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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 64-44

THE MUSKOX DRILLING PROJECT

(Canadian Contribution to the International Upper Mantle Project No. 40)

(Report, 10 plates and 14 figures)

D. C. Findlay and C. H. Smith

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Abstract

The Muskox drilling project was devised to sample the unexposed part of a layered mafic-ultramafic intrusion in order to provide cores and structural data for use in determining its origin and cooling history. A total of 10,089 feet of diamond drilling was completed. Three vertical holes were drilled to depths of 4,000, 3,593 and 2,496 feet. The report deals with the reasons for drilling; planning; drilling operations; and preparations for continuing studies of the cores. Drilling specifications, and equipment are described, and the geological logs of the holes summarized. Petrographic, mineralogic, chemical and isotopic studies are in progress. Down-hole geophysical logs (gamma ray, neutron, self potential, resistivity, heat flow, and seismic velocity) were made, as well as paleomagnetic and electrical resistivity measurements on the cores.

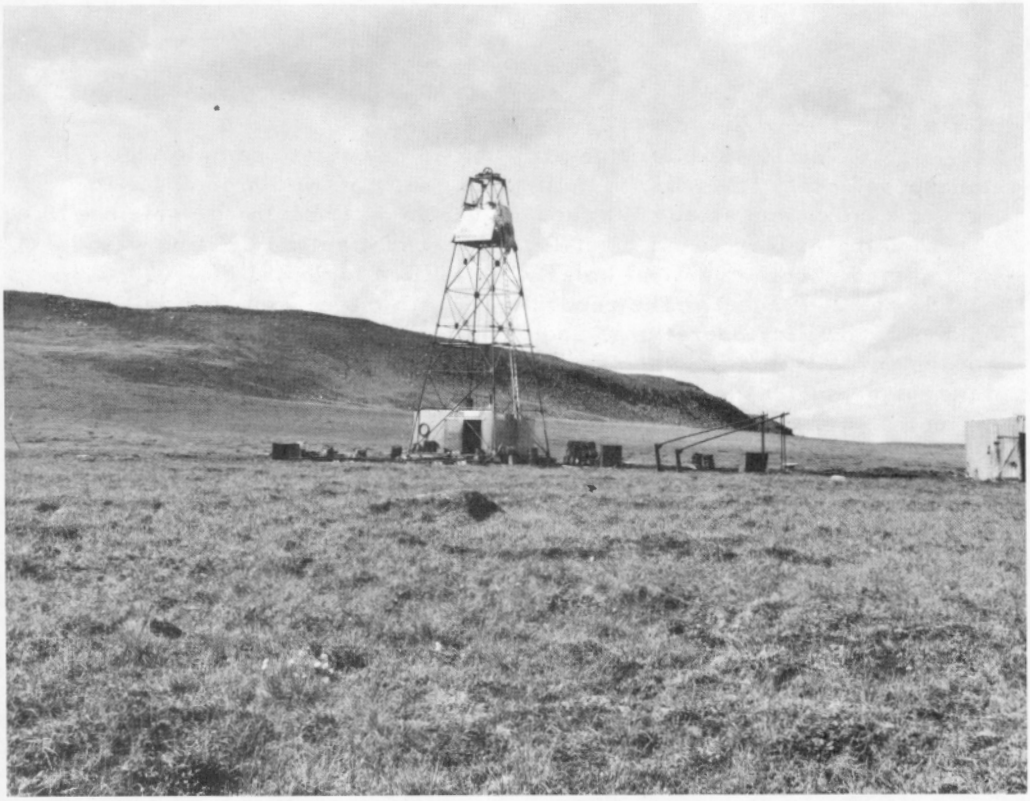

PLATE I. D. C. F. 7-2-63
Muskox South drill site, Speers Lake. In the background a resistant olivine-bearing clinopyroxenite layer dips north (away from drill). The base of the hill and foreground are underlain by easily eroded serpentinite formed from dunite.

Chapter I

INTRODUCTION

During the period May 10th to September 25th, 1963, a total of 10,089 feet of diamond drilling was carried out on the Muskox Intrusion in the District of Mackenzie, Northwest Territories. Three vertical holes, designated Muskox South, Muskox North, and Muskox East, were drilled to depths of 4,000, 3,593, and 2,496 feet respectively. This report deals with various aspects of the overall drilling program - the reasons for drilling, the planning, the actual drilling operations, and preparations for continuing scientific study of the cores obtained. It is partly a narrative of the field operations, since one purpose of the report is to document the experiences gained for the benefit of future drilling operations. Studies of the drill cores bearing on the petrology, mineralogy, chemistry and isotope geology of the Muskox Intrusion, and the geophysical properties of its rocks, are underway and will be the subject of future reports.

Drilling for Scientific Purposes

Diamond drilling projects related to scientific studies have increased in number during the past few years, and are continuing to do so under the stimulus of the International Upper Mantle Project. Ultradeep drilling projects are currently being planned in both the U. S. A. (Mohole Project) and the U. S. S. R. (Azerbaidzan; Urals; Karelia; Black Sea; and Kurile Islands). These programs will involve drilling to depths never previously reached, and will require the development of advanced drilling techniques and instrumentation to ensure successful completion. The modest drilling programs of other countries, such as the Muskox operation described here, utilize existing drilling technology to obtain geologic and geophysical data. Regardless of scale, each project seeks to explore the nature and problems of those vast regions of the earth presently hidden to direct observation. Hitherto, knowledge of these subsurface regions has been obtained largely by the indirect methods of geophysics.

The future aims of deep drilling have both academic and economic application. The experience obtained will have immediate value in exploration of the deeper parts of mining districts. The instruments required to measure the physical properties of rocks in drill holes, as well as interpretations of this data, will be of future value in the search for hidden ore deposits. Many ore minerals are considered to be derived from the deeper earth zones, and the chemical and mineralogical information from deep drilling will provide knowledge of their abundance, migration, and concentration into ore

deposits and thus aid in the search for new deposits. Heat flow studies will assess the possible industrial use of thermal energy from the earth's interior. Studies of electrical properties have application to certain fields of electro-magnetic communication, in addition to their use in prospecting methods.

Igneous Intrusions as a Source of Mantle Data

Igneous intrusions provide the only available samples from the deeper parts of the earth, and in this respect are of similar use as meteorites, which provide the only samples from outer space.

Mafic and ultramafic intrusions are of particular interest because they are derived from the deeper parts of the earth's crust and the mantle. They are abundantly exposed at the earth's surface, but their scientific importance varies greatly. Some are uniform in composition and merely provide a single indication of the composition of their parent source. Others have been altered by later events, both chemically and physically, so that they are no longer representative of their original source material. Still others have been torn apart so that only remnants attest to their original size and composition. This is not the case with the Muskox Intrusion described herein. This intrusion contains a great variety of rock types, which indicate not only its original composition, but the type of physical and chemical processes that took place as the magma cooled. The completeness of exposure and simplicity of structure allow quantitative evaluation of these processes. In other words, it is a model experiment, using mantle materials, carried out by nature on a scale of size and number of components that cannot be duplicated in the laboratory, yet small and well-enough exposed to allow reconstruction of its original condition in the field.

Studies of the type described in this report provide an indirect appreciation of the chemistry and chemical processes of the mantle. These methods of study, coupled with the understanding provided by small scale laboratory experiments, must continue to guide our understanding of the inaccessible parts of the earth until such time as ultradeep drilling is an actuality rather than a possibility.

Acknowledgments

The planning and conduct of the Muskox drilling program involved the assistance of many people. Their roles are noted under the following headings and are gratefully acknowledged.

Planning - S.C. Robinson*
Transportation - Wardair (Canada) Ltd.
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Field supervision - A. (Ned) Beaulieu, drill foreman; R.F.J. Scoates, J.G. Robinson, R. White, field assistants.
Sample preparation - H. Hay, J. Paris*
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Mineralogic studies - G. Pouliot, J. Jambor, R. Delabio, J.A. Chamberlain*
Chemical and spectrographic analyses - J. Maxwell, J. Lynch*
Isotopic studies - R. Wanless*, A. Sasaki**
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Palaeomagnetic study - W.A. Robertson**
Heat flow - A. Beck, A. Judge, University of Western Ontario
Electrical properties - L. Collett*
Statistical analyses - F. Agterber

*Officers of the Geological Survey of Canada.
**National Research Council Post Doctorate Fellows.

Chapter II

GEOLOGY OF THE MUSKOX INTRUSION

The Muskox Intrusion outcrops in the Coppermine River area, Northwest Territories, from latitude 66°11'N, longitude 114°42'W to latitude 67°14'N, longitude 115°04'W (Fig. 1). It crosses the Arctic Circle about 100 miles east of Port Radium on Great Bear Lake, and about 300 miles north of Yellowknife. Preliminary descriptions have been published by Smith (1962)[1] and Smith and Kapp (1963) and only a general summary is given here.

The intrusion (Fig. 2) outcrops in a Precambrian basement unit of folded metasedimentary and gneissic rocks, cut by small masses of granodiorite (K/Ar age of 1,765 m.y.). The basement is overlain unconformably at the north by a gently dipping sequence of sandstone, dolomite and basalt (K/Ar age of 1,200 m.y. and less). A swarm of diabase dykes cuts all the rocks of the area.

The intrusion (Figs. 2, 3) is dyke-like in plan and funnel-shaped in cross-section. It outcrops in a north-northwesterly direction for 74 miles. A gravity survey by the Dominion Observatory suggests it may extend an additional 75 miles to the north, under the sandstone-basalt cover that forms its roof.

Structure

External Shape

The shape of the intrusion is analogous to that of a sailing ship with a deep keel plunging 4 degrees toward the north. The southern half (Fig. 2), outcropping for 37 miles, represents the steeply dipping keel, or feeder extension, exposed at the surface. The northern half represents the hull, or main body of the intrusion. At the extreme north the deck, or synclinal-shaped roof, plunges under the cover of sandstones and basalts.

The symmetry of the intrusion, in plan, is broken by a northerly-trending fault (Fig. 2), which displaces the western side of the intrusion. The fault has an apparent horizontal displacement of 5 miles. The walls of the intrusion dip inward at angles ranging from 58 degrees near the Coppermine River to 22 degrees at the extreme northeastern end. The intrusive roof probably has a shallow dip to

---

[1]Names and/or dates in parentheses refer to publications listed in the References.

the north, but locally it is irregular with apophyses from the intrusion projecting into the overlying sandstone cover.

Internal Units

The internal structure of the intrusion is divided into four units (Fig. 3). These are the feeder, the marginal zones, the central layered series, and the upper border zone.

The feeder is nearly vertical, and contains bands of bronzite gabbro and picrite parallel to its walls. The origin of the vertical banding is interpreted as due to flowage differentiation during movement of the magma through the feeder fracture (Bhattacharji and Smith, 1964).

The marginal zones are 200 to 1,200 feet thick and parallel the inward-dipping walls of the intrusion (Plate IIA). Bronzite gabbro occurs on the country rock contact and grades inward, with increasing olivine content, through picrite and feldspathic peridotite to peridotite. This sequence can also be explained by flowage differentiation during emplacement of the magma. Pyrrhotite and copper-nickel sulphides occur discontinuously along the gabbro-country rock contact.

The central layered series is 6,000 to 6,500 feet thick and comprises 35 megascopically definable layers having individual thicknesses from 10 to 1,100 feet (Plate IIB). Generally, successive layers are distinctive in composition and have well defined contacts. Interval variations are small in comparison to the differences between adjacent layers, but many layers do vary significantly in composition both vertically and laterally. The layers die out near the marginal zone and do not reach the outer walls. The series as a whole has a slightly synclinal form, its long axis plunging 4 degrees to the north and its edges dipping inward at 5 to 20 degrees. Not uncommonly the layers have surface dips of 5 to 20 degrees northerly, steeper than the plunge of the series as a whole.

