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THE MUSKOX INTRUSION, A RECENTLY DISCOVERED LAYERED INTRUSION IN THE COPPERMINE RIVER AREA, NORTHWEST TERRITORIES, CANADA[1]

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ABSTRACT

The Muskox intrusion is a Precambrian layered basic pluton, 74 miles in length, which is dike-like in plan and funnel-shaped in cross-section. Its internal structure is divided into four principal units—a feeder, marginal zones, a central layered series and an upper border group. The feeder contains bronzite gabbro and picrite in zones parallel to the nearly vertical walls. The marginal zones parallel the walls of the intrusion which dip inward at angles of 23 to 57°, and grade inward from bronzite gabbro at the contact through picrite and feldspathic peridotite, to peridotite and, in places, dunite. The central layered series is 8500 feet thick and contains 38 main layers of dunite, peridotite, pyroxenites and gabbros which vary in thickness from 10 to 1800 feet. These layers are nearly flat-lying and discordant to the marginal zones. The upper border group is 200 feet thick and is characterized by an upward gradation from granophyre-bearing gabbro to granophyre. Preliminary calculations indicate that the Muskox intrusion has a higher olivine content than would normally be expected from a magma chemically similar to its chill facies and it is concluded that the chill phase only represents the fluid portion of the solid (olivine)-fluid magma.

INTRODUCTION

The Muskox Intrusion is a new addition to the growing family of layered intrusions. It has certain unique features which distinguish it from other layered intrusions such as the presence of a feeder, and the fact that its base, walls and roof are all exposed. This paper will deal with only one aspect of the intrusion—the apparent difference between the bulk composition of the intrusion and its chill phase. The intrusion is under study as part of the Canadian program for the International Upper Mantle Project and aeromagnetic, gravity and drilling programs are planned in addition to the detailed petrologic, mineralogical and chemical studies.

LOCATION AND PREVIOUS WORK

The Muskox Intrusion outcrops in the northwestern corner of the Canadian Shield (Fig. 1). It crosses the Arctic Circle at a point about 90 miles east of Port Radium on Great Bear Lake.

The intrusion was discovered by H. Vuori of the Canadian Nickel Company in 1956, and was mapped by Smith in 1959, assisted by Kapp in 1960, on a scale of 1 inch to 1000 feet. The mapping data is summarized on five sheets published at a scale of 1 inch to ½ mile (Smith, 1962). The regional geology was mapped by a helicopter-supported geological survey led by J. A. Fraser (1960) in 1959, and an aeromagnetic survey was completed by the Geological Survey in 1961.

[1] Canadian Contribution to the International Upper Mantle Project No. 5. Published by permission of the Director, Geological Survey of Canada.

REGIONAL GEOLOGY

The Muskox Intrusion outcrops in a basement complex of steeply dipping gneiss and metasedimentary rocks having a dominant north-northwest structural grain. The basement is cut by granodiorite which has a K/Ar age on biotite of 1765 m.y.

The basement is overlain unconformably by a sequence of sandstone, dolomite and basaltic flows which dip gently to the north, where they form a cover over the older basement. All the rocks of the area are cut by north-northwest-trending diabase dikes.

The Muskox Intrusion follows the grain of the basement rocks, but at the unconformity it has spread out to develop its funnel-shaped cross-section. The roof has barely penetrated the sandstone member of the cover, fragments of which are included in the granophyre of the upper border group. The Muskox Intrusion is dated, from biotite in picrite of the marginal zone, at 1155 m.y.

STRUCTURAL FORM

External form. The Muskox Intrusion is 74 miles long, is dike-like in plan and funnel-shaped in cross-section. Its structural form is analogous to that of a sailing ship with a deep keel, plunging at an angle of less than 5° toward the north. The southern half (Fig. 2), which outcrops for 37 miles, represents the deep keel or feeder extension, exposed at the surface. The northern half represents the hull, and the extreme north the deck or roof, plunging under the cover rocks.

