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THE MONGOWIN PLUTON

by

K. D. CARD

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ABSTRACT

The Mongowin pluton is a small igneous intrusion which cuts Huronian rocks south of Espanola, Ontario. It is approximately 1485 million years old and belongs to a group of post-Huronian intrusions which occur along the north shore of Lake Huron. It is a composite body and consists of olivine amphibolite, quartz diorite, and trondhjemite. Chemical and mineralogical analyses show that these rocks are genetically related and probably represent two successive injections of magma with some differentiation in situ. Alteration of the olivine in the olivine amphibolite has produced serpentine and magnetite. An unusual vein of colloform magnetite, apparently the result of colloidal deposition, occurs in the ultramafic rocks. Disseminated sulphide mineralization with minor amounts of copper, nickel, and cobalt occurs near the outer contacts of the ultramafic rocks.

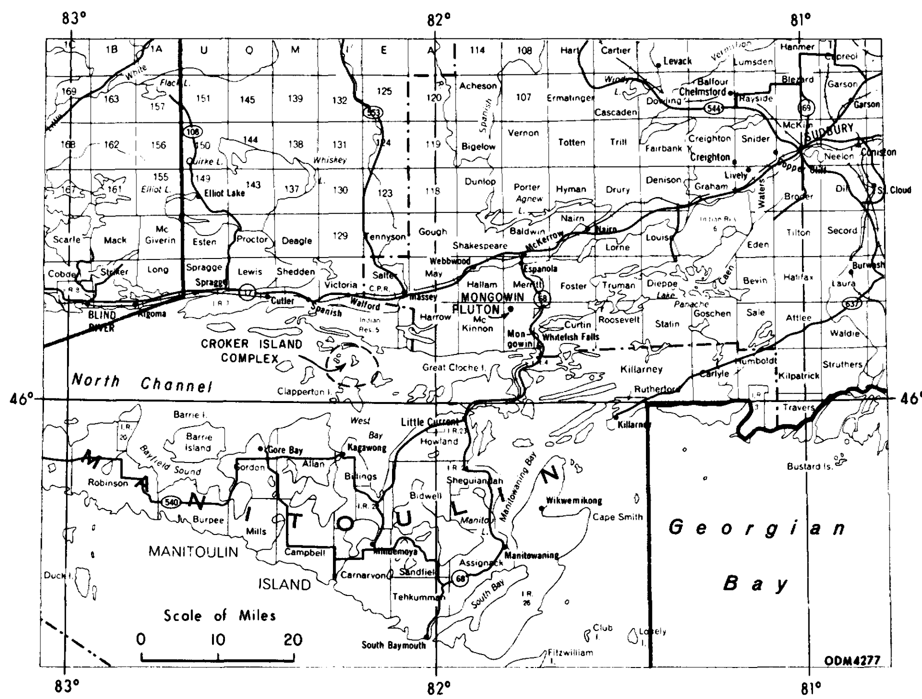

Figure 1 -Location Map

THE MONGOWIN PLUTON

District of Sudbury

By K.D. Card[1]

INTRODUCTION

The Mongowin pluton is a small composite intrusion of Precambrian age which occurs in lots 11 and 12, concession VI, Mongowin township, about six miles south of Espanola, Ontario. It intrudes rocks of the Huronian Gowganda Formation. A distinct circular magnetic anomaly is associated with the pluton (GSC, aeromagnetic map 1522G, Whitefish Falls, Ontario).

The Mongowin pluton is one of several composite intrusions which cut Huronian rocks along the north shore of Lake Huron. The Croker Island Complex is another member of this group (Card 1965) and the large circular magnetic anomalies on Manitoulin Island may be caused by similar intrusions.

PREVIOUS WORK

There are minor amounts of nickel-copper sulphide and magnetite mineralization associated with the body, and consequently it has been investigated several times in the past.

Moore (1929; 1932) described the body and the unusual colloform magnetite vein associated with it. Phemister (1939) described the rocks and the sulphide mineralization. Falconbridge Nickel Mines Ltd. drilled the body and performed a magnetic survey prior to 1939. Exploration work has not disclosed economic concentrations of metals.

The present work was carried out by the writer in the summer of 1965 in conjunction with detailed mapping of Mongowin township (Ontario Dept. Mines map P.391).

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GENERAL GEOLOGY

The pluton is elliptical in surface plan, and is approximately 2600 feet long and 1400 feet wide (Figure 2). It intrudes conglomerate, quartzite, and argillite of the Gowganda Formation on the north limb of the Bass Lake syncline. It apparently cuts several amphibolite bodies which are members of a post-folding, northwest-trending system of mafic dikes.

The intrusion is composed of several rock types. The northern two-thirds of the body is an olivine amphibolite, an ultramafic rock of unusual mineralogy. The middle one-sixth is quartz diorite, and the southern one-sixth is trondhjemite. The contact between the olivine amphibolite and the quartz diorite, although not exposed in outcrop, is apparently abrupt. The quartz diorite-trondhjemite contact, on the other hand, is gradational.

Petrography

Olivine Amphibolite:

The olivine amphibolite is a dark greenish-black rock composed of olivine, pyroxenes, amphiboles, and minor chrome spinel. In addition, the olivines are partly serpentinized and the pyroxenes uralitized. The texture is distinctly poikilitic with large (1 to 5 cm.) platy crystals of amphibole and pyroxene enclosing olivine crystals about 1 mm. in diameter (Photograph 1).

The olivine has a positive optic angle ($2V_z$) of about 85°, indicating that its composition is approximately $Fo_{95}Fa_5$. The olivine is more or less completely replaced by fibrous chrystotile, platy antigorite, and magnetite (Photograph 2). Some serpentine pseudomorphs after olivine are composite with antigorite cores and chrysotile rims. The magnetite is either disseminated throughout the pseudomorphs, or collected in the form of small veinlets.

The pyroxenes are pigeonite and augite. Augite occurs as exsolution lamellae parallel to the (001) plane of the host pigeonite, and as blebs within pigeonite and amphibole.