Alternating layers of dunite, olivine clinopyroxenite, and subordinate olivine gabbro form the lower layers. In the central part, orthopyroxenite and websterite are interlayered with peridotite and dunite. All the olivine-rich layers are serpentinized at the surface, but some unaltered sections were cut in the south drill hole. The upper part of the layered series is gabbro, with feldspathic and picritic websterite layers. The gabbro becomes gradually richer in interstitial granophyre upward. The layering is due to gravitative fractional crystallization modified by flowage.

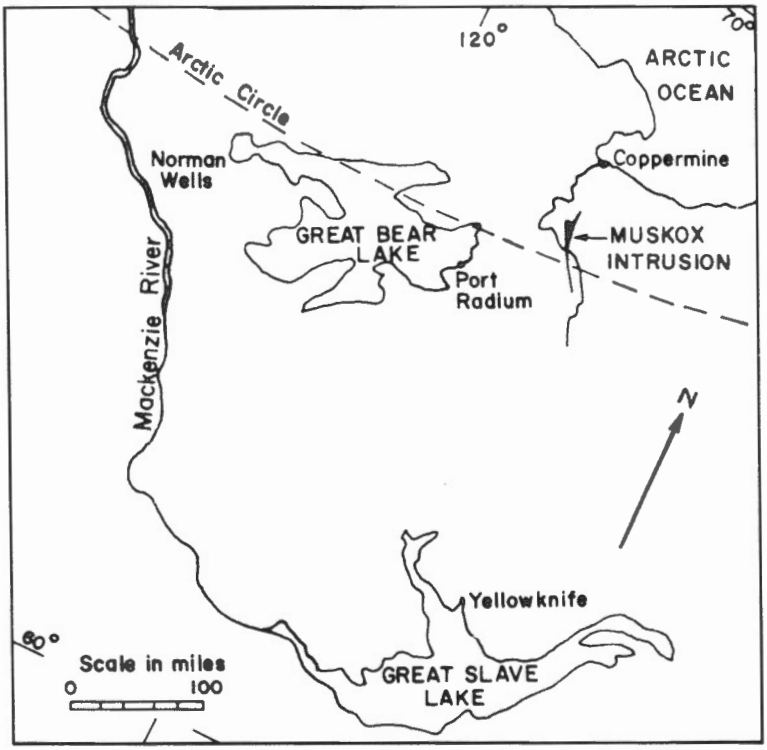


Figure 1. Location of the Muskox Intrusion.

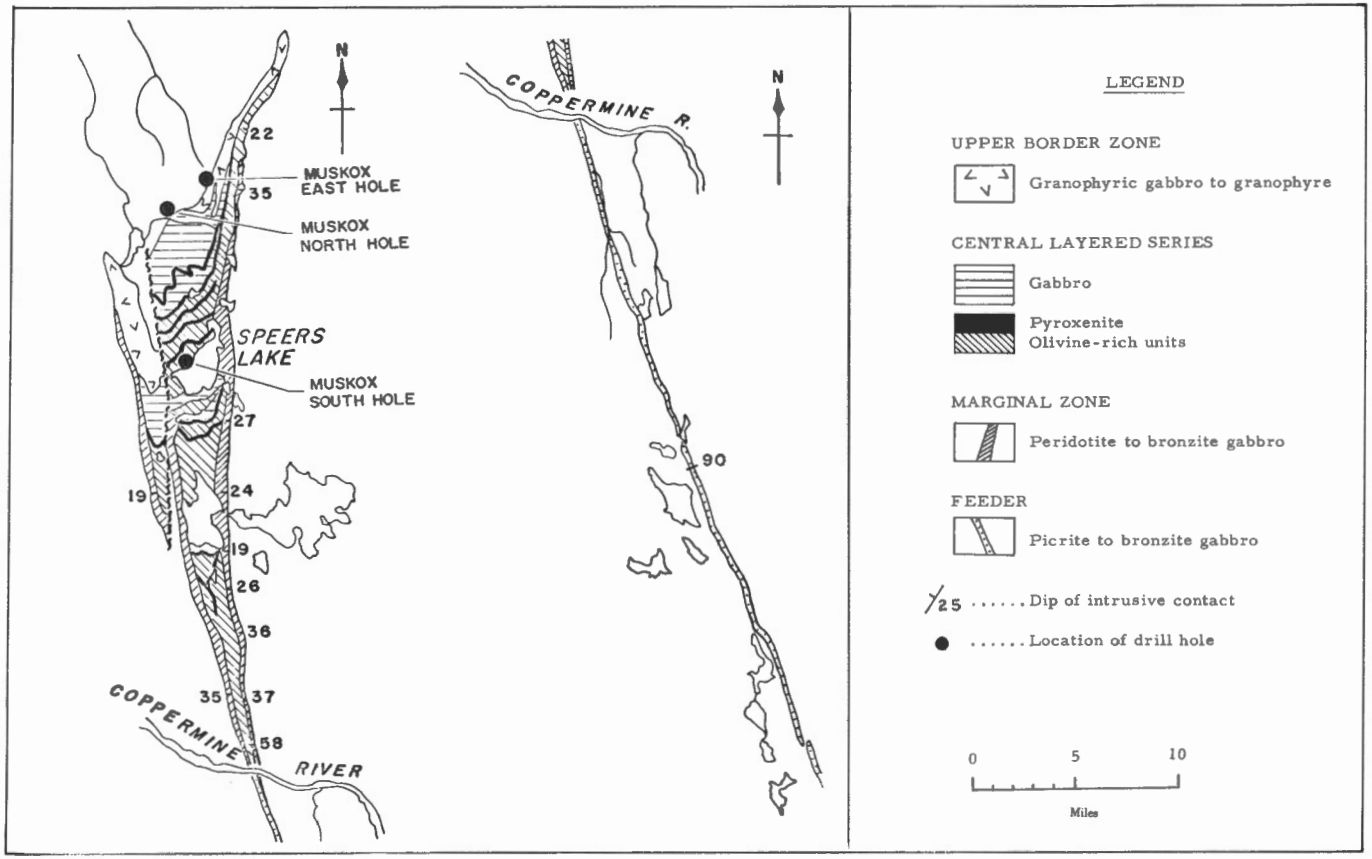


Figure 2: Generalized geology of the Muskox Intrusion. Northern half of intrusion is on the left, southern half on right.

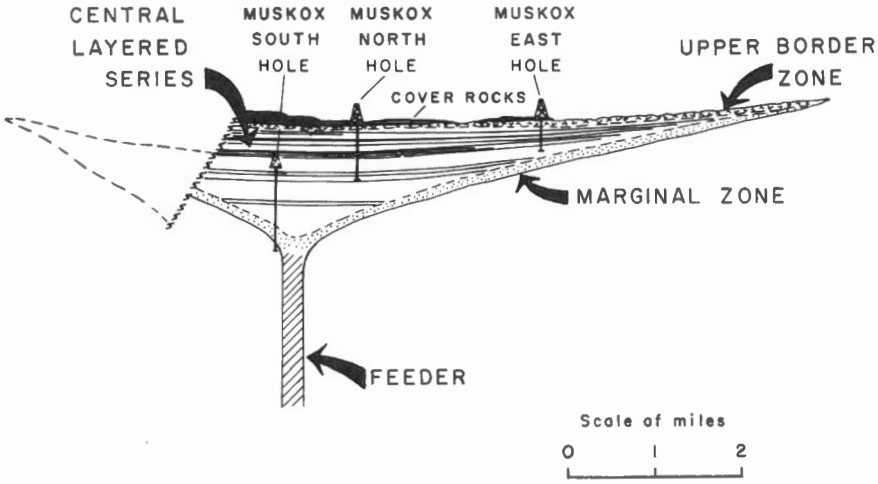


Figure 3. Idealized vertical section showing location of drill holes in relation to the main structural units of the Muskox Intrusion.

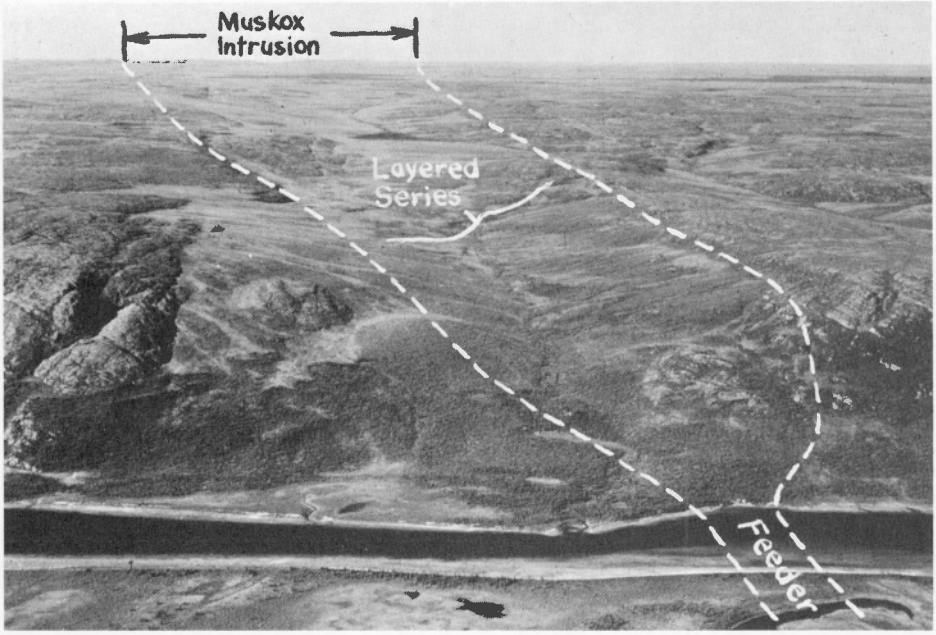


PLATE II A. 112804-H

View from Coppermine River, looking north along axis of intrusion. The 58° inward dip of the east wall is shown by the change in trend of the dashed line on right side of photo.

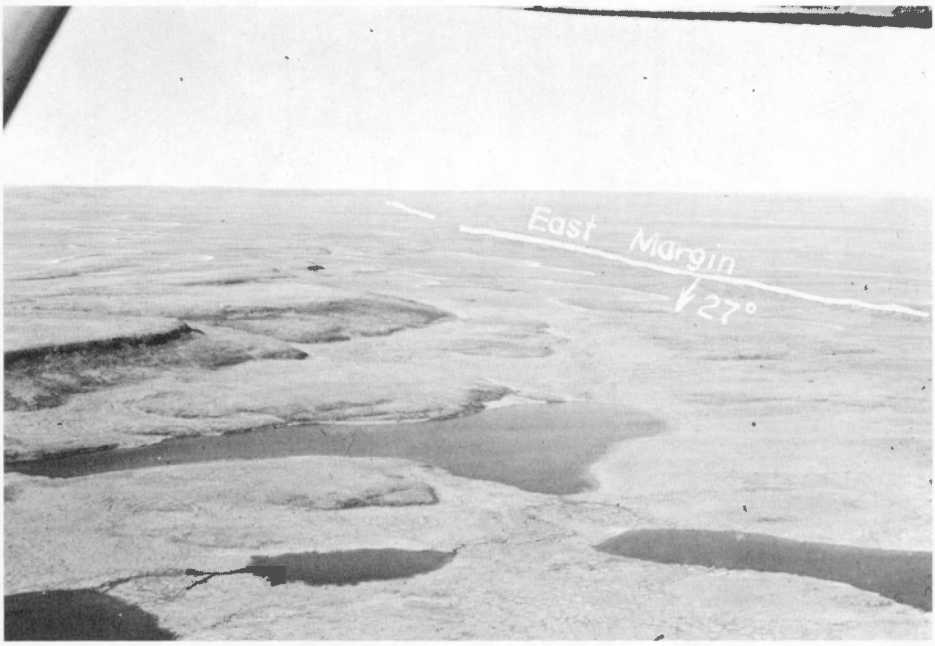


PLATE II B. 112804-A

Resistant pyroxenite layers in soft serpentinized dunite south of Speers Lake. Layers dip 10° to left and east contact of intrusion dips 27° toward viewer.

