspar floating in the matrix. Crossed-nicols, X25.

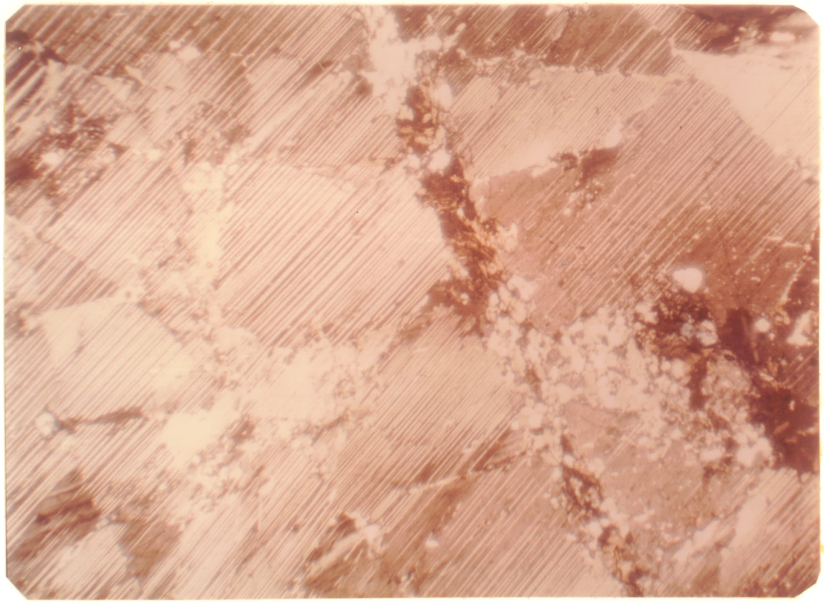


FIGURE 16a: Photomicrograph showing the characteristic polysynthetic twinning of the ovoid plagioclase. Note also the granulation along the numerous, minute fractures. Crossed-nicols, X25.

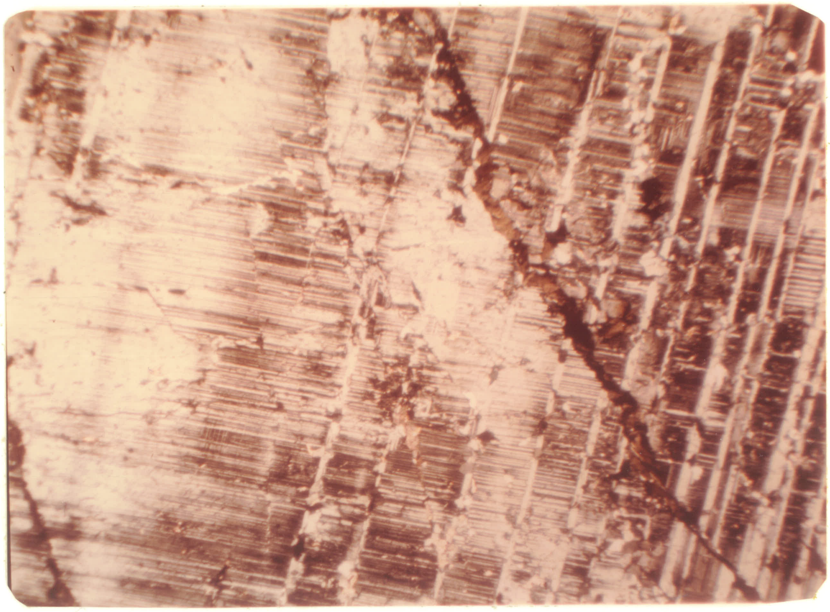


FIGURE 16b: Photomicrograph showing the typical thinning in unison of polysynthetic twinning (left). Note also the fine pericline twinning in one set of the albite twins. Crossed-nicols, X25.

secondary twinning. Minute structural deformations in the lamellae such as faults, fractures, kinks and bends are evidence of physical deformation. It is not clear whether the twins developed during growth of the plagioclase phenocrysts or as a direct result of later deformation (Figure 16b). In Figure 17b, the larger, less well-defined twins have been offset by fractures and may pre-date the fracturing whereas the thinner, more continuous lamellae have been displaced to a lesser degree and may have formed as a result of the fracturing. However, the larger ill-defined twins, are only present where associated with the fractures; here they cut across the thinner, dark lamellae. This suggests these large twin lamellae might also have resulted from the fracturing. Thus, the twinning is variable and in places appears to be the result of local stress and post-crystalline deformation. Granulation is commonly developed along the fractures (Figures 16a and 17b).

The composition of the plagioclase was determined by measuring the indices of refraction of fused samples and of oriented cleavage flakes, and also by universal stage methods (for a description of the procedure used in each of the above methods, see Appendices 2a, 2b). The ovoids are weakly zoned; compositions vary randomly from An_{70-92} (fusion method) from An_{77-83} (cleavage method) and from An_{75-94} (universal stage method).

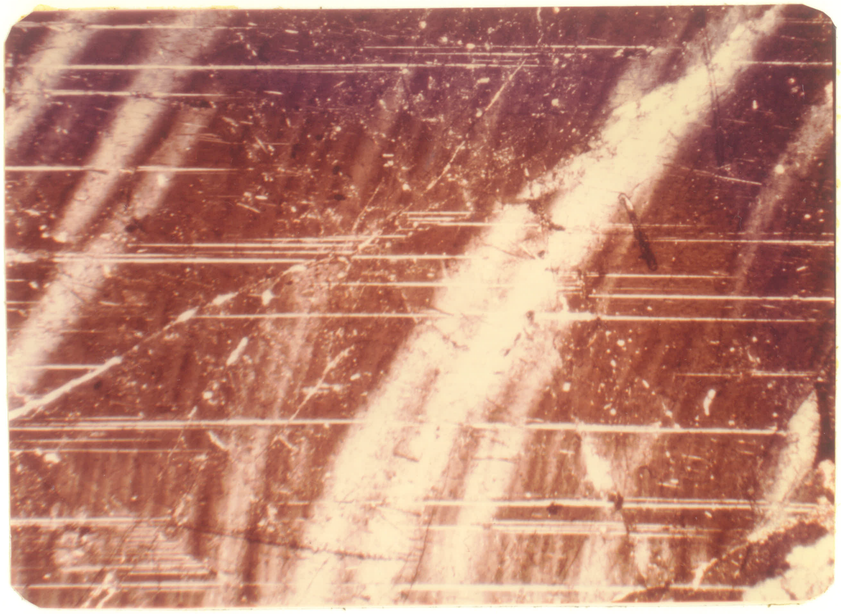


FIGURE 17a: Photomicrograph of twinning relations within the ovoid plagioclase. The earlier, hazier twinning appears to be displaced by the latter, thinner lamellae. Crossed-nicols, X25.

