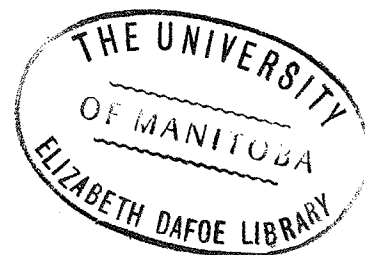


PETROLOGICAL, STRUCTURAL AND MAGNETIC
STUDIES OF A LAYERED BASIC INTRUSION,
BIRD RIVER SILL, MANITOBA

A Thesis
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ABSTRACT

The Bird River Sill, situated in southeastern Manitoba is a layered ultramafic to basic intrusive. In this sill 45 layers consisting of serpentized peridotite interlayered with chromite bearing layers, pyroxenite, gabbro, anorthositic gabbro, anorthosite, hornblende gabbro, and porphyritic gabbro form a thickness of approximately 2,000 feet.

Primary structures in the chromite bearing layers and in the gabbros are evidence of thermal or density currents in the magma during crystallization and cryptic variation of anorthite percent in the plagioclase shows an inverted trend indicating crystallization downwards from the roof as well as accumulation on the floor of the magma chamber.

Complex faulting across and parallel in strike to the layering of the Sill has resulted in apparent change in thickness of, and omission of rock units in the Bird River Sill.

Magnetic susceptibility study and a vertical field magnetic survey indicates a lack of magnetite in the gabbroic rocks. The consequent magnetic signature can thus be utilized with a knowledge of the geology to prospect for non-magnetic chromite in the Bird River Sill.

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Accompanying geologic map enclosed in back cover.

INTRODUCTION

Location, Access, and Topography

The portion of the Bird River Sill studied is situated in the Superior Province of the Precambrian Shield of southeastern Manitoba, approximately 35 miles east of Lac du Bonnet. The Bird River Sill outcrops extensively in this area, marginal to, and north of Peterson Creek.

Two "all weather" roads, (Provincial Trunk Highways, 314 and 315), linking Lac du Bonnet, Bird Lake, and Cat Lake, provide access to within 1/4 mile of the study area. Winter trails bridge Peterson Creek and join with these roads 1.5 miles southwest of, and 1.4 miles northeast of the junction of P.T.H. 314 and P.T.H. 315. Within the map area winter logging trails provide good access to all points, and afford a measure of location control.

The topography is typical of most of the Precambrian Shield and consists of high rock outcrop, surrounded by low, wet, or tree covered ground, Relief is moderate and seldom exceeds 50 feet.

Drainage in the area is by way of Peterson Creek west into the Winnipeg River system. Peterson Creek is not navigable.

Glacial deposits observed consist of boulder till, minor gravels, and varved clays. Glacial striae, chatter marks, and plucking features indicate movement of the Patrician ice sheet as having been from North 40° East.

Previous Work and Economic Development

The first systematic exploration in the Bird River area was conducted by J.B. Tyrell in 1898. In 1912 E.S. Moore correlated the rocks of this area with those of the Rice Lake district to the north.

The discovery of copper-nickel sulphide deposits near Maskwa in 1917 prompted study of the Bird River Sill by Colony (1920,-21), McCann (1921), and Cooke (1922). In 1942 the discovery of chromite in the Sill resulted in extensive investigation by Bateman (1942,-43,-45) and Brownell (1942). Later, regional mapping was conducted by Springer (1948,-49,-50), and Davies (1952,-55). Selected aspects of the Bird River Sill have been studied by Osborne (1949), and Gait (1964).

In previous literature the portions of the Bird River Sill studied are known as the Chrome and Page Properties, (see also Fig. 1, page 7). This nomenclature is retained below, and the following excerpt from Davies et al (1962) is a concise summary of the development of the chromite deposits in this area.

"Parts of the main chrome band have been drilled to a depth of 650 feet and indicated reserves of 874,000 tons grading 25.2 percent Cr_2O_3 on the Page Property, and 1,220,000 tons grading 18.2 percent on the Chrome Property. The actual reserves are probably many times these figures, for only parts of each property have been drilled and the chromite bands are generally persistent."

The iron content of the chromite in these deposits precludes further development and recovery of the chromite without extensive beneficiation processes.

Adjacent to, and east of the study area, copper-nickel sulphides are being explored by Bird River Mines Ltd., and copper-nickel mining operations are being conducted by Dumbarton Mines Ltd. Although interest in the Bird River Sill was first generated by the discovery of sulphide occurrences in the Sill, their relationship to the Sill is not known with any certainty, (Karup-Moller, 1971).

Present Work and Acknowledgements

The ensuing study was undertaken under the auspices of the Ultramafic Project of the Manitoba Mines Branch, and the Department of Earth Sciences, University of Manitoba. The particular study area was chosen for the extensive exposure of the Bird River Sill.

Field work was conducted during the summer and fall of 1970, utilizing pace and compass methods supplemented by vertical aerial photographs, the centres of which are indicated on the accompanying geologic map. Mapping was conducted on a scale of 1 inch = 1/4 mile; the accompanying geologic map being of the same scale. Detail mapping and geophysical work utilized air photo enlargements (1 inch = 330 feet).

The writer would like to acknowledge the assistance of C.D. Anderson and A.C. Turnock of the University of Manitoba.

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GENERAL GEOLOGY

Introductory Statement

The ensuing discussion of the rocks adjacent to the Bird River Sill is not intensive. The stratigraphy of these rocks however, provides a necessary key to the structural interpretation of the area.

All of the consolidated rocks of the study area are of Precambrian age. These rocks are subdivided into two groups; the Rice Lake Group, and the Intrusive rocks (Table 1).

The Rice Lake Group, the oldest group in the area, consists of a conformable or paraconformable assemblage of metavolcanic and metasedimentary rocks. Metagabbro sills, the Bird River Sill, and a large quartz diorite - granodiorite body, (Great Falls Pluton, McRitchie, 1971) are intrusive into the Rice Lake Group.

In the study area these rocks are represented in complexly faulted segments of the south limb of an easterly plunging anticline (Figure 1).

RICE LAKE GROUP

In the study area the rocks of the Rice Lake Group consist of a metamorphosed assemblage of pillowed and flow volcanics, tuffs, fine to medium grained clastic sediments, and conglomerate. These rocks flank the Bird River Sill; the metavolcanic assemblage lying north of, or "below" the Sill, and the metasedimentary

TABLE OF FORMATIONS

RECENT and PLEISTOCENE			Boulder till, sand, gravel, clay	
UNCONFORMITY				
P R E C A H M B R A I N A N	A	I N T R O D U C T I O N A L	Quartz diorite - granodiorite	
			INTRUSIVE CONTACT	
			B	Porphyritic gabbro
			I R	Hornblende gabbro
			R I	Anorthositic gabbro, anorthosite, gabbro
			D V S	Pyroxenite
			E I	Serpentinized peridotite with interlayered chromitite
			R L	and chromiferous peridotite
			L	Marginal gabbro
			INTRUSIVE CONTACT	
			Metagabbro	
			INTRUSIVE CONTACT	
			RICE LAKE GROUP	Greywacke, crystal tuff, polymict conglomerate; derived schists Basalt, porphyritic andesite; derived schists

TABLE 1

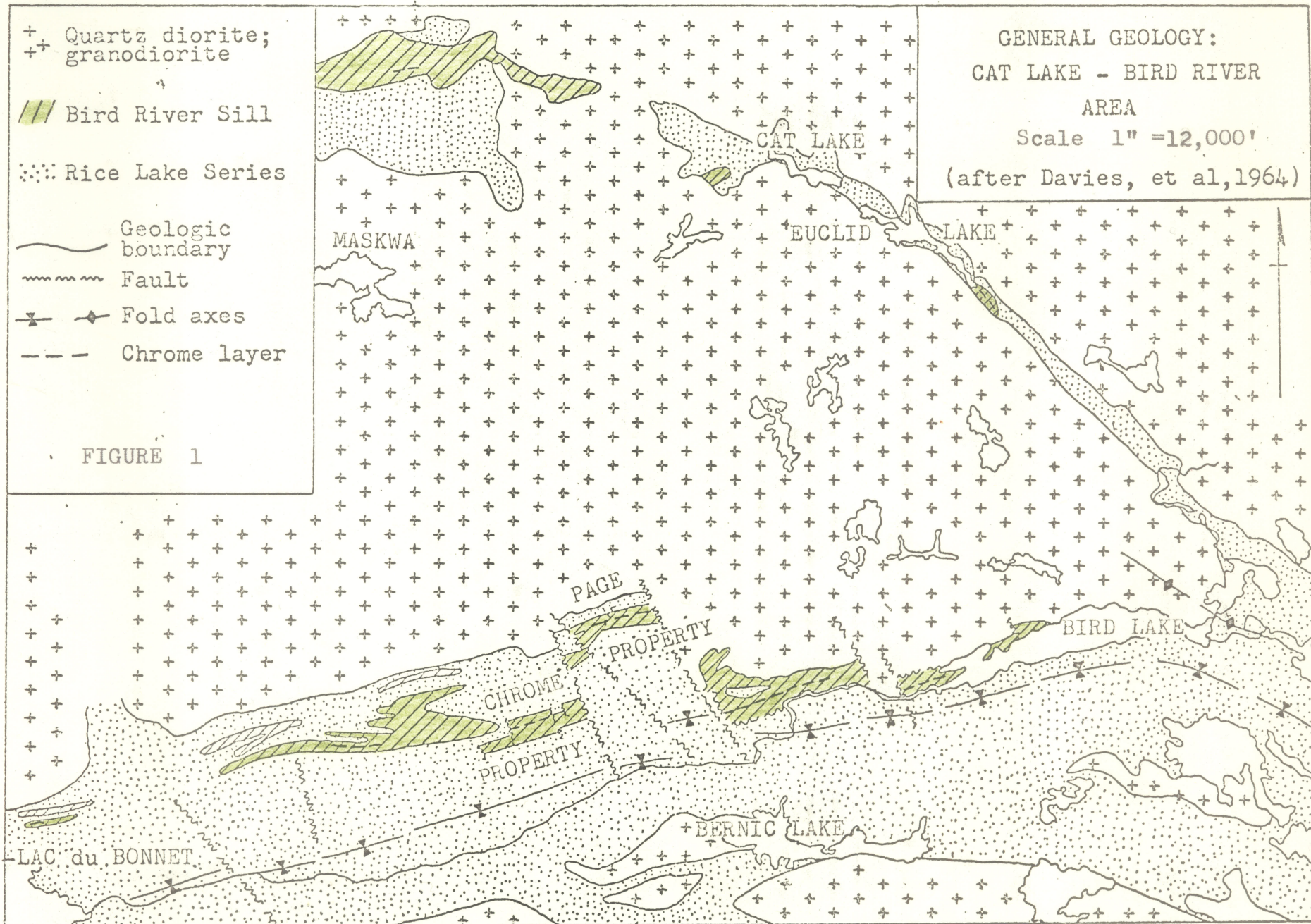


FIGURE 1

assemblage lying south of, or "above" the Sill, Variation of this relationship is the result of faulting.

Dip attitudes in the Rice Lake Group are steep to vertical; strikes are east to northeasterly. Relict volcanic pillows and cross bedding in the metasediments have south - facing tops in the area of the Chrome and Page Properties.

Basalt, porphyritic andesite; derived schists (Map unit 1)

Metamorphosed pillow lavas (1a) are the dominant volcanic rocks. These rocks are dark grey to black weathering, fine to medium grained, and massive to weakly schistose. Pillow structures and relict selvaged edges are well preserved. East of the Page Property, these rocks are characterized by greenish grey weathering, a fine grained texture, moderate schistosity, a siliceous appearance, and garnet metacrysts. Pillow structures in the garnetiferous rock are generally elongate, and often have been completely obliterated by the foliation development.

Both the garnetiferous and the pillowed metavolcanics are seen to consist of nearly equal distributions of hornblende and plagioclase. Accessory and secondary minerals comprise fibrous amphibole, magnetite, chlorite, albite, epidote - clinozoisite, carbonate, quartz, sulphides, and east of the Page Property, garnet.

Porphyritic andesite forms a narrow metamorphosed flow interlayered with the pillowed lavas. This rock is light green to grey weathering, has a fine grained groundmass, is massive, and is characterized by 10 to 15 percent of large (up to 3/8 inch) plagioclase phenocrysts. At one location stretched vesicles are preserved.

In thin section the margins of the plagioclase phenocrysts are corroded, and the plagioclase is saussuritized. The groundmass consists of hornblende and plagioclase (albitized) with minor magnetite, quartz, epidote, carbonate, chlorite, and pyrite.

Greywacke, crystal tuff, polymict conglomerate; derived schists (Map unit 2)

Metamorphosed greywackes outcrop extensively south of the Bird River Sill, and form the major portion of the metasedimentary succession. These rocks are greyish to black weathering, fine to coarse grained, and massive to strongly schistose; lepidoblastic schistosity being imparted by the development of micaceous minerals. Bedding is generally poorly defined and individual beds seldom are in excess of several inches in thickness. Cross bedding structures are not common, and other primary structures were not observed.

The metagreywacke consists of quartz, combined feldspars, hornblende and/or biotite. Sericite, chlorite, magnetite, carbonate, and sulphides are minor constit-

uents.