Several thin chromite layers are present, containing minor copper-nickel sulphides, and occurring just below two of the orthopyroxenite layers.

The upper border zone is characterized by the presence of granophyre and quartz in a thin zone of variable thickness along the roof of the intrusion. It is more extensive in the eastern and western parts of the intrusion than along the central axis. Within the zone there is a general upward gradation from granophyric gabbro through mafic granophyre to granophyre. The units are not sharply defined and pegmatitic facies are common. At places along the roof, the zone includes a breccia of sandstone and other roof rocks cemented by granophyre. The lower boundary of the zone is not clearly defined since interstitial granophyre also occurs in the gabbros of the upper part of the layered series. The zone represents the residuum of the highly differentiated magma, collected along the roof of the intrusion.

Chapter III

GEOLOGICAL PLANNING FOR THE DRILLING PROJECT

Purpose of the Drilling Project

Geological mapping during 1959 and 1960 outlined the essential features of the intrusion. The mapping provided samples for a start on laboratory studies, and made it possible to interpret the subsurface structure and to make an approximate estimate of the abundance of individual rock components in the intrusion. However, many aspects of the petrologic studies were handicapped by a lack of surface exposures for certain units. It was recognized that drilling would enlarge the geologic picture by providing a continuous sample through the intrusion, and that this would allow a more meaningful interpretation of chemical, mineralogical, and isotopic data, since analyzed samples could be precisely located within the framework of the intrusion.

The main objectives of the drilling program were as follows:

(1) To provide a complete core section from roof to floor of the intrusion. Surface mapping had indicated the distribution of each rock type in the intrusion but some, especially the soft serpentinite layers, did not outcrop well enough to be sampled. Absence of these outcrops made it difficult to study the complete chemical evolution of the magma. Many boundaries between layers are poorly exposed owing to differences in weathering properties between adjacent rock units. In order to study the causes of this separation into layers it is important to have fresh, properly oriented material so that the chemical and physical changes across the boundaries can be completely described. These transition areas provide key information on the causes of magma fractionation. The drilling project accomplished this sampling objective, with a core recovery of over 97 per cent.

(2) To verify the stratigraphic sequence outlined by surface mapping and indicate whether unknown rock units existed in the intrusion, economic or not, whose presence was important to interpretations of the chemical history of the magma.

(3) To locate unaltered (unweathered and unserpentinized) ultramafic rocks that would allow the study of alteration processes related to both the deuteric stage of alteration and possibly deep surficial weathering in the intrusion. Unserpentinized rocks were encountered below 1,600 feet in the south drill hole.

(4) To confirm the structural interpretations of the intrusion, especially the layer thicknesses as measured on surface. The thicknesses are important in calculating the original composition of the Muskox magma, and in volumetric considerations of the chemical data. Drilling reduced the calculated thickness of the intrusion from 8,500 feet to about 6,500 feet. The original thickness estimate was too high because calculations were based on surface dips of layers, which were 2 degrees steeper than the general plunge found at depth. In addition, two surface layers were eliminated from the type section, as drilling confirmed they were repeated on the surface by faulting.

(5) To provide holes for various types of in-hole geophysical studies, which could be correlated with the measurement of similar properties in the laboratory. The collection of geophysical data, well correlated with corresponding petrographic data, will assist the planning of future deeper drill holes.

Selection of the Drill Sites

The Muskox drilling project was devised essentially as a means of sampling the unexposed parts of the intrusion and therefore absolute depths of drilling were of secondary importance.

The project was originally planned around a 10,000 foot vertical hole, starting in cover rocks north of the intrusion and penetrating the entire intrusion from roof to base. The single hole approach offered certain advantages from the viewpoint of continuity of sample and depths obtained, but it became apparent in the early stages of planning that a multi-hole program was economically more practical. The multiple-hole program would provide additional subsurface structural control and also fulfil the sampling objectives. Accordingly, the site selection studies were based upon a plan for two holes to a maximum depth of 5,000 feet.

Detailed field surveys for drill site selection were carried out during 1962. The two general areas of investigation were the northern contact of the intrusion and the Speers Lake area (Fig. 2). These were the areas in which drill holes could be located so that horizons encountered at the bottom of the north hole would correlate with those at the top of the south hole (see Fig. 3). The main objectives in site selection were as follows:

(1) To ensure the thickest possible section of the layered series and still breach the intrusion wall near the join area between the feeder and marginal zone.

(2) To avoid shear zones, or diabase dykes, which would cause caving in the holes and poor core recovery. The diabase dykes in the

area tend to dip steeply, and their intersection in the drill holes could result in several hundred feet of diabase, rather than Muskox, core.

(3) To facilitate the drilling operation by providing a site on or near bedrock which was as accessible and close to a water supply as geological conditions would allow.

As an aid in location of drill sites, several types of geophysical information were available. In 1961 an airborne magnetometer survey was carried out over the intrusion, and in 1962 detailed ground magnetometer surveys were made over preliminary site areas. At the same time, detailed geologic mapping (1" = 100') was carried out near the sites, for correlation with the magnetic surveys. In 1962, a detailed gravity survey was completed over the intrusion area by the Dominion Observatory, as part of a regional gravity survey of the Coppermine map-area. Information from these geophysical surveys was correlated with the known geologic data, and used to select the final drill sites.

The pertinent geologic, magnetic (aerial and ground), and gravity data for the two drill sites, as well as for various alternate sites that were considered, are summarized in Figures 4 and 5. From the results of the aeromagnetic surveys (Geological Survey of Canada, 1963) it appears that magnetic highs correlate with an abundance of secondary magnetite in shear zones and should be avoided in selecting a drill site. Gravity highs probably reflect the thicker section of the intrusion overlying the feeder. This is confirmed at the south site by the close correlation of the feeder position obtained from structural data with the gravity high (Fig. 5).

At the north drill site (Muskox North) the gravity high lies at a considerable distance west of the hole location. Location of the hole over the gravity high would have resulted in drilling an excessive thickness of cover rocks before reaching the roof of the intrusion. Since the north hole would only penetrate the upper layers of the intrusion, locating it over the feeder was not critical. The remarkable continuity of layers shown by surface mapping indicated that this hole could be safely moved laterally from the axis of the intrusion for a considerable distance without affecting the thickness of the layers encountered (see Fig. 3). Site 1 (Fig. 4) was eliminated as being too close to the eastern margin of the intrusion, and site 2, as being on line with faults mapped at the surface. Site 3 required drilling an estimated 650 feet of cover rocks. The final site chosen provided a good bedrock setup, 2,200 feet from water for drilling. It was west of the main magnetic high, and considered to be underlain by 150-250 feet of cover rocks (the actual footage drilled was 202 feet). The principal drawback to this location was the presence of a diabase dyke, outcropping to the northwest. The dyke is 200 feet thick and dips

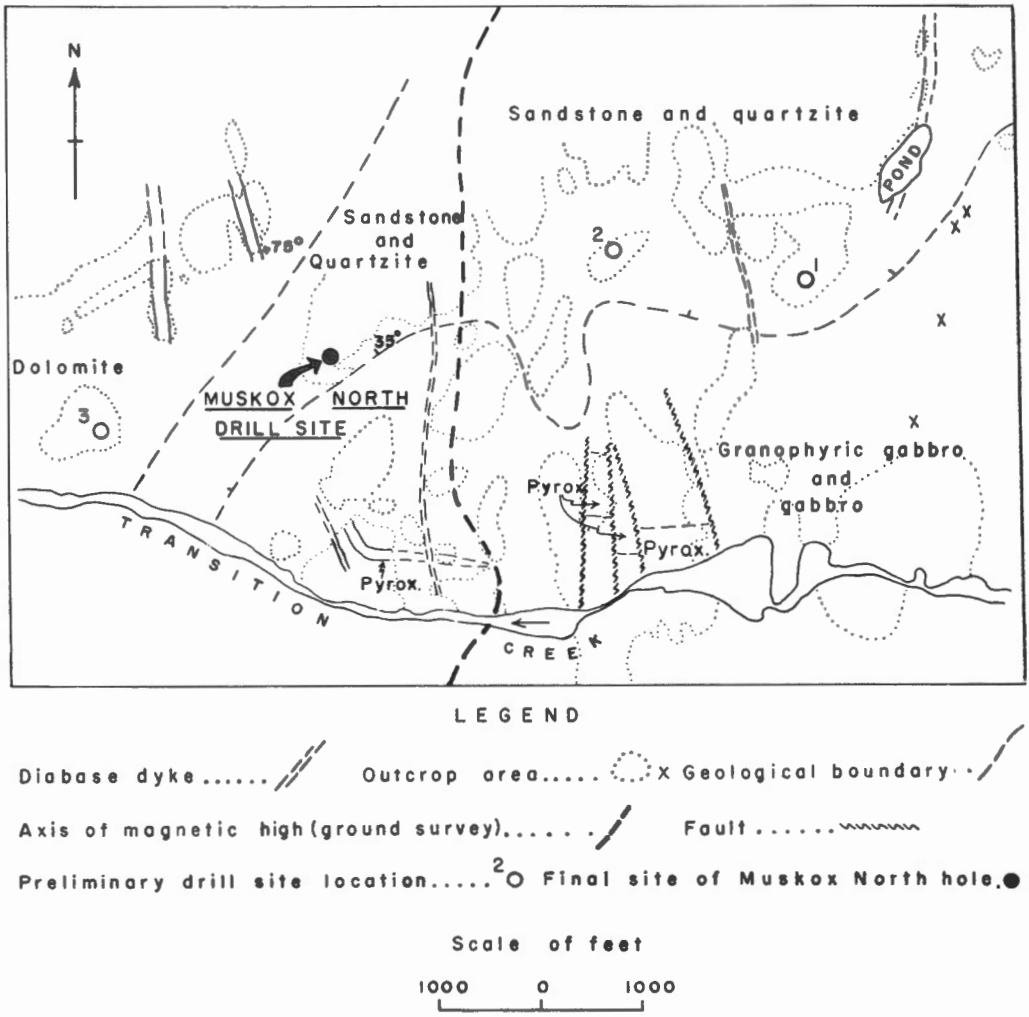


Figure 4. Detail of Muskox North drill site.

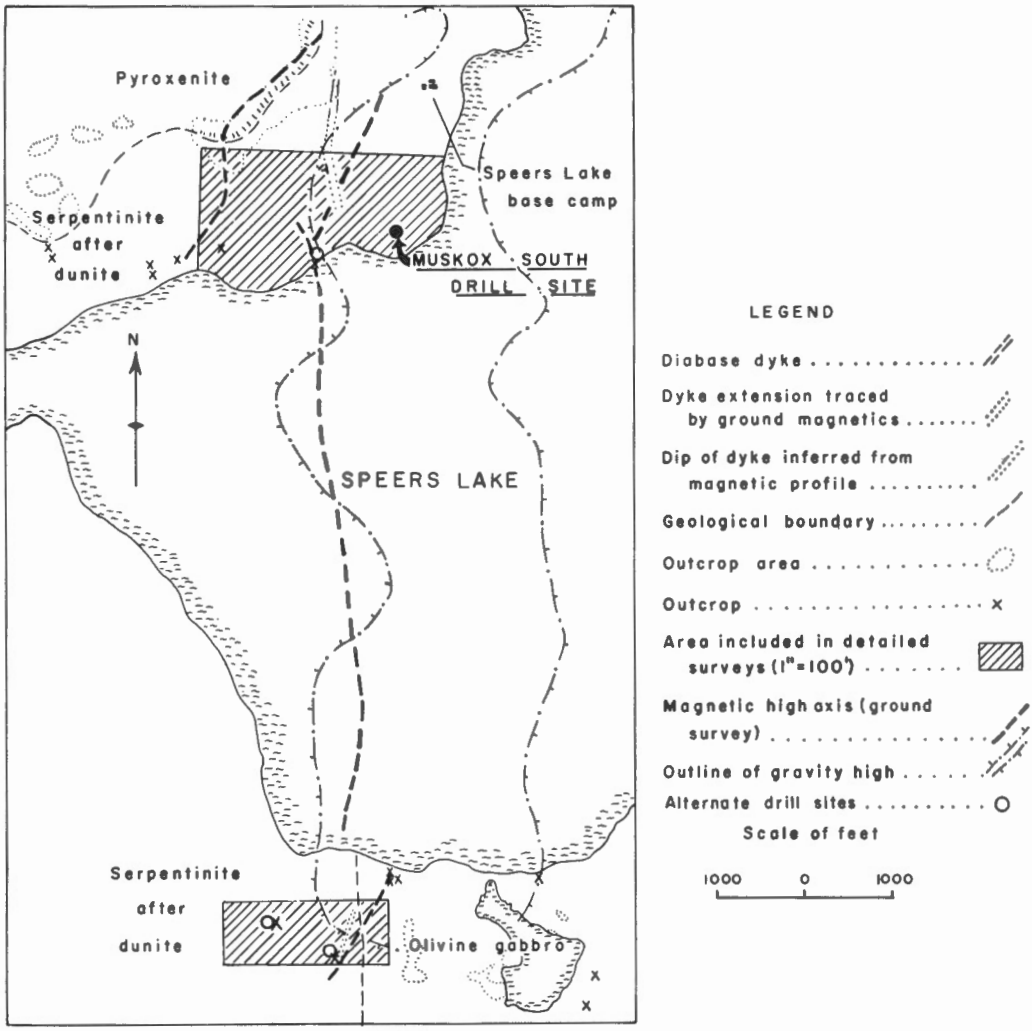


Figure 5. Detail of Muskox South drill site.