The symmetry of the intrusion in plan is broken

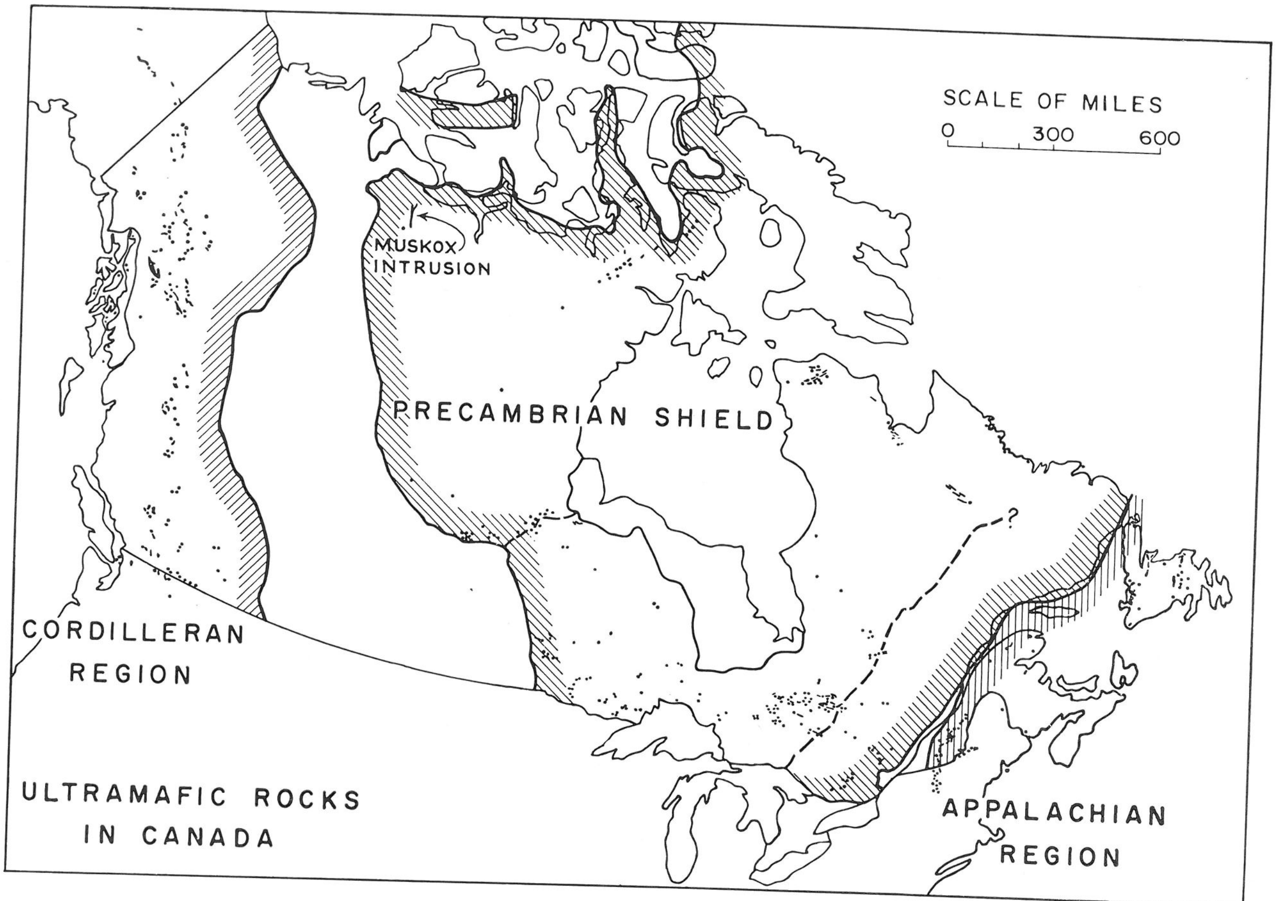

FIG. 1. Index map, showing location of the Muskox Intrusion.

by a northerly-trending fault which cuts the western side of the intrusion. The fault has a horizontal displacement of 5 miles. When the displacement along the fault is restored (in Fig. 2, A′ moves to A, and B′ moves to B) the intrusion is seen to be symmetrical in plan with two northward projecting limbs formed as its syncline-shaped roof plunges under the cover rocks.