Locally, large (up to 2 inch) rounded quartzofeldspathic clasts give rise to conglomeratic phases in the metagreywacke. These clasts may comprise up to 40 percent of the rock and are often rodded in the foliation plane.

South of the Chrome Property several narrow (2-3 inch) chert beds are interlayered with the metagreywacke. The chert is light grey to cream in colour, aphanitic, and massive. These beds are generally fragmented or brecciated and associated with pyrrhotite mineralization in and near fold structures.

Metamorphosed crystal tuff outcrops near P.T.H. 315 south of the Chrome Property. This rock is greyish weathering, massive to schistose, and displays large euhedral plagioclase crystals interspersed throughout a fine to medium grained matrix. Random orientation of the plagioclase crystals, and a poorly defined bedding in the unit suggest a rapid waterlain origin, which is substantiated by the presence of large rounded granitic clasts.

The crystal tuff consists of up to 45 percent plagioclase crystals set in a matrix of fibrous amphibole, plagioclase, biotite, sericite, zoisite, quartz, and carbonate. Secondary quartz, and carbonate are present as numerous irregular small blebs and stringers injected concordantly into the bedding.

Metamorphosed polymict conglomerate outcrops

east of, and is in fault contact with the central faulted block of the Bird River Sill. This conglomerate is dark weathering, moderately schistose, and characterized by large, rounded, medium to coarse grained amphibolite clasts, as well as smaller granitic clasts. These clasts are rodded vertically in the foliation plane.

Cobble sized amphibolite clasts comprise up to 30 percent of the rock, whereas the granitic clasts, of pebble size and saccharoidal appearance, seldom exceed 10 percent. The argillaceous appearing groundmass consists chiefly of amphibole, biotite, and feldspars, with minor amounts of quartz, sericite and carbonate.

INTRUSIVE ROCKS

The discussion of the intrusive rocks is limited in the following section to the gabbro, present as small sills in the metavolcanic rocks, and to the quartz diorite-granodiorite within the map area.

Metagabbro (Map unit 3)

Metamorphosed gabbro is present as faulted segments of a narrow sill which lies to the north of, and in close proximity to the base of the Bird River Sill. As this gabbro was only observed in the metavolcanic rocks, its positioning in Table 1 is therefore arbitrary.

The metagabbro forming this sill is generally dark grey to black weathering, medium to coarse grained, and

massive. Contacts with the metavolcanic rocks are poorly defined, being gradational over several feet.

Plagioclase and amphibole are the dominant minerals of the gabbro; the amphibole content forming from 60 to 75 percent of the rock. In thin section the plagioclase forms subhedral corroded and extensively saussuritized equant grains, which are partly encroached on by fibrous amphibole. Zoisite, carbonate, magnetite, chlorite, quartz, and traces of sulphide are common throughout.

Quartz diorite - granodiorite (Map unit 9)

Quartz diorite and granodiorite form the major part of the Great Falls Pluton (McRitchie, 1971) which is intruded into the metavolcanic rocks north of the Bird River Sill. The body is heterogeneous in nature and shows little or no systematic variation in the distribution of the quartz diorite and granodiorite phases.

The quartz diorite - granodiorite is greyish to pink weathering, coarse to very coarse grained, and massive to weakly gneissic. Quartz diorite phases are typified by small blebs of bluish quartz which display an augen shape where the rock is foliated. Hornblende, biotite, and plagioclase form up to 90 percent of the rock. Quartz and magnetite are accessory, and sericite, chlorite and epidote are common alteration products.

Intrusive contacts between the Great Falls Pluton

and the metavolcanic rocks are exposed along a pronounced air photo lineament north and west of the Page Property. Here the contact is marked by minor wall rock brecciation, quartz-carbonate stringers, and large angular stoped blocks of the metavolcanic rock. East of the Page Property, near Peterson Creek, the Great Falls Pluton lies in fault contact with the Bird River Sill and the garnetiferous metavolcanic rocks of Map unit lb.

THE BIRD RIVER SILL

The Bird River Sill is a layered body formed through gravity segregation of crystals during cooling; the resulting rock types of which range from ultramafic to intermediate in composition. The intrusion and crystallization of the magma, based on structural and lithologic relationships, occurred while the Rice Lake Group of rocks was essentially horizontal.

Seven rock units, forming 45 layers, were identified in the Bird River Sill. In addition, a previous study by Osborne (1949) indicates the presence of a marginal gabbro facies.

The rock units (Fig. 2) are described in order of crystallization.

Marginal Gabbro

A marginal gabbroic facies, termed olivine pyroxene gabbro by Osborne (1949) was observed by Osborne in core from a diamond drill hole which intersected the basal contact of the Bird River Sill and the metavolcanic rocks. This gabbro, which is not exposed in the study area, is described by Osborne as exceeding 30 feet in thickness and consisting of;

"...medium grained basic plagioclase, extensively altered to rectangular patches of clinozoisite....the only primary

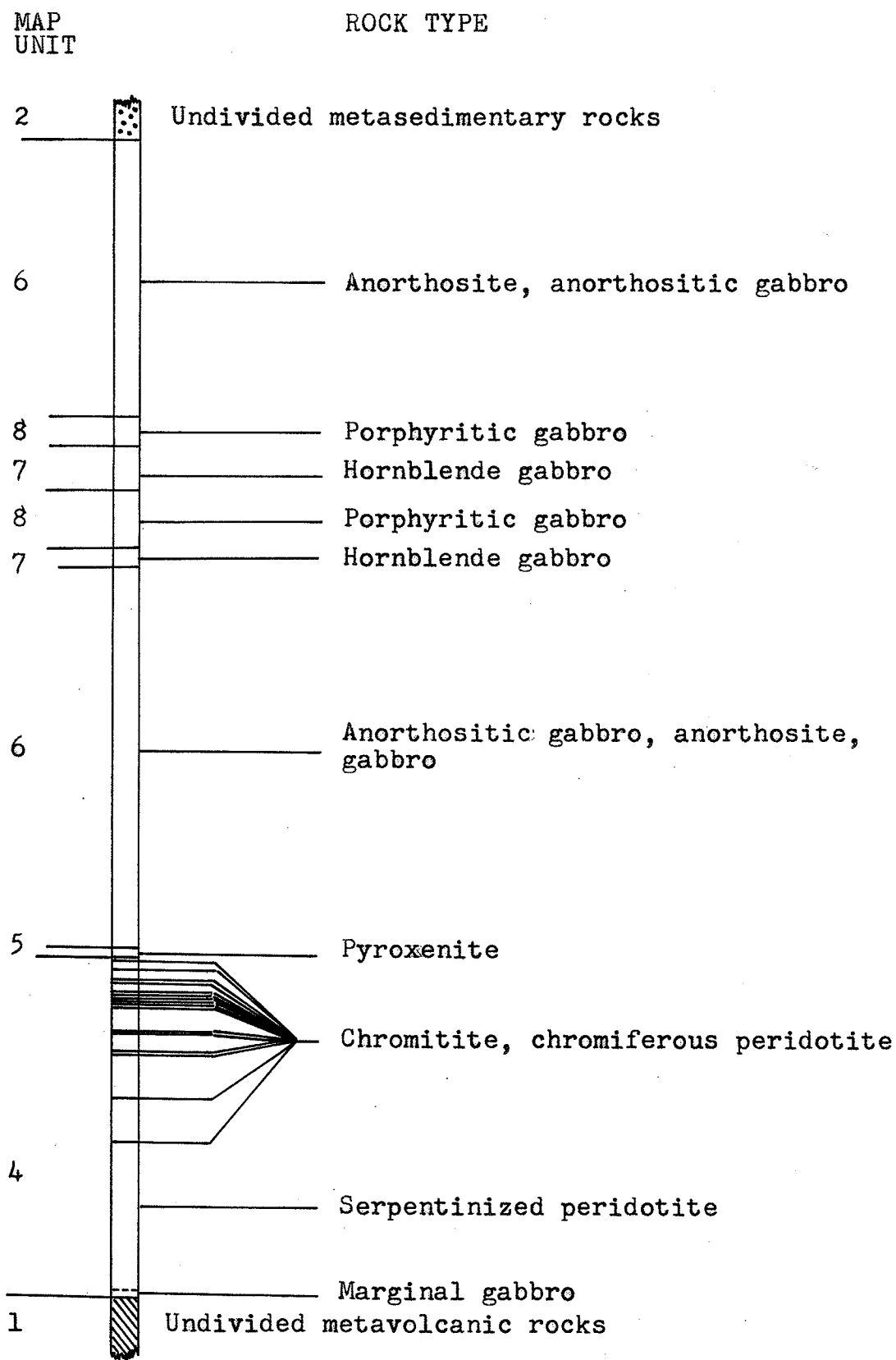


FIGURE 2: Stratigraphy of the Bird River Sill

mineral seen in the gabbro. Parts of the rock consist merely of clino-zoisite - plagioclase patches in a matrix of fine tremolite needles and mesh-like prochlorite. In many places however, tremolite occurs as large platy crystals, one tremolite crystal commonly enclosing a number of clinozoisite - plagioclase patches. Part of the tremolite in these large crystals is crowded with dusty specks, and part is clear. The clear areas are uniform in size, rounded, and have sharp boundaries with the dusty tremolite. Some of them have prochlorite cores. With crossed nicols, the clear areas are just as sharply outlined, as they have higher interference colours than the dusty tremolite. The clear areas are interpreted as representing original olivine, and the dusty tremolite as representing original pyroxene."

The features described above are similar with features of the gabbroic rocks higher up in the layered series:

Serpentinized peridotite (Map unit 4)

Serpentinized peridotite, interlayered with chromiferous peridotite, forms 19 distinct layers and comprises the basal portion of the Bird River Sill which is approximately 600 feet in thickness.

The serpentinized peridotite near the base of the Sill is typically brown to rusty weathering, massive, and coarse grained. Large (1/4 inch) tremolite metacrysts,

pseudomorphous after pyroxene, stand out in relief on the weathered surfaces. These metacrysts constitute up to 30 percent of the rock and poikilitically enclose granular magnetite and/or chromite. Chromite is also present as fine disseminations and imparts a patchwork appearance to several of the layers (Plate 1).

Cumulate textures are well preserved in the upper portion of the serpentized peridotite. This upper portion is characterized by light apple green weathering, is massive, and coarse grained. Serpentine pseudomorphous after olivine forms large ($1/8$ inch) ovoids that constitute up to 60 percent of the rock (Plate 2). These ovoids, with euhedral to anhedral fine to medium grained chromite, are poikilitically enclosed in a greyish matrix of tremolite and pale green chlorite.

Two narrow layers in the serpentized peridotite are comprised of coarser (up to $1/4$ inch) serpentine ovoids, a feature which is also common adjacent to chromiferous layers (Plate 3).

In thin section the serpentized peridotite displays intensive and varied alteration. Pyroxene near the base of the Sill is extensively altered to tremolite, which in some cases encroaches on the serpentine ovoids, and in other cases sharply terminates against these ovoids. Chromite is not abundant, and magnetite is generally present as fine dusty grains in relict diallage parting of the pyroxenes, or as selvages marginal to the serpentine



PLATE 1: Chromite disseminations and patches in serpentized peridotite.

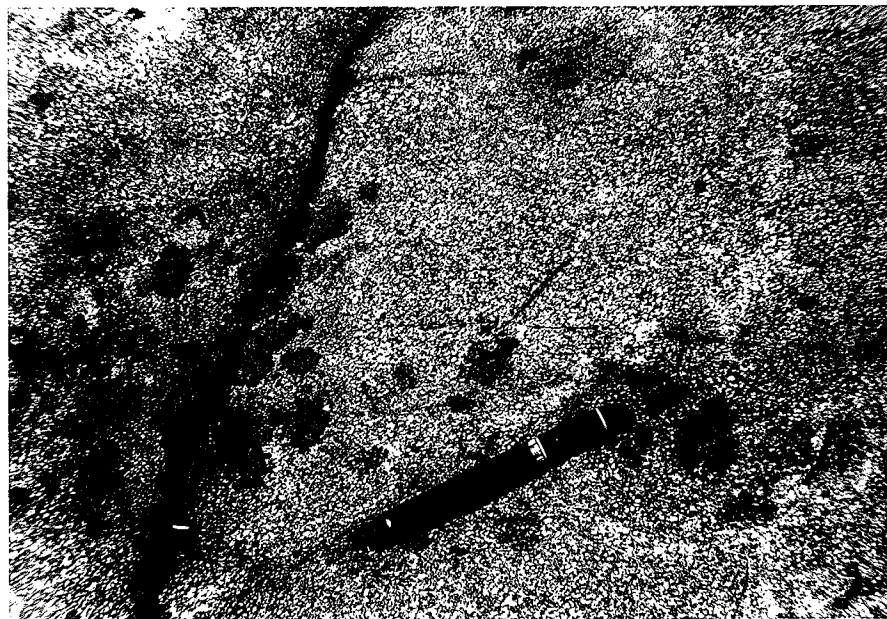


PLATE 2: Serpentine pseudomorphs after olivine in serpentized peridotite.



PLATE 3: Coarse serpentine ovoids at base
of chromite layer.

pseudomorphs. Serpentine group minerals consist chiefly of antigorite and chrysotile.