75 degrees easterly. It could not be traced toward the drill site by magnetometer, but it was anticipated the dyke might be encountered in the drill hole. One diabase dyke was in fact cut in the hole, between 2,657 and 2,840 feet; it is probably the anticipated dyke although the drill hole intersection indicates the dip of the dyke is shallower (65°E) than estimated from surface information.

The south drill area (Fig. 5) is crossed by magnetic and gravity highs. Bedrock in this area is sparse, as Speers Lake is underlain by soft serpentinite. Magnetic highs follow shear zones in the serpentinite and lie east and west of the gravity high, which appears to mark the axis or feeder of the intrusion. Location of the drill site near the gravity high was more essential at this site than at the north drill site in order that the drill would penetrate the lower layers, which have a restricted lateral extent near the feeder (see Fig. 3). Possible drill sites on the south and northwest shores of Speers Lake were examined. The south shore area was eliminated for structural reasons, as collaring the hole so low in the stratigraphic section reduced the opportunity for overlap and correlation with the north hole. In addition outcrops are scarce and a magnetic high lies near the better locations on the south shore. The drill site selected for the south hole (Muskox South) suited the principal geologic criteria and was close to water. It was not a bedrock site, however, although bedrock was considered to be close to surface at this point, based on the ground magnetic survey. In actual fact, the depth to bedrock turned out to be 45 feet and proved more troublesome than anticipated (as discussed in the section on drilling operations, later in this report).

During the course of the actual drilling, it became apparent that the shallower dips encountered would reduce the total section to be penetrated in the two holes. Accordingly, a third hole (Muskox East) was located on bedrock, 2 miles northeast of Muskox North. Its purpose was to sample the upper layers of the intrusion where they change in thickness toward the margins. This hole confirmed that the granophyric upper border zone is thicker toward the margins of the intrusion than in the centre whereas the other layers, with a few exceptions are thinner toward the margin (Fig. 14).

Chapter IV

OPERATIONAL PLANNING FOR THE PROJECT

The preliminary planning and mobilization of equipment and personnel are described in this chapter. The drilling specifications set out by the Geological Survey as a guide for tendering are included in Appendix A. Although the methods of planning and bidding described here will be improved in the light of further experience, presentation of information from the Muskox project will indicate some of the factors and problems involved in planning, cost estimating, and bidding.

Drilling Specifications

In October, 1961, 50 Canadian diamond-drilling companies were contacted concerning their interest and experience in deep drilling in arctic regions. First specifications called for a single 10,000-foot hole through the intrusion, but this plan was eventually abandoned and a program of 5,000-foot holes developed.

The final specifications (Appendix A) generally followed accepted Canadian practice, and were designed to discourage erratic bidding by providing as complete information as possible on the anticipated drilling conditions. The change in plan from a single 10,000-foot hole to two 5,000-foot holes was expected to reduce the costs by allowing contractors to bid on the basis of utilization of more readily available standard equipment, and routine diamond drilling techniques, which fell within the range of past drilling experience of many of the companies.

In retrospect, the specifications proved fairly straightforward in application and the only clause that caused uncertainty was that concerning casing (clause 7, Appendix A). This is a difficult problem to resolve to the complete satisfaction of both contractor and client, but it is probable that reaming and placing of casing on a straight cost per foot basis might have been a more workable approach. Clause 17 (core handling) was not strictly adhered to in the field, for it proved more practical for members of the Geological Survey supervisory party (see Chapter VI) to check and sample the cores prior to boxing and shipping.

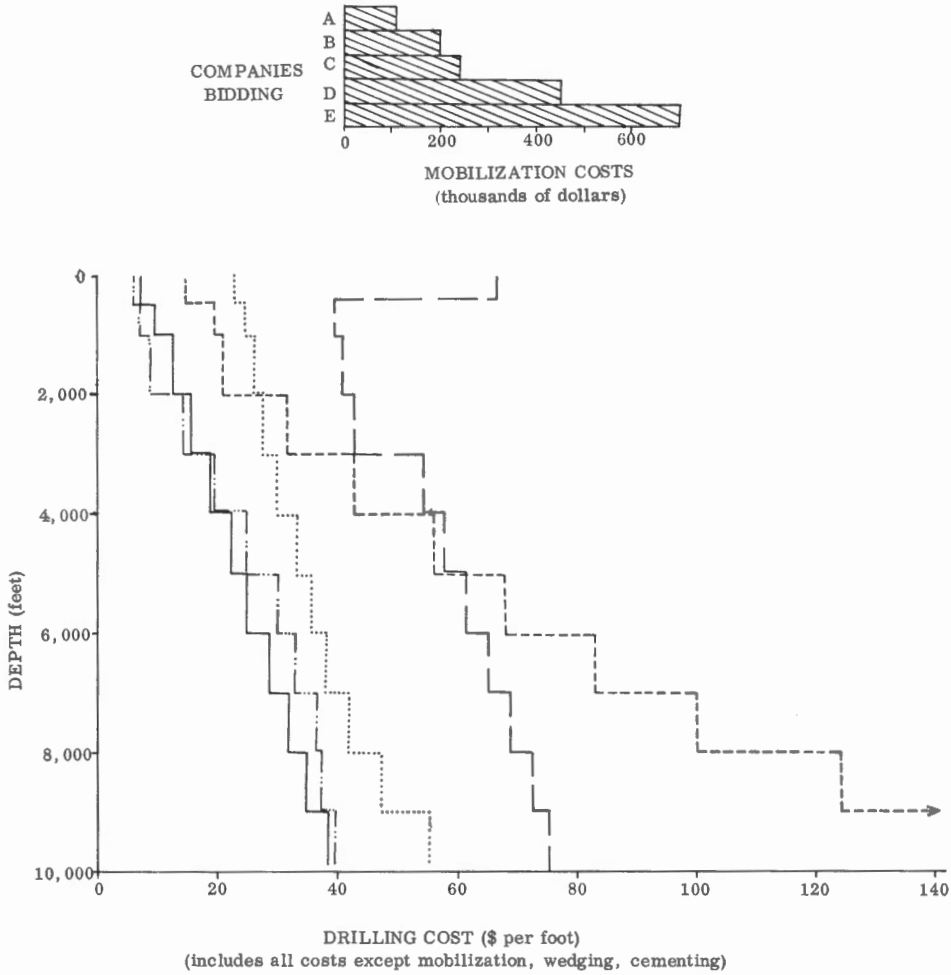


Figure 6. Range of bids on proposed 10,000-foot, BX-size, diamond-drill holes.

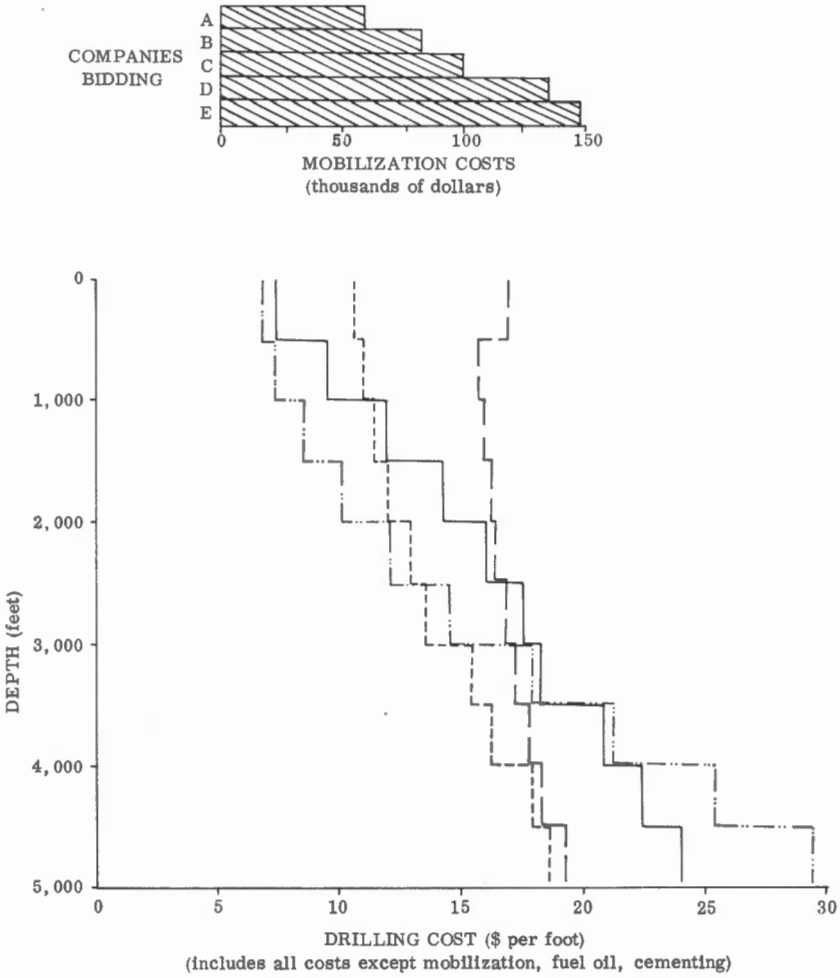


Figure 7. Range of bids on two 5,000-foot, BX-size, diamond-drill holes.

Tenders

Bids were received from seven companies on the original 10,000-foot hole; the wide range in these bids is shown in Figure 6. The spread in bids is due principally to inexperience in diamond drilling to this depth, because none had previously been attempted in Canada. The higher cost estimates reflect the intention of certain companies to purchase deep-drilling equipment for the project, while the lower bids are from companies planning to modify existing equipment. Extreme variations in mobilization bids reflect an unrealistic appraisal of cost factors involved in mobilization due to inexperience in drilling in remote arctic regions. None of the bids were acceptable and as a result the specifications were altered to the multiple-hole program.

The bids received for the final program (Fig. 7) still show a considerable range although less than for the 10,000-foot hole. The closer bidding undoubtedly reflects the experience of contractors who had previously drilled to these depths. The spread in mobilization bids was high, reflecting again the lack of experience and uncertainty related to arctic drilling.

Costs

The costs discussed here refer to the percentage costs to the Geological Survey rather than the true costs of the project. The reasons for omitting the true costs of the operation can be appreciated, since the drilling was carried out by a private contractor engaged in a highly competitive industry.