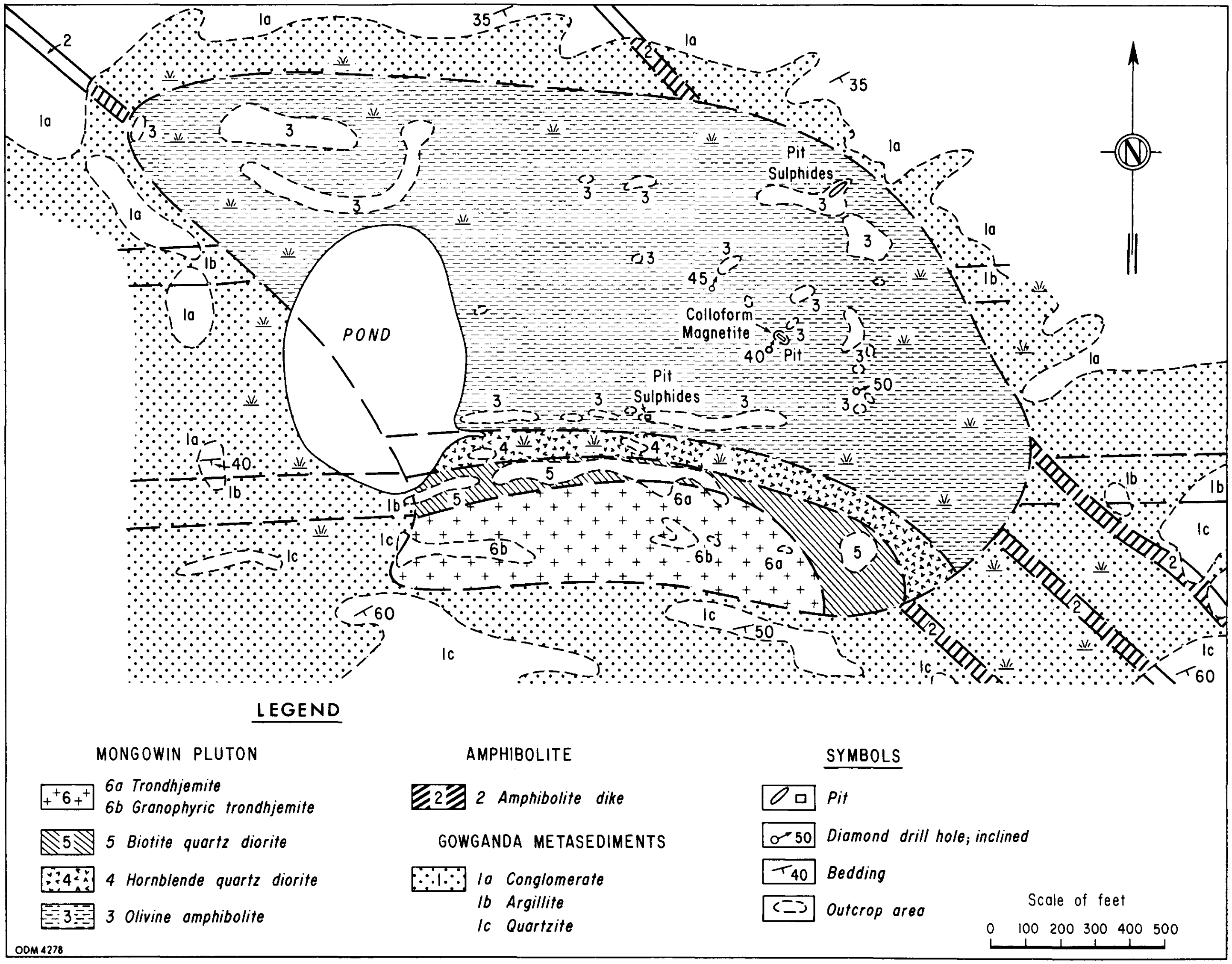

Figure 2 - Geology of the Mongowin Pluton

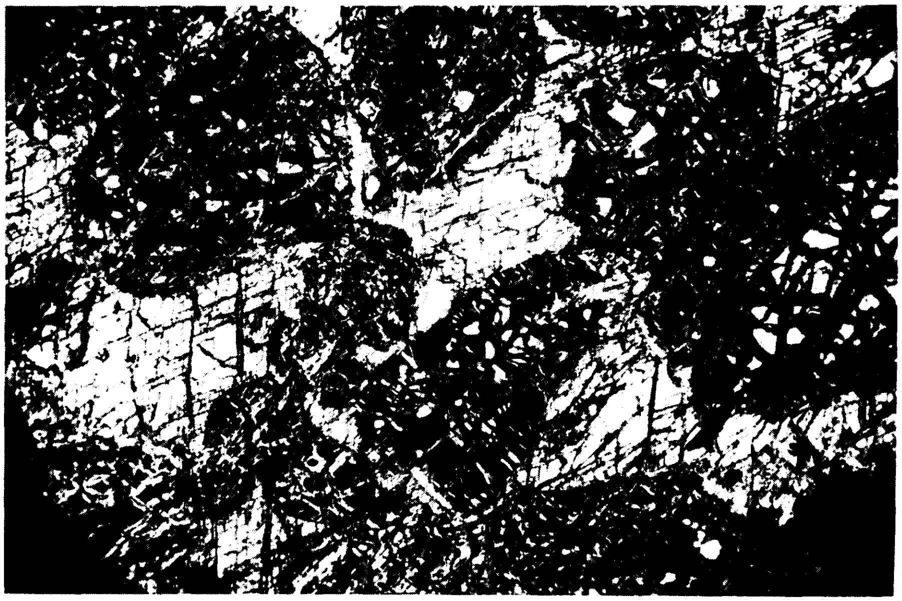

Photo 1. Photomicrograph of olivine amphibolite.

Photo 2. Photomicrograph of serpentinized olivine amphibolite.

The main amphibole is anthophyllite, but cummingtonite and green hornblende are also present. The amphiboles appear to replace pigeonite. This replacement is probably due to magmatic processes, rather than deuteric-type alteration such as serpentinization.

The pyroxenes and amphiboles are slightly uralitized. Minor amounts of actinolitic amphibolite, talc, chlorite, and magnetite have been produced by this alteration.

Modal analyses of olivine amphibolites are given in Table 1. The samples were taken from the northern, central, and southern portions of the ultramafic zone. The proportion of olivine to pyroxene probably varied originally from about 3:1 to 1:1. The amount of magnetite averages about 12 percent, thus accounting for the magnetic anomaly produced by the ultramafic rocks.

Table 1 Modes of Olivine Amphibolites

Sample	CM-65-M2	CM-65-M5	CM-65-M6
Olivine	8.9	52.1	60.4
Serpentine	50.6		
Pigeonite	4.7		
Augite	x	37.1	27.8
Amphiboles	20.6		
Actinolite	x	x	
Talc	x	x	
Chlorite	x	x	x
Spinel	x		
Magnetite	15.2	10.8	11.8
Estimated Original Mode			
Olivine	75	60	70
Pyroxene	25	40	30

x Present in trace amounts.

There is apparently no layering, nor any consistent pattern in variation of the proportions of the major primary minerals. There is variation in the intensity of serpentinization, and in the proportion of amphiboles to pyroxenes. In general, the olivine and pyroxenes are better preserved in the interior than in the outer portions of the ultramafic zone.

Quartz Diorite:

There are two varieties of quartz diorite present, a hornblende quartz diorite which occurs immediately south of the ultramafic rocks, and a biotite quartz diorite unit to the south of the hornblende quartz diorite.

The hornblende quartz diorite is a dark grey, medium-grained (½mm.) rock composed of green hornblende, saussuritized plagioclase ($An_{28 \pm 5}$), clinozoisite, quartz, muscovite, sphene, and chlorite.

The contact between the hornblende quartz diorite and the olivine amphibolite, although not exposed in outcrop, is apparently sharp. However, the lower part of the quartz diorite zone is rich in amphibole, containing more than 50 percent hornblende, so it is possible that there are very amphibole-rich phases present in the drift-covered interval.

The biotite quartz diorite is composed of plagioclase, quartz, biotite, chlorite, muscovite, clinozoisite, and minor carbonate, zircon, and apatite. Sphene, leucoxene, and magnetite are present in variable amounts as composite grains which were presumably formed by alteration of magnetite-ilmenite intergrowths.

The plagioclase is normally zoned from about $An_{30 \pm 3}$ to $An_{5 \pm 5}$. In most crystals, the strong zoning occurs only in a thin (0.01 mm.) outer shell. In other cases, there is patchy, diffuse zoning throughout the crystal.

Modal analyses of typical hornblende and biotite quartz diorites are given in Table 2.

Table 2 Modes of Quartz Diorites

Sample No.	CM-65-M8 Hornblende Quartz Diorite	CM-65-M10 Biotite Quartz Diorite	CM-65-M17 Biotite Quartz Diorite	CM-65-M23 Biotite Quartz Diorite
Plagioclase	15.2	49.0	44.7	35.5
Quartz	11.2	13.5	14.3	22.0
Amphibole	47.4			
Chlorite	26.2	10.3	22.0	20.7
Biotite				
Muscovite	x	18.2	10.0	18.2
Clinozoisite	x	x	3.3	
Carbonate		x	x	
Sphene	x			
Leucoxene	x	9.0	5.7	3.6
Magnetite	x			
Plagioclase Composition	$An_{28\pm5}$	$An_{30\pm3}$ to $An_{5\pm5}$	$An_{30\pm3}$	$An_{28\pm3}$ to $An_{5\pm5}$

x Present in trace amounts.

Trondhjemite:

There are two textural varieties of trondhjemite present; equigranular trondhjemite and granophyric trondhjemite.

