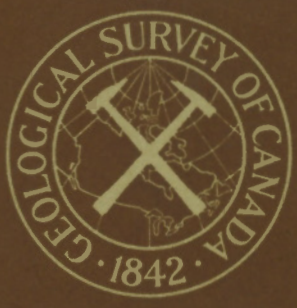

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

John S. Scott

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PAPER 61-25

NOTES ON THE MUSKOX INTRUSION, COPPERMINE RIVER AREA, DISTRICT OF MACKENZIE

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[Report, Map 36-1961 (Sheets 1 to 5) and 1 figure]

C. H. Smith

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By
C.H. Smith

DEPARTMENT OF
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CANADA

CONTENTS

Illustrations

54304-1—2½

NOTES ON THE MUSKOX INTRUSION, COPPERMINE RIVER AREA, DISTRICT OF MACKENZIE

INTRODUCTION

The Muskox Intrusion is a layered basic intrusion that is dyke-like in plan and funnel-shaped in cross-section. Its three-dimensional form is similar to the hull and keel of a sailing ship. As it plunges flatly to the north-northwest, the keel section is exposed along the southern half of the intrusion (approximately 37 miles) and the hull is exposed in the northern half. The keel, or feeder, contains bronzite gabbro and picrite in zones parallel with the nearly vertical walls, whereas the hull contains a great variety of gently dipping layers including dunite, peridotite, and various types of pyroxenites, gabbros, and granophyres.

This report presents a preliminary description of the petrography and structure of the Muskox Intrusion. The intrusion offers excellent opportunities for the study of the chemistry of basaltic magma differentiation because of the variety of rock types it contains and because its feeder, sides and roof are all exposed. Detailed petrographic, mineralogical, and chemical investigations are in progress on the samples collected.

Location

The Muskox Intrusion outcrops in the Coppermine River area of the District of Mackenzie, Northwest Territories, about 90 miles northeast of Port Radium on Great Bear Lake. It extends from 42 to 114 miles south of Coppermine on Coronation Gulf—more precisely, from lat. 66°11'N, long. 114°42'W, to lat. 67°14'N, long. 115°04'W, a distance of 74 miles (see index map on accompanying geological maps).

The area is accessible by chartered aircraft from Yellowknife, approximately 300 miles away.

History and Previous Work

The area in which the Muskox Intrusion outcrops was unmapped prior to 1956, the year it was discovered by H. Vuori of the Canadian Nickel Company during an aerial reconnaissance. Visible from the air are two rows of rusted outcrops, caused by marginal sulphide deposits, which outline the part of the intrusion north of Coppermine River. The more important parts were quickly staked and drilled during the summers of 1957-59. In the course of this work an airplane crash claimed the lives of three geologists—J.P. McGregor, E.C. Speers and J. Stanbridge—and the

pilot—D.W. Marceau. The prominent lakes of the area have thus been named after these people in recognition of their work.

The author began mapping in 1959 with the assistance of D.C. Findlay and W.D. Tedlie and completed the field work in 1960, assisted by H.E. Kapp, a post-doctoral fellow with the Geological Survey, and T. Dougan. Mapping was done on aerial photos enlarged to a scale of 1 inch to 1,000 feet, but the results are reduced to the present scale of 1 inch to 1/2 mile in order to bring the field map to a more convenient size. The results of petrographic studies carried out by Kapp at the Geological Survey during the tenure of his fellowship will be published later.

The regional setting of the Muskox Intrusion was outlined during a helicopter-supported geological survey led by Fraser (1960)[1]. An airborne magnetometer survey was carried out by the Geological Survey during 1961, the results of which are being compiled for publication.

In addition to the assistance provided by numerous members of the Geological Survey, the writer wishes to acknowledge the cooperation of the Canadian Nickel Company, especially J.K. Diebel and H.F. Zurbrigg, who provided drill cores and assistance during the course of the field studies. P.M. Bradshaw, H.L. Lovell, R. Mongeau, C.L. Redstone, T. Sadlier-Brown, and D.G. Smith served as field assistants, and their work is greatly appreciated.

GENERAL GEOLOGY

The Muskox Intrusion outcrops in a basement complex (1-7)[2] of Precambrian metasedimentary and igneous rocks. Biotite from granodiorite (6) in this complex has a K/Ar age of 1,765 m.y., which is similar to other ages obtained to the west, toward Great Bear Lake. Outcropping north of the intrusion are flatly dipping cover rocks of sedimentary and basaltic composition which at one time covered the Muskox area and formed part of the roof under which the Muskox Intrusion was emplaced. The cover rocks are cut by the Muskox Intrusion, which has a K/Ar age of 1,155 m.y., and thus their age is effectively bracketed between 1,155 and 1,765 m.y.