Table 1 summarizes the cost of the entire drilling program. Drilling costs account for slightly over one-half (54.0%) of the total cost. Mobilization costs are relatively high because the inaccessibility of the area required supply by aircraft alone. Spring flooding along the truck route between Edmonton and Yellowknife required additional mobilization flying. The utilization of a large DC-6 freighter aircraft operating into a prepared ice strip at Speers Lake reduced the flying costs considerably compared to the anticipated cost of mobilization by smaller aircraft.

Costs involved in construction and maintenance of a 5,000-foot airstrip on the ice of Speers Lake (Table 4) are low because there were no rental charges for the D-4 tractor loaned by the Department of Transport, and the tractor was operated by the drill crew. The costs shown represent reconnaissance flights, freighting of the tractor to and from Speers Lake, and tractor repairs. The fuel oil costs represent the purchase of 25,000 gallons of oil plus about 550 drums

used in transportation and storage. Only 19,300 gallons were consumed and the remainder was disposed of through Crown Assets.

Table 1

Overall Cost Distribution for the Project

	Per cent of Total Cost
A. Mobilization	
1. Drilling equipment, materials and supplies	23.6
2. Airstrip construction and maintenance (ice strip)	2.1
3. Air freighting of fuel oil	6.4
B. Drilling costs	54.0
C. Fuel oil	5.0
D. Geophysical well-logging	5.1
E. Field supervision	
Logging and sampling of cores, supervision of drilling and well-logging	3.8
	100.0

Table 2 shows the cost distribution for drilling alone. The major item, core drilling, includes the contractor's profit in addition to such operational costs as wages, diamonds consumed, camp maintenance and supply, equipment depreciation, repairs, taxes, etc. Overburden penetration costs are low because two of the holes started in bedrock. Reaming, cementing, and casing costs resulted from the necessity of sealing off the upper fractured and altered sections of the Muskox South and Muskox East holes. Casing costs were higher than normal because it was necessary to leave casing in the holes for future heat flow studies. In a normal drilling operation some of this casing could probably have been recovered.

Table 2

Distribution of Drilling Costs

	Per cent of Total Cost
Overburden penetration	0.4
Core drilling	90.2
Reaming	2.5
Cementing	1.0
Material left in holes (Casing and non-recoverable diamond costs)	4.3
Acid tests	0.5
Wedging	---
Moving to new site	1.0
Rental time during geophysical surveys	0.1
	100.0

Mobilization

The first stage of field operations involved mobilization of equipment, supplies, and fuel at the Speers Lake base. Because of the remoteness of the project site, efficient mobilization was a complex and important part of the operation, and involved the coordination of numerous transportation and logistic schedules to ensure arrival of the bulk of equipment and materials, well before the ice at Speers Lake started to break up. The most important factor in mobilization planning was to ensure schedules that would coincide with the period of optimum weather conditions for flying heavy aircraft into the area, usually between the end of March and the early part of May.

Drilling equipment was shipped from North Bay, Ontario, to Peace River, Alberta, via railway piggyback, in February 1963. The initial shipment comprised 4 truck loads with a total weight of about 60 tons. From Peace River, the equipment was trucked 631 miles via the new all-weather road to Yellowknife, where it was assembled at the airport for air freighting into Speers Lake. In addition to the drilling equipment, other materials and supplies were collected locally (Edmonton and Yellowknife) and assembled at the Yellowknife staging point. These latter consisted mainly of lumber and materials for camp construction, and miscellaneous drilling supplies. A final and vital truck load from North Bay, consisting mainly of drill rods and casing (totalling 28,000 lb.), arrived in Hay River in late April, where it was delayed for 10 days owing to severe flooding. Eventually, this load was flown to Yellowknife and ultimately airlifted to Speers Lake (Plate IIIA).

To prepare for the airlift, an advance crew of drilling personnel flew to Speers Lake on April 3rd in a ski-equipped Otter aircraft, and started an icestrip for the DC-6 aircraft that was utilized for heavy freighting. The airstrip was constructed with a D-4 Caterpillar tractor, equipped with blade shoes and grousers, flown in by Bristol Freighter aircraft. By April 18th, after some delays due to adverse weather - high winds and drifting snow on the lake - an icestrip 150 feet wide and 5,000 feet long was completed and the airlift began. Transport of the bulk of the drilling equipment, camp material, and supplies required six DC-6 flights carrying a total load of about 156,000 pounds (Plate IIIB). In addition six trips with the Bristol 170 Freighter aircraft and one DHC-3 Otter trip were required for freighting miscellaneous equipment, supplies, and personnel. The total weight transported during this phase of the airlift was about 218,000 lb. (Table 3).

The fuel requirements, consisting of 25,000 gallons of number 1 Winter Grade Diesel fuel, and about 1,500 gallons of gasoline, were airlifted in 45 gallon drums from Norman Wells 350 miles to the southwest, and from Yellowknife. The fuel haul required eight DC-6 trips from Norman Wells and one (the last) from Yellowknife. The DC-6 carried 63 barrels or approximately 2,800 gallons per trip (Plate IIIC).

The main part of the air-freighting, by DC-6, was completed by May 13th, and on May 22nd the last Bristol Freighter flight was made to Speers Lake. This marked the end of the heavy flying. At this point about 230 tons of equipment, materials, supplies, and personnel had been airlifted to Speers Lake.

Data on the airlift are summarized in Table 3 below. The figures include the initial transportation of all equipment, materials, fuel, and personnel to the job site, but do not include the regular supply flights (generally on a weekly basis) or flying related to air-strip construction. Table 4 summarizes data and costs for airstrip construction and maintenance at Speers Lake.

Table 3

Airlift Data

Aircraft	No. of Trips	From	To	Total Wt. lb. (approx)
A. Drilling Equipment and Materials				
DC-6	6	Yellowknife	Speers Lake	156,000
Bristol Freighter	6	Yellowknife	Speers Lake	60,000
Otter	1	Yellowknife	Speers Lake	2,000
			Total -	218,000
B. Fuel				
DC-6	8	Norman Wells	Speers Lake	218,790
DC-6	1	Yellowknife	Speers Lake	27,555
			Total -	246,345

PLATE III A.
Unloading BX drill rods from Bristol 170 Freighter at Speers Lake, May, 1963. (N. F. B. photo.)

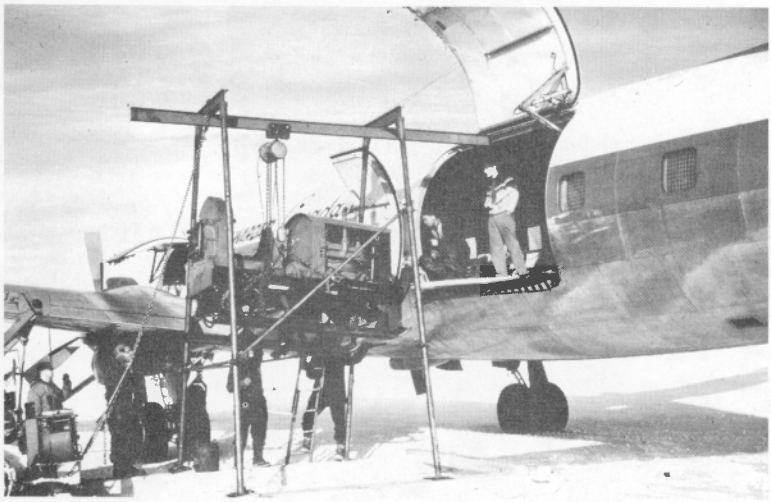


PLATE III B.
Unloading Boyles BBS-3 diamond drill from DC-6 aircraft on ice-strip at Speers Lake, April, 1963. (N. F. B. photo.)
112804-F

PLATE III C.
Unloading part of 25,000 gallon fuel oil supply at Speers Lake, April, 1963. (N. F. B. photo.)
112804-D

Table 4

Airstrip Construction and Maintenance Data

Construction period	- April 6-18
Delays due to	- High winds and drifting snow. Mechanical trouble with D-4 tractor.
Equipment	- One caterpillar D-4 tractor equipped with blade shoes (3" blade clearance) and grousers.
Strip Dimensions	- 5,000' x 150-165'. Markers at 500 foot intervals.

Airstrip Costs

A. Flying		
2 Bristol 170 trips (tractor and blade; fuel)	2,212.00	
2 Otter trips	1,399.20	
1 Beaver trip (reconnaissance)	477.00	
	4,088.20	$4,088.20
B. Fuel, Gas and Oil		451.96
C. Tractor Maintenance and Repairs		
Installing grousers, blade shoes, and winterizing	397.28	
Freight charges on parts	37.48	
Repairs at end of operation	416.62	
	851.38	851.38
		$5,391.54

Chapter V

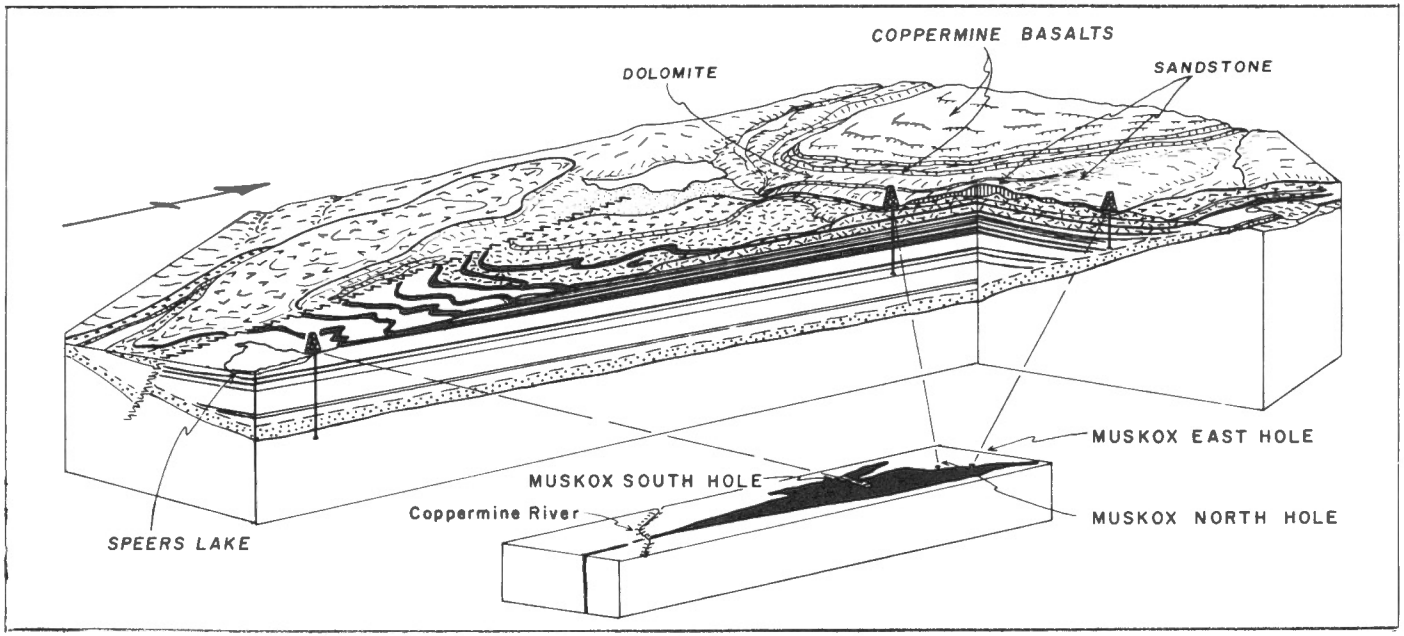
DRILLING OPERATIONS

Drilling commenced on May 10th at the Muskox North hole, and finished on September 25th, when the last run was made to a depth of 2,496 feet in the Muskox East hole. Throughout much of this period, two of the three holes were being drilled simultaneously. Drilling was carried out continuously except for short shut down periods due to mechanical troubles or delays caused by various in-hole operations such as reaming and cementing.