The medium-grained (1mm.), light grey equigranular trondhjemite is in gradational contact with biotite quartz diorite. It is composed of albite ($An_{3\pm3}$), quartz, radiating sheaves of muscovite, and minor chlorite, zircon, apatite, sphene, leucoxene, and carbonate.

The equigranular trondhjemite grades southward into pink, medium-grained (1mm.) trondhjemite with a distinct granophyric texture (Photograph 3). The rock consists mainly of a granophyric intergrowth of albite ($An_{3\pm3}$) and quartz, with radiating muscovite sheaves, and minor chlorite, carbonate, zircon, and tourmaline.

Modal analyses of typical trondhjemites are given in Table 3.

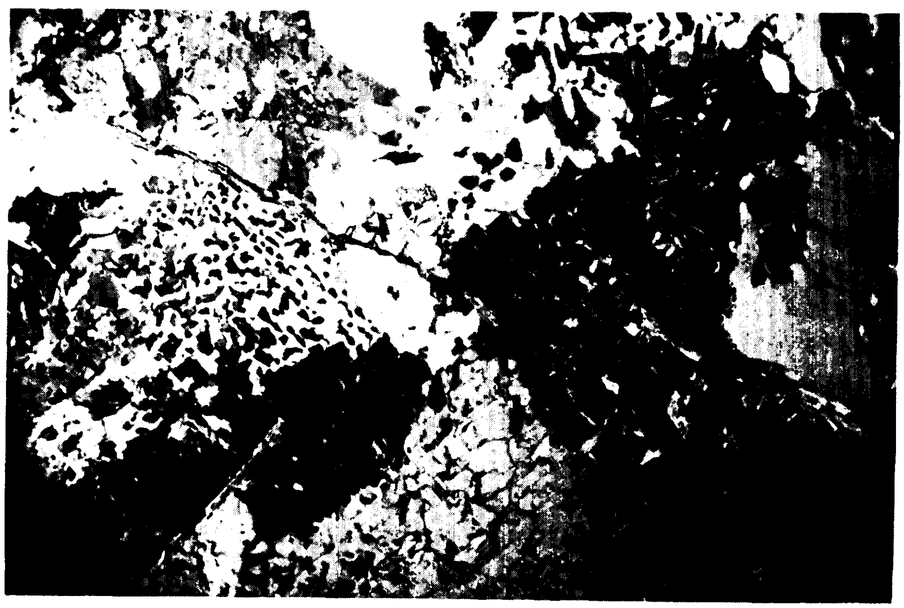

Photo 3. Photomicrograph of granophyric trondhjemite.

Table 3 Modes of Trondhjemites

Sample No.	CM-65-M11 Trondhjemite	CM-65-M12 Granophyric Trondhjemite	CM-65-M14 Granophyric Trondhjemite
Plagioclase	45.6	40.3	30.3
Quartz	22.6	36.7	42.7
Chlorite	6.4		3.0
Muscovite	21.1	20.0	10.6
Carbonate, Sphene and Accessories	4.3	3.0	3.4
Plagioclase Composition	$An_{3\pm3}$	$An_{3\pm3}$	$An_{5\pm5}$

Mineralogical and Chemical Variations

The rocks of the pluton display systematic and inter-related variations in mineralogy and bulk chemistry. Figure 3 shows the mineralogical variations for the body as a whole while Figure 4 depicts the bulk chemical variations.

The northern two-thirds of the body was probably originally peridotite composed of 50 to 75 percent olivine and 25 to 50 percent pyroxene. The amphiboles now present in the ultramafic rocks probably formed by inversion of the pyroxene. Chemically, the olivine amphibolite is similar to peridotite, and there is little chemical variation throughout the ultramafic portion of the body (Analyses 1 to 5, Table 4).

Serpentinization has apparently produced little chemical change. Chemical analyses of little serpentinized (Analysis 1), and highly serpentinized (Analysis 3) olivine amphibolites with approximately the same original mineral compositions are given in Table 4. These show that there has been little bulk chemical change on serpentinization, other than a possible change in FeO/Fe_2O_3 ratio.

There is an abrupt change in mineralogy and bulk chemistry at the ultramafic-quartz diorite contact. The olivine, pyroxene, cummingtonite, and chrome spinel of the olivine amphibolite are replaced by the hornblende, oligoclase, and quartz of the quartz diorite. These mineralogical changes are reflected in the bulk chemistry by an abrupt decrease in MgO and Cr_2O_3, and increase in Al_2O_3 and SiO_2 (Figure 4, Table 4). The hornblende quartz diorite is gabbroic to dioritic in chemical composition (Analysis 6, Table 4).