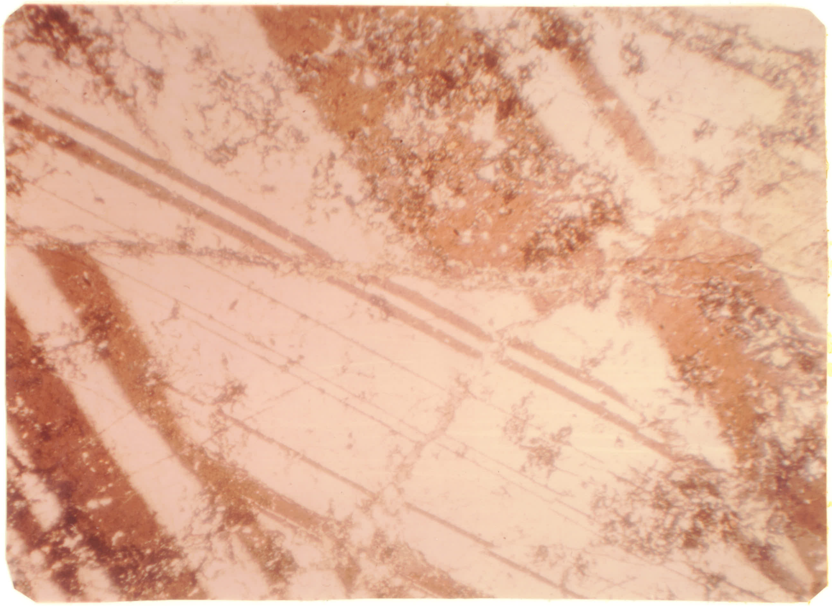


FIGURE 17b: Photomicrograph of two sets of twin lamellae in the ovoid plagioclase. The earlier, hazier, thicker lamellae have been offset by the fractures while the thinner lamellae have not. Note also the granulation along the fractures. Crossed-nicols, X25.

The results show considerable variation in composition. According to Foster (1955), many of the standard plagioclase determinative methods give ambiguous results for certain portions of the composition range. Although Poldervaart (1950) discussed the advantages and limitations of some of the methods of plagioclase determination, comparison between the methods is rarely, if ever, described in the literature.

The refractive index methods permit comparison because they were done on split samples. After crushing the chip samples, half the sample was determined by the fusion method and half by the cleavage method. The results indicate that the compositions determined by the cleavage method are more constant and are slightly lower than the compositions obtained by the fusion method (Appendix 2a). Compositions determined by the fusion method are in the same range and are comparable to compositions determined on the universal stage. The reason for the lower, more consistent values of the cleavage method is not known.

In contrast to the ovoid plagioclase, the plagioclase in the matrix is smaller (1 to 2 mm.), lath-shaped and is less affected by alteration. The laths are randomly oriented and regularly distributed, except locally where they are concentrated in loosely-packed clusters. Twinning, after the albite and Carlsbad laws, distinguishes the matrix plagioclase from the ovoid plagioclase (Figure 18). The lamellae of the matrix plagioclase are thicker, show little evidence of deformation and appear to be primary in accordance with the criteria of Vance (1961).

The undulatory extinction exhibited by the laths suggests strong zoning. From universal stage determinations, the zoning grades continuously from An_{85} in the core to An_{51} at the margins.

Secondary Minerals

Hornblende comprises in excess of 50 per cent of the matrix of the ovoid gabbro at Bernic Lake. It occurs as randomly oriented, stumpy, dark green to black, subhedral prisms, and as radiating masses of fibrous aggregates that are strongly pleochroic from green-blue to light green-yellow. The fibrous hornblende is a product of near-complete recrystallization of the prisms (Figure 18).

Hornblende is also found in minor abundance in two habits within the ovoids. First, fibrous hornblende occurs, its position often being structurally controlled along fractures or more rarely in crystallographic planes. Second,

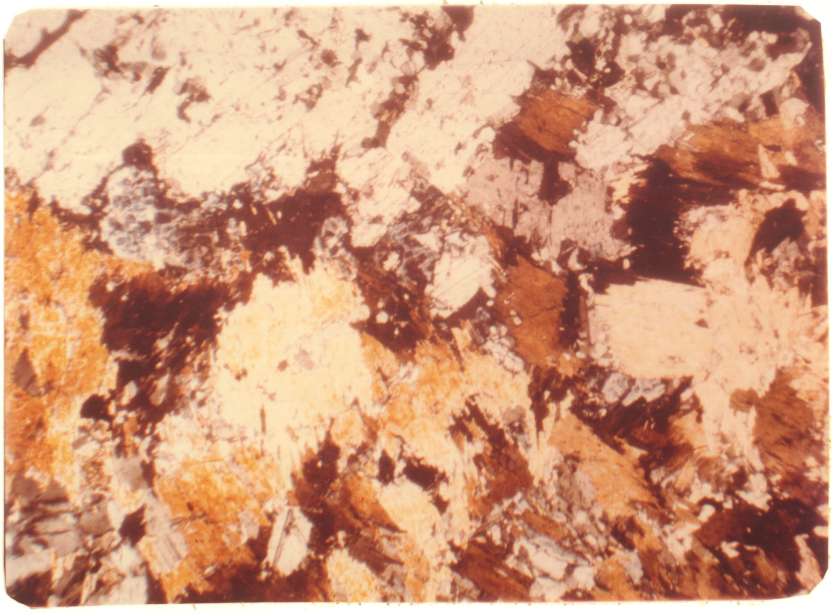


FIGURE 18: Photomicrograph of an ovoid margin and the matrix showing the recrystallized nature of the amphibole. Note also the corroded border of the ovoid and the raft of ovoid plagioclase (center of photomicrograph) separated out into the matrix. Crossed-nicols, X25.

hornblende occurs as microinclusions throughout the ovoid plagioclase. The microinclusions form individual, acicular crystals, that are parallel to cleavage or randomly oriented.