The feeder of the intrusion is dike-like and vertically dipping, similar in attitude to the satellite diabase dikes. It is 500 to 1800 feet wide, somewhat wider than the diabase dikes which have an average width of about 100 feet. The northern half of the intrusion has inward-dipping sides, whose dips have been calculated from drill holes and are summarized in Fig. 2. They vary from 58° on the south to 22° at the extreme northeast end.

Internal units. The internal structure of the intrusion is divided into four principal units—the feeder, the marginal zones, the central layered series and the upper border group.

The *feeder* is distinctive in having units of bronzite gabbro and picrite parallel to the nearly vertical walls. The southern end of the feeder is filled with gabbro but, as it is traced northward, picrite occurs first as pods and then as a continuous band along the center. On approaching the Coppermine River, two bands of picrite are found, bounded on both sides by gabbro. The latter is chilled against the country rocks, but not against the picrite. The picrite does not appear to represent a separate intrusion, but a segregation in the center of the feeder.

The *marginal zones* parallel the inward dipping walls of the intrusion and are from 200 to 1200 feet thick. They grade inward from hypersthene gabbro at the contact through picrite and feldspathic peridotite, to peridotite and, in places, dunite. In other words, the marginal zones are gradational zones in which plagioclase decreases, and olivine increases, inward. Accompanying this change in mineral abundance is a change in mineral composition, with olivine becoming more magnesian, and plagioclase becoming more calcic, inward. Nickel-copper sulfides and