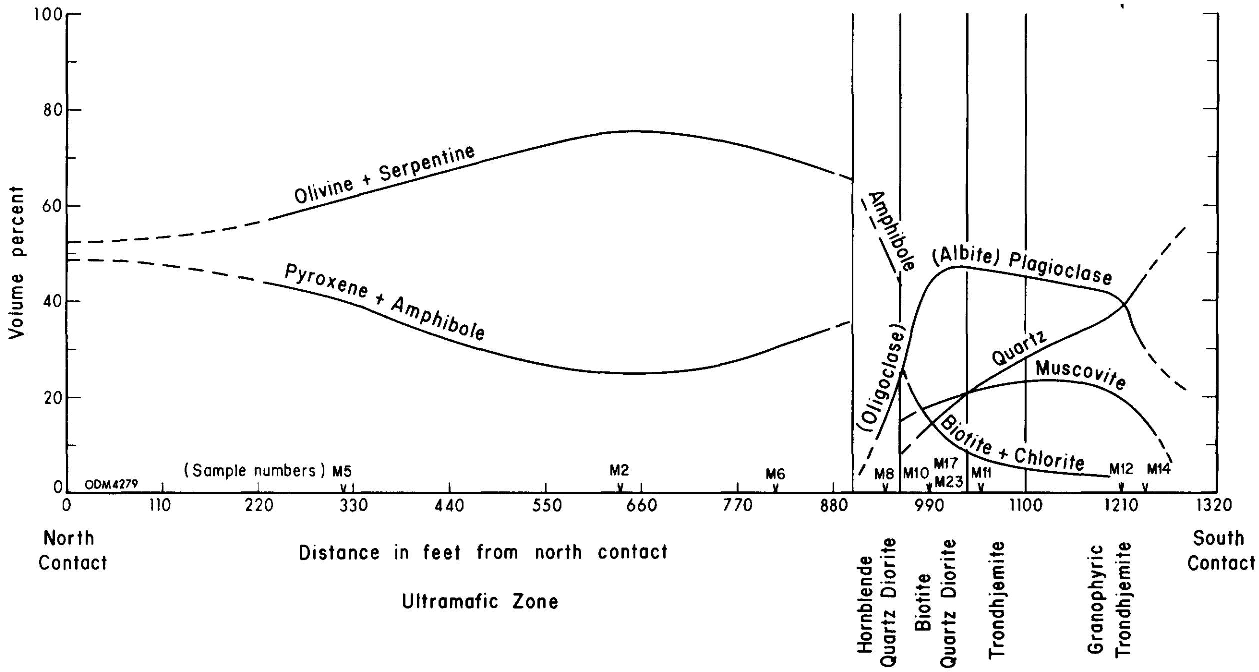

Figure 3 – Mineralogical Variations across the Mongowin Pluton

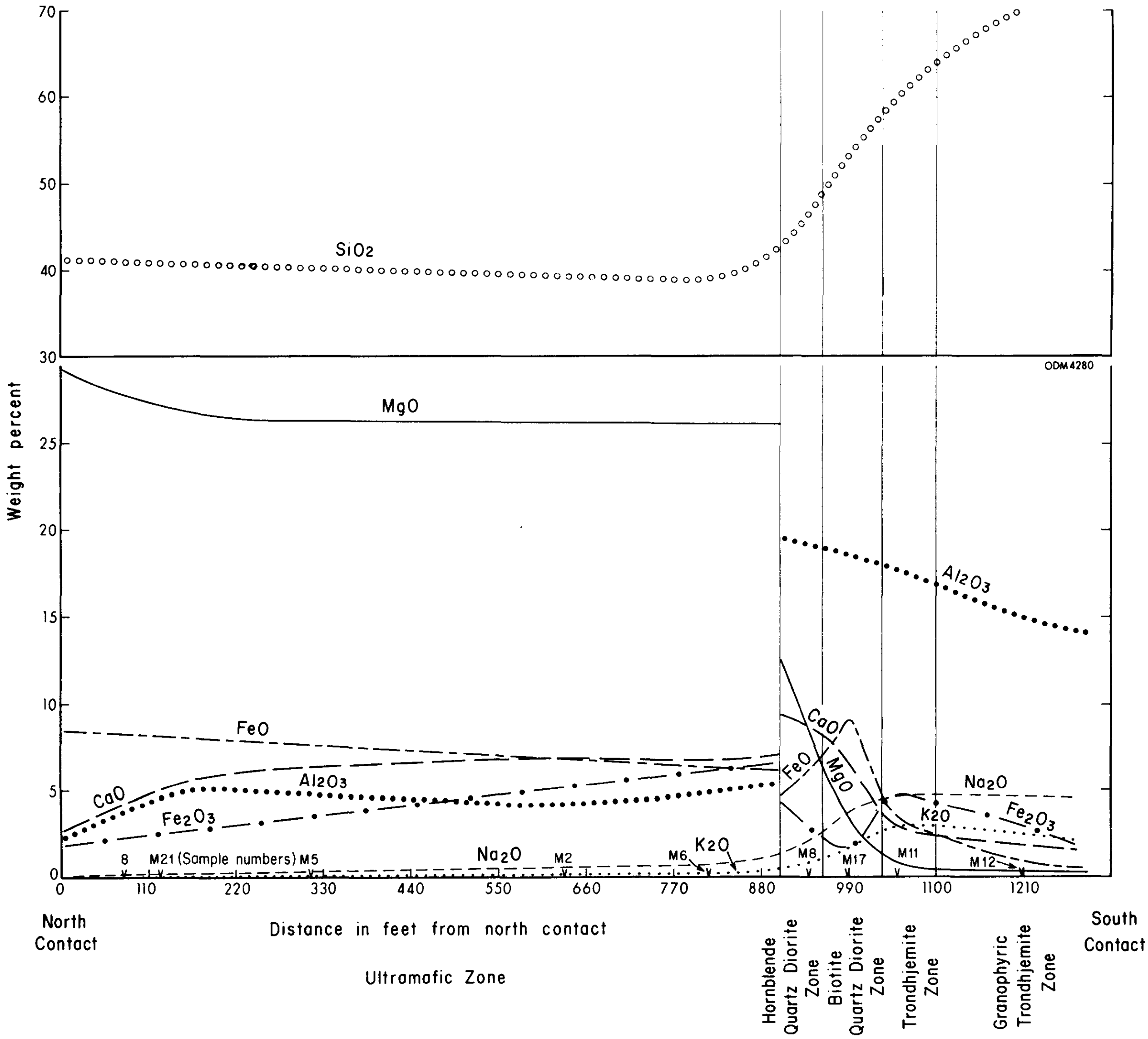

Figure 4 – Chemical Variations across the Mongowin Pluton

Table 4 Chemical Analyses of Rocks and Minerals of the Mongowin Pluton

Sample No.	1 CM-65-M2	2 CM-65-M5	3 CM-65-M6	4 BRM-65-8	5 M-21	6 CM-65-M8	7 CM-65-M17	8 CM-65-M18	9 CM-65-M11	10 CM-65-M12	11	12
Rock Type	Olivine Amphibolite	Olivine Amphibolite	Olivine Amphibolite	Olivine Amphibolite	Olivine Amphibolite	Hornblende Quartz Diorite	Biotite Quartz Diorite	Contact Quartz Diorite	Trondhjemite	Granophyric Trondhjemite	Green Serpentine	White Serpentine
SiO_2	38.20	38.73	38.42	41.23	42.44	49.76	50.99	64.50	58.98	70.03	40.80	41.90
Al_2O_3	4.12	4.46	4.98	4.40	5.45	19.43	17.02	14.70	17.55	14.93	1.12	0.32
Fe_2O_3	4.86	7.07	6.43	2.95	2.25	2.22	1.50	1.15	4.98	2.75	7.46	1.48
FeO	6.71	5.77	6.35	7.94	7.65	5.91	9.45	4.26	3.18	0.65	(Total Fe)	3.34
MgO	26.24	21.28	25.91	28.30	26.31	7.54	3.54	1.69	0.52	0.04	35.02	39.44
CaO	6.80	10.73	6.52	4.80	5.86	8.71	6.30	2.95	2.60	1.94	Nil	0.33
Na_2O	0.32	0.26	0.71	0.31	0.49	1.75	3.68	3.44	4.58	4.50	Nil	
K_2O	0.12	0.07	0.12	0.16	0.18	1.30	0.89	2.46	2.70	2.38		
H_2O+	9.22	8.86	8.08	7.09	6.14	2.22	2.97	2.15	1.54	0.79		
H_2O-	0.60	0.74	0.33	0.11	0.09	0.02	0.03	0.05	0.05	Nil	2.02	
CO_2	0.52	0.22	0.34	0.20	0.41	0.38	1.57	2.29	2.26	1.50		13.55
TiO_2	0.24	0.23	0.26	0.80	1.15	0.22	1.28	0.46	0.18	0.05		
P_2O_5	0.03	0.02	0.03	0.12	0.25	0.02	0.51	0.03	0.11	0.02	Trace	
S	0.14	Nil	0.10	Nil	Nil	0.06	Nil	Nil	0.43	0.59		
MnO	0.14	0.11	0.16	0.10	0.12	0.11	0.13	0.08	0.04	0.03		
Cr_2O_3	0.69	0.62	0.64	0.76	0.91	Nil	0.01	0.15	0.01	<0.01		
V_2O_3	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.02	< 0.01	<0.01		
Total	98.47	99.20	99.40	99.29	99.73	99.68	99.88	100.39	99.71	100.20		100.36
L.O.I.	11.59	10.51	9.70			3.16	4.41	4.42	3.66	2.47	14.76	

The hornblende quartz diorite passes gradationally into biotite quartz diorite by replacement of hornblende by biotite and chlorite. The amount of plagioclase, quartz, and muscovite increases from north to south in the quartz diorite zone. The amount of magnetite probably decreases. The composition of the plagioclase is constant throughout the quartz diorite zone. The corresponding chemical changes are increases in SiO_2, Na_2O, and K_2O. FeO, Al_2O_3, and CaO reach a maximum in the lower part of the quartz diorite zone, and then gradually decrease.

The trondhjemite zone is characterized by the presence of albite rather than oligoclase, and muscovite rather than biotite and chlorite. The amount of quartz continues to increase, whereas the amount of plagioclase decreases slightly. The mineralogical changes are reflected in gradual decreases in Al_2O_3, MgO, CaO, and total iron oxides, and an increase in SiO_2 from north to south. The amounts of Na_2O and K_2O are fairly constant throughout the zone. The Fe_2O_3/FeO ratio increases in the southern part of the trondhjemite zone.

Figure 5a is an FeO-MgO-alkalis diagram of the analyzed rocks of the pluton. Their compositions, expressed in terms of weight percent of the oxides, fall on or near a smooth curve. This differentiation curve corresponds closely to the differentiation curve of the Palisades sill and the Nipissing sills which are interpreted by Hess (1960) to be examples of intermediate differentiation typical of thick sills.