Minor chlorite is present in the ovoids and matrix. Within the ovoids, it forms randomly oriented, fanshaped crystal aggregates (Figure 19a). These aggregates are commonly found along fractures, but are also present within individual crystals of plagioclase. Chlorite within the matrix forms very fine-grained scaly masses at the expense of hornblende.

Clinozoisite is a common alteration product, associated with calcite and minor epidote. Within the ovoids it forms columnar aggregates, anhedral masses and euhedral prisms (Figure 19a). It is present to a lesser extent in the matrix and in the gabbroic flanks as anhedral masses, concentrated in the wispy, leucocratic zones (Figure 14b).

Sericite, albite, quartz and carbonate also form minor alteration products within the ovoid plagioclase; they are concentrated along fractures and crystal boundaries.

Chemical Data

Chemical data and CIPW norms of the ovoid anorthositic gabbro are given in Table 2. Sample 7, from the chilled contact

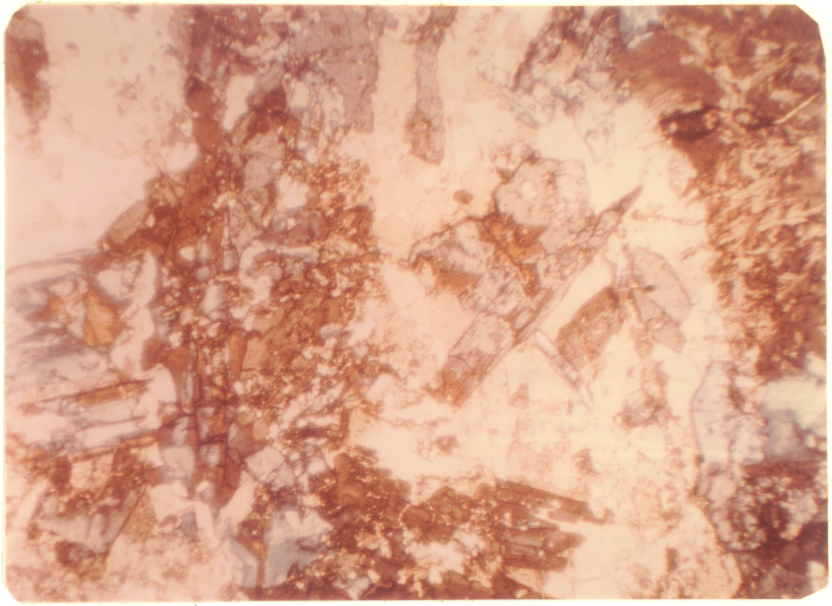


FIGURE 19a: Photomicrograph showing ovoid plagioclase altering to carbonate, euhedral prisms of clinozoisite and chlorite. Crossed-nicols, X25.

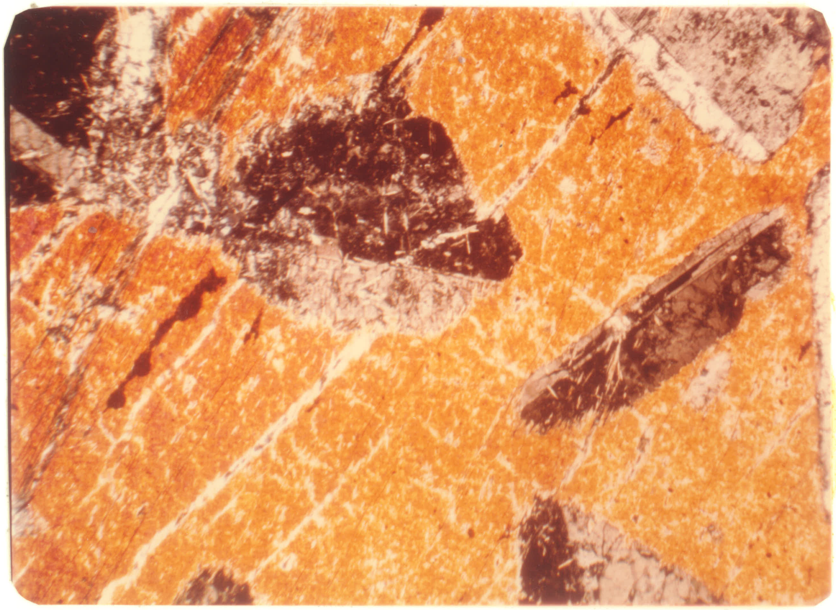


FIGURE 19b: Photomicrograph of the matrix of the ovoid anorthositic gabbro on the Page property of the Bird River Sill. Cross-nicols, X25.

TABLE 2: Chemical and normative compositions of the ovoid anorthositic gabbros and related rocks.