The Muskox feeder generally followed the north-northwesterly structural grain of the basement rocks, while the upper part of the intrusion widened out near the unconformity between the two major country-rock units. The unconformity has apparently exerted a structural control on the emplacement of the basic magma, impeding its upward movement and causing it to spread out into its present funnel-shaped form.

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[1]Fraser, J.A.: North-central District of Mackenzie, Northwest Territories; Geol. Surv., Canada, Map 18-1960.

[2]Numbers in parentheses refer to map-units on the accompanying maps.

TABLE OF FORMATIONS

Era	Unit	K/Ar Age of Enclosed Biotite	Lithology
PRECAMBRIAN			Diabasic gabbro dykes and sills
	Intrusive Contact		
	Muskox Intrusion	1,155 m.y.	Dunite, peridotite, pyroxenites, gabbros, and granophyre
	Intrusive into Hornby Bay sandstone; not in contact with Coppermine River Series.		
	Coppermine River Series		Basaltic flows; minor sedimentary rocks
	Hornby Bay Group		Dolomite
			Sandstone
	Unconformity		
		1,765 m.y.	Massive granodiorite-granite
	Intrusive Contact		
			Minor gabbroic dykes Acid volcanic rocks Greenschists, amphibolite Quartz-biotite-feldspar gneiss Paragneiss Quartz-mica schist, quartzite, graphitic slate

COUNTRY ROCKS

The oldest rocks in the area are siliceous sedimentary rocks with minor slaty layers (1). They are grey-weathering, thinly bedded quartz-mica schists and quartzites, containing both muscovite and biotite, and in places red garnet and andalusite porphyroblasts. Folds in these rocks have north-northwesterly axes, with a strong axial-plane cleavage, and plunge both north and south at angles of 20 to 40 degrees.

Paragneiss (2) is a mixture of sedimentary bands (1) with lesser amounts of granitic material. Parts are rusty weathering due to the weathering of iron-bearing silicate minerals, principally biotite, and from a distance may be confused with the rust zones due to sulphide minerals. Tourmaline is a common accessory mineral among these rocks.

Greenschists (3) are a minor rock type, and are most common east of Drill Lake where they are interbedded with quartzitic rocks. They are composed of fibrous amphibole, epidote, and some plagioclase.

Silicic volcanic rocks (4) are red-weathering schistose rocks with quartz and feldspar phenocrysts that occur southwest of All Night Lake. They are of limited extent.

The quartz-biotite-plagioclase gneiss (5) has conformable structures with the paragneiss and sedimentary rocks with which it is interlayered, and is considered as a more metamorphosed phase of them. It is a grey-weathering, coarse-grained to pegmatitic rock with very contorted foliation outlined by schlieren of biotite. Its principal minerals are quartz and sodic plagioclase, with various amounts of biotite. Plagioclase forms porphyroblasts up to 3 inches in size, which is distinctive of the map-unit. Adjacent to the Muskox Intrusion are sanidine and cordierite of contact-metamorphic origin.

Granodiorite (6) occurs as small stocks in the northern part of the area, or as sills and dykes in the quartz-biotite-plagioclase gneiss (5). It is a pale brownish grey weathering, fine- to medium-grained rock, distinguished from unit 5 by its uniform texture and mineral composition. It contains quartz and sodic plagioclase, with lesser amounts of potash feldspar and biotite. Biotite from a small sill in gneiss north of Coppermine River was dated at 1,765 m.y.

Granite (7) is restricted to the north end of the area, where it occurs as a pink, coarse-grained, deeply weathered rock. In thin section it appears highly altered, and contains quartz, orthoclase, and chlorite. Its contact with the Muskox Intrusion is not exposed, and it is assumed to be of pre-Muskox age.

The basement rocks are overlain unconformably by gently dipping sedimentary and basaltic rocks (8-10). The Hornby Bay sandstone (8) is a brown-white, friable to glassy sandstone with minor quartz pebbles. It outcrops at the north end of the intrusion, and occurs as xenoliths within it. In the map-area its thickness is of the order of 650 feet, but west of the area Fraser (1960) estimated it to be about 4,000 feet thick.