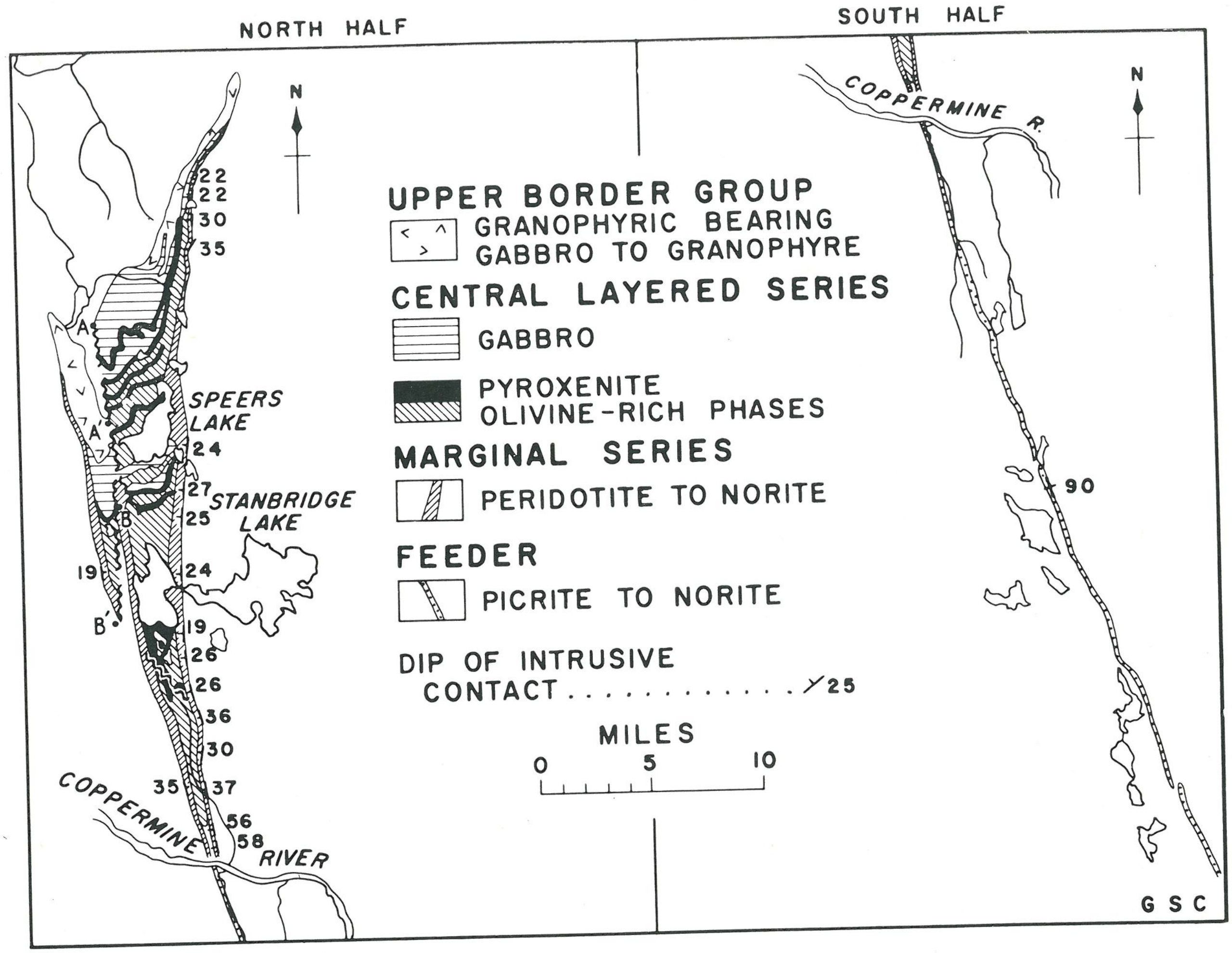

FIG. 2. Structural units of the Muskox Intrusion.

pyrrhotite occur sporadically along the wall of the intrusion.

The *central layered series* is approximately 8500 feet thick. It has 38 main layers, varying in thickness from 10–1850 feet. Small scale layering is present, but uncommon. The series contains alternating layers of dunite (serpentinized), peridotite, feldspathic peridotite, picrite, olivine clinopyroxenite, websterite, orthopyroxenite, troctolite, olivine gabbro, gabbro, norite and anorthositic gabbro. The layers have sharply defined contacts, in contrast to those of the marginal zones. They dip gently to the north at a similar angle to the overlying cover rocks and are thus discordant to the marginal zones. Chromite occurs in one pyroxenite horizon and contains disseminated copper-nickel sulfides and platinum group metals.

The *upper border group* is arbitrarily defined by the appearance of granophyric intergrowths and quartz in the upper gabbro units. The rock units are not sharply defined but grade upward, within a thickness of 200 feet, from granophyre-bearing gabbro to mafic granophyre, granophyre and intrusive breccia. In a mineralogical sense, the upper border group is a zone in which granophyric intergrowths and quartz increase upward at the expense of mafic minerals.

Some Quantitative Considerations of the Muskox Magma

It is possible to construct a fairly accurate composite cross-section of the Muskox Intrusion. The extension of the feeder is exposed, the inward dips of the walls are known, the roof is exposed, the thickness of many of the layered units can be measured directly in the field, and the plunge of the intrusion can be determined both by calculating the plunge of