OXIDE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	49.50	47.85	47.45	47.15			45.27	48.40
Al_2O_3	14.81	16.89	24.84	20.82			17.91	17.50
Fe_2O_3	1.65	1.75	1.36	0.19			0.00	0.82
FeO	7.68	7.72	3.32	2.96			5.59	8.21
MgO	8.65	7.80	4.05	6.95			14.53	8.55
CaO	11.85	13.02	14.83	12.75			7.25	9.80
Na_2O	1.95	1.49	1.60	2.62			1.52	2.01
K_2O	0.38	0.33	0.29	0.52			0.59	1.50
H_2O^+	1.75	1.59	1.10	2.43			3.57	1.93
H_2O^-							0.10	
CO_2	0.33	0.19	0.20	2.46			tr.	0.40
T_1O_2	0.64	0.54	0.31	0.11			0.00	0.44
P_2O_5	0.17	0.16	0.10	0.08			0.00	0.04
MnO	0.17	0.17	0.10	0.07			0.00	0.17
S%				0.007	0.007	0.007	0.00	0.01
Cr_2O_3				0.276	0.095	0.150	0.09	0.05
Cu (P.P.M.)				11	8	8		
Ni (P.P.M.)				87	156	66	0.00	0.02
TOTAL	99.53	99.50	99.55	99.42			99.49	99.85
Mg/Fe	1.68	1.49	1.59	3.95			4.62	1.70

GROSS CIPW NORM (WEIGHT %)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PLAG.	50.53	54.21	76.33	69.72			56.2	62.3
PYR.	43.27	38.27	20.59	16.13			20.8	19.1
OL	2.10	3.49		11.33			20.6	16.9
MT	2.453	2.59	2.0	0.29				0.9
IL	1.246	1.05	0.6	0.22				0.6
AP	0.404	0.38	0.25	0.20				0.1
CR				0.43			0.1	0.1

NOTE: Key to sample numbers is on Page 41.

Key to Chemical Analyses of Table 2

(1) Gabbroic matrix of the ovoid anorthositic gabbro at outcrop B (Figure 3) Bernic Lake. K. Ramlal, analyst.

(2) Gabbroic matrix and 10% by volume of ovoid anorthosite, outcrop B (Figure 3) form Bernic Lake. K. Ramlal, analyst.

(3) Representative sample of ovoid anorthositic gabbro from outcrop A (Figure 3) Bernic Lake with approximately 60-70% by volume of ovoid anorthosite. K. Ramlal, analyst.

(4) Representative sample of ovoid anorthositic gabbro from the Chrome property of the Bird River Sill containing 40-50% by volume of ovoid anorthosite. K. Ramlal, analyst.

(5) Representative sample of the ovoid anorthositic gabbro from the Page property of the Bird River Sill.

(6) Ovoid anorthositic gabbro from the Page property of the Bird River Sill, containing 40% by volume of ovoid anorthosite. K. Ramlal, analyst.

(7) Marginal gabbro, Bird River Sill, Chrome property, from Osborne (1949): "altered drill hole specimen, about 15 feet below the base of the peridotite".

(8) Gabbroic stock of unknown age ("Cup" gabbro of Figure 2). (Analyst, D. Brown) from Trueman (1971).

of the Bird River Sill (Osborne, 1949) and sample 8, from the "cup gabbro" (Trueman and Macek, 71-A-1 map unit 4) shown in Figure 2 are included for comparative purposes.

The normative plagioclase correlates well with the amount of plagioclase visually estimated initially, to be in each sample.

Analyses (3) and (4) are typical of the ovoid anorthositic gabbro at Bernic Lake and the Chrome property respectively; they are similar in composition to the "leopard rocks" from the Labrador Trough (Barragar, 1960) and to dikes from the Beartooth Mountains (Prinz, 1964). The "cup" gabbro (analysis 8) is similar to the gabbroic matrix of the ovoid gabbro at Bernic Lake, except it is slightly higher in alkali content, which may be due to metasomatism from the nearby granitic intrusions (D.L. Trueman, personal communication).

Cr_2O_3, NiO, CuO and S values (Table 2) show little, if any correlation to cryptic variation of these elements in the Bird River Sill (Trueman, personal communication).

Figure 20 is an MgO - Fe_2O_3+FeO - Na_2O+K_2O plot of analyses from Table 2. The "cup" gabbro (analysis #8) is similar in composition to the representative sample of the Bernic Lake ovoid anorthositic gabbro (analysis 3), whereas the Bird River Sill appears to be significantly different in