Structural Relationships

The pluton is located on the north limb of a major fold, the Bass Lake syncline (Ontario Dept. Mines map P.391). It straddles the contact between the lower part of the Gowganda Formation which is mainly conglomerate and argillite, and the upper part of the formation which is mainly quartzite and argillite. The intrusion sharply transects the bedding and secondary foliation of the country rock and is itself unfoliated. The same stratigraphic members of the Gowganda Formation are continuous on both sides of the pluton.

The contact between the quartz diorite phase of the intrusion and Gowganda quartzite and argillite is exposed at the southwest edge of the pluton. The quartzite is glassy and brecciated within a few feet of the contact. The argillite has been metamorphosed to a biotite hornfels within about five feet of the contact. The contact is approximately vertical where it is exposed in outcrop. Diamond drilling indicates that the northern contact dips steeply outward (Phemister 1939). Thus the pluton sharply transgresses the trends of the country rocks. It was apparently forcefully intruded into a previous folded sedimentary sequence.

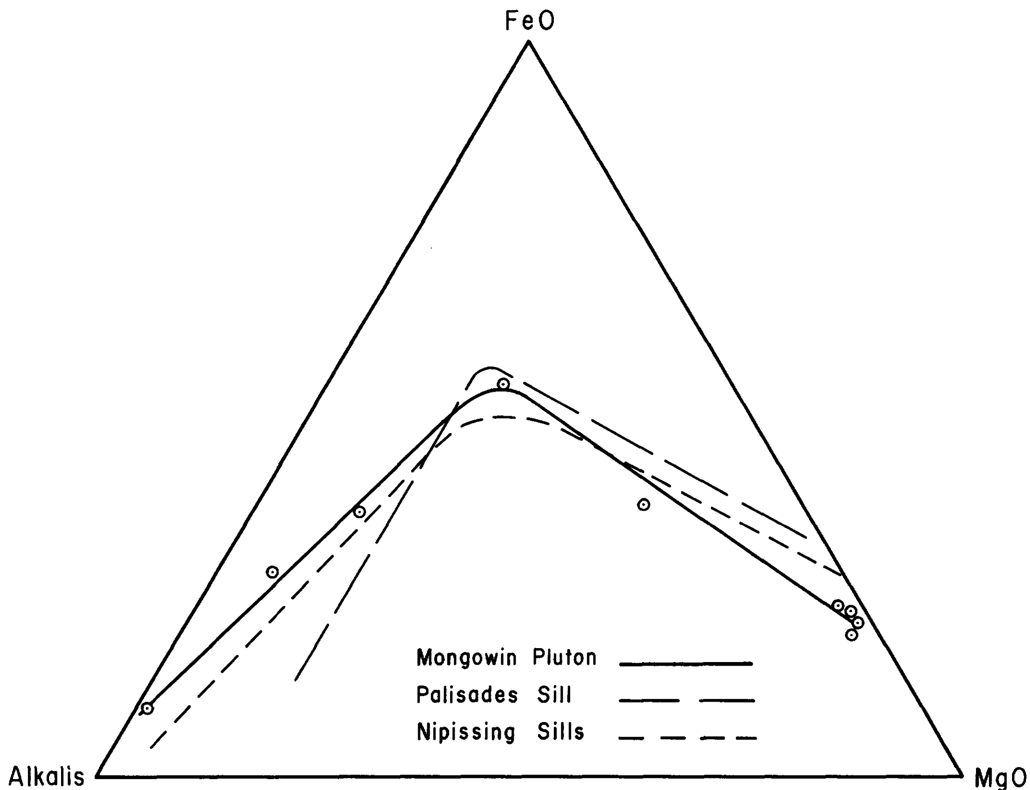

Figure 5a

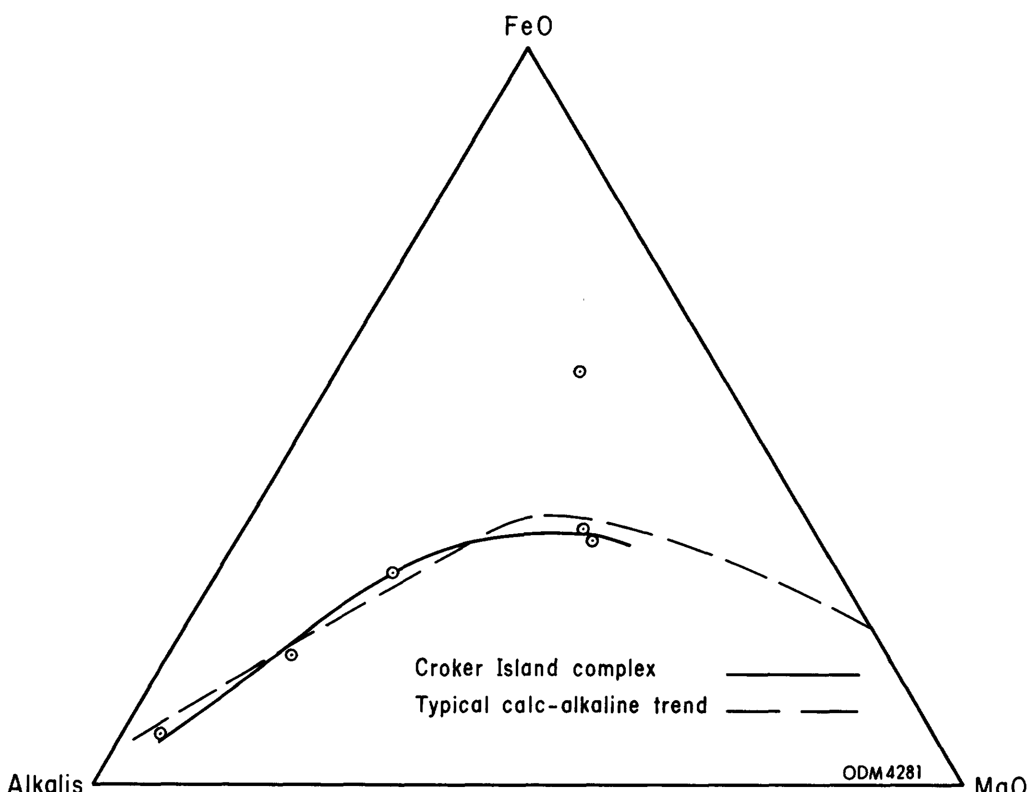

Figure 5b

Figure 5—FeO-MgO-Alkalis Differentiation Diagrams

Age and Correlation

The Geological Survey of Canada (Lowdon 1963, p. 71, 72) has obtained a date of 1485 million years on muscovite from the granophyric trondhjemite by the K/A method. This age compares favourably with the 1450±50 million year Rb/Sr whole rock age of the Croker Island Complex (Van Schmus 1965).

Granitic rocks and metamorphic minerals from the Penokean fold-belt in Upper Michigan and central Wisconsin have ages of about this order. Muscovite from metamorphic rocks in Baldwin and Drury townships to the northeast have ages of 1405 and 1440 million years, although the major metamorphism was of Penokean age (1800±100 million years). Recent Rb/Sr whole rock age dating carried out by T.E. Krogh in the Grenville Province to the south reveals the presence of plutonic rocks with primary ages of about 1300 and 1500 million years (Davis et al, 1967). Possibly the Mongowin pluton and the Croker Island Complex were emplaced at about the time of major orogenic events in the Grenville Province.

Petrology

The relatively smooth, continuous variation in chemical composition displayed by the different zones of the body (Figure 6) and their close spatial relationship indicates that the various rock-types were derived from a single magma source. There is, however, an abrupt change in mineralogy and chemistry at the ultramafic-quartz diorite contact, indicating that the body may be a composite intrusion. A magma, of peridotite composition was injected first, followed closely by a dioritic magma. The ultramafic magma solidified quickly, apparently before any significant crystal settling could occur. The dioritic magma, on the other hand, did differentiate to produce gabbroic, dioritic, and trondhjemite rocks.