In the upper portion of the serpentized peridotite the alteration is less extreme. Relict pyroxene with prominent diallage parting marked by dusty magnetite, poikilitically encloses the serpentine ovoids after olivine. Tremolite alteration however is common and the tremolite is formed at the expense of the pyroxene. Antigorite has completely replaced the olivine, forming the serpentine ovoids, and is in turn cut by vein and mesh chrysotile associated with magnetite. Minor penninite is often present as small irregular patches marginal to the serpentine ovoids. Disseminated chromite, fine to medium grained and subhedral, is prominent, poikilitically enclosed in both the relict pyroxene and tremolite. Small serpentine nuclei are common in the centres of many of the chromite grains.

Chromiferous peridotite, chromitite

Chromiferous peridotite and chromitite form 18 well defined, persistent layers within the serpentized peridotite (Map unit 4). Chromitite layers, comprised almost wholly of chromite, are generally of the order of 1 inch in thickness, with exceptional variation being of the order of 1.5 feet thick. Chromitite layers closely interlayered with serpentized peridotite give rise to zones of chromiferous peridotite (Plate 4).



PLATE 4a: Massive chromite (chromitite) interlayered with serpentinized peridotite.



PLATE 4b: Delicate interlayering of chromite and serpentinized peridotite forming chromiferous peridotite.

Primary structures are common in the chromiferous layers. These consist of interpenetration of chromite and serpentized peridotite (Plate 5) and disruption of chromite layers (Plate 6). Similar features in the Bushveld Complex have been described by Cameron (1959) as being the result of "periodic structural disturbance or movements in the magma." Indication of movement in the Bird River Sill magma is further substantiated by "scour and fill" structures in the chromitite (Plate 7).

In thin section the chromitite and chromiferous peridotite are seen to consist of chromite and an unidentified chlorite. Euhedral to subhedral chromite shows slight rounding of grain boundaries, irregular fractures, and some contain small nuclei of serpentine. The matrix consists of colourless to very pale green, weakly pleochroic chlorite which displays dark greyish interference colours. Bateman (1943, -45) has identified this chlorite as amesite.

Pyroxenite (Map unit 5)

Altered pyroxenite forms a narrow layer in contact with and stratigraphically above the serpentized peridotite. The upper and lower contacts of this layer were not observed, due to poor exposure; the position of this layer being characterized by a narrow topographic, possibly fault depression. Spatial relationships of ad-



PLATE 5: Interpenetration of chromitite and serpentinitized peridotite.



PLATE 6: Disrupted chromite in serpentinitized peridotite.

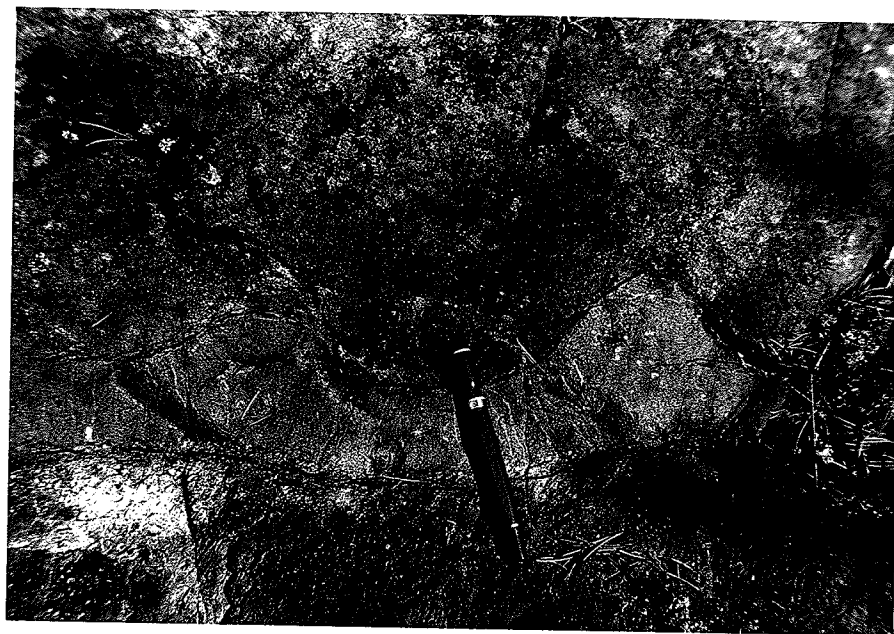


PLATE 7: Scour and fill channel in chromi-
tite layer.

jacent layers, above and below the pyroxenite, indicate that the layer is not in excess of 50 feet in the map area.

The pyroxenite is rusty weathering, coarse to very coarse grained, and massive to highly schistose. Massive pyroxenite displays a very coarse knotted appearance on weathered surfaces, a result of pseudomorphic replacement of the original pyroxene by tremolite (Plate 8).

In thin section the pyroxenite is seen to consist dominantly of tremolite which poikilitically encloses pseudomorphs after olivine and plagioclase. Plagioclase and minor chromite are the only primary minerals present.

Tremolite has pseudomorphically replaced both the original olivine, and almost all of the plagioclase. Despite continuity of the tremolite from the pyroxene through the olivine and plagioclase pseudomorphs, grains and grain boundaries of the pseudomorphs contrast markedly and the olivine and plagioclase are seen to have comprised about 10 percent of the original rock. Both the olivine and plagioclase were present as small subhedral to anhedral equant grains.

Dusty magnetite, carbonate, clinozoisite, and chlorite (penninite) are present in minor quantities, the magnetite being the most abundant. Chromite, present as subhedral to anhedral crystals is widely disseminated throughout the unit.



PLATE 8: Coarse knotted appearance of pyroxenite as a result of pseudomorphic replacement of pyroxene by tremolite.

Anorthositic gabbro, anorthosite, gabbro (Map unit 6)

Anorthositic gabbro, anorthosite, and gabbro form the major portion of the Bird River Sill, with an estimated thickness of 1,200 feet. The distribution of these rocks is shown in Figure 3. Contacts between layers within this unit are generally gradational and are placed where mineralogical or textural variation is significant; these layers being persistent throughout the map area.

Gabbro forms the basal portion of Map unit 6, and is approximately 80 feet in thickness. The gabbro is greyish green weathering, very coarse grained and massive.

Plagioclase (An 94) is present in equal distribution with interstitial actinolite which in thin section is noted to poikilitically enclose pseudomorphs after olivine. These pseudomorphs, similar to those in the marginal gabbro, are small anhedral equant grains of colorless to blue green pleochroic amphibole comprising about 5 percent of the rock. Plagioclase, twinned on Carlsbad, Albite, Carlsbad - Albite and Pericline laws, forms large (<1 inch) crystals, strongly zoned, strained and micro-faulted with some saussuritization. Actinolite is present as anhedral feathery and blade-like aggregates which in part cut the plagioclase. Chlorite, some penninite, saussurite and albite form minor alteration products, usually associated in deformational zones.

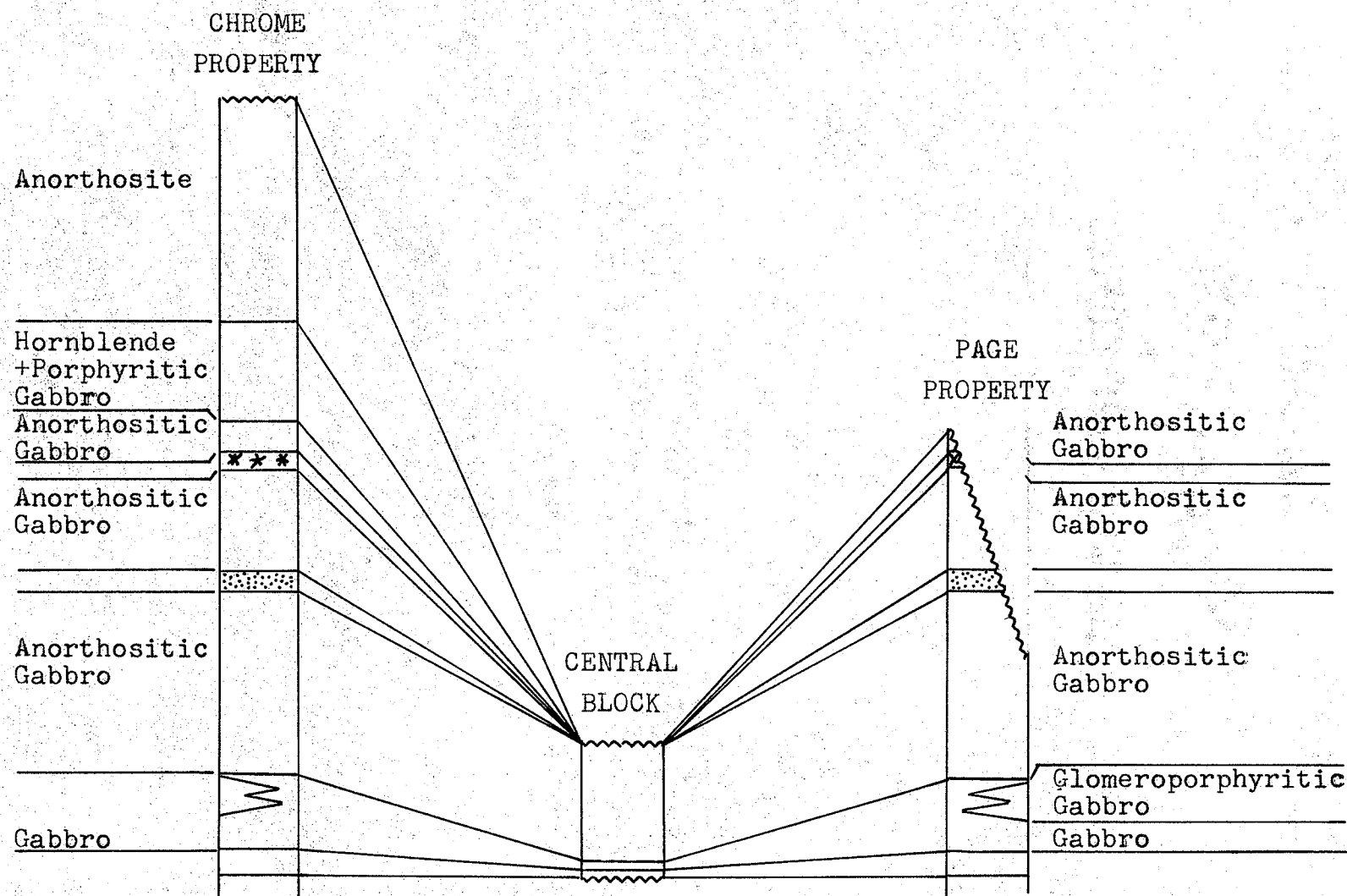


FIGURE 3: Schematic representation of the distribution of anorthositic gabbro, anorthosite, and gabbro (Map unit 6) in the Chrome and Page Properties of the Bird River Sill
LEGEND: fault ~~~~~, poikalitic gabbro :::::, synneussitic gabbro *

Anorthositic gabbro is the dominant rock type in Map unit 6, showing only textural variation. The anorthositic gabbro is greyish white weathering, very coarse grained, and massive. Plagioclase forms up to 90 percent of the rock which is typified by large blades of interstitial green actinolite (Plate 9). Two narrow layers (Fig. 3) are characterized by pronounced poikilitic and synneussitic textures imparted by the actinolite (Plate 10).

Plagioclase (An 94 - An 56) comprises up to 90 percent of the anorthositic gabbro, and in thin section is seen to be twinned on all laws, zoned, bent, broken, strained, and partly saussuritized. Fibrous and blade-like actinolite, blue green pleochroic, in part cuts, and is interstitial to the plagioclase. Chlorite, sericite, saussurite and albite are minor alteration products.

Anorthosite predominates in the upper part of Map unit 6 and in the extreme west of the map area lies in sheared contact with the metasedimentary rocks above the Sill. The anorthosite (> 90 percent plagioclase) is greyish to white weathering, very coarse grained, and massive. Minor interstitial bladed actinolite is of random occurrence.

In thin section the anorthosite is seen to consist almost solely of plagioclase (An 90 - An 56) which displays the same habit as that of the anorthositic gabbro. Actinolite forms shreddy aggregates interstitial to, and cut-



PLATE 9a: Interstitial actinolite in anorthositic gabbro.