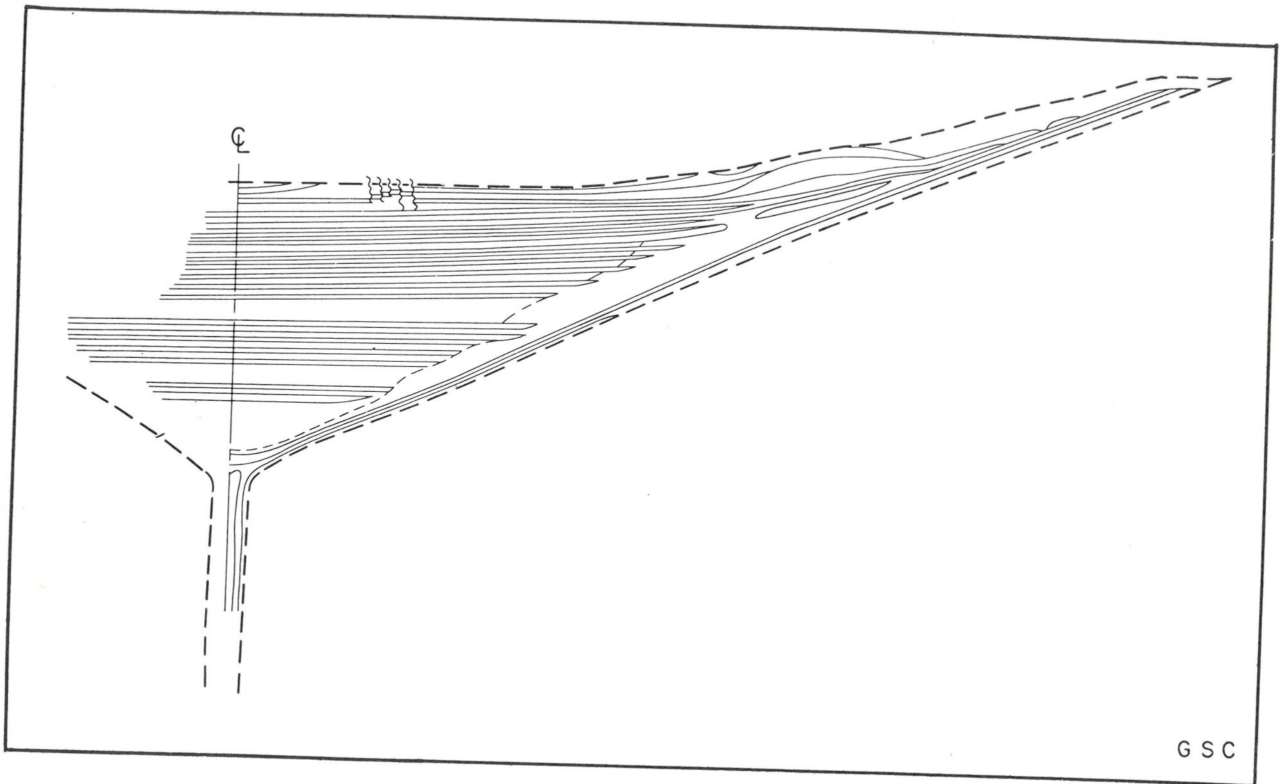

FIG. 3. Typical cross-section of the Muskox Intrusion.

the intersection of the walls and by measuring the dip of layers in the field.

Cross-sections of the form shown in Fig. 3 have been prepared on a scale of 1 inch to 1000 feet, and the relative cross-sectional area of each map-unit determined. Only the eastern half of the cross-section has been used in the volume calculations, since the western side is faulted. The symmetry of the intrusion in plan and the similar inward dip of the opposite margins indicate that this assumption is valid.

Figure 3 shows the disposition of the layered series in relation to the margins of the intrusion. Notice how the layers approach, but do not reach, the margins of the intrusion, and are discordant in attitude to the margins. From a cross-section of this type the composition of the Muskox magma was calculated, and the approximate proportion of rock types is:

Ultramific rocks (including dunite, peridotite, pyroxenites and picrite)	approx. 75%
Gabbro	approx. 15%
Granophyre	approx. 8%
Rock fragments	approx. 2%

This calculation, although approximate, indicates the extremely ultramafic composition of the Muskox magma.