The differentiation process is a problem. The layering is apparently vertical and is parallel to the walls of the intrusion which are also vertical. The body was emplaced after regional folding and there is no possibility that it differentiated horizontally and was later rotated to its present position. Possibly the differentiation took place by diffusion in the magma at right angles to the walls of the magma chamber. Diffusion gradients set up by border contamination of the magma by the

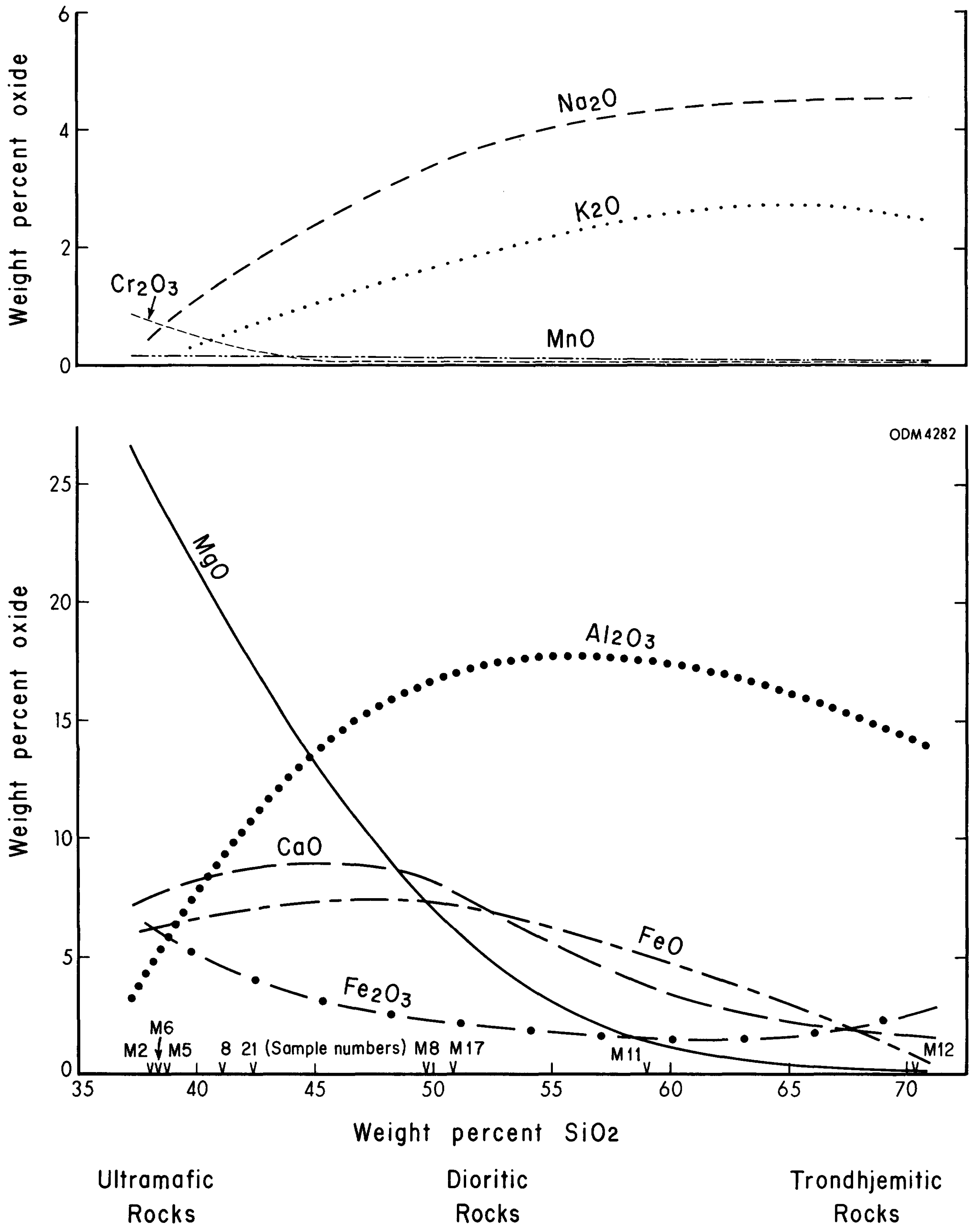

Figure 6 – Harker Chemical Variation Diagram for the Mongowin Pluton

quartzitic sediments may have produced the observed rock sequence. Chemical analyses of a quartz diorite sample taken from the contact (Analysis 8) and a quartz diorite sample (Analysis 7) taken about 35 feet inside the contact are given in Table 4. Comparison of the two analyses suggests that there may have been border contamination of the magma by partial assimilation of the siliceous, aluminous country rocks. It is possible that compositional changes at the contact could produce gradients sufficiently effective to account for the observed differentiation.

The overall differentiation trend, as shown in Figure 5a, is parallel to the normal calc-alkalic trend. However, the differentiation trend of the Mongowin pluton is toward residual liquids rich in Na_2O, rather than K_2O as in normal calc-alkalic rock suites. Differentiation toward a sodic residuum has been termed the trondhjemite trend by Lipman (1963). The original composition of the magma presumably determines which trend the residual liquids will follow.

Comparison of the Differentiation Trends of the Croker Island Complex and the Mongowin Pluton

The Mongowin pluton and the Croker Island Complex are thought to be members of the same intrusive series since they are approximately the same age and are both calc-alkalic. However, there are some mineralogical and chemical differences between the two bodies.

The Croker Island Complex consists of rocks ranging from pyroxene gabbro to granite. There are representatives present of practically every member of the calc-alkalic rock series between these two end members. The intermediate and granitic varieties are apparently dominant. The Mongowin pluton, on the other hand, consists mainly of peridotite, with lesser amounts of intermediate and granitic rocks. There are no pyroxene gabbros present.

The chemical variations exhibited by the rocks of the Croker Island Complex are given in Figure 7 and chemical analyses in Table 5. The Harker variation diagrams show that the trends of Al_2O_3, K_2O, and MgO are similar in the two bodies. In the Croker Island Complex, Na_2O reaches a maximum in the intermediate rocks and then decreases, whereas it increases continuously in the Mongowin pluton. CaO and FeO reach a maximum and then decrease