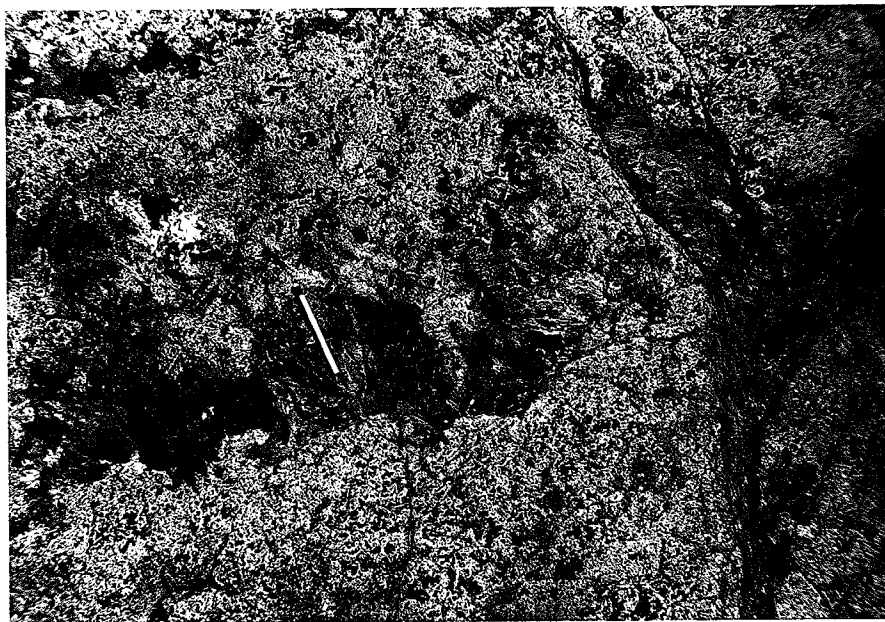


PLATE 9b: Coarse blades of interstitial actinolite in anorthositic gabbro.

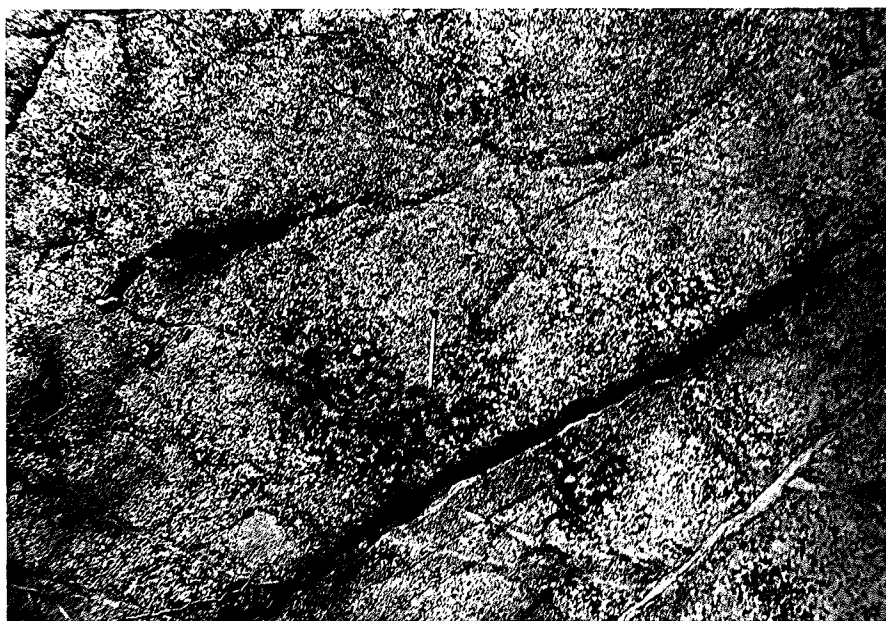


PLATE 10a: Poikilitic texture exhibited by actinolite in plagioclase of anorthositic gabbro.

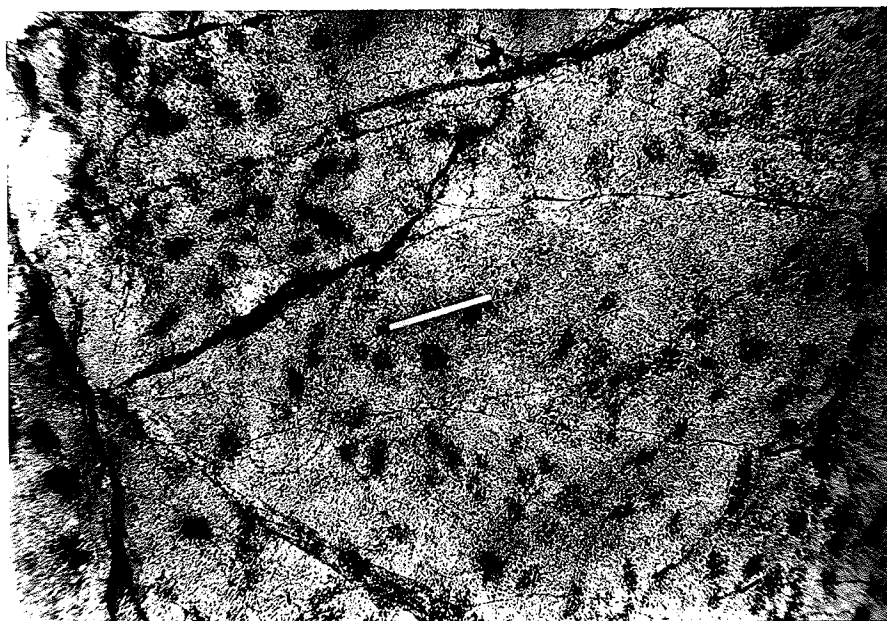


PLATE 10b: Synneussitic texture of actinolite in anorthositic gabbro.

ting the plagioclase. Biotite is present in small amounts near the top of the Sill, and saussurite, chlorite and albite are common throughout.

Glomeroporphyritic gabbro was observed on both the Chrome and Page Properties, where it forms narrow (50 feet) layers in the anorthositic gabbro. These layers are in gradational contact with the anorthositic gabbro and appear to wedge out along strike; their total exposure being less than 200 feet along strike.

The glomeroporphyritic gabbro is dark grey green weathering, very coarse grained and massive. On the Chrome Property large (1 - 6 inch) spheres and irregular aggregates of plagioclase are enclosed in a matrix of bladed actinolite. On the Page Property the rock is similar, excepting that coarse actinolite is in equal distribution with a finer grained gabbro in the matrix (Plate 11).

Minor sinistral faulting has resulted in a progressive off-setting of the glomeroporphyritic gabbro.

Hornblende gabbro (Map unit 7)

Hornblende gabbro forms two layers in the Bird River Sill, the lower of which lies in sharp contact with the anorthositic gabbro of Map unit 6 (Plate 12). This unit outcrops extensively on the Chrome Property only, and has a total thickness of approximately 150 feet.

The hornblende gabbro is dark grey to black



PLATE 11: Glomeroporphyritic gabbro on Page Property.



PLATE 12: Layered contact between hornblende gabbro and anorthositic gabbro.

weathering, coarse grained, massive, and is characterized by a delicate layering (Plate 13).

In thin section the rock consists dominantly of hornblende, with lesser amounts of plagioclase (An 76 - An 54). The plagioclase forms narrow, twinned, zoned, and saussuritized laths. These laths are enclosed by brownish to blue-green amphibole, and are cut by fibrous aggregates of actinolite. Minor interstitial quartz is also present in the upper hornblende gabbro layer.

Clinozoisite, albite, and chlorite are formed at the expense of the above assemblage, and leucoxene forms irregular patches associated with, and cutting the fibrous actinolite.

A tendency for the plagioclase to lie with the c-axis oriented in the common layering plane is apparent in thin section, giving rise to "igneous lamination" (Wager, 1968). This feature may have been the result of crystal precipitation in the presence of lateral magma currents, thus giving rise to the delicate layering (Plate 13).

Porphyritic gabbro (Map unit 8)

Porphyritic gabbro is exposed on the Chrome Property and forms two layers which are interlayered with the hornblende gabbro. The total thickness of these two layers is approximately 170 feet, and they are characterized by irregular zones of slightly more feldspathic and non-

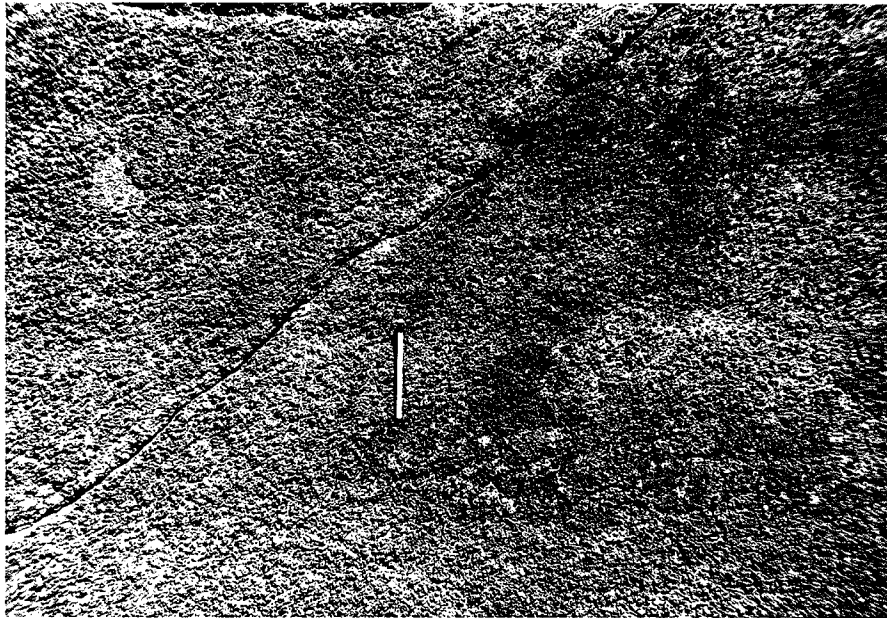


PLATE 13: Delicate layering in hornblende gabbro.

porphyritic gabbro.

The porphyritic gabbro is greyish to black weathering, coarse grained, massive, and porphyritic. Large phenocrysts of hornblende, mantled by plagioclase, are sporadically developed and form up to 25 percent of the rock (Plate 14).

In thin section the rock consists of equal distributions of sub-ophitic amphibole and plagioclase (An 85 - An 54). The amphibole consists of the hornblende phenocrysts, interstitial hornblende, and fibrous actinolite. The plagioclase is present as small narrow, twinned, poorly zoned, euhedral, partially saussuritized laths cut by the actinolite. The phenocrysts consist of brownish green strongly pleochroic hornblende with narrow blue-green alteration haloes. These haloes are in turn mantled by euhedral plagioclase laths which form a pseudo augen structure that trails out in the layering plane.

Clinozoisite, albite, chlorite, and leucoxene form minor alteration products; the leucoxene displaying a marked preference for the fibrous amphibole. Interstitial quartz is scattered throughout, and in some places forms up to 3 percent of the rock.

Overlying the upper layer of porphyritic gabbro is a 20 to 30 foot thick zone which grades from a dark grey green amphibole rich gabbro to a light grey, fine to coarse grained massive, siliceous appearing rock comprised

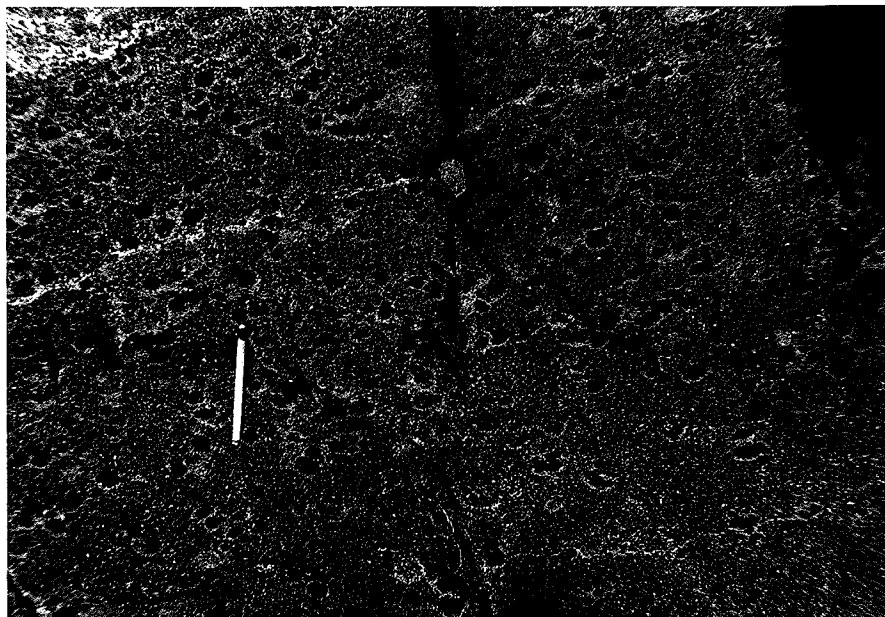


PLATE 14: Porphyritic gabbro.

mainly of plagioclase and quartz. Near the base of this zone actinolite forms long (2 - 3 inches) bladed crystals oriented perpendicularly to the layering plane, and anorthositic stringers are common.

In thin section the upper portion of the zone is seen to consist dominantly of plagioclase (An7 - An2) which is intimately intergrown with quartz (Osborne, 1949). This assemblage extensively corrodes highly saussuritized twinned subhedral plagioclase laths which form up to 15 percent of the rock. Fibrous actinolite, interstitial to and cutting the plagioclase, shows decrease in abundance towards the top of the zone. Minor biotite and leucoxene comprise 1 to 2 percent of the rock.

STRUCTURAL GEOLOGY

The regional setting of the map area has been described above and is shown in Figure 1. Development of the Bird River - Cat Lake anticline was probably syntectonic with the emplacement of the Great Falls Pluton, and although not known with certainty, this event may have been responsible for the development of the foliation observed in the Rice Lake Group of rocks. The lack of a similar foliation in the rocks of the Bird River Sill may therefore be a reflection of the competence of these rocks. Evidence was not observed that might indicate that the foliation in the Rice Lake Group was developed prior to the intrusion of the Sill.