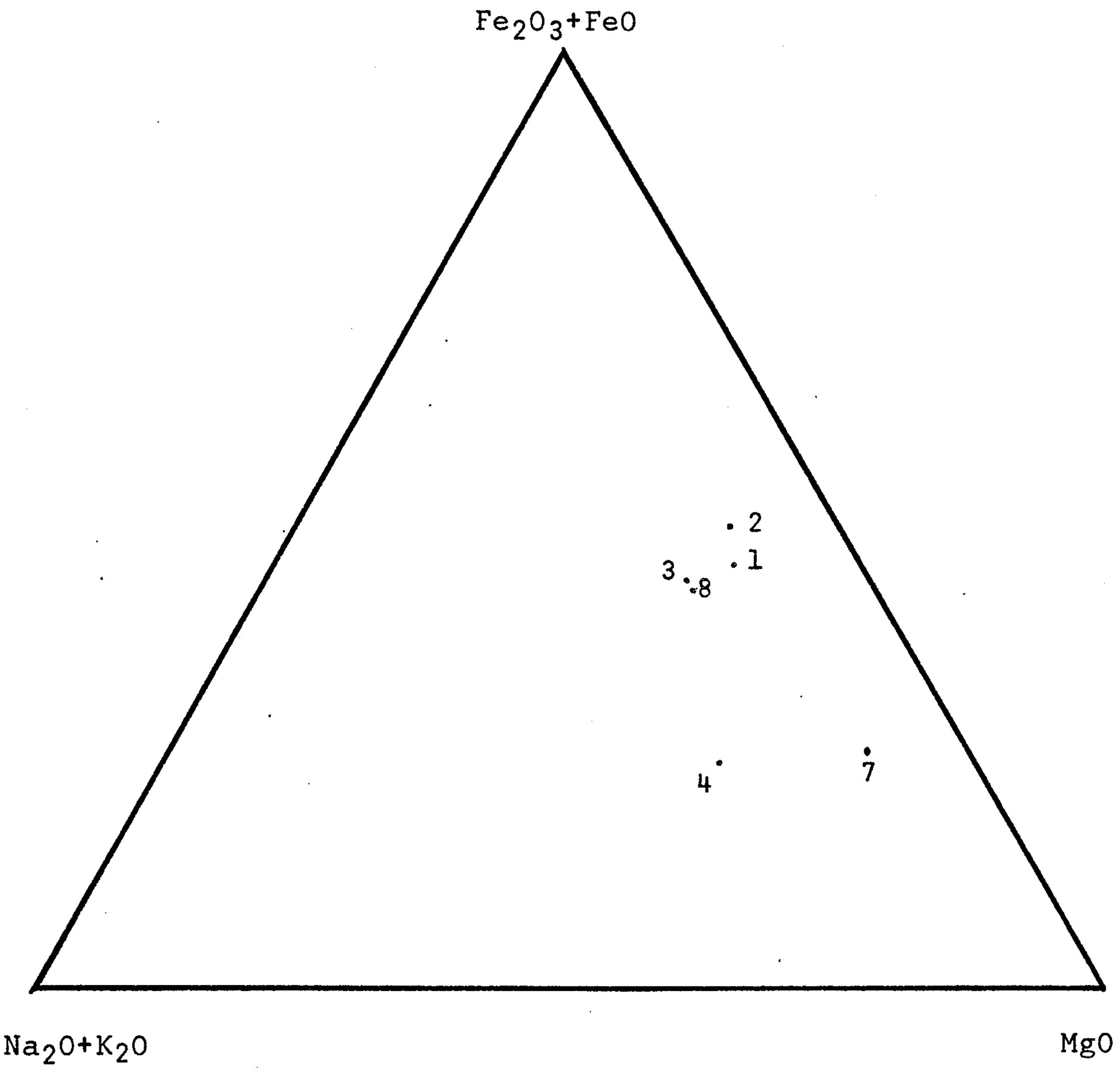


FIGURE 20: AFM plot of chemical analysis of TABLE 2. The numbers correspond to those of the analysed samples of TABLE 2.

chemical composition being more enriched in Mg. The representative sample of the ovoid anorthositic gabbro within the Bird River Sill (analysis 4) is closer in composition to the Bird River Sill (analysis 7) although it is slightly lower in Mg content and higher in alkali content.

OVOID ANORTHOSITIC GABBRO IN THE BIRD RIVER SILL AND OTHER RELATED GABBROS

Comparison to the Bird River Sill Ovoid Occurrences

The location of ovoid anorthositic gabbro within the Bird River Sill (Trueman, 1971) is shown in Figure 2. It forms narrow concordant layers up to 50 feet thick near the base of the gabbroic portion of the sill, and is particularly well developed on the Page and Chrome properties. On the Page property, the ovoid rock is exposed continuously along strike for 500 feet. In the Maskwa area, (Figure 2) it is exposed in patches that may form linear bands (Trueman, personal communication). The ovoid anorthositic gabbros associated with the Bird River Sill are offset by faulting and also wedge out along strike.

The ovoid rocks of the Bird River Sill are characterized by the following features:

i) The Bird River Sill ovoids are generally smaller and more densely packed, averaging 3-4 inches in diameter, and make up 40-50 per cent of the rock (Figure 21).

FIGURE 21: Ovoid anorthositic gabbro on the Chrome property in the Bird River Sill.

ii) Although ellipsoidal ovoids were observed, the majority are spherical. Irregular aggregates were also noted.

iii) The matrix of the ovoid rocks within the Bird River Sill is less completely recrystallized than the Bernic Lake gabbro. At the Chrome property, the matrix is composed of broad plates of green actinolite (Figure 21). At the Page property the matrix is more gabbroic in texture and consists of approximately equal amounts of plagioclase and actinolite (Figure 19b). The difference in the degree of recrystallization between the Bernic Lake Sill and the Bird River Sill may be related to the size of the bodies involved: i.e. the smaller bodies will be affected more readily and more completely by external conditions.

iv) The (Bird River Sill) ovoids vary randomly in composition from An_{90} to An_{79} and are unzoned. The matrix plagioclase at the Page property has a composition of An_{80} and is unzoned.

Other Gabbroic Rocks in the Area

Gabbroic rocks in the Bird River area fall into 4 categories:

i) thin, partly recrystallized intravolcanic sills within the volcanic sequence;
ii) recrystallized basaltic rocks along the margins of the volcanic pile;
iii) the Bird River Sill; and
iv) an irregular stock, indicated as the "Cup" gabbro in Figure 2.

The first group, the intravolcanic metagabbro sills appear to be contemporaneous injections into the volcanic pile. The rocks of the second category are restricted in occurrence to xenoliths and contact zones within the metavolcanics near granitic intrusions. These rocks appear to represent more completely recrystallized equivalents of the rocks of the metavolcanic pile.

The Bird River Sill as a whole has been described in the chapter on Regional Geology. The differentiation sequence is given in Table I.

The "Cup" gabbro, an irregular stock 2 miles north of Bernic Lake, has heretofore been thought by the early mappers to conform to, and be a part of the Bird River Sill, but recent mapping indicates that it cuts across the regional foliation (Trueman and Macek, 1971-A-1) and appears to be in fault contact with the Bird River Sill. The "Cup" gabbro is markedly similar in texture, mineralogy and chemical composition to the matrix of the ovoid gabbro at Bernic Lake (Trueman, personal communication).

CONCLUSIONS

Relation of Ovoid Anorthositic Magma at Bernic Lake to Bird River Area

The ovoid anorthositic gabbro at Bernic Lake and the Bird River Sill probably stem from the same source. Features that indicate a co-magmatic origin for the two include:

i) both are characterized by considerable amounts of anorthosite, a rock which does not occur commonly in the Superior Province of the Canadian Shield.

ii) the composition of the plagioclase ranges up to An_{90-95} in both sills.

iii) the unusual ovoid texture is found at Bernic Lake and within the layered sequence of the Bird River Sill, and nowhere else in the area.

iv) both sills are massive, and have less well-developed foliation than the country rocks.