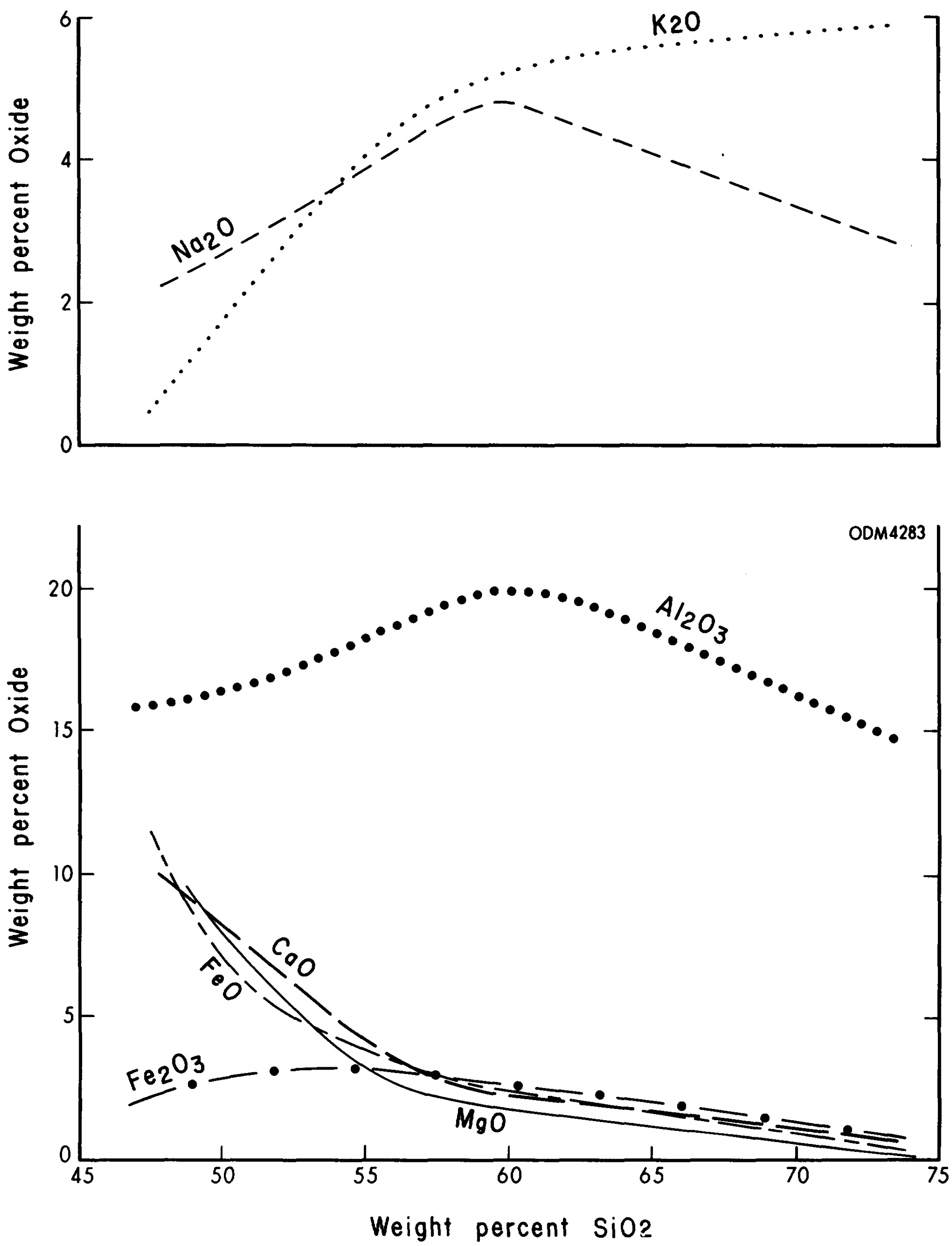

Figure 7 — Harker Chemical Variation Diagram for the Croker Island Complex

Table 5 Chemical Analyses of Rocks of The Croker Island Complex

	Gabbro CC-36	Gabbro NS-64-1	Gabbro CC-43	Syenodiorite CC-26	Monzonite CC-27	Granite CC-29
SiO_2	44.70	50.85	51.00	54.85	59.40	72.87
Al_2O_3	16.09	16.57	15.90	18.08	19.86	14.93
Fe_2O_3	2.50	1.73	3.33	3.29	2.47	0.89
FeO	11.25	6.00	5.63	4.40	2.45	0.65
MgO	5.68	6.95	7.30	3.27	1.89	0.33
CaO	9.52	8.26	8.20	4.06	2.49	0.66
Na_2O	2.66	2.41	2.64	3.52	4.83	2.95
K_2O	0.52	2.02	1.75	4.72	4.77	5.83
H_2O+	0.26	0.53	1.02	0.93	0.59	0.29
H_2O-	0.09	0.26	0.10	0.15	0.06	0.08
CO_2	0.09	0.41	Nil	0.41	0.25	0.42
TiO_2	2.21	1.55	1.41	1.56	0.94	0.21
P_2O_5	0.26	0.48	0.46	0.33	0.49	0.03
S	0.05	0.12	Nil	Nil	0.10	Nil
MnO	0.21	0.09	0.09	0.08	0.05	0.01
Cr_2O_3	0.05	0.15	Nil	Nil	Nil	0.02
V_2O_3	0.05	0.03	0.03	0.02	0.02	Nil
Total	99.19	98.41	98.86	99.67	100.66	100.17
S.G.	3.03	2.90	2.84	2.76	2.70	2.62
L.O.I.	1.12	2.01	1.51	1.24	0.74	0.71

in the Mongowin pluton, whereas they decrease continuously in the Croker Island Complex. The granitic rocks of the Croker Island Complex are enriched in potash relative to soda, whereas the reverse is true in the Mongowin pluton.

The differentiation trend of the Croker Island Complex is given in Figure 5b. The differentiation exhibited is typical of little differentiated calc-alkalic rock suites (Hess 1960).

The composition of the parent magma was probably intermediate (quartz dioritic) in the case of the Croker Island Complex. Differentiation occurred mainly in the magma chamber and the various rock types were formed by successive intrusions of appropriate composition. The Mongowin pluton parent magma was probably gabbroic. Differentiation into an ultramafic fraction and an intermediate (quartz dioritic) fraction occurred in the magma chamber. The ultramafic magma was emplaced first, followed shortly after by a dioritic phase which differentiated in situ.

AEROMAGNETIC DATA

The Mongowin pluton, like the Croker Island Complex, produces a pronounced, circular aeromagnetic anomaly. Until the Croker Island Complex was investigated (Card 1965), it was taken for granted that such anomalies indicated the presence of alkalic complexes such as those to the north in the Chapleau area. This assumption was of some economic importance in view of the fact that the alkalic complexes commonly contain niobium (columbium) and rare-earth minerals, whereas the calc-alkalic complexes do not. The calc-alkalic complexes, especially those with mafic and ultramafic rocks, are more apt to contain copper-nickel sulphide mineralization or serpentine.

If the large magnetic anomalies on Manitoulin Island are produced by calc-alkalic intrusions, exploration for columbium and rare-earths would probably be a waste of time and money. However, investigation of these areas by geophysical methods for sulphide deposits may be warranted.

COLLOFORM MAGNETITE

Disseminated magnetite occurs throughout the pluton, especially in the ultramafic rocks. Much of the disseminated magnetite in the olivine amphibolite was produced by serpentinization of the olivine.

There is an unusual occurrence of colloform magnetite in the central part of the ultramafic zone (Figure 2). The vein consists of masses of colloform magnetite with botryoidal outer surfaces coated with massive serpentine. The magnetite occurs in brecciated, serpentinized olivine amphibolite and is closely associated with veinlets of calcite and serpentine. Calcite is intergrown with magnetite, and veinlets of calcite and serpentine cut the magnetite. The magnetite vein varies from less than 1 inch to about 6 inches in thickness and extends to a depth of at least 15 feet.

Sections through magnetite nodules show concentric layering and a radiating structure (Figure 8). The banding is due to variations in grain size, to variations in the development of the radiating bladed structure, and to serpentine layers. The banding is confined to the outer parts of most nodules; the inner portions are generally coarse-grained and display good radiating structure. This structure is produced by blade-like crystals of magnetite about 2 mm. wide and up to 6 mm. long. The bladed crystals may extend through several layers, but more commonly are confined to the inner, massive parts of nodules. The radiating magnetite blades are iridescent and are commonly coated with serpentine. Individual blades exhibit magnetic polarity.

The magnetite is very pure, and a chemical analysis given by Moore (1932) shows its composition to be that of theoretically pure magnetite. A spectrographic analysis of the magnetite detected the following elements in trace amounts.