TABLE I. CHEMICAL COMPOSITION OF MUSKOX CHILL PHASE COMPARED TO OTHER LAYERED INTRUSIONS

	Bushveld[1]	Stillwater[2]	Skaergaard[3]	Muskox[4]
SiO_2	51.45	50.68	47.97	50.68
Al_2O_3	18.67	17.64	18.32	13.55
Fe_2O_3	0.28	0.26	1.23	1.17
FeO	9.04	9.88	8.58	9.08
MgO	6.84	7.67	8.09	9.70
CaO	10.95	10.47	10.77	11.22
Na_2O	1.58	1.87	2.42	1.79
K_2O	0.14	0.24	0.21	0.63
H_2O^+	0.34	0.42	0.61	0.53
H_2O^-	0.03	0.06	0.09	0.06
P_2O_5	0.09	0.09	0.08	0.10
TiO_2	0.34	0.45	1.32	1.06
MnO	0.47	0.15	0.12	0.18
	100.22	99.88	99.81	99.75
$\frac{\text{MgO}}{\text{FeO}}$	0.76	0.78	0.94	1.07

[1] Daly, 1928, quoted by Hess, 1960, p. 152.
[2] Hess, 1960, p. 152.
[3] Wager, 1960, p. 375.
[4] Average of 2 analyses by S. Courville, Geological Survey of Canada.