If the sills are co-magmatic, chemical analysis of the ovoid anorthositic gabbro at Bernic Lake should approximate either the bulk composition of the Bird River Sill, or a later differentiated portion of the Sill. The ratio of ultramafic to mafic rocks suggests that the magma of the layered intrusion was originally a picrite (D.L. Trueman, personal communication), and was thus more mafic in composition than the magma at Bernic Lake. The bulk composition of the Bird River Sill is richer in magnesium (Table 2) than the Bernic Lake Sill. Osborne's composition (1949) of the chilled margin of the Bird River Sill (analysis 7, Table 2) indicates the Bird River Sill is higher in magnesium and alkalies than the ovoid anorthositic gabbro at Bernic Lake. Several other differences exist between the ovoid anorthosite in the Bird River and Bernic Lake sills; including differences in location on the AFM plot, in the normative olivine content, in the unzoned plagioclase of the matrix, and in the mineralogy of the matrix.

The Bird River Sill ovoid anorthositic gabbro is close in composition to the magma that formed the bulk of the Bird River Sill: i.e. it is richer in magnesium than the ovoid rock at Bernic Lake. The difference in bulk chemical composition between the Bird River Sill and the Bernic Lake Sill can be explained by differentiation. It is possible that the ovoid anorthositic gabbro at Bernic Lake is a later differentiate of the same magma that formed the Bird River Sill. If the two are co-magmatic, the magnesium could have been used up in the formation of olivine in an earlier-intruded stage of the Bird River Sill, before intrusion of the Bernic Lake gabbro, resulting in depletion of the remaining magma in magnesium.

The apparent conformable and consistent relation near the base of the gabbroic portion of the sill and the similarity in mineralogy of the Bird River ovoid anorthositic gabbro and the Bird River Sill itself suggest they may be continuous with one another, the former being a differentiate of the latter. However, the departure of the Cr_2O_3, NiO and S values in the matrix of the Bird River Sill ovoid rock (analyses 4, 5 and 6) from the cryptic variation of the same elements across the Bird River Sill (page 42 of this thesis) and the absolute need for a confining system (i.e. a roof and a basement under these conditions) make it improbable that the ovoid rock could have formed <u>in situ</u> as a differentiate of the Bird River Sill.

The ovoid anorthositic gabbro associated with the Bird River Sill may have been intruded earlier than the Bernic Lake ovoid anorthositic gabbro. In addition to the bulk chemistry and plagioclase composition, further evidence in support of an early intrusion of the Bird River Sill ovoid anorthositic gabbro is the fact that the plagioclase ovoids within the gabbro of the Bird River Sill are smaller than at Bernic Lake. If the Bird River Ovoids were intruded at an earlier stage, they presumably had less time to grow than the ovoids in the gabbro at Bernic Lake.

The similarity of the "Cup" gabbro in texture, mineralogy and chemical composition to the matrix of the ovoid anorthositic gabbro at Bernic Lake suggests a genetic relationship with the Bernic Lake gabbro. However, the "Cup" gabbro lacks plagioclase ovoids. It is likely both the "Cup" gabbro and the Bernic Lake ovoid gabbro were intruded shortly after intrusion of the Bird River Sill.

Origin of the Ovoid Texture

Previously described ovoid anorthositic gabbros have the following features in common:

i) All the occurrences are in a Precambrian environment.

ii) They all contain large, rounded, polycrystalline aggregates and/or crystals of plagioclase.

iii) Without exception, they are concentrated in narrow dikes and/or sills.

iv) Commonly material of similar composition to the matrix hosting the polycrystalline aggregates occurs along the margins of the narrow bands of ovoid rock.

The origin of the ovoid anorthositic gabbro has been hypothesized by Baragar (1960, 1967) and Prinz (1964) to be a flow differentiation mechanism. The process involves the intrusion of a relatively homogeneous crystal mush into a narrow, constricted passage.

The sharp contacts between the ovoids and the matrix imply little or no interchange of material between the matrix and the ovoids has occurred. The fracturing of the ovoids, the polysynthetic twinning of plagioclase in the ovoids (probably due to external pressures), the generally steep plunge of many of the ovoids, and their high calcium content all indicate that the ovoid plagioclase crystallized early, and that the behaviour of the plagioclase was thereafter governed by movement of the surrounding magma. The absence of alignment of the plagioclase crystals within the ovoids indicates that their accumulation into tightly packed clusters took place under quiescent conditions, before intrusion of the crystal-mush. Ferromagnesian minerals that may have crystallized contemporaneously may have separated out of the magma by sinking. The uniform size and weakly developed zoning of the ovoids can be attributed to growth in a liquid of the same density as the crystals, thereby allowing the plagioclase crystals to remain suspended and in complete contact with the surrounding liquid. Moreover, the uniformity in size and in composition of the plagioclase aggregates discounts any notion that they actually represent a top accumulation of the lighter fraction, similar to the anorthositic porphyritic sills in northeastern Minnesota described by Phinney (1969) that was subsequently tectonically broken up. If this had happened, then it would be expected that the fracturing would produce blocks of all sizes which is not the case.

At some time after the development of the ovoids, the magma began to flow. The clusters were caught up in the magma like inclusions and were rounded by abrasion. They were more competent than the surrounding magma, and were fractured on impact with their neighbours. The suspended crystals and/or crystal aggregates tended to migrate towards, and be concentrated in, the inner portion of the flow, leaving the liquid magma at the margins. This flow differentiation mechanism was shown by Bhattacharjii (1967) to be experimentally reproducible. Bridgewater and Harry (1968) also called on this process to explain the presence of anorthositic xenoliths in the central portions of Precambrian intrusions in South Greenland.

After the sill was emplaced, crystallization of the remaining magma proceeded rapidly, and formed the medium-grained gabbroic matrix. Deuteric solutions were deposited in fractures in the ovoids and may have been partly responsible for the alteration of the ovoid plagioclase. However, the possibility that the alteration of the ovoid plagioclase was caused by regional metamorphism must not be overlooked.