A buff-weathering dolomite (9), containing stromatolites, oolitic structures, and salt casts, conformably overlies the Hornby Bay sandstone. It is approximately 500 feet thick, but thickens to the west where Fraser (1960) reported a thickness of 4,000 feet.

The Coppermine River basalts (10), which lie conformably on the dolomite, are of historic interest as the source rock for the native copper sought by Samuel Hearne on his expeditions from 1769 to 1772. They extend to the north outside the map-area, where their thickness is reported by Fraser (1960) as 11,000 feet. They are reddish-greyish-brown, fine-grained to aphanitic rocks composed of labradorite and clinopyroxene as phenocrysts and as ophitic intergrowths accompanied by iron oxides. Amygdules are common, and contain carbonate, zeolites, and chlorite.

Diabasic gabbro dykes (29) form a dyke swam parallel with the Muskox Intrusion. A few are older, but most cut the intrusion and the overlying Coppermine basalts. None is known to cut the overlying Palaeozoic rocks north of the map-area, and because of petrographic similarities the dykes are assumed to be related to the Coppermine vulcanism. The dykes vary from 25 to 400 feet in width and are steeply dipping to vertical. In addition to their essential minerals they commonly contain free quartz and granophyric patches.

MUSKOX INTRUSION

The Muskox Intrusion has the form of the hull and keel of a ship, and within it a large variety of rock types have formed by magmatic differentiation. The rock types range in composition from dunite to granophyre. They occur in four different structural units (illustrated in Fig. 1). The feeder outcrops for 37 miles from the Coppermine River south, and the other units outcrop north of the river. The marginal zone varies from gabbro to peridotite in composition and records the changes in magma composition as it cooled from the walls inward. The central layered series is an 8,500-foot sequence of flatly layered rocks, discordant to the marginal zone, and sitting inside the intrusion like the yolk of an egg. The base of the upper border zone is arbitrarily defined as that place where granophyric intergrowths are present in amounts greater than 3%. It represents a zone of reaction and contamination between the basic magma and the overlying sedimentary roof rocks.

Mineral deposits of possible economic significance associated with the intrusion include marginal pyrrhotite, nickel-copper deposits, and a chromite layer containing disseminated copper-nickel sulphides and platinum-group metals.

ROCK TYPES

Dunite (11) is a brown-weathering, dark green to black rock whose original composition was dominantly olivine, with only minor amounts of pyroxene, plagioclase, and spinel. Typically it is a completely serpentinized rock with secondary magnetite veins in

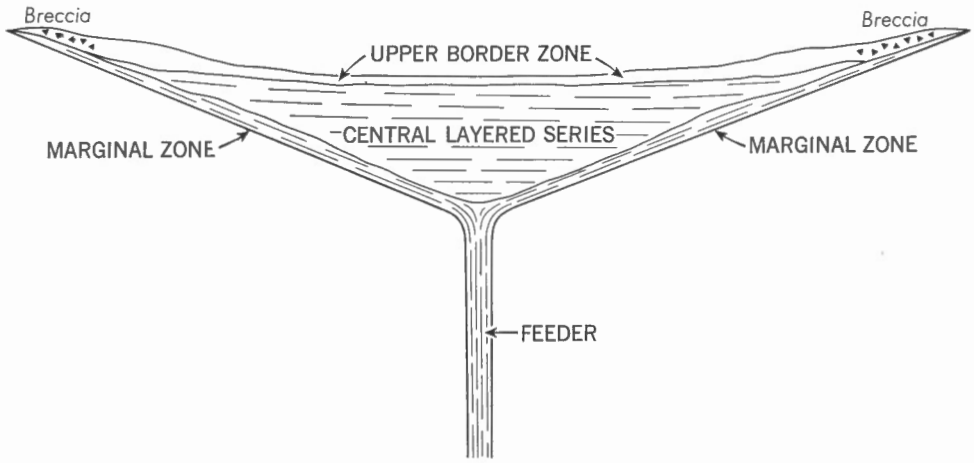

Figure 1. Structural units of the Muskox Intrusion

places up to 1/2 inch wide. It is easily susceptible to erosion and thus poorly exposed. In thin section its mesh texture is well displayed and it contains approximately 97% serpentine, with magnetite, spinel, and hydrogarnet formed from plagioclase. There are nine dunite layers in the Muskox Intrusion which range in thickness from 10 to 1,850 feet. Their lower and upper contacts are well defined and sharp, but their lateral contacts are gradational where they pass into the peridotite of the marginal zone.