Faulting

Faulting, the dominant structural feature in the map area, may be classed on the basis of direction, into four groups. These are; parallel to layering, north - south trending, northwesterly trending, and at a shallow angle to the layering. The latter class, not prominently developed, results in an extension of the layering, and is probably related to the faulting parallel to layering. The first three classes are described below, the north - south and northwesterly trending faults being described together.

Faults parallel in strike to that of the layering of the rocks were observed at the basal and upper con-

tacts of the Sill on the Chrome Property, and along the upper contact of the Sill on the Page Property. Field evidence, and drill core information further suggest the presence of similar faulting within the pyroxenite layer. Divergence in direction of this faulting has resulted in braiding, and a wide zone of cataclasis above the Sill (Plate 15).

Equal area projection of data from the faults parallel to layering and drill core data indicate a divergence of dip from that of layering such that these faults transect the layering of the rocks at 10 to 15 degrees; in some places this divergence being as great as 35 degrees. The dips of these faults however are generally steeply south.

Faulting in north and northwesterly directions is responsible for the offsets observed in the rocks of the map area. These faults, possibly transgressive, cut the layering at high angles and display dips which range from 74 degrees west to slightly east of vertical (Plate 16). In the ultramafic rocks these faults are marked by brecciation, development of picrolite, and drag features. Little deformation is evident where the faults cut the gabbroic rocks.

Several features of the north and northwesterly trending faults were described by Bateman (1943) as being suggestive of rotational faulting. These features include

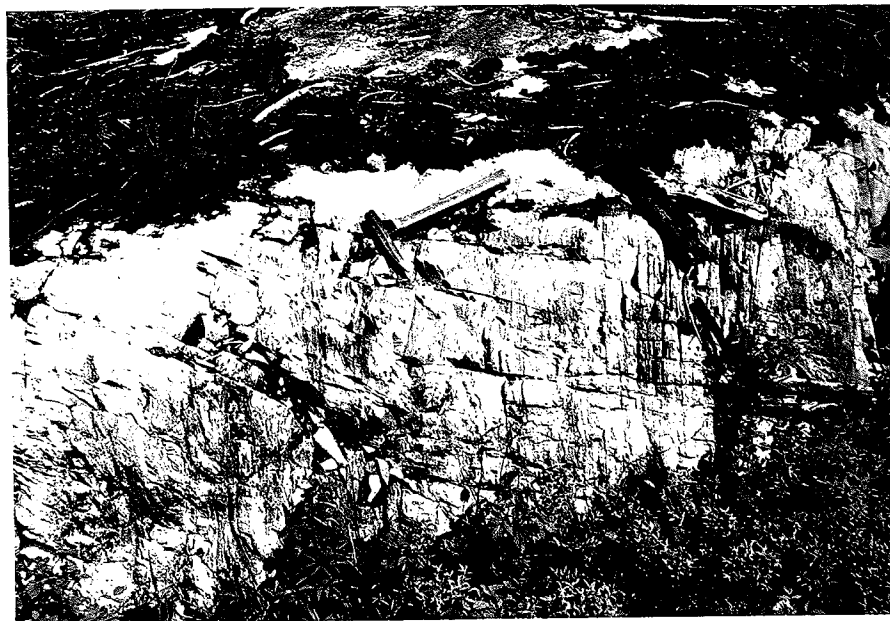


PLATE 15: Cataclasite in fault south of the Chrome Property.



PLATE 16: Northwesternly faulting on Chrome Property. Note also progressive displacements on small scale faults.

progressively greater amounts of offsetting in chromite layers with changes in dip of those layers, and apparent abrupt termination of the faults. Corresponding to these observations is the apparent change in thickness of rock units.

The change in thickness of rock units, and the extent of offsetting cannot be accommodated by simple rotation without significant changes in dip. Such changes in dip were not observed in the field. Donn and Shimer (1958) indicate that rotational affects and dip changes are common however, in and near the termination of strike slip faults. In conjunction with this, the change in thickness of rock units is a result of dip slip movement on those faults parallel and sub-parallel to the layering of the rocks.

Structural synthesis

In the study area several of the north and north-westerly trending faults truncate the easterly trending faults, and in some cases these faults terminate against the easterly trending faults. Both of these relationships have also been described by Davies (1955) in the Bird Lake area. The truncation of the easterly trending faults and the lack of possible offsetting in the north and north-westerly faults suggests therefore that the easterly faulting antedates the northerly faults.

In conjunction with movement on the northerly trending faults it is proposed that renewed movement of a dip slip nature took place on the easterly trending faults resulting in thickness changes of rock units within the separate blocks formed of the Bird River Sill.

In Figure 4, a schematic representation, faults shown in section are inherent, and the plan view displays the affect of subsequent movement on the outcrop pattern of the rocks. In Figure 4 (A) no movement has been affected and a true section of the Sill is shown. Figure 4 (B) displays the results of movement such that XX - YY is normally faulted to the level of AA - BB. The case in Figure 4 (C), with the faults inclined as is the actual situation, indicates the manner in which the gabbroic rocks have been placed in juxtaposition with the basal peridotite layers, exemplified at the east end of the Chrome Property.

The metagabbro sill and the porphyritic andesite have been included in Figure 4 and despite the faulting maintain a fairly constant separation from the basal contact of the Sill. In the map area this relationship is best exhibited north of the small central block of the Sill, and at the west end of the Chrome Property.

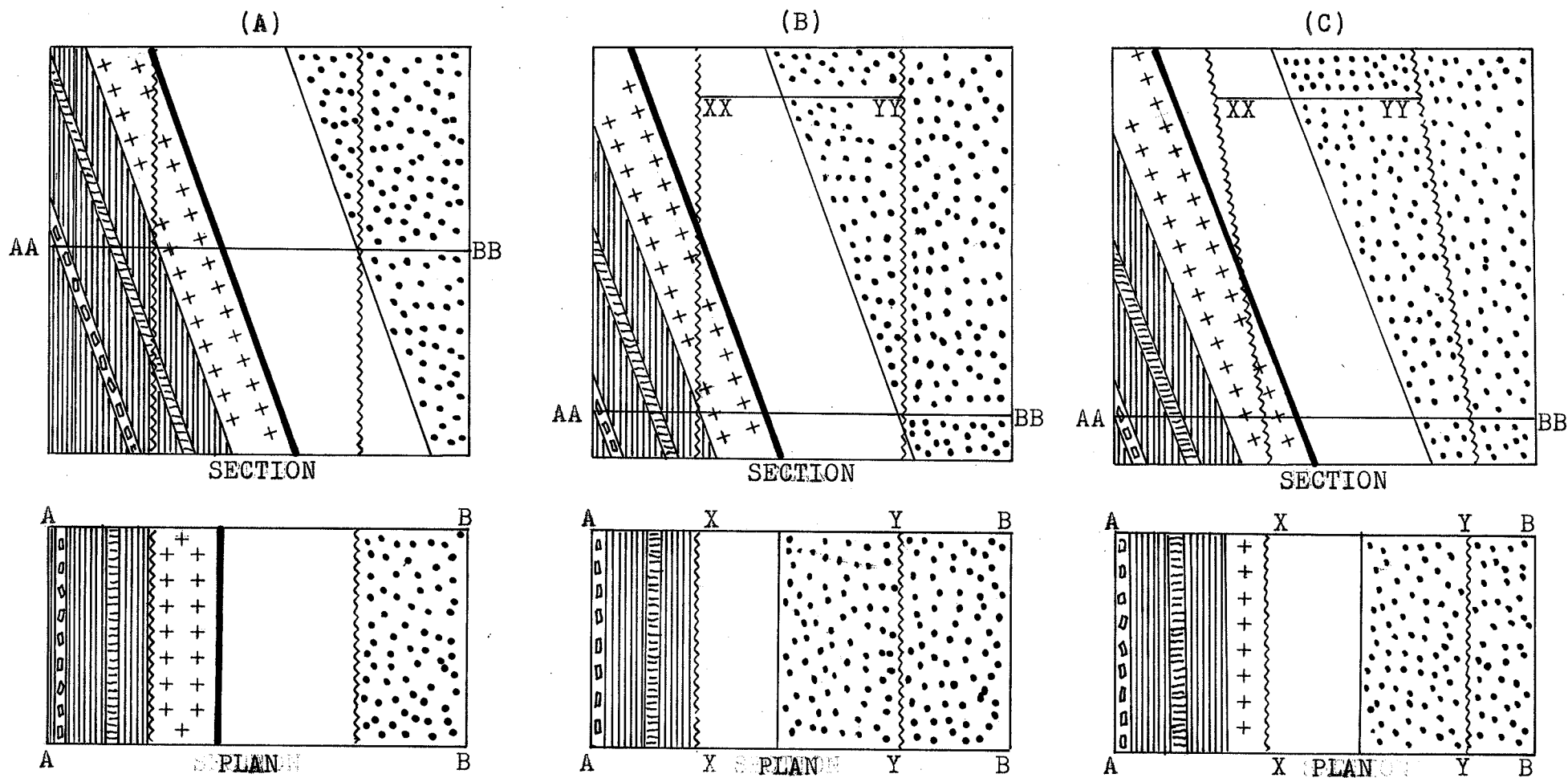
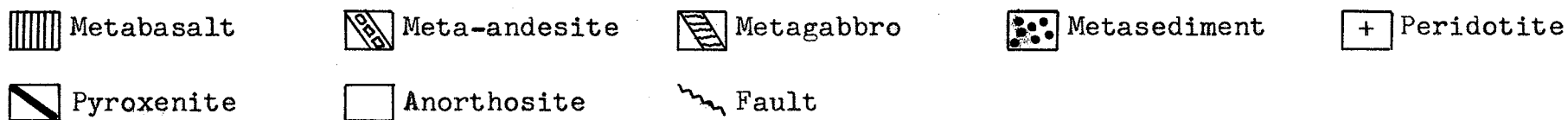


FIGURE 4: Schematic representation of faulting in the Bird River Sill



PETROGENESIS OF THE BIRD RIVER SILL

Chemical and normative data

Chemical analyses of rocks in the Bird River Sill, obtained from previous literature (Bateman, 1943, Osborne, 1949) are presented in Table 2, with corresponding CIPW normative data. Table 3 displays chemical analyses of the chromite bearing rocks; these data being taken from Bateman (1945) and Gait (1964).

The normative data given in Table 2 display a high percentage of plagioclase feldspar in the serpentized peridotites. This plagioclase is not present, but is a reflection of the chromite content. The chromite, because of its high alumina content has been described by Gait (1964) as a chromian spinel, an observation which is in accord with that of Thayer (1946) who notes that chromites found in peridotites associated with gabbro tend to be high in alumina.

The ratio of ferrous and ferric iron in a rock is considered by Wager (1968) to represent the oxidation state of the magma at the time of crystallization. The lack of ferric iron in analysis (1) (Table 2) of the marginal gabbroic rock therefore indicates a low oxidation state at the time of intrusion of the Bird River Sill. This oxidation state undergoes a change which is reflected by increase in ferric iron (analyses 2, 3, 4, Table 2) and this change is further indicated by increase in normative magnetite (Wager, 1968).

CHEMICAL ANALYSES

OXIDE	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SiO ₂	45.27	36.59	33.08	38.16	40.19	49.31	54.00
Al ₂ O ₃	17.91	13.79	8.76	8.71	25.50	23.22	19.02
Fe ₂ O ₃	0.00	1.12	4.70	6.10	0.52	0.04	0.00
FeO	5.59	8.40	4.33	5.52	4.08	5.64	6.47
MgO	14.53	24.18	30.45	31.33	9.87	5.18	6.81
CaO	7.25	6.19	5.54	0.83	11.33	13.01	10.53
Na ₂ O	1.52	0.04	0.16	0.21	2.68	2.17	2.64
K ₂ O	0.59	0.01	0.00	0.00	0.37	0.26	0.35
H ₂ O +	3.57	8.74	8.40	6.41	4.18	0.80	1.10
H ₂ O -	0.10	0.28	0.14	0.09	0.16	0.00	0.03
CO ₂	tr	0.05	3.00	1.76	tr	0.00	0.00
TiO ₂	0.00	0.13	0.10	0.26	0.00	0.00	0.00
P ₂ O ₅	0.00	0.02	0.13	0.18	0.00	0.00	0.00
S.	0.00	0.00	0.16	0.08	0.00	0.00	0.00
Cr ₂ O ₃	0.09	0.10	0.38	0.53	0.09	0.00	0.00
MnO	0.00	0.28	0.02	0.06	0.00	0.00	0.00
NiO	0.00	0.00	0.23	0.15	0.00	0.00	0.00
TOTAL	99.49	99.92	99.38	100.38	98.97	99.63	100.95

CIPW NORM (WEIGHT %)

MINERAL	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Q							2.0
OR	3.7						2.0
AB	13.8	0.3		1.9	0.8	18.5	22.3
AN	38.7	33.6	26.5	3.2	59.4	53.4	39.0
NE			0.8		12.5		
DI						5.7	
HE						3.9	
EN	16.3	5.4		40.0		6.0	13.8
FS	4.5	1.3		2.0		4.8	9.7
FO	15.8	42.6	60.8	31.4	18.2	3.0	
FA	4.8	11.4	13.2	1.7	5.6	2.7	
LA			1.2				
C	1.7	2.7		7.9			
MT		1.7		9.6	0.7		
IL		0.2	0.2	0.5			
CR	0.1	0.1	0.6	0.8	0.1		
AP			0.2	0.4			
PY			0.3	0.1			

TABLE 2: Chemical and normative data of rocks
in the Bird River Sill

(con.)