The drilling period spanned varying weather conditions, from pre-breakup, essentially winter conditions at the start, through normal summer operations, and into the late fall pre-freeze-up period. Consequently, wide ranges in actual drilling conditions were encountered, from permafrost drilling with its special problems and techniques at the start, through changing conditions due to the varying physical properties and structural characteristics of the rocks penetrated, and finally to the added problems of deeper drilling. Technical and performance data on the drilling were recorded in as much detail as possible, but, since the prime function of the operation was to recover core samples through the intrusion rather than carry out research in drilling, there are unavoidable gaps in the technical records. Many of these omissions would only have been rectified by installation of more expensive recording instruments on the drills and ancillary systems. It is probable that greater instrumentation to obtain accurate and detailed technical data should be included in future drilling programs.

The drilling operation was fully successful, in that all the Geological Survey requirements concerning core recovery (better than 97%), hole deflection (less than 4° from vertical), and target depths, were met.

In this chapter, the various aspects of the actual drilling operations are described. The first part is essentially a narrative account of the drilling, to provide a chronological outline of the experiences encountered. In the following sections, details of equipment, procedures, and special problems such as permafrost drilling, technical records, and performance data are discussed. In following the progress of the three holes - Muskox South (4,000'), Muskox North (3,593'), and Muskox East (2,496'), reference may be made to Figure 8, which shows the locations of the holes, and to Figure 9, which summarizes their vital statistics and performance records.



LEGEND

Sandstone and quartzite roof rocks

Drift-covered area

MUSKOX INTRUSION

Granophyric rocks

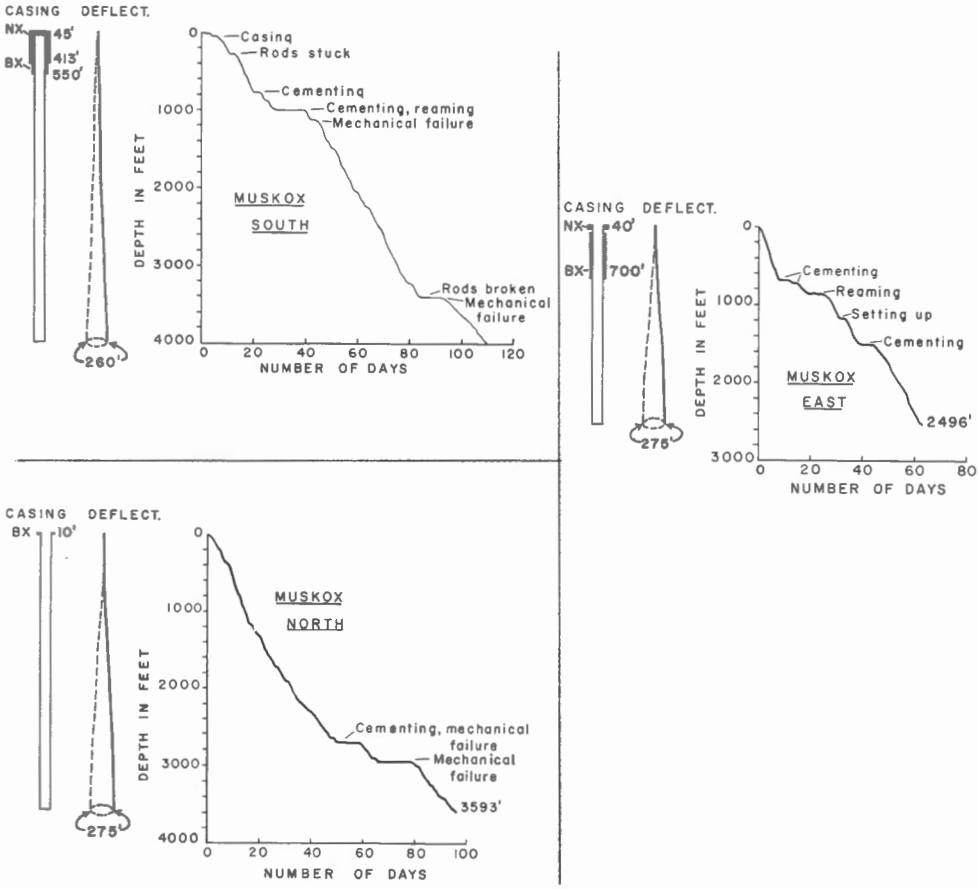
Gabbros

Pyroxenites

Dunite and peridotite

Marginal Zone rocks (peridotite, picrite, norite)

Figure 8. Relation of drill holes to internal structure of intrusion. Position of feeder not shown.



SUMMARY

	SOUTH	NORTH	EAST
SITE	45' Ovrb.	Bedrock	Bedrock
COLLAR ELEV.	1759.6'	1682.8'	1893.5'
PERMAFROST DEPTH	660'	700'	
HOLE DEPTH	4000'	3593'	2496'
CASING	413' NX 550' BX 46' H	4' NX 10' BX	40' NX 90' Gap 570' BX
MAX. DEPARTURE	130'	138'	138'
DRILLING DAYS	110	97	63
AV. ADVANCE/DAY	36.4'	37.0'	39.6'
AV. PENETRATION RATE (FEET/HR)	3.77	2.80	3.40
AV. BIT FOOTAGE	43.0	49.2	55.5
CORE RECOVERY (%)	97.3	98±1	98.7

Figure 9. Summary of drill hole data.

Narrative Account of Drilling

In late April and early May, prior to completion of the air-freighting operations into Speers Lake, work was started on the Muskox South (Speers Lake) and Muskox North (Transition Creek) drill sites. The Muskox South site, located on overburden, was cleared of snow and levelled, so that by May 5th the site was ready, and the erection of a 52-foot steel tower for the Boyles Brothers BBS-3 drill was begun (Plates IVA, VA). During this same period overland hauling of fuel and equipment by Bombardier tractor to the Muskox North site, 7 1/2 miles to the north, was completed and assembly of a 65-foot derrick for the Boyles Brothers BBS-4 drill was begun at the site (Plate IVB). Muskox North was collared in bedrock, thus involving fewer problems in site preparation than Muskox South, and core-drilling commenced there on May 10th. At Muskox South, the more complicated tower took longer to erect, but by May 14th sinking of casing through overburden had started. Muskox East, the last hole to be drilled, was not collared until July 25th after much of the drilling at Muskox South and Muskox North had been completed. The east site, 2 miles northeast of Muskox North, was on outcrop, and the hole was started using an Inspiration #3 drill with a standard three-legged wooden tripod giving a 20-foot pull (Plate VB). On completion of Muskox North, the heavier BBS-4 drill was moved to Muskox East to finish that hole. A summary of the drilling and ancillary equipment used in the project is given in Appendix B.

Muskox South Drill Hole

At Muskox South, the 45 feet of overburden encountered gave considerable trouble during the first few days of drilling. Hole design there called for; (a) H casing to bedrock; (b) NX casing a foot or so into bedrock; and (c) BX casing several feet into bedrock to provide a firm starter for BX core-drilling. The NX casing was to be sunk and then removed, after the inner BX casing was driven, to leave an airspace between BX and H casing. This was a safety factor in the event that the BX casing might have to be later freed by re-driving NX casing. This turned out to be a fortunate precaution, because it was necessary ultimately to ream the BX casing to a depth of 550 feet in the hole. The difficulties encountered in sinking H casing through overburden stemmed from an anomalous absence of permafrost from a few feet below surface to a depth of 40 feet. This resulted in unfrozen, unconsolidated sand and boulders continually jamming the casing, and necessitated repeated backing off and re-driving before the casing was finally seated in bedrock. A 3 7/8" Tricone bit, coupled with the intermittent use of casing bits to cut larger boulders, eventually proved fairly successful in penetrating the overburden.

PLATE IV A. 112804-I

View looking south over Speers Lake. Preliminary site preparation for Muskox South hole, May, 1963. (N.F.B. photo.)

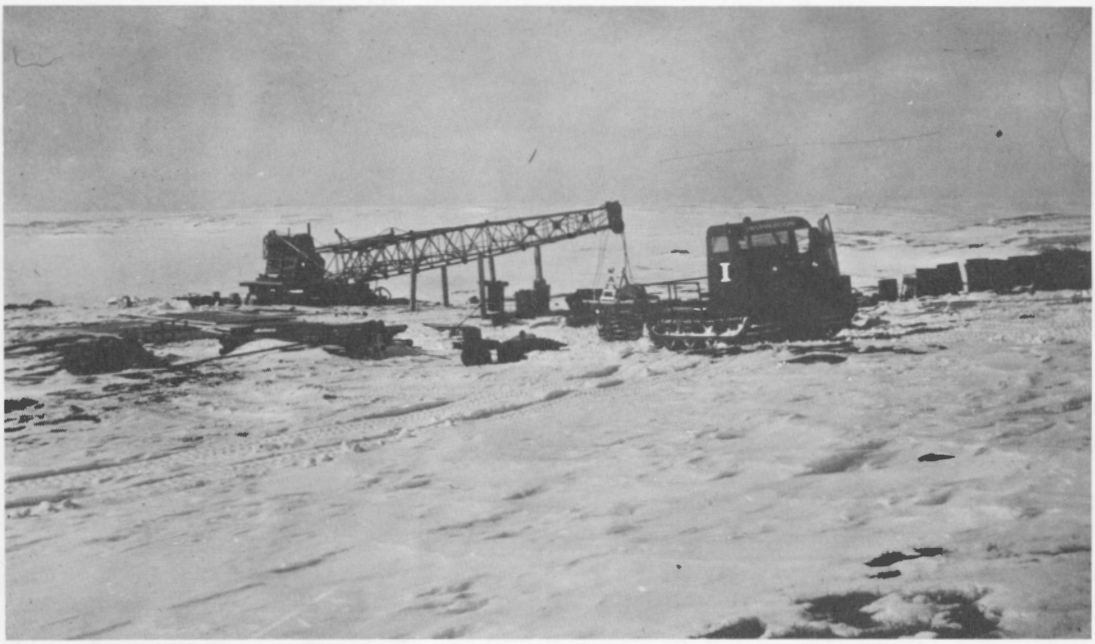
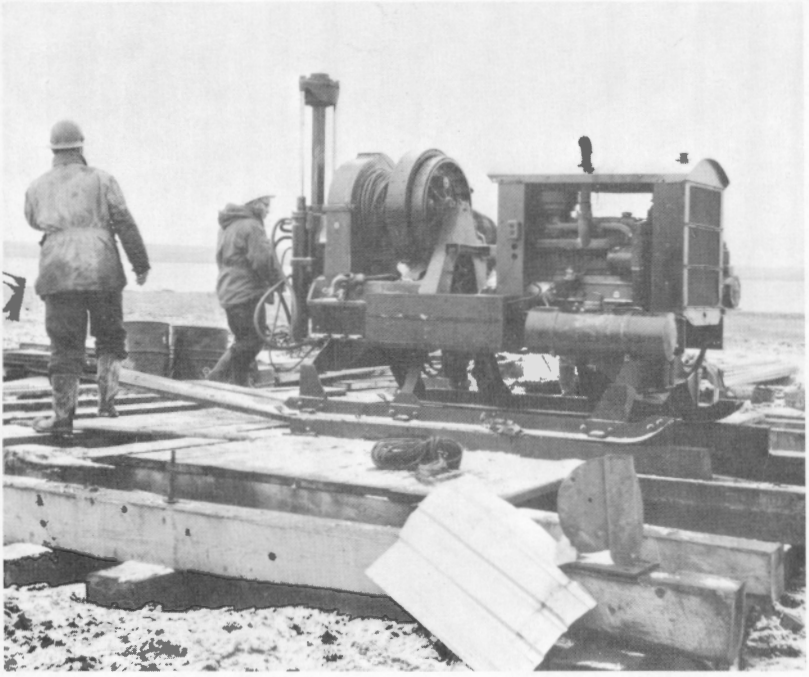


PLATE IV B. 112804-J

Assembly of derrick at Muskox North drill site prior to raising. View looking south. (N.F.B. photo.)