Peridotite (12) is a variant of dunite that contains more than 10% pyroxene. It occurs as discrete layers, and also as a phase of the marginal zone. In the marginal zone it grades toward the side of the intrusion into feldspathic peridotite (13) containing 5 to 10% plagioclase; whereas in the layered series it forms both homogeneous layers and heterogeneous layers ranging from dunite to feldspathic peridotite in composition. There are six layers—ranging from 35 to 250 feet in thickness—of peridotitic composition; generally these contain accessory plagioclase altered to hydrogarnet. These rocks are also strongly serpentinized but less so than the dunite. They contain olivine (chrysolite), orthopyroxene (bronzite), and clinopyroxene, the latter being commonly poikilitic in habit. Biotite is an accessory mineral, as are chrome spinel and in places sulphide minerals.

Picrite (14) is a greyish brown-weathering rock differing from peridotite in its high plagioclase content (15-30%) and from gabbro in its high olivine content (20-50%). It is a fine- to medium-grained rock with a porphyritic or subophitic texture, and contains olivine (chrysolite), orthopyroxene (bronzite), clinopyroxene, and plagioclase (labradorite) in roughly equal amounts, as well as biotite in amounts up to 7%. It occurs only rarely in the layered series as a local facies of feldspathic peridotite or as part of an olivine-bearing pyroxenite layer west of Transition Lake. Its common mode of occurrence is in the marginal zone or in the central part of the feeder. In the marginal zone south of Speers Lake it forms a transitional phase of the order of 15 to 40 feet thick between feldspathic peridotite and norite or bronzite gabbro. North of Speers Lake, picrite forms the contact or 'chill' phase of the intrusion. In the feeder, picrite is confined to the central parts and is everywhere bordered by bronzite gabbro or norite. There the picrite occurs as a nearly vertical band or bands parallel with the feeder walls and varying from 75 to 300 feet in width. Its contacts with gabbro show no sign of chilling, but are gradational over less than a foot and are well marked by the difference in weathering colour between the brown picrite and grey gabbro.

Pyroxenites (15-18) are restricted to the layered series where they form sharply defined layers varying from 10 to 175 feet in thickness and traceable along strike for up to 8 miles. In general orthopyroxene appears to be more abundant relative to clinopyroxene in the higher pyroxenites. Olivine clinopyroxenite (15) is a brown-weathering medium-grained rock that forms six layers in the lower part of the layered series. Its principal constituent is anhedral augite, but it contains up to 40% serpentine after olivine and small amounts of opaque minerals. A stratification due to variation in olivine-pyroxene abundance is common in these layers.

Table of Rock Types

The rocks formed within the Muskox Intrusion are essentially of one age, and they are classified here and on the legend in the order of a theoretical differentiation sequence. This is approximately the actual order of formation of the rock types although variations do exist; for instance the norite chill phase (22) formed before the dunite layers (11). The compositions given are not intended to indicate the theoretical compositional range of each rock name but rather the actual range found in the Muskox Intrusion.

Range of Modal Compositions in Map-units of the Muskox Intrusion

Map-Unit	Rock Name	Olivine*	Pyroxene (combined)	Ortho-pyroxene	Clino-pyroxene	Other Mafic Minerals	Plagioclase	Granophyric Aggregates	Potassium Feldspar	Quartz
28	Intrusive breccia.....									
27	Granophyre.....	-	-	-	-	10-20	15	60-70	15	15
26	Mafic granophyre	-	-	-	-	15-30	15-30	25-35	15	15
25	Granophyric gabbro ...	-	-	-	0-10	20-30	30-35	10-30	10	10
24	Granophyre-bearing gabbros.....	-	-	-	0-15	20-30	35-45	3-10	-	-
23	Anorthositic gabbro.....	10	-	5-20	5-20	-	60-85	-	-	-
22	Bronzite gabbro and norite.....	5	-	15-30	15-30	3	40-50	2	-	1
21	Gabbro	3	-	15	30	3	35-65	3	-	2

20	Olivine gabbro.....	10-15	-	10	40-60	-	40-50	-	-	-
19	Troctolite.....	40-50	-	-	-		50-60	-	-	-
18	Orthopyroxenite	10	-	60	40	3	15	-	-	-
17	Websterite.....	10	-	40-60	40-60	-	15	-	-	-
16	Clinopyroxenite.....	10	-	40	50	-	3	-	-	-
15	Olivine clino-pyroxenite	10-50	-	5	50	-	-	-	-	-
14	Picrite	20-50	-	5-25	15-30	7	15-30	-	-	-
13	Feldspathic peridotite .	50-80	10-40	-	-	3	3-10	-	-	-
12	Peridotite.....	50-90	10-50	-	-	3	3	-	-	-
11	Dunite	90	10	-	-		3	-	-	-

*Amount of serpentine in each rock type is included in olivine content.