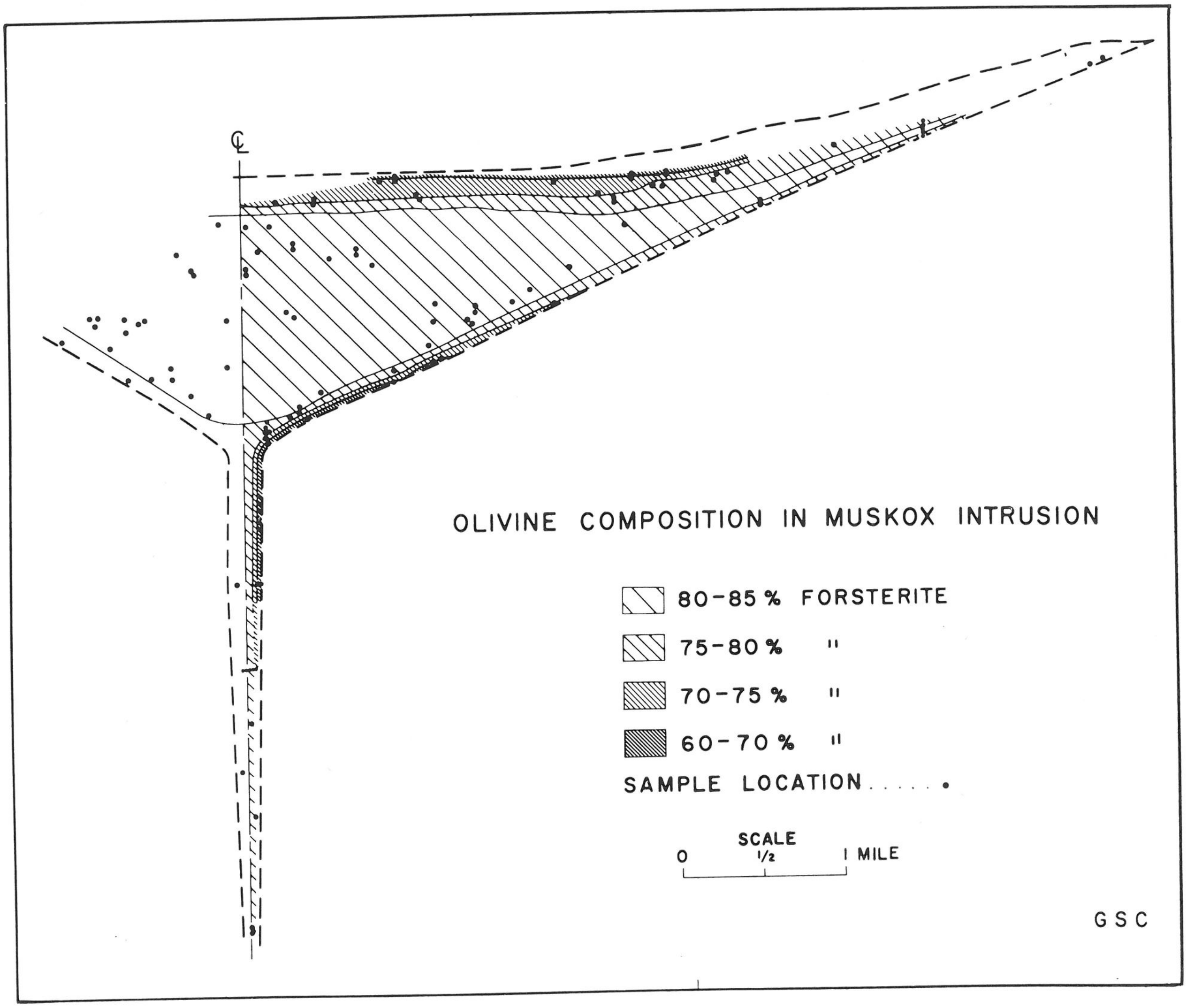

FIG. 4. Olivine variations in the Muskox Intrusion.

Similar calculations can be made of the mineral abundance in the intrusion based upon the cross-sectional areas of rock units and their modal analyses. These calculations indicate that the olivine content of the intrusion is of the order of 58%.

In order to learn whether the cryptic variations among mineral phases indicated significant discontinuities in the layered sequence that might be considered evidence for multiple intrusion, studies of olivine compositions are underway. The results to date indicate the simple overall pattern shown in Fig. 4. Olivine with a forsterite composition over 80% occurs in the core of the intrusion, throughout most of the layered series. Within individual layers in the layered series the variation in olivine composition is small, less than 2–3%. Olivines between 70–80% forsterite occur toward the top, sides, and into the feeder. Olivines with a composition of less than 70% forsterite are restricted to the roof and the margins of the intrusion. The symmetry of this pattern suggests that the greater abundance of ultramafic rocks in the intrusion is not related to successive injections of unrelated magmas but that they formed during a single cooling process.

Table I shows the composition of the Muskox chill phase compared with the chill phases of other layered intrusions. The Muskox chill is slightly more mafic than that of the other intrusions, but not sufficiently to account for the high olivine content calculated for the intrusion itself.

The conclusion to be drawn from the Muskox structural data is that the chill phase is not representative of the bulk composition of the intrusion. Various explanations could be used to try to explain away the difference between the chill phase and bulk composition.

Hess (1960, p. 166) has commented on the absence of a thick zone of feldspathic rocks in the Great Dike to compensate for the thick ultramafic portion and assumes the feldspathic component had a wide lateral extent. This explanation cannot apply to the Muskox intrusion, for the lateral extent is limited by the exposed walls. One might assume the feldspathic phase changes in abundance along the long axis, either up-dip where it has been eroded away or down-dip where it can only be found by drilling. This explanation does not seem probable.

The interpretation that the chill phase represents the composition of an intrusion is a basic assumption in any quantitative study of layered intrusions. In most instances it is not possible to assume otherwise, since intrusions are generally not well exposed even in two dimensions. The Muskox Intrusion is completely exposed in two dimensions, that is its base, sides and top are exposed, and here the imbalance between intrusion composition and chill phase is seen. The explanation may depend on the properties of solid-liquid mixtures, during the intrusion of which the liquid portion lubricates the margins and forms the chill phase while the solids (olivine crystals) are relatively concentrated away from the walls and thus are not frozen into the chilled sample. Such segregation is known to take place during the transport of solid-fluid mixtures in pipe lines. At any rate it is apparent that the relation of chill phases to bulk magma composition requires critical review before being used as a basis for interpreting the geochemistry and cooling history of layered intrusions. This is a field of petrologic research which will have to be evaluated by laboratory studies on intrusion mechanics.

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