In summary, the probable sequence of intrusions from a single mafic magma in the Bird River-Bernic Lake area was as follows: Intrusion of the Bird River Sill and subsequent differentiation of this sill into the layered sequence given in Table I. This was followed closely in time and space by the consecutive intrusions of (i) the ovoid anorthositic gabbro into the Bird River Sill,(ii) the ovoid anorthositic gabbro into the metavolcanics at Bernic Lake (which presumably drained the magma chamber of plagioclase ovoids) and, (iii) the "Cup" gabbro. These last three intrusions probably occurred almost contemporaneously, but in the order stated.

APPENDIX I

TABLE 3: Structural Data on the Orientation of the Ovoids at Bernic Lake

	Apparent Plunge		Attitude of Exposed Surface	
Number	Strike (degrees Azimith)	Dip* (degrees)	Strike (degrees)	Dip** (degrees)
A outcrop				
1	268	13	219	19
2	263	16	219	19
3	82	15	295	17
4	107	11	325	18
5	282	84	204	84
6	292	4	271	13
7	65	7	294	12
8	79	12	314	12
9	118	16	27	15
10	237	54	100	69
11	130	49	84	60
12	103	24	76	46
B outcrop				
1	275	18	250	22
2	272	70	170	70
3	345	71	260	71
4	90	4	135	8
5	70	32	135	35
6	295	61	295	90
7	85	90	285	85
8	10	67	10	90

	Apparent Plunge		Attitude of Exposed Surface	
Number	Strike (degrees Azimith)	Dip* (degrees)	Strike (degrees)	Dip** (degrees)
C outcrop				
1	233	4	192	8
2	245	13	194	17
3	77	3	10	10
D outcrop				
4	71	17	331	18
5	260	16	101	30
6	43	55	22	75

* dip in same direction as strike azimith.
** dip to the right of the strike azimith.

APPENDIX 2a

Description of the Fusion Method and the Cleavage Method used in Determining the Composition of the Plagioclase

The accompanying table of this appendix gives the composition of the plagioclase determined by fusion and by cleavage flakes. Essentially, the fusion method involved quenching of the plagioclase to obtain a glass. Chip samples of the ovoids, obtained in the field, were ground and crushed to approximately 200 mesh. The crushed material obtained was divided such that half went to the fusion method and the remaining half was reserved for the cleavage flake method.

The material for fusion was placed at the tip of a carbon electrode spaced about 1/8 inch away from a second electrode. The material was fused by passing a strong electric current through the electrodes. Care was taken in keeping the time of fusion (approximately 10-12 seconds) constant. Upon cooling under room temperatures, the glass was crushed and placed under immersion oils of known refractive index until a match was obtained. Approximately seven glasses for each sample were checked. It was not necessary to average any of the seven results as all correlated well. The refractive indices of the set of standards were measured just prior to use and calibrated to 0.002. The anorthite content was obtained from the correlation graph by Deer, Howie and Zussman (1963). The accuracy obtained is believed to be within ± 0.002.

The composition of the remaining portions of the divided samples of APPENDIX 2a were obtained using the revised cleavage flake curves after Morse (1968). The curves are based on low plagioclase and this requirement was verified using the diagrams and X-ray powder method described by Bambauer (1967). The few samples X-rayed were found to be low or in the intermediate range although the results are in the higher An composition range which is somewhat ill-defined.

Cleavage flakes were placed under the same set of oils as described previously until a match was obtained. Grains were sought which showed sharp cleavage edges and uniform birefringence with as little alteration as possible. Next, the grains were turned from extinction to the maximum birefringence to determine the gamma and alpha vibration directions. In each case only the lower refractive index was measured. Both the lower refractive index curves of Morse measured from the 010 and the 001 cleavages do not differ appreciably and it was considered sufficient to not bother distinguishing between the two types in thin section examination. Generally 5 to 7 different chips were crushed, mounted in various oils and measured for each sample. In most cases, the correlation between the chips was good and, therefore, representative of the whole sample. As many grains as possible were observed and checked in each crushing. A match was obtained when the criteria given by Bloss (1961) was met and the accuracy of measurement is believed to be within ± 0.002 R.I.

With reference to the ovoid numbers in the following table:

i) The sample numbers are taken on traverses across the ovoids from one edge to the opposite edge.

ii) Ovoid numbers come from "A" outcrop with numbers 3, 4, 5, taken in a south to north line across the sill. The remaining 4 were taken along strike.

iii) Ovoid numbers 12, 13, 14 are taken across strike of the sill exposed on "D" outcrop. Ovoid numbers 15 and 16 are from "B" outcrop.

iv) Ovoid #10 is from "A" outcrop and number 11 is from "D" outcrop south of number 12.

TABLE 4: Plagioclase Composition in the Bernic Lake Sill

Ovoid Number	Sample Number		Anorthite Per cent (by fusion)	Anorthite Per cent (by cleavage flakes)
3	1		85	79
	2		84	79
	3		85	80
4	1		88	77
	2		85	79
	3		84	79
	4		81	77
5	1		73	77
	2		77	77
	3		77	79
	4		75	81
6	1		85	81
	2		90	79
	3		85	79
	4		85	79
7	1		78	79
	2		82	77
	3		78	77
8	1		90	79
	2		90	77
	3		87	79
	4		87	79
9	1		92	83
	2		87	79
	3		85	79
	4		88	79
12	1		93	80
	2		70	78
	3		72	78
	4		76	77
13	1	Rim	87	79
	2	Core	85	83
14	1		85	79
	2		97	79
	3		85	79
	4		95	79
15	1		90	81
	2		90	83
	3		94	?
16	1		87	81
	2		85	81
	3		87	81

APPENDIX 2b

TABLE 5: Plagioclase Composition using the Universal Stage

Thin Section	Core of Ovoid	Rim of Ovoid	Matrix
I-3	91 or 79		86 (core) - 54 (rim)
I-3	94		80
Chrome	80		
Page	90 or 74		80
Page	79		
B-2	75		85 (core) - 60 (rim)
B-2			85 (core) - 58 (rim)
AB-6	79		
AB-6	no value due to deformation		
Bl-A	92	90	90
Bl-A			87.5
I-2	90	88	84 (core) - 51 (rim)
I-2	93		84 (core) - 52.5 (rim)

Key to Thin Sections of APPENDIX 2b

12, 13, and AB-6 are from "A" outcrop at Bernic Lake.