Clinopyroxenite (16) ranges in composition from true clinopyroxenite containing more than 80% augite, to bronzite clinopyroxenite containing up to 40% bronzite. There are five clinopyroxenite layers, and the extreme variations in composition are found between different layers rather than in a single layer. In fact single layers may be quite homogeneous from base to top. Clinopyroxenite contains up to 10% olivine (chrysolite) and in places minor amounts of labradorite; opaque minerals are rare.

Websterite (17) is a brownish green-weathering, medium-grained rock containing approximately equal amounts of bronzite (40-60%) and augite, with minor amounts of olivine and labradorite. The two principal websterite layers range from 20 to 50 feet in thickness, but websterite phases are found in part of the uppermost pyroxenite layer, which is somewhat variable in composition.

Orthopyroxenite (18) occurs in a single 150- to 175-foot layer whose bronzite content ranges from 60 to 80%. It also contains up to 15% labradorite and 15% clinopyroxene, as well as minor amounts of olivine and biotite. This layer is marked by a well-defined zone containing chromite accompanied by copper-nickel sulphides and platinum-group metals—a zone which is similar in many respects to the Merensky Reef of the Bushveld Complex in South Africa.

Gabbroic rocks (19-25) occur as part of the feeder filling, the chill phase of the marginal zone, the upper part of the layered series, and the lower part of the upper border zone. In the upper border zone of the intrusion the gabbroic rocks do not form well-behaved layers like those lower in the layered series, but grade both laterally and vertically, by changes in mineral proportion and texture, into different types of gabbro.

Troctolite (19) is not a common rock type but occurs in isolated outcrops in the layered series south of McGregor Lake. It probably occurs as thin layers (10 feet or less) in the lower parts of the layered series, or locally as a facies of the olivine-gabbro layers. Troctolite is a medium-grained crudely banded rock, composed of roughly equal amounts of black serpentine after olivine, and the alteration products of plagioclase—prehnite, zoisite, and hydrogarnet.

Olivine gabbro (20) forms the two lowermost gabbro layers—approximately 100 feet thick—south of Speers Lake. It is a brownish grey-weathering rock with characteristic black serpentine pseudomorphs after olivine. It is medium grained and contains about 10% chrysolite, the major constituents being clinopyroxene and plagioclase. The orthopyroxene content varies from 0 to 15 per cent. Olivine gabbro also occurs within the marginal zone where bronzite gabbro grades into picrite, but because of the gradational nature of the contact only bronzite gabbro and picrite were mapped. However, olivine gabbro (20) of the layered series differs from that of the marginal zone in its lower orthopyroxene content and its sharply defined upper and lower contacts.

The normal gabbro (21) occurs in the upper part of the layered series, where it forms a zone about 300 feet thick grading

upward with increasing granophyre content into granophyre-bearing gabbro (24). As this change is not accompanied by a structural break it is difficult to define and map precisely in the field. The gabbro is grey weathering, medium to coarse grained, subophitic in texture, and contains labradorite (approximately 50%), augite in excess of bronzite by a ratio greater than 2 to 1, and minor amounts of granophyre, biotite, chlorite, and iron oxides.

In the bronzite gabbro (22), resinous bronzite crystals are more conspicuous than in the normal gabbro (21). It has two modes of occurrence. A laminated bronzite gabbro forms layers stratigraphically below the gabbro (21), differing from it megascopically by the presence of a well-developed planar structure caused by aligned plagioclase plates. Otherwise, apart from a slightly higher bronzite content, it is chemically similar to unit 21, which it grades into near the margins of the intrusion. A distinctive type of bronzite gabbro (22), grading in places into norite, occurs as the marginal or chill phase of the intrusion and also as a medial zone along sections of the feeder. It is a grey-weathering rock with a subophitic texture whose grain size varies from medium to aphanitic as the contact with the country rock is neared. It commonly contains small pegmatitic patches of similar mineralogical composition. Orthopyroxene, ranging in composition from bronzite to hypersthene, is present in amounts about equal to the clinopyroxene in this rock, but the former is more conspicuous in hand specimens because of the presence of large resinous crystals. Plagioclase is labradorite in composition, commonly zoned, and apparently of a high-temperature form according to X-ray study. In the marginal zone, olivine increases in abundance into the intrusion as the gabbro grades to picrite. Within the feeder section the transition from gabbro to picrite is relatively abrupt and well defined, whereas in the marginal zone of the main part of the intrusion the transition is gradational. In the latter areas the gabbro zone is about 20 to 50 feet thick; in the feeder, individual zones vary from 100 to 800 feet in thickness.