D. C. F. 9-7-63

PLATE V A. Boyles BBS-3 drill with hydraulic head used to drill to 4,000 feet on Muskox South hole (see Appendix B).

D.C.F. 1-6-63

PLATE V B. Inspiration Mark 3 drill with hydraulic head used to start Muskox East hole to depth of 1,175 feet (see Appendix B).

By May 19th, the H casing had been driven to bedrock at a depth of 45 feet, NX casing to 48 feet and then removed, BX casing to 51 feet, and core drilling began (Plate VIA).

The most difficult drilling conditions in Muskox South were encountered in the upper 1,500 feet of the hole (Fig. 9) where much of the rock is heavily serpentinized dunite (over 75% serpentine). The rock is soft, commonly closely fractured, caves easily, and tends to form a thick, highly viscous and sticky mud or sludge. This sludge, on mixing with rod grease, became caked on rods and casing walls and eventually accumulated until the rod string could no longer be turned. Also, the extreme softness of the rock over much of this section caused problems in keeping casing in position during drilling. In one instance, a section of BX casing broke off through in-hole vibrations because of poor seating, and travelled down the hole a distance of 130 feet before becoming solidly jammed. Attempts to recover the broken segment were unsuccessful and it was eventually necessary to ream NX casing to a depth of 413 feet to free it. Above 550 feet, several strong fracture zones in serpentinized dunite were intersected, and severe caving from these zones could not be stopped by cementing. As a result, the BX casing was reamed to 550 feet to seal off these zones. Between 550 feet and about 900 feet, additional caving areas were penetrated, but after several attempts they were cemented sufficiently to allow drilling to proceed.

Trouble was also encountered during the early stages of drilling when the heat generated by drilling thawed the muskeg, resulting in formation of a muddy cavity several feet deep and wide around the collar of the hole. This lack of firm support for the outside H casing caused it to gradually work downward during drilling, so that additional 1-foot sections had to be added from time to time to keep the water-return outlet above ground level. Thawing beneath and around the drill platform also caused some instability of the tower and set-up. Both of these situations were partly rectified by hauling gravel fill and placing it under the sills and around the collar.

In addition to delays caused by poor drilling conditions in the upper 1,000-1,500 feet of the hole, progress was slowed by mechanical problems with the drill itself. Considerable delay was caused by breakdowns, repair, and waiting for replacement parts (Fig. 9). As a result, by June 30 after 1 1/2 months of drilling, the hole had only reached 1,381 feet.

The drilling record improved considerably during July as less serpentinized rocks were encountered and the major mechanical problems with the drill were rectified. At the end of July a depth of 3,215 feet had been reached, the monthly advance being 1,834 feet.

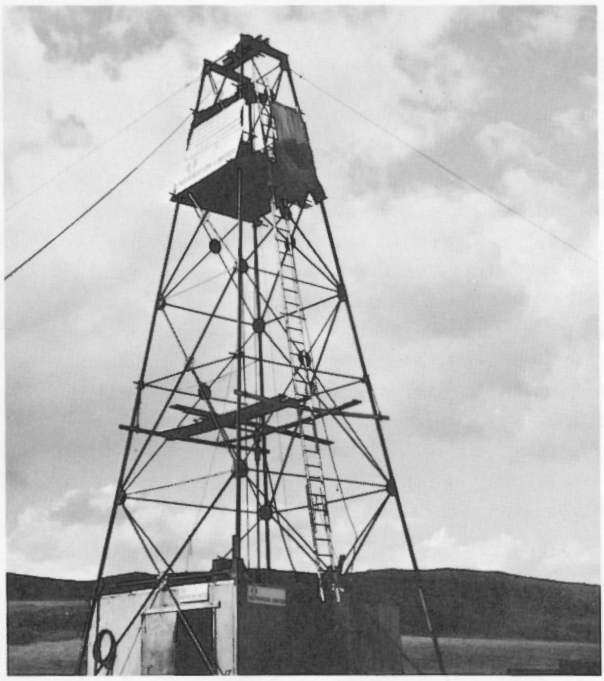


PLATE VI A.
Drilling at the Muskox South site with BBS-3 diamond drill and 52-foot sectional steel tower. Drill is set up over 45 feet of overburden overlying serpentinized dunite. A resistant pyroxenite layer outcrops in background.

D. C. F. 7-3-63

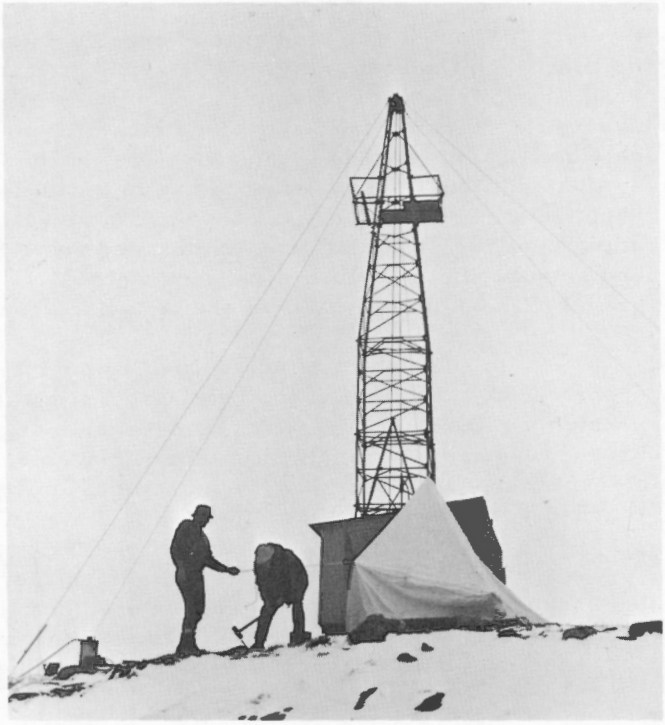


PLATE VI B.
The Muskox North drill site in May. The 65-foot needle derrick and BBS-4 drill are set up on a sandstone outcrop in the roof of the intrusion. (N. F. B. photo.)

Drilling progressed satisfactorily during August, although at slower rates of advance owing to the increased depths. The hole was completed on September 1st at its target depth of 4,000 feet in footwall rocks (quartz-feldspar gneisses) below the west wall of the intrusion.

After drilling was completed, and before the rig was dismantled, fuel oil was pumped into the upper 1,300 feet of the hole to keep it unfrozen for subsequent in-hole geophysical logging. This required about 250 gallons of oil.

An unusual feature of this hole was the extreme wear of in-hole equipment (drill rods, casing, core barrels, testing barrels etc.) In the upper 1,500-2,000 feet it was extremely difficult to keep grease on the rods and, after a few drilling days, steel became polished and worn as if attacked with a grinding wheel. The rods used were the

PLATE VII. D.C.F. 6-5-63

Twisted and ruptured BW series rods recovered from Muskox South hole. Excessive wear leading to rupture was probably caused by the abrasive action of fine magnetite and chromite crystals released from serpentinite and carried in suspension in return water.

relatively thin walled "BW" series, which proved too light for these high-wear conditions. They frequently became worn through, resulting in split rods, water loss, and not uncommonly a broken rod string that had to be fished out and repaired (Plate VII). By the end of drilling nearly 1,000 feet of BW rods had been discarded owing to excessive wear or splitting. The wear was probably caused by magnetite and chromite released from the serpentinized dunite during coring under fluid pressure and acting as efficient abrasives while in suspension in the return water. The serpentinite normally contains 3-7 per cent finely disseminated secondary magnetite, with locally higher concentrations in thin veinlets, as well as about 2 per cent chromite. This interpretation is supported by the observation that at greater depths (below about 1,700 feet) where dunite is a fresher, harder, and more coherent rock, wear on in-hole materials was less pronounced.

Muskox South required 110 days to drill and the average rate of progress (including the sinking of casing) was 36.4 feet per 24 hour day. The actual penetration rates averaged 3.77 feet per hour after correction for time losses. The average bit footage was 43.0 feet per bit. Wedging was not required, as the hole was kept within 2-4 degrees of the vertical. The calculated radius of departure from the vertical, at 4,000 feet depth, is 130 feet. Linear core recovery was 97.3%.

Muskox North Drill Hole

The Muskox North hole (Plate VIB) was the most satisfactory of the three holes from the viewpoint of drilling conditions and performance data. In the later stages of drilling, however, mechanical problems caused delays that considerably reduced the overall performance record.

The hole was collared in bedrock and the casing was placed without difficulty. A bulls-eye casing pattern was used, as in the south drill hole. The outside H casing was sunk to 4 feet, NX casing to 6 feet and BX casing to 10 feet. No reaming was required in the hole.

The top rock unit in the hole is a hard sandstone, commonly closely fractured. Drilling progress was slow in the sandstone and bit footages averaged only 22.7 feet (Fig. 10). Water return was poor owing to loss through fractures in the rock. At the start of drilling, the water source at Transition Creek was frozen to the bottom and water was hauled by tractor from a small lake about one mile away. Despite these adverse conditions drilling progressed satisfactorily, particularly after the 200-foot thick sandstone cap had been penetrated and the relatively softer upper gabbroic rocks of the intrusion were

entered. By July 8, after 58 days of drilling, the hole had reached a depth of 2,750 feet (as compared to 1,381 feet for Muskox South in approximately the same period). At this depth, the hole had completely penetrated the sequence stratigraphically above the collar unit of Muskox South, and had entered the down-dip extension of the upper serpentinized dunite unit of the south hole. The only difficulty during this period was caused by a strong fracture zone at 2,640 feet. Drilling continued with difficulty past the zone but, after a few days, caving halted further progress. The caving area was cemented successfully, after some difficulty in getting the cement to harden and drilling continued.

Progress on this hole dropped off sharply in July (Fig. 9) because of a series of mechanical problems, and a monthly total of only 411 feet was completed. Once these problems were corrected, however, drilling proceeded without serious delay to a depth of 3,593 feet by August 13. The drill was then moved to complete the Muskox East drill hole.

Muskox North required 97 days to complete and showed an average drilling rate of 37 feet per 24-hour day. The average penetration rate was 2.80 feet per hour. Bit footages were higher than in Muskox South, averaging 49.2 feet per bit. No wedges were required as the hole remained within 2-4 degrees of the vertical and had a maximum calculated radius of departure of 138 feet at a depth of 3,550 feet. Core recovery in the hole was approximately 98 per cent.

In-hole equipment wear, such as encountered in Muskox South, was not serious in this hole, partly because of the lesser thickness of serpentinized dunite penetrated, and partly because heavier B standard series drill rods were used.

After drilling was completed, water circulation was maintained through a supply pump at Transition Creek, to keep the hole open for subsequent geophysical logging surveys. Unfortunately, before the entire sequence of geophysical surveys could be completed, a small temperature probe became jammed in the hole at a depth of 550 feet. The stuck probe disrupted water circulation, and the hole froze to surface. Unsuccessful attempts were made in September to thaw the hole with hot water, but this caused further blockage as loose rock fell into the hole.

Muskox East Drill Hole

The Muskox East hole was the last to be drilled and in many respects was the most difficult. The problems were mainly caused by

very fractured rocks but adverse weather conditions due to drilling in late September added further difficulties.

The hole was collared on July 25th at an outcrop site. An Inspiration INS-3 drill was used to start the hole, but after a depth of 1,175 feet, the larger BBS-4 drill and tower were moved from Muskox North to complete the hole.

Drilling in the upper 700 feet of the hole was severely hampered by caving from numerous fracture and shear zones and progress was slow and erratic. Delays due to only partly successful attempts to cement caving areas were frequent. Ultimately, it was necessary to seal off the walls in the upper part of the hole by reaming NX casing to 40 feet to free the original 40 feet of BX casing and then continuing with BX casing to 700 feet. Because of insufficient BX casing at the site, a 90-foot gap (40 feet to 130 feet) was left between the bottom of NX casing and the top of BX casing (Fig. 9). This casing gap caused no difficulty in subsequent drilling. Between 700 feet and 1,800-2,000 feet, the conditions encountered were only slightly better, although cementing, coupled with the use of Driscose (a commercial gelatinous additive) in the drilling water, provided sufficient firmness to the walls of the hole to allow drilling to proceed. Below 2,000 feet, in more coherent peridotitic horizons, drilling conditions improved considerably, and the hole was completed on September 25th at a depth of 2,496 feet.