Copper - $<$0.001%	Titanium - 0.02%
Nickel - $<$0.001%	Lead - 0.01%
Cobalt - $<$0.001%	Platinum - None

The serpentine associated with the magnetite is a dense, massive variety ranging from creamy white to dark green in colour. The colour differences are apparently due to variations in the amount of iron present. A cream-coloured serpentine (Analysis No.12, Table 4) contains about 5 percent total iron whereas a

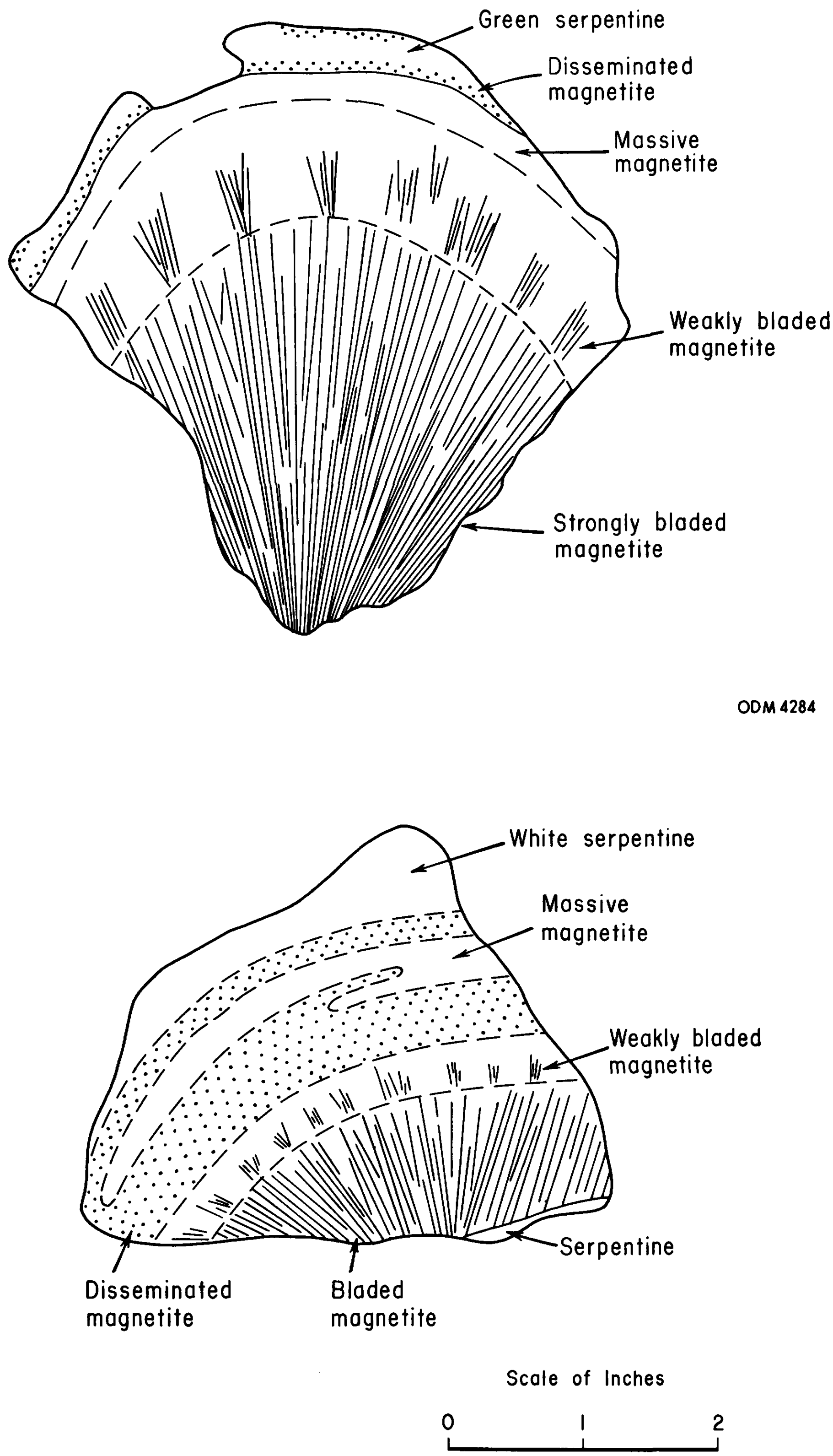

Figure 8 – Sketches of Colloform Magnetite Nodules

a light green serpentine specimen contains over 7 percent total iron (Analysis No.11, Table 4).

The calcite is ordinary white vein calcite and clear Iceland spar. The spar occurs as small lenses in the serpentine, and as crystals intergrown with magnetite and serpentine. Calcite occurs as rims around ultramafic "breccia" fragments in massive green serpentine. Several crustiform veinlets consist of alternating layers of calcite, serpentine, and magnetite.

The colloform magnetite, the dense serpentine, and the calcite were probably formed by a common process; it seems logical to suppose that this process was similar to that which produced magnetite and serpentine throughout the ultramafic rocks.

Moore (1932) postulated that the colloform magnetite vein was originally botryoidal limonite which was metamorphosed to magnetite by the injection of "granite". This does not seem probable however, as the "granite" is in reality a differentiate and not a later intrusion. Also, x-ray studies by Moore (1932) showed no evidence of pseudomorphism after a hydrous oxide.

The colloform magnetite appears to have been deposited from a colloidal suspension. Features indicative of colloidal origin include the concentric layering, the radiating structure, and the calcite and serpentine veinlets and coatings which could represent fillings of syneresis cracks. Stevenson and Jeffery (1964) suggest that the colloform magnetite of the Mongowin pluton was formed by a process first postulated by Shand (1947). This process consists of concentration of iron in the residual liquids in the form of a hydrosol of ferrous hydroxide. This hydrosol would lose water and the hydroxide is oxidized to magnetite. Large amounts of water are released by the reaction, and this could account for the abundance of serpentine in and around the magnetite.

An alternative hypothesis is that the magnetite, serpentine, and Iceland spar were formed during serpentinization of the olivine amphibolite. Chloride-rich hydrous solutions would alter the olivine to serpentine and iron oxides. The iron would be in an ionic state in the HCl solution. During crystallization, an intermediate colloidal state of aggregation could have existed long enough for the deposition of the colloform magnetite. The deposition of the magnetite was probably brought about by reaction between HCl solutions and carbonate in the altered olivine amphibolite. Stevenson and Jeffery (1964) postulate that the Empire amphibolite colloform magnetite deposit was formed by a similar process.

SULPHIDE MINERALIZATION

Pyrrhotite, chalcopyrite, and minor pyrite occur near the northern and southern contacts of the ultramafic zone. The sulphides are mainly disseminated but there are a few massive patches. Polished section examination shows that chalcopyrite appears to replace pyrrhotite. The ratio of pyrrhotite to chalcopyrite averages about 4:1.

Assays of samples by the writer and from Phemister (1939) disclose the presence of trace amounts of copper, cobalt, and nickel in olivine amphibolite which contains no sulphides, and increasing amounts of these metals in rocks with increasing amounts of disseminated sulphides (Table 6). Copper, nickel, and cobalt are presumably present in the femic silicates in the unmineralized rock.

The presence of trace amounts of copper, nickel, and cobalt in the ultramafic rocks indicates that the rocks themselves are a possible source of the metals. Trace amounts of metals present in the olivine are released during serpentinization. If the hydrous solutions effecting this alteration contain sulphur in one ionic form or another, this could combine with the copper and nickel to produce pyrrhotite and chalcopyrite. The sulphides would either be distributed throughout the rocks, or could migrate to suitable "traps" such as contacts and breccia zones.

Table 6 Copper, Nickel, Cobalt and Gold Assays

Sample No.	BRM-65-8 Sulphide-free olivine amphibolite	R-9 Minor Sulphide Mineralization	Disseminated Sulphides	Less Disseminated Sulphides	Disseminated Sulphides with massive patches
Cu	< 0.01%	0.26%	0.07% 0.07% 3.00%	0.44%	0.89%
Ni	< 0.05%	0.47%	1.04% 1.05% 0.55%	0.21%	0.28%
Co	< 0.05%	< 0.05%			
Au			0.01 oz./ton 0.01 oz./ton Trace		

Sample	Heavily Disseminated Sulphides	Massive Sulphide	Massive Pyrrhotite
Cu	0.39%	2.38%	Trace
Ni	0.84%	3.82%	2.43%
Au			0.01 oz./ton

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