Anorthositic gabbro (23) forms a single, thin, 15- to 25-foot layer which, because of its coarser grain size and higher plagioclase content, forms a distinctive horizon marker north of Speers Lake and southwest of Speers Lake within the Canoe Lake fault zone. It varies in composition within the layer; the lower parts are hypersthene gabbro in composition whereas the top of the layer, in places, is anorthosite. Apart from its normal mineral components it also contains about 5% olivine.

Granophyre-bearing gabbro (24) is a term used for the gabbroic rocks containing an estimated granophyre content of 3 to 10%. This unit is restricted to the roof of the intrusion where it grades downward into normal gabbro (21) and upward into granophyric gabbro (25), the latter containing 10 to 30% granophyre. Although the stratigraphic position of units 24 and 25 as transitional phases between the underlying gabbro and overlying granophyre is well defined, the gradational nature of the rock types both vertically and laterally makes their precise mapping difficult. The increase in granophyre content in the gabbroic rocks is accompanied by an increase in the amphibole (from pyroxene) and titaniferous magnetite content and the presence of zircon and apatite.

The silicic phases (26-28) form an estimated 8% of the volume of the Muskox Intrusion. They occur as a discontinuous capping over the intrusion and are apparently thicker toward its edges (i.e. west of Canoe Lake and north of Drill Lake) than in the centre (between All Night Lake and Transition Lake).

Mafic granophyre (26) grades downward into granophyric gabbro (25). It varies from red to grey, depending partly on its granophyre content, and is extremely variable in grain size and composition. It contains up to 30% mafic minerals (amphibole and chlorite) and 25 to 35% granophyric aggregates, as well as plagioclase, sanidine, and quartz. Apatite, zircon, titaniferous magnetite, leucoxene, and tourmaline are found in both mafic granophyre (26) and normal granophyre (27).

Granophyre (27) is a red- to orange-weathering, fine- to medium-grained equigranular rock composed of 60 to 70% granophyric aggregates, 10 to 20% chlorite and biotite, and lesser amounts of sericitized plagioclase, quartz, and sanidine. It occurs as a fairly uniform rock unit, containing in places rounded or embayed rock fragments about an inch in size and coated by dark chlorite rims.

Granophyre (27) forms the matrix for the intrusive breccia (28), which is a heterogeneous unit containing up to 60% angular to subrounded rock fragments. The fragments vary in size from sub-microscopic to more than 1,000 feet. Hornby Bay sandstone (8) fragments, in places not even recrystallized, are most abundant, but fragments of older quartzite and slate (1), granite (7), gneiss (5), and graphite are also present.

STRUCTURE

External Form

The external form of the Muskox Intrusion (Fig. 1) can be interpreted from several groups of observations.

1. The plan shape of the intrusion shows it to be a long dyke-like body widening to the north. As presently exposed it does not appear to be symmetrical about its long axis for its eastern side now extends much farther north than the western side. However, this is due to the Canoe Lake fault, along which the western side of the body has been displaced to the south as well as dropped. If the faulted segment of the intrusion were moved back into position, the symmetry of the intrusion would be restored.

2. South of Coppermine River the feeder section is similar in form to the satellite diabase dykes. It is steeply dipping, from vertical to 80°E. These contacts can be readily observed and measured in the field, but north of Coppermine River where the walls of the intrusion flatten it is more difficult to measure their true dip directly. There the dips have been calculated from diamond-drill holes, and they show that the eastern contact dips inward,

flattening from 57°, north of Coppermine River, to 22° near the extreme northeast end. South of McGregor Lake, where dips can be calculated on the western contact, similar dips are found, and as field observations indicate inward dips along the faulted extension also, it is assumed that the intrusion is symmetrical in section as well as in plan.

3. The computed vertical thickness of the layered section of the intrusion is a composite figure, calculated as follows: (a) the thickness from McGregor Lake south can be calculated from the known inward dips of the opposite contacts and the horizontal width of the body; (b) where the west side of the intrusion is faulted, the stratigraphic thickness is calculated by distances measured parallel with the axis of the intrusion and the dips of the layers as measured in the field, which vary from 0 to 10°NNW; (c) where pyroxenites or gabbro layers are exposed, their thickness was measured directly in the field and these values were used. By these methods a figure of 8,700 feet was obtained for the vertical thickness of the intrusion between Coppermine River and its roof.