Key to Chemical Analyses (Table 2)

- (1) Marginal gabbro...after Osborne (1949); "altered drill hole specimen, about 15 feet below the base of the peridotite."
- (2) Serpentinized peridotite...after Osborne (1949); "Drill hole specimen about 150 feet above the base of the peridotite." D. Robertson, analyst.
- (3) Serpentinized peridotite...after Bateman (1943); "Surface specimen, immediately beneath chromite horizon." R.J.C. Fabry, analyst.
- (4) Serpentinized peridotite...after Bateman (1943); "Surface specimen, from above the chromite horizon." R.J.C. Fabry, analyst.
- (5) "Olivine diallage gabbro"...after Osborne (1949); from the base of the "upper gabbroic series".
- (6) Hornblende gabbro...after Osborne (1949); "from upper gabbroic series. Surface specimen, about 550 feet above the top of the peridotite."
- (7) Hornblende gabbro...after Osborne (1949); "with interstitial Ab 70 (An 30) plagioclase and quartz, from upper gabbroic series. Surface specimen, about 950 feet above the top of the peridotite."

TABLE 3: Partial chemical analyses of chromitite and chromiferous peridotite in the Bird River Sill

OXIDE	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
SiO ₂	13.1	9.4	13.8	11.0	21.0	14.8	29.2	18.5
Al ₂ O ₃	18.7	19.4	14.8	17.8	14.5	8.2	9.8	15.2
Fe ₂ O ₃								
FeO	18.4	19.5	14.0	18.4	11.1	18.6	6.7	11.2
MgO	5.2	4.3	25.0	20.5	24.2	23.5	28.5	26.1
CaO	1.1	0.7	0.4	0.5	3.6	0.6	6.0	2.9
Na ₂ O				0.02	0.03		0.1	0.01
K ₂ O								
H ₂ O ±								
CO ₂								
TiO ₂			0.2	0.28	0.15	0.24	0.04	0.27
P ₂ O ₅	0.1	0.1						
S								
Cr ₂ O ₅	26.3	29.3	20.4	27.3	18.5	32.7	6.5	15.5

(8)...average of several partial analyses of Page ore; after Hudson's Bay Mining and Smelting Co., as reported in Bateman, (1943).

(9)...Hudson's Bay Mining and Smelting Co., as reported in Bateman (1943).

(10) - (14)...whole rock analyses as reported in Gait (1964). K. Ramlal, analyst.

(15)...average of 5 analyses of the main zone, after Gait (1964). K. Ramlal, analyst.

Differentiation trend

Figure 5 is a standard plot showing behavior of $MgO - FeO$ - and total alkalis in the Bird River Sill. This trend is contrasted with similar data (inset) after the Skaergard (Wager, 1968) and Stillwater (Hess, 1960) complexes.

A trend line is not shown in Figure 5 for the Bird River Sill data, as a best fit line would be subject to bias on the basis of the limited chemical data. Points given are therefore numbered according to the analysis number in Table 2.

A broad trend in Figure 5 is apparent showing some iron enrichment from early to middle stages of crystallization, and a later stage of alkali enrichment. This differentiation trend is not however, well defined.

Crystallization sequence

Previous workers, (Bateman 1943, Osborne 1949, Springer 1949, Davies 1952, -55) have described several and varied origins for the Bird River Sill. These include; two separate intrusive events, such that the gabbroic and ultramafic rocks were not differentiates in situ, the concept of several small separate intrusions giving rise to the irregularity in thickness as well as subsequent differentiation, and intrusion and differentiation in a highly irregular magma chamber, giving rise to observed changes in thickness. The latter two cases recognize a

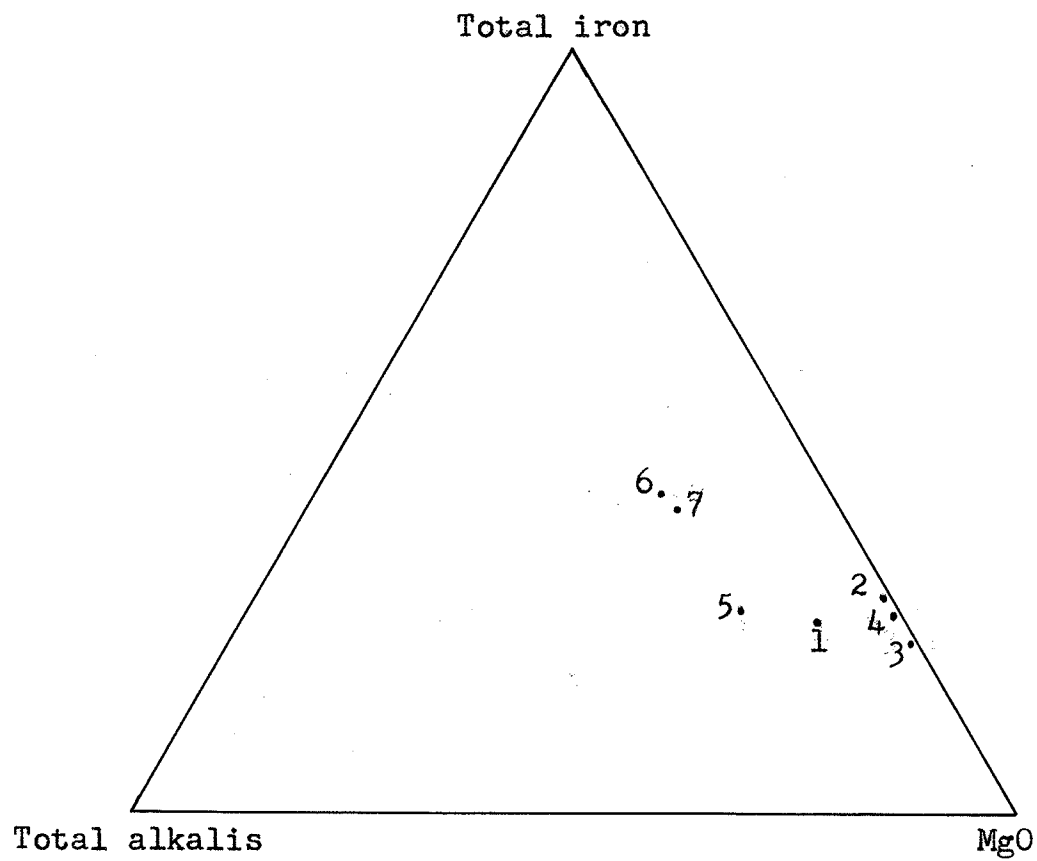
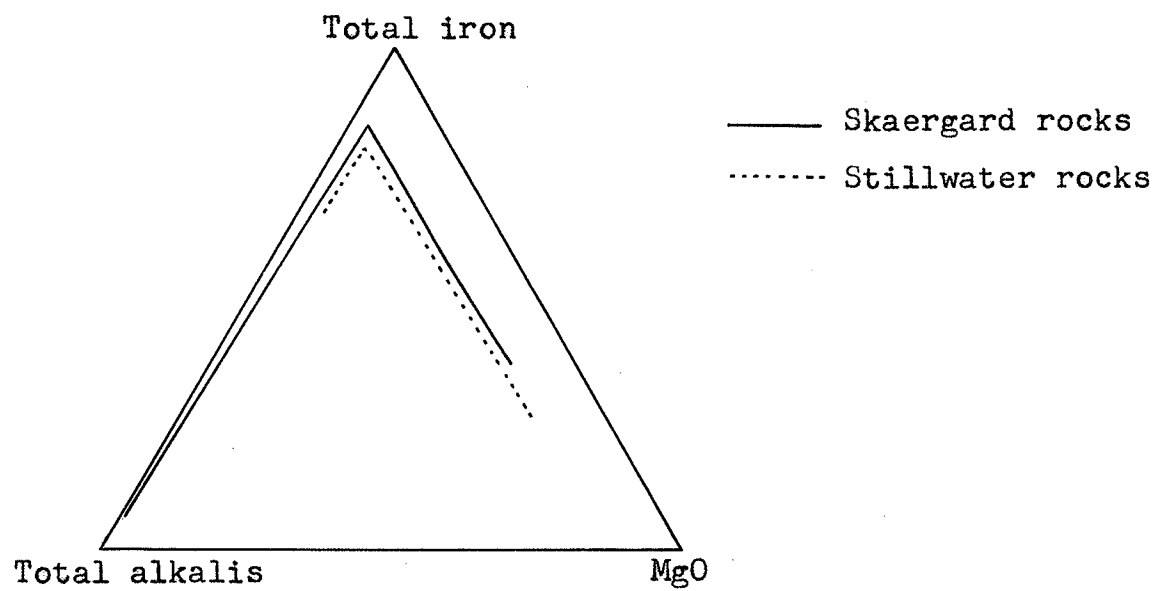


FIGURE 5: Differentiation trend of the Bird River Sill

differentiation in situ and this mode is appealed to below. The nature of the variation in thickness, and omission of map units is recognized as being a result of structural deformation, and it is considered that the Sill magma was injected as a sill-like body along an inherent plane of weakness; the metavolcanic - metasedimentary contact.

Post-crystallization alteration of the Sill has to a large extent masked the primary nature of the rocks, and as a result, interpretation of the crystallization sequence is based on relict textures and minerals, normative mineralogy, and primary structures as evidenced in the chrome layers and gabbroic rocks.

The intrusion of the Sill magma was accompanied by the formation of a chilled marginal facies; the basal gabbro described by Osborne (1949). Analytic data for this gabbro indicates that the magma was, by the ratio of iron oxides, in a low oxidation state.

Textural evidence indicates that olivine formed as a cumulus phase and with chromite co-precipitated from the magma. Pyroxene formed as an intercumulus phase, giving rise to peridotites. Normative data suggesting the formation of plagioclase has been attributed to the alumina content of the chromite.

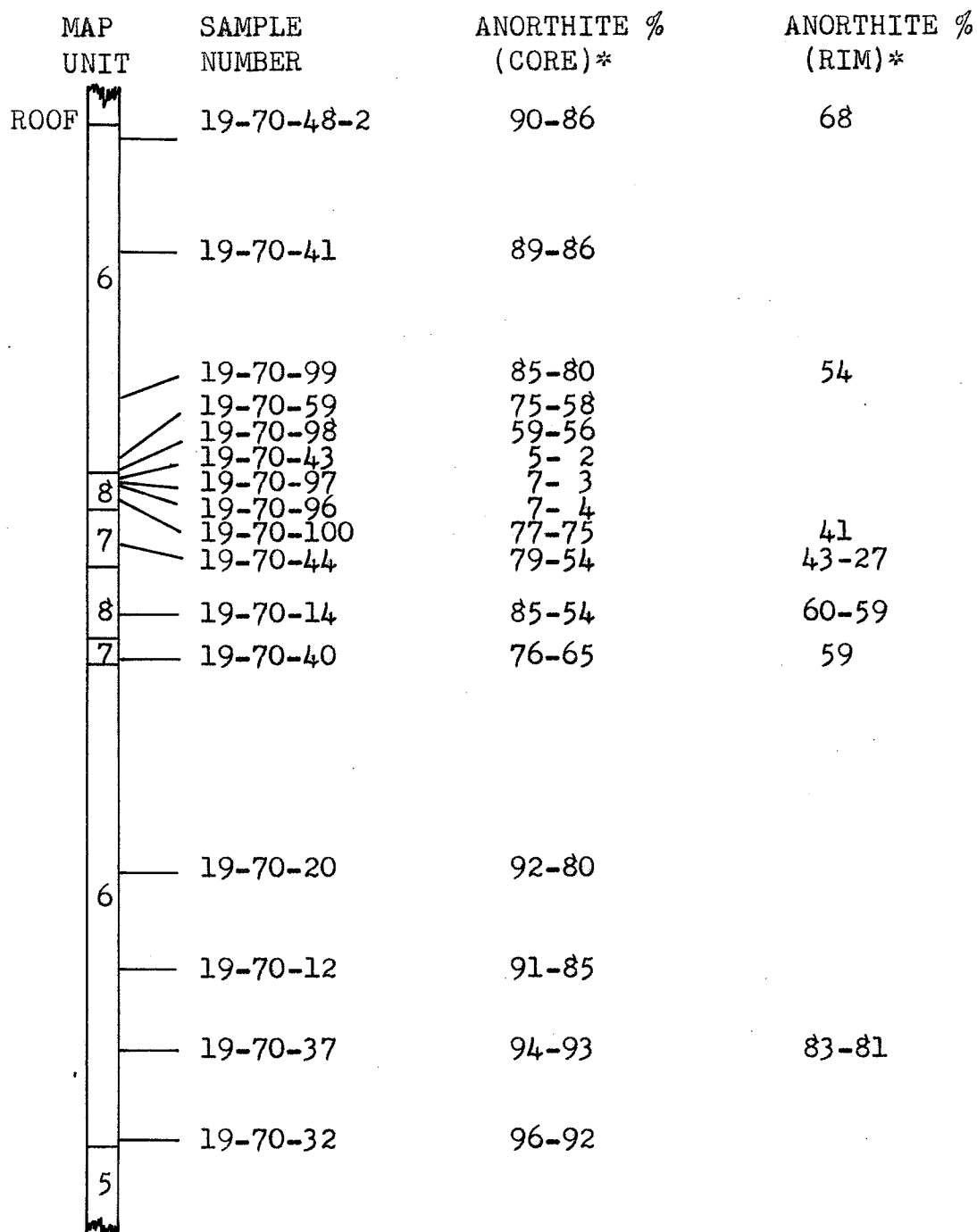
During the formation of the ultramafic cumulates the magma appears to have undergone change in oxidation state which is shown by the chemical analyses (Table 2, # (2), (3), (4)). Similar change, reflected in the ratio

of iron oxides, has been suggested by Jackson (1963) as being responsible for the origin of massive chromite layers in the Stillwater Complex. Primary structures evidenced in the deformation of the chromitite and chromiferous peridotites of the Sill indicate the formation of density or thermal convective currents in the magma by the time chromite precipitated as a sole cumulus phase.