B2, Bi-A are from "B" outcrop at Bernic Lake.

Note: The above compositions were determined by Mr. J.J. Macek of the Manitoba Mines Branch.

List of References

Bambauer, H.U., Corlett, M., Eberhard, E., and Viswanathan, K.
1967: Diagrams for the Determination of Plagioclase using X-ray Powder Methods, Schweiz, Mineralogishe and Petrographische Mitteilungen, V. 47/1, p. 333-349.

Baragar, W.R.A.
1960: Petrology of Basaltic Rocks in Part of the Labrador Trough, G.S.A. Bull., V. 71, pp. 1590-1644.

1967: Wakuach Lake Map-Area, Quebec-Labrador, Geol. Surv. Canada, Mem. 344.

Barth, T.F.W.
1969: Feldspars, Wiley-Interscience, Toronto.

Bhattacharjii, S.
1967: Mechanics of Flow Differentiation in Ultramafic and Mafic Sills, J. Geol., V. 25, pp. 101-112.

Bloss, F. Donald
1961: An Introduction to the Methods of Optical Crystallography, Holt, Rinehart and Winston, New York.

Bridgewater, D., and W.T. Harry
1968: Anorthosite Xenoliths and Plagioclase Megacrystals in Precambrian Intrusions of South Greenland, Meddr. Grønland, Bd. 185, No. 2.

Butrenchuk, S.B.
1970: Metamorphic Petrology of the Bird Lake Area, Southeastern Manitoba, M.Sc. Thesis, University of Manitoba.

Davies, J.F.
1952: Geology of the Oiseau (Bird) River Area, Lac du Bonnet Mining Division, Manitoba Mines Br. pub. 51-3.

1955: Geology and Mineral Deposits of the Bird Lake Area, Manitoba Mines Br. pub. 54-1.

Davies, J.F., Bannatyne, B.B., Barry, G.S. and H.R. McCabe
1962: Geology and Mineral Resources of Manitoba, Manitoba Dept. Nat. Resources, Manitoba Mines Br.

Deer, W.A., Howie, R.A. and J. Zussman
1963: Rock-Forming Minerals, Volume 4; Longmans, London.

Fahrig, W.F.
1955: Lac Herodier, New Quebec, Geol. Surv. Canada, Paper 51-23.

Foster, W.R.
1955: Simple Method for the Determination of the Plagioclase Feldspars, Amer. Min., V. 40, No. 3 and 4, pp. 179-185.

Frarey, M.J.
1952: Willbob Lake, Quebec and Newfoundland, Geol. Surv. Canada, Paper 52-16.

Heimlich, R.A. and G.K. Manzer
1973: Flow Differentiation within Leopard Rock Dikes, Bighorn Mountains, Wyoming; Earth and Planetary Science Letters. V. 17, pp. 350-356.

Hudec, P.P.
1964: Big Trout Lake Area; Ontario Dept. of Mines Geol. Report No. 23.

Karup-Møller, S., and J.J. Brummer
1971: Geology and Sulfide Deposits of the Bird River Claim Group, Southeastern Manitoba, in Turnock A.C. (ed.), Geol. Assoc. Canada Special Paper 9, pp. 143-154.

MacRitchie, W.D.
1971: The Petrology and Environment of the Acidic Plutonic Rocks of the Wannipigow-Winnipeg Rivers Regions, S.E. Manitoba, in Geology and Geophysics of the Rice Lake Region, S.E. Manitoba, Manitoba Mines Br. Pub. 71-1.

Morse, S.A.
1968: Revised Dispersion Method for Low Plagioclase, Amer. Min. V. 53, pp. 105-115.

Osborne, T.C.
1949: Petrography and Petrogenesis of the Bird River Chromite Bearing Sill, M.Sc. Thesis, Univ. of Manitoba.

Poldervaart, A.
1950: Correlation of Physical Properties and Chemical Composition in the Plagioclase, Olivine, and Orthopyroxene Series, Amer. Min., V. 35, pp. 1067-1079.

Prinz, M.
1964: Geological Evolution of the Beartooth Mountains, Montana and Wyoming. Part 5. Mafic Dike Swarms of the Southern Beartooth Mountains, Geol. Soc. America Bull., V. 75, pp. 1217-1248.

Rousell, D.H.
1965: Geology of the Cross Lake Area; Manitoba Mines Br. Pub. 62-4.

Springer, G.D.
1949: Geology of the Cat Lake - Winnipeg River Area, Manitoba Mines Br. Prelim. Rep. 48-7.

1950: Mineral Deposits of the Cat Lake - Winnipeg River Area; Manitoba Mines Br. Pub. 49-7.

Spry, A.
1969: Metamorphic Textures, Pergamon Press, Toronto.

Trueman, D.L.
1970: Geology of the Chrome and Page Properties: Bird River Sill, Manitoba Mines Br. Prelim. Map Ser. 1970-A-1.

1971: Petrological, Structural and Magnetic Studies of a Layered Basic Intrusion, Bird River Sill, Manitoba, Unpub. M.Sc. Thesis, Univ. of Manitoba.

Trueman, D.L., and J.J. Macek
1971: Geology of the Bird River Sill; Manitoba Mines Br. Prelim. Map Ser. 1971-A-1.

Vance, J.A.
1961: Polysynthetic Twinning in Plagioclase, Amer. Min. V. 46, #9 and 10, pp. 1097-1119.