4. The plan view of the northern end or roof of the intrusion is that of a plunging syncline, and when the roof contacts are projected onto a vertical section, assuming an average 5-degree northerly dip based on the dip of the layered series, an open synclinal shape is constructed as in Figure 1.

Internal Structural Units

The internal structure of the Muskox Intrusion may be divided into four principal units (Fig. 1)—the feeder, the marginal zone, the central layered series, and the upper border zone—and each has distinctive smaller structures and petrographic features.

Feeder

The feeder forms the southern half of the intrusion as now exposed. It extends from Coppermine River south, or approximately 37 miles. If one assumes an average 5-degree northerly plunge, then the exposed section of the feeder may represent a vertical thickness in the intrusion of up to 3 1/2 miles.

The width of the feeder varies from 500 feet at the southern end, to 1,800 feet west of Muskox Lakes. Its contacts are steeply dipping—from 80°E to vertical—and chilled against the country rocks. The two principal joint sets in the feeder are at N5 to 20°W and 70 to 80°E, and at N65 to 80°E and 80°N to vertical. In places diabasic gabbro dykes follow the feeder contacts, indicating multiple intrusion. One of the diabasic gabbro dykes is older than the Muskox feeder, as shown by crosscutting relations west of Muskox Lakes.

Bronzite gabbro and norite (22) fill the feeder at the southern end, and form its marginal parts farther north. As the feeder is traced northward, lenses of picrite (14) appear along the

centre, becoming more continuous to the north. Picrite is everywhere confined to the central parts of the feeder and nowhere occurs along the edges. Near Spider Lakes, two distinct picrite zones appear, separated by a central gabbro zone; and near Muskox Lakes, as many as four picrite zones occur where the feeder twists as it cuts across an older diabase dyke.

The various gabbro zones do not appear to differ in microscopic characteristics, but although the marginal gabbros are chilled against the country rocks the central gabbros do not show chill contacts. Gabbro-picrite contacts are parallel with the feeder walls and are easily mapped due to the brown weathering of the picrite and grey weathering of the gabbro. In places they are gradational over 1 foot; elsewhere they are abrupt. The marginal gabbro contains wall-rock inclusions in places, but none was found in the central parts of the feeder.

The feeder section is not continuous over its entire length. In places it is offset and although faults may be responsible, the offsets resemble those commonly due to an échelon intrusion of discontinuous diabase dykes.

Marginal Zone

The marginal zone of the Muskox Intrusion, present from Coppermine River north, is a gradational series of rock types that parallel the margins of the intrusion and are discordant to the central layered series. The zone varies from 200 to 1, 200 feet in width, and grades inward from bronzite gabbro at the contact, through picrite and feldspathic peridotite, to peridotite and in places dunite.

The contact gabbro is continuous from Speers Lake south, but to the north it thins and picrite becomes the contact phase. The gabbro is chilled locally but in places the contact is difficult to define because of contact metamorphism and the development of pyroxene in the contact hornfels. No contacts are recognizable in the marginal zone, the changes being gradational and accomplished by a decrease in plagioclase and an increase in olivine from the margin into the intrusion.

Accompanying the changes in the relative abundance of the minerals in the marginal zone are changes in the compositions of the minerals themselves. Both olivine and orthopyroxene increase their iron content toward the contact, and plagioclase becomes more sodic; the plagioclase is a high-temperature form.

The rock and mineral changes noted in the marginal zone are structurally reverse to those in a normal layered intrusion. In the marginal zone olivine increases upward, plagioclase increases downward, the iron content of olivine and orthopyroxene increases downward, and the soda content of the plagioclase increases downward.

Central Layered Series

This series is composed of alternating layers of dunite, peridotite, pyroxenites, and gabbro. The sequence of layers shows an overall normal variation, with dunite most abundant at the base, pyroxenites in the middle, and gabbro at the top. The upper limit is arbitrarily drawn at the appearance of granophyric intergrowths, the succession then being called the upper border zone.