Muskox East was drilled in 63 days, for an average progress rate of 39.6 feet per 24-hour day. Average penetration rate was 3.40 feet per hour. In spite of the generally poorer drilling conditions in this hole, bit footages were the highest of all holes, averaging 55.5 feet per bit. Core recovery was 98.7%.

Deflection in this hole was greater than in Muskox South and and North, being about 4 degrees from the vertical over most of its length. The maximum calculated radius of departure at 2,496 feet was 138 feet. It is probable that if conditions had permitted, wedges would have been used in attempts to straighten this hole early in its course. However, because of the poor condition of the walls, and the amount of caved material at the bottom of the hole at any given depth (usually from 2 to 20 feet) wedging was not attempted.

On completion of drilling and in-hole geophysical studies 250 gallons of fuel oil were pumped into the hole in an attempt to keep it open for future heat flow measurements.

Drilling Procedures

Certain technical details relating to the drilling operation are described in the following sections. A summary of the drilling and related equipment used in the project is given in Appendix B.

Field Organization

At the start of the operation, duplicate camps were established at Speers Lake (Muskox South) and 7 miles north at Transition Creek (Muskox North). Camps consisted of two wooden aluminum-sheeted buildings, and tents on plywood floors (Plate VIIIA). Buildings and tents were oil heated, using 60,000 BTU space heaters for the former, and 35,000 BTU heaters in the latter. Electric power for lighting, power tools, and blowers on force-feed oil cook-stoves was supplied by 3-kw diesel generating plants. Communications between camps and with Yellowknife were maintained by 60 watt, 6-channel, two-way radios, while 1.8-watt portable transceivers provided local and mobile communications.

The Speers Lake camp was the only one directly accessible by aircraft, and was used as the main base of the operation. Supplies were flown from Yellowknife by ski- and float-equipped aircraft, usually on a weekly basis, then distributed by Bombardier to the North and East camps.

Normal crew complements at each camp included 6 drillers, 1 cook, and a geologist and assistant. Camp management and maintenance was the responsibility of the drill contractor job foreman.

Drilling Methods

Conventional Canadian diamond drilling techniques were practised on all holes. Drilling proceeded on the basis of three 8-hour shifts per day, 7 days a week, except during intermittent periods of staff turn-overs and machine breakdowns. During the short period in August when both Muskox North and East were being drilled simultaneously, two 12-hour shifts per day were utilized.

The Muskox South hole was drilled with an hydraulic equipped Boyles Brothers BBS-3 drill (Plate VA). Attempts were made to keep bit pressures to optimum values of about 1 1/2 tons, with the use of an hydraulic head pump pressure gauge. However, this was difficult to achieve because, in practice, the drillers tended to depend more on "feel" rather than correlation between pump pressures and bit pressures. As a result, actual bit pressures undoubtedly fluctuated erratically during drilling. Because of the extreme softness of the rock (serpentized dunite) in much of the south hole, bit pressure requirements were probably not as critical as might be the case in harder rocks where more careful control drilling techniques would be demanded.

PLATE VIII A. Speers Lake base camp, June, 1963. The two buildings are aluminum-sheeted and insulated. Smaller building in centre is office; larger building to right is combination cookhouse and bunkhouse. Tents and other storage building were added during summer. (N. F. B. photo.)

PLATE VIII B.
Laying out drill cores in 2-foot treated cardboard boxes. (N. F. B. photo.)

On the Muskox North and East holes the standard feed-gear setting for the BBS-4 drill was usually 450 T. P. I. (turns per inch). In uniform sections this was occasionally decreased to 300 T. P. I., whereas when the hole showed a tendency to deviate it was increased to 600 T. P. I. More frequent changing of bits also helped to arrest the deflection tendency.

Fifteen and twenty foot double tube core barrels were used. In much of the rock, particularly in the relatively fresh dunite encountered below 1,700 feet in the south hole and the gabbroic and pyroxenitic layers in the north hole, it was frequently possible to cut 15 to 20 feet of core before pulling. Generally, rigid type stainless steel inner tubes were used but in sections of blocky or muddy ground, single tube 15-foot barrels were used. In one particularly bad section in Muskox North, a 3-foot floating inner tube in a 15-foot barrel was tried, with only limited success.

Optimum water pressures in drilling were generally about 300 p. s. i., but pressures fluctuated considerably depending on the rock formation. Mudding problems were common, particularly in serpentinized dunite and peridotite, and in the early stages of drilling, pressures up to 700 p. s. i. were common under these conditions. Part way through the season, pressure systems were fitted with release valves set for 600 p. s. i. Flow-meter instrumentation was not included in the systems.

Calcium chloride solutions, heated water, and lake temperature water (50-52°F) were used at various times for drilling fluid. In the Muskox East hole, a high viscosity Driscose additive was used, with some success, to strengthen the walls of the hole in badly caving sections. Drilling fluids and temperatures are discussed in detail in the section on permafrost drilling, later in this report.

Cores were placed book-fashion in 2-foot cardboard boxes, each box holding 10 feet of BX core (Plate VIIIB). Footages were recorded to the nearest inch on wooden blocks placed at the ends of runs, and at the start and finish of each box. The cardboard boxes were generally unpopular with drillers, because dealing with short 2-foot layouts required more time and greater care in placing core, than with the more familiar 5-foot boxes. In the early stages of drilling, mixed core in the boxes was fairly common, but the problem was largely overcome as drillers became more familiar with the short boxes. In spite of these drawbacks, the cardboard core boxes are considered to be a distinct advantage in drilling operations in remote areas, because they are light - a full box averaged 22-23 lbs -, easy to handle, and can be stacked efficiently in small spaces. Their lighter weight and compactness relative to wooden boxes reduces transportation costs. It was necessary to reinforce the corners of

the cardboard boxes with fibre tape as well as to close them securely with tape prior to transport.

Drill Hole Deflection

Tolerance limits for drill hole deflection were not excessively critical as drilling was directed toward planar, rather than pinpoint targets. A deflection of up to 4 degrees from the vertical was thus considered permissible before wedging. This would allow reliable measurements of thicknesses of rock units, ensure a reasonably small departure distance at completion depth (less than 150 feet from the vertical), and avoid undue wedging, which would add to costs and create additional hazards in the holes. This latter was a particularly important factor, since expensive logging tools would be lowered into the holes on completion of drilling.

Drill holes were surveyed for inclination only, at approximately 100-foot intervals to depths of about 2,000 feet; below these depths test intervals were approximately 200 feet. Standard acid etch test procedures were employed, using 4% hydrofluoric acid. No azimuth surveys were made since most of the rock units are sufficiently magnetic to cause deviation of a compass needle.

The Muskox South and North holes remained within the tolerance limits (4 degrees from vertical) throughout their lengths, without the use of wedges. Departure distances from the vertical were less than 140 feet on both holes. The Muskox East hole showed a greater tendency for deflection than the other two, and in a few parts of the hole exceeded 4 degrees from the vertical. However, as noted previously, wedging was not attempted because of the fractured condition of the walls in this hole as well as the shallower projected depth. In spite of this, the departure of this hole at 2,496 feet was only 138 feet, and was thus comparable to those of the Muskox South and Muskox North holes.

The reasons for the surprisingly small deflection tendencies experienced in these holes are varied. One factor which probably tended to retard deflection was that the majority of rock boundaries were intersected at nearly right angles. This cannot be the whole explanation, however, because in several parts of the drill holes, the hard, dense chill zones of diabase dykes were intersected at very low angles (15° - 20°) without obvious deflection of the holes. Reduction of drilling feed rates and frequent change of bits to ensure better cutting conditions may also have reduced deflection tendencies.

Permafrost Drilling

Few data are available on permafrost depths in this part of the Northwest Territories. Maximum depths of 280 feet have been recorded in the Giant Yellowknife Mine and a depth of 320 feet was reported from the Eldorado mine at Port Radium (Bateman, 1949), but both these locations are south of the present area. In addition, they are close to large bodies of water (Great Slave Lake, and Great Bear Lake), which may affect permafrost depths (see below).

Contrary to expectations before the project started, permafrost drilling gave little difficulty. Permafrost depth at the Muskox North site is about 700 feet, as determined from in-hole temperature measurements carried out after the hole was completed. At the Muskox South hole, estimates of permafrost depth derived from the spontaneous potential log give an approximate depth of 660 feet. A gap in permafrost in this hole, from a few feet below surface to a depth of about 40 feet, is probably related to the proximity of Speers Lake, as this interval coincides approximately with the lake depth. The lake is less than 600 feet away from the collar.

During sinking of casing in all holes, only cold water was used as a drilling fluid and no difficulties due to freezing were encountered. With the start of core drilling in the Muskox South and Muskox North holes, heated solutions of $CaCl_2$ were used until depths of 700-800 feet were reached. To handle the solutions two 250-gallon steel tanks were connected in tandem, and heating coils were set up at the supply pumps and in the solution tank circulation system (Plate IX). Solution tanks became mudded with sludge in a short time, particularly at Muskox South while drilling in serpentinized dunite, and required cleaning every few days.

Calcium chloride solution strengths ranged from 3-3 1/2 lb/gal (S. G. = 1.10) at the beginning of drilling when surface temperatures ranged between +15°F and +45°F, to 1-1 1/2 lb/gal near the end of drilling with calcium chloride in June, when surface temperatures were generally slightly above freezing at night, rising to the 50s and 60s during the day. No systematic recordings of solution temperatures were kept, but based on spot measurements, input temperatures were 60-65°F, and solution return temperatures above 50°F.

At depths greater than 700-800 feet, heated lakewater was used as drilling fluid, with input temperatures of 70-75°F and return temperatures of 60-65°F. In the summer months (July and August) the heating coils were disconnected, except for intermittent periods in late August, and water of lake temperature (50-52°F) served successfully as a fluid.

PLATE IX A. Tandem arrangement of two 250-gallon solution tanks used for calcium chloride drilling in permafrost at the Muskox North hole. The coil stove and solution pump are visible in the right background. (N. F. B. photo.)

PLATE IX B. Mixing calcium chloride in a solution tank at the Muskox South hole. In the early stages of permafrost drilling calcium chloride strength was 3-3 1/2 lb/gal. (N. F. B. photo.)

On the Muskox East hole, heated lakewater was used throughout the drilling. Temperatures were comparable to those discussed above. Important factors in successful permafrost penetration appear to be; a) size of equipment used in drilling; and, b) depth of holes. In deep holes where drilling is continuous over long periods, using relatively heavy equipment (BX), friction heat probably causes considerable thawing about the hole. Calcium chloride solutions must be used initially to penetrate the permafrost section but, once this is accomplished the heat of drilling appears sufficient to allow the use of water alone as a fluid. The drills were shut down from time to time for periods up to 3-4 hours, without freezing of unheated lakewater in the holes. With water circulation maintained through the lowest rod-string by the pumps, the drills were inoperative for periods up to 24 hours without freezing problems. In the Muskox North hole, however, in late August and two weeks after the completion of drilling, obstruction of the water circulation by a small probe jammed at 550 feet caused immediate freezing to the surface.

Cementing

Cementing was attempted three times in the Muskox South hole, once in the Muskox North hole, and four times in the Muskox East hole, requiring a total of 56 bags Ciment Fondu. Standard cementing procedures were employed, with cement mixtures being pumped in through the rod string. With few exceptions, the cementing results were unsatisfactory. The main difficulty was to get the cement to harden sufficiently for coring. Waiting time on two cementing operations was generally 2-3 days, and even after this period, uniform hardness was commonly not achieved. Sections through cemented areas were often washed out by fluid pressures, rather than drilled out. Calcium chloride was used as an