The first appearance of plagioclase was coincident and overlapping with the culmination of olivine precipitation. Both the olivine and plagioclase, not abundant, were enclosed by pyroxene, probably augite, forming the pyroxenite.

Plagioclase forming almost to the exclusion of other minerals resulted in transition from normal gabbroic rocks above the pyroxenite to anorthositic and anorthosite gabbros. The nature of the related amphibole in these rocks is uncertain, as replacement textures are not apparent. Colony (1920) interpreted the rocks as having been a norite, with the amphibole having formed by the uralitization of hypersthene, a view held also by Osborne (1949). Karup-Moller (1971) interpreted the amphibole as being primary on the basis of its texture.

Cryptic variation of anorthite content in the plagioclase of the gabbroic rocks is shown in Figure 6. These data indicate that with the formation of the lower member of Map unit 6, crystallization, or accumulation, commenced from the roof of the Sill downwards, thus forming the upper member of Map unit 6. The culmination of crystal-



(Vertical scale: 1"=330')

FIGURE 6: Anorthite content of plagioclase:
Gabbroic rocks of the Bird River Sill

* values given represent range of several determinations.
Determinations by J. Macek, Manitoba Mines Branch,
utilizing Fedorov stage and curves after Fediuk (1961).

lization may therefore be represented by the extensive corrosion and alteration observed in those rocks containing the albite feldspar (An₂ - An₇). Current movement indicated by the development of glomeroporphyritic gabbro and igneous lamination were still operative as crystallization commenced at the roof.

The appearance of primary hornblende in the porphyritic gabbro and subsequently formation of the altered zone represent the last stages of crystallization of the late hydrous phase of the magma; these rocks being sandwiched into their stratigraphic position by the earlier formed anorthositic gabbro. A similar tendency for the positioning of the last formed rocks has been described by Holtz (1953) for the granophyres of the Dillsburg Sills.

Deuteric alteration undoubtedly followed crystallization, giving rise to serpentization and probably some uralitization. The extent of this alteration is uncertain as later hydrothermal affects, consanguinous with regional metamorphism have been superimposed on the Sill.

Petrogenetic considerations

The behavior of magnetite formation in a magma has been discussed extensively by Wager (1968) with respect to the oxidation state of the magma. Accordingly a highly oxidized magma will reflect an increased amount of early

formed magnetite, and display little iron enrichment at later stages, than a corresponding magma of low oxidation state. Concurrent with such development will be an increased amount of anorthosite and anorthositic gabbro, and an increased amount of granophyre.

These trends may be exhibited by the Bird River Sill which contains a proportionately high volume of anorthositic rock, a possibly late residuum as evidenced in the altered rocks above the porphyritic gabbro, and little if any magnetite in the gabbros. This lack of magnetite is further corroborated by geophysical study.

MAGNETIC STUDY OF THE BIRD RIVER SILL

Geophysical study of the Bird River Sill consisted of magnetic susceptibility determinations and a vertical field magnetic survey. This work was conducted primarily on the Chrome Property (see accompanying map) which was selected because of its extensive exposure and ease of geologic correlation. Trial observations were also conducted on the Page Property to test the validity of extrapolation of results to other parts of the Sill.

Magnetic susceptibility

In theory the effective magnetization of a rock or rock unit is the vector sum of remnant and induced magnetization. Induced magnetization is the response of the rock to an ambient magnetic field, and the intensity of this induced magnetization is directly proportional to the ambient field applied. The constant of proportionality is termed the magnetic susceptibility and is denoted as K .

In practice the magnetic susceptibility of a rock may be considered as proportional to the volume percent of magnetite in the rock (Dobrin, 1960). Ilmenite affects magnetic susceptibility, but to a considerably lesser extent in comparison to magnetite.

Magnetic susceptibility measurements of the Bird River Sill were conducted in situ through use of a Carey Foster type susceptibility bridge. The advantage of this

apparatus is that larger amounts of rock are involved in the determinations and data thus obtained are considered more representative. A complete description of this type of apparatus is given by Hood (1967).

Data were obtained systematically in conjunction with the magnetometer survey, and also randomly on various layers or rock types in the Sill. These data are presented in Figure 7 which displays the range of values observed for the separate rock types of the Sill.

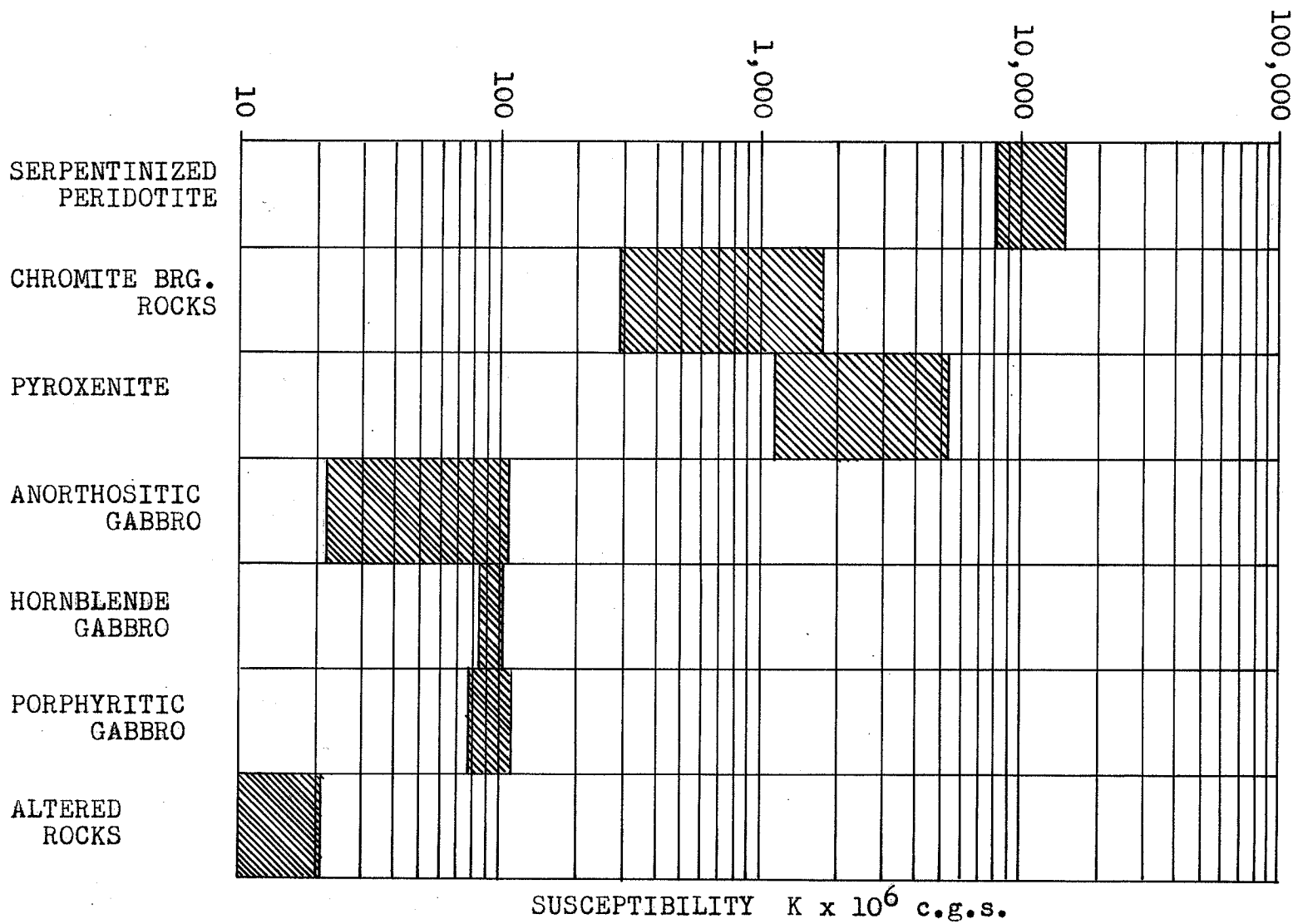
The serpentized peridotite and pyroxenite display high susceptibility reflecting both primary magnetite and magnetite attendant with the serpentization process. The gabbroic rocks are characterized by anomalously low values of susceptibility which in part is probably related to the presence of ilmenite rather than magnetite.

Chromitite and chromiferous peridotite display susceptibility values that fall within the range of that of the serpentized peridotite, although the mean value of several determinations of the chromite bearing rocks is considerably less than that of the serpentized peridotite. The overlap in susceptibility values of these two rock types precludes sufficient susceptibility contrast to enable detection of the chromite bearing rocks using conventional magnetic means.

Vertical field magnetometer survey

The vertical magnetic field survey was conducted

FIGURE 7: Range of magnetic susceptibility values in rock types of the Bird River Sill.



with a Sharpe SM-4 fluxgate magnetometer. Measurements were taken at 25 foot intervals on lines spaced at 400 foot intervals. These lines were oriented across the strike of layering in the Sill, and controlled through use of vertical aerial photo enlargements (1"=330'). Base readings on each line were closed at half hour periods with a common base. Drift was negligible.

Data obtained from this survey are presented in Figure 8 and are shown in superposition with the corresponding geology.

The magnetic signature of the Sill is a direct expression of the magnetic susceptibility, both of which are shown in Figure 9. The magnetic susceptibility profile is noted to be high and variable over the ultramafic rocks, but is essentially flat, as are the magnetic profiles, over the gabbroic rocks.

The variable nature of the vertical field over the ultramafic rocks masks the presence of the chromite bearing layers, and identity of these layers was only by direct observation. The narrow thickness (maximum 10 feet) of the chromite bearing layers further precludes any magnetic isolation of these layers unless a very close station interval is maintained. The results of such a survey would nevertheless be highly interpretive and the detection of chromite bearing rocks fortuitous.