The layered series is 8,500 feet thick and is composed of 38 main layers ranging from 10 to 1,850 feet in thickness. Smaller-scale layering is present in the olivine pyroxenite and troctolite, but in many cases the layers appear as thick homogeneous units. The layers increase in lateral extent upwards, as the intrusion widens, to a pre-faulting lateral width of 6 miles. They are essentially planar and vary in dip from flat to an average of 10°NW, which is similar to the dip of the overlying Coppermine basalts. They are sharply defined at their base and top, although minor variations in mineral abundance near some contacts suggest they are not as abrupt as they appear in the field. Within some layers there is a trend toward more olivine at the base and more orthopyroxene at the top, although reverse trends with olivine at the top and plagioclase at the base were also noted.

The layers continue to within 1,200 to 2,000 feet of the margins of the intrusion where they may steepen slightly, change in composition, and die out. Orthopyroxene becomes more abundant in certain layers laterally toward the margins, thus dunite layers may grade laterally into peridotite.

The complete range of cryptic layering in the series has not yet been worked out but it appears to range from Fo_{90} to Fo_{60} in the olivine series and from En_{92} to En_{65} in the orthopyroxene series.

Upper Border Zone

This zone is characterized by the presence of granophyric intergrowths in amounts of from 3 to 70 per cent, and represents a change in the chemical composition of the intrusion related to its structural position at the roof.

The zone, about 200 feet thick, can be subdivided on the basis of its granophyre content into units ranging from granophyre-bearing gabbro (24) to true granophyre (27). These units are crudely parallel with the layered series and the roof, but lack the continuity along strike, the consistent thickness, the cumulate textures, and the abrupt contacts of the layered series. The gradational increase of granophyre content with height is comparable to the increase of plagioclase toward the contact in the marginal zone of the intrusion.

The granophyre rock unit (27) is not continuous over the entire intrusion; it is absent in the centre where granophyric

gabbro (25) occurs at the contact. Granophyre is more abundant at the margins where it forms the matrix of the intrusive breccia (28).

Rock fragments ranging up to 1,000 feet in size are common in the top of the upper border zone, forming up to 60% of the intrusive breccia unit. The granophyre matrix is chilled and contains sanidine, but the lack of recrystallized fabric in many of the inclusions suggests that the magma did not have a large supply of heat. Tourmaline, apatite, chlorite, and amphibole are indications of a higher volatile content in this part of the intrusion.

ORE-MINERAL DEPOSITS

Two types of economic mineral deposits are associated with the Muskox Intrusion: sulphide deposits occur along the margins of the intrusion, and a chromite-sulphide horizon occurs within a pyroxenite layer of the central layered series.

The sulphide deposits along the margins are well defined from the air by bright orange-red rust zones which outline parts of the east and west contacts from Coppermine River north. Disseminated to massive sulphides occur close to the margins of the intrusion, although disseminated sulphides are also found a few tens of feet into the country rocks or up to 1,000 feet into the marginal zone of the intrusion. Breccia ore, with country-rock fragments in a pyrrhotite matrix, is common. Pyrrhotite is the principal mineral in the marginal deposits, in places having crystal faces up to 1 foot in size which are surrounded by rims of chalcopyrite. Pentlandite and carrolite are visible in polished sections. Galena is associated with the sulphides in places. Assays of grab samples from the marginal sulphide deposits average less than 0.8% Ni and 0.8% Cu, and approximately 0.1% Co. Platinum-group metals average 0.3 gram/ton of platinum and 3.5 grams/ton of palladium.

The chromite-sulphide layer is similar to the Merensky Reef of the Bushveld Complex of South Africa. It occurs near the upper part of the central layered series, 15 feet above the base of a pyroxenite layer that dips 10°NW. The pyroxenite layer can be traced for 7 miles, but due to poor outcrops the chromite layer was traced for only 3 1/2 miles. The chromite-sulphide layer is 8 to 15 inches thick and contains up to 50% disseminated chromite and 1 to 2% disseminated pyrrhotite and chalcopyrite. Plagioclase, in places pegmatitic, is more abundant in the mineralized zone than elsewhere in the pyroxenite host rock. An average of assays of seven grab samples from this layer is 0.25% Cu, 0.15% Ni, 15.3% Cr_2O_3, 0.1% V, 0.01% Co, 0.40 gram/ton Pd, and 0.16 gram/ton Pt. A sulphide concentrate from this layer, approximately 85% pure, assayed 8.4 grams/ton Pd and 0.6 gram/ton Pt.

A second chromite band, 1 inch thick, occurs in a feldspathic peridotite layer 55 feet below the chromite-sulphide reef. Apart from this thin layer, chromite is scarce in the intrusion.