Correlation of geology and magnetic studies

Magnetometer surveys have been conducted elsewhere on

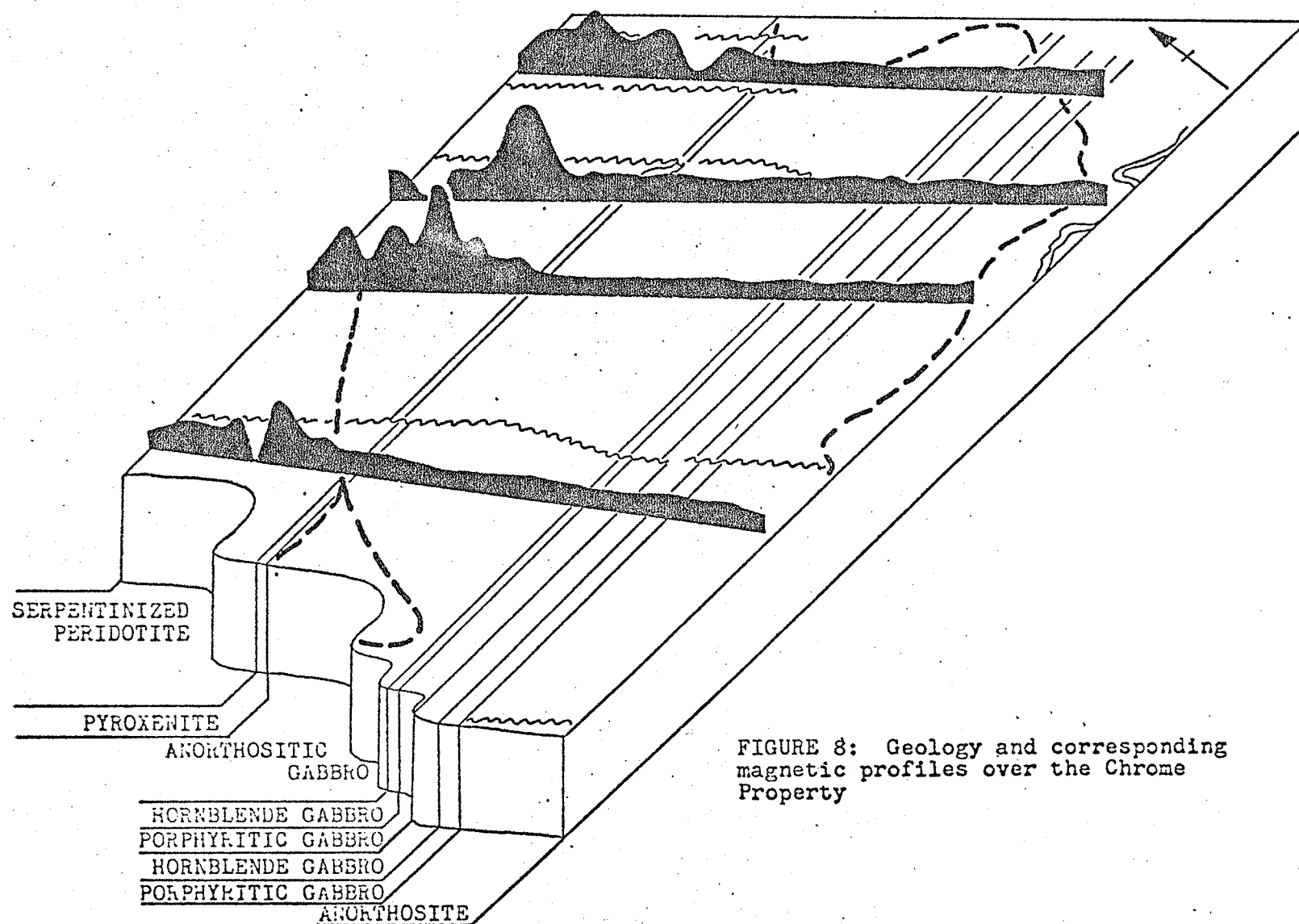


FIGURE 8: Geology and corresponding magnetic profiles over the Chrome Property

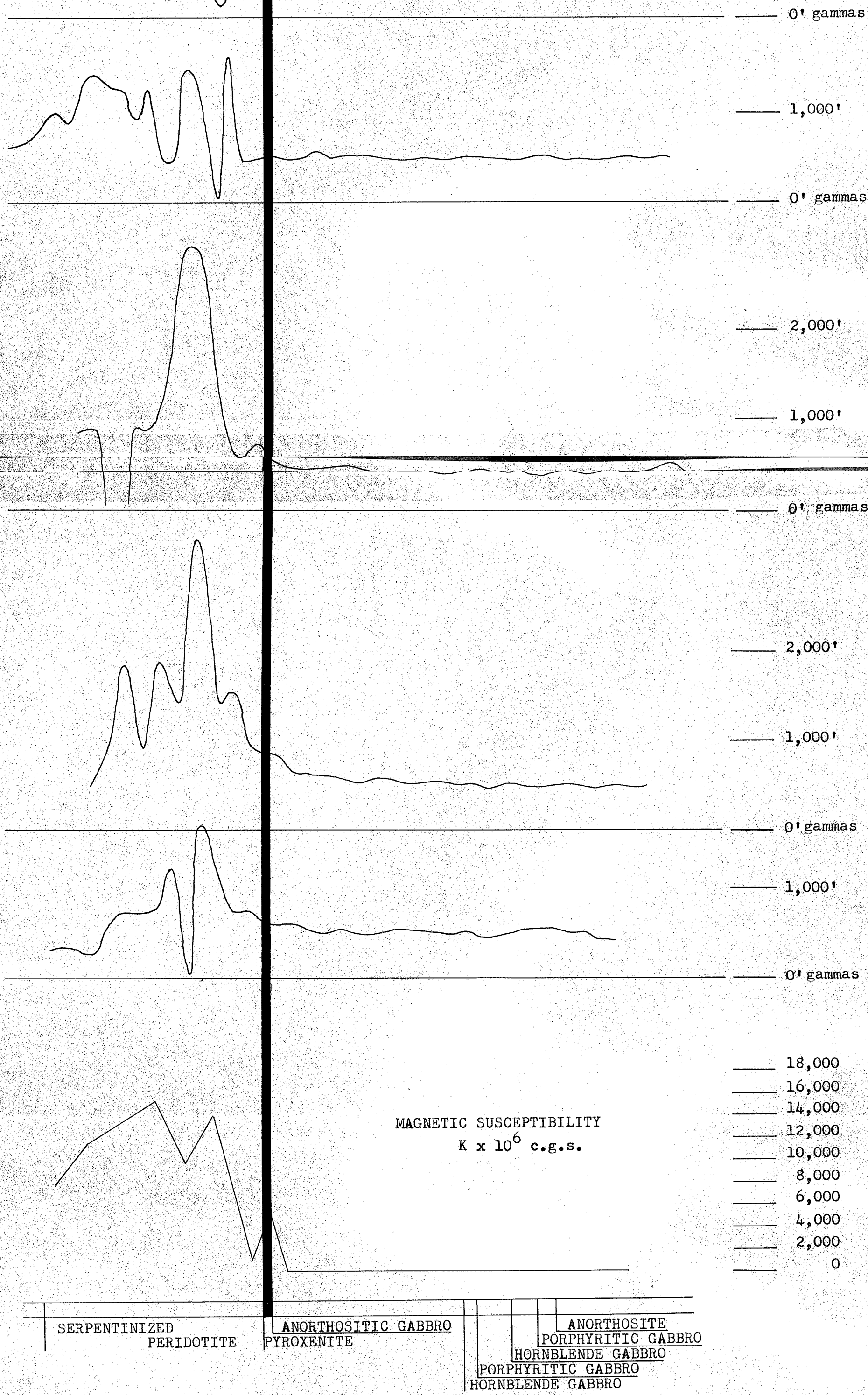


FIGURE 9: Susceptibility and magnetic profiles: Chrome Property

the Bird River Sill in prospecting for chromite (Bateman, 1943). This work was done with a foreknowledge of the geology, and the magnetic signature was presumably utilized in defining the ultramafic - gabbro contact, with which the chromite bearing layers maintain a fairly constant stratigraphic relationship.

The magnetic signature of the Bird River Sill can be extrapolated to other areas of the Sill, and as a result indirect prospecting for chromite can be carried out with magnetic means. Such a procedure is in accord with Hawkes, (1953), but in the specific case of the Bird River Sill is contradictory to his conclusions.

Study of aeromagnetic data of the Bird River - Cat Lake area indicates the presence of significant magnetic anomalies over segments of the Bird River Sill. Other segments consisting of the gabbroic rocks only, lack corresponding anomalies. It is suggested therefore that hitherto undiscovered or unexposed sections of the Sill may exist, for example in the Anson Lake area, and consist only of the gabbroic rocks, lacking magnetic expression.

CONCLUSIONS

Within the map area the Bird River Sill is intrusive along the contact between the metavolcanic and metasedimentary rocks of the Rice Lake Group. This sill, approximately 2,000 feet in thickness, was, on the basis of structural attitudes intruded while the Rice Lake Group was essentially horizontal. The intrusion of the Sill was accompanied by the formation of a chilled marginal gabbro (Osborne, 1949), after which peridotites, now serpentized, began to form as cumulus rocks. Chemical data suggest that subsequent change in oxidation state of the magma may have affected precipitation of chromian spinel and later gave rise to extensive volumes of anorthositic gabbros. Inter-layered with the anorthositic gabbros are hornblende and porphyritic gabbro.

Primary structures exhibited in deformation, bifurcation of, and scour structures in the chrome bearing layers indicate that thermal or density currents were present in the magma. This is further corroborated by lamination in hornblende gabbro.

Variation of anorthite content of the plagioclase in the gabbroic rocks indicates that crystallization of the gabbros proceeded from both the roof and floor of the magma chamber inwards, culminating in a zone of alteration of these gabbros.

Faulting along the basal and upper contacts of the Sill, and across the layering has resulted in a complex

outcrop pattern. Contemporaneous movement on the two fault systems is displayed by changes in thickness and absence of rock units. Strike slip components on faults across layering has offset major segments of the Sill, with movements of the order of 5,000 feet.

Magnetic susceptibility determinations of the gabbroic rocks of the Sill indicate a lack of magnetite in these rocks. The magnetic signature of the Sill, a consequence of the distribution of magnetite, is evident in magnetometer work, and thus with knowledge of the geology, magnetic methods may be utilized in prospecting for chromite in the Bird River Sill.

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LEGEND

- 9 Quartz diorite - granodiorite
- 8 Porphyritic gabbro
- 7 Hornblende gabbro
- 6 Anorthositic gabbro, anorthosite, gabbro
- 5 Pyroxenite
- 4 Serpentinized peridotite with interlayered chromite
- 3 Metagabbro
- 2 Greywacke, crystal tuff, polymict conglomerate; derived schists
- 1a Basalt, porphyritic andesite; derived schists
- 1b Basalt, porphyritic andesite; derived schists

SYMBOLS

- Geological boundary (defined, approximate)
- Igneous layering (inclined, vertical)
- Bedding (inclined, vertical, tops shown by arrow)
- Foliation (inclined, vertical)
- Fault (defined, approximate)
- Area of rock outcrop
- Swamp, muskeg
- Air photo center
- Trench
- Gravel pit
- Road
- Trail
- Building



315

LAKE

WINNIPEG

MAP AREA



date)
by arrow)

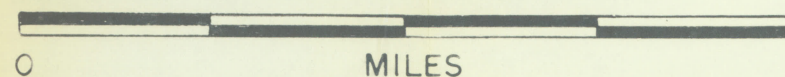
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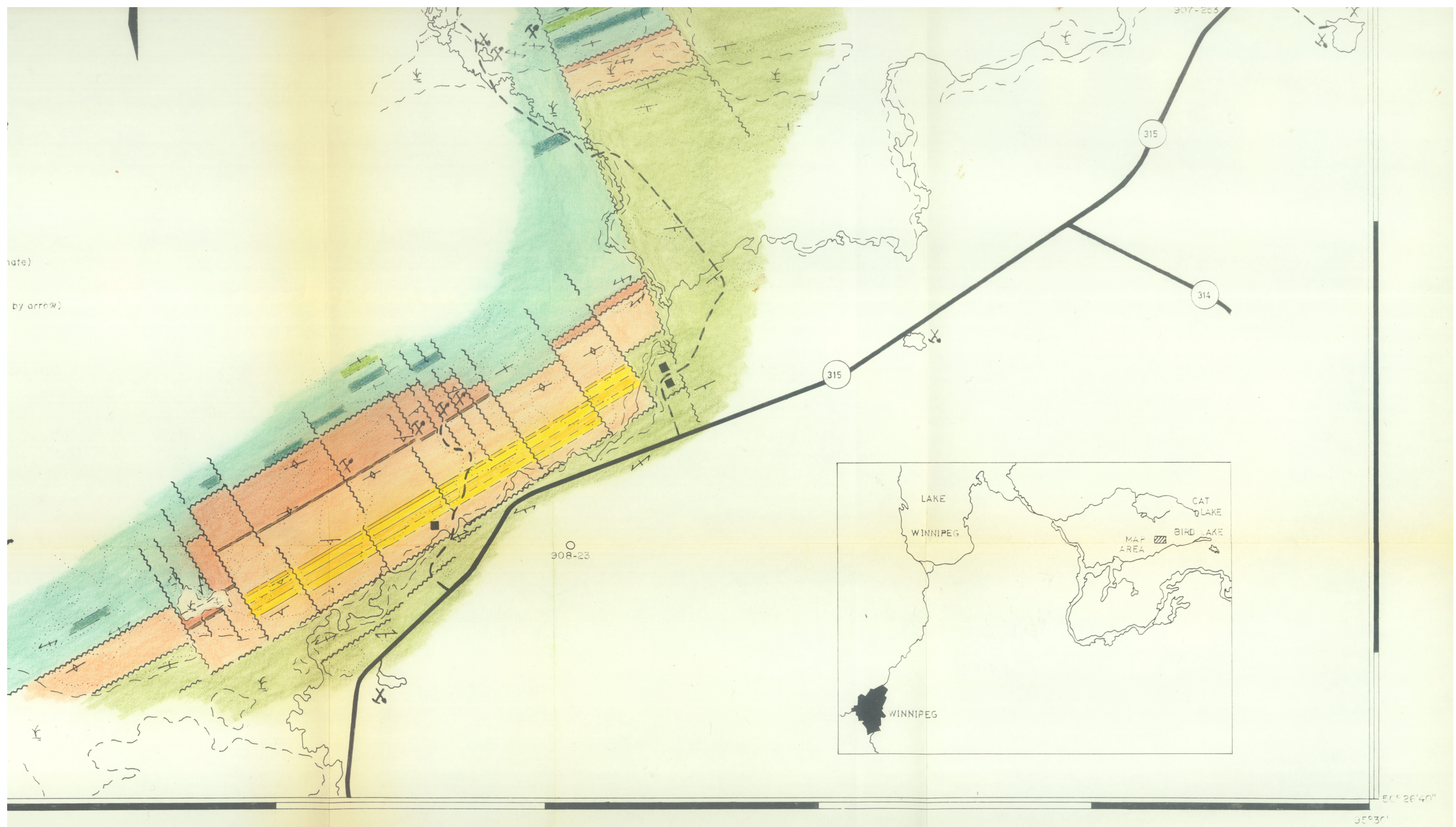
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GEOLOGY OF THE CHROME AND PAGE PROPERTIES : BIRD RIVER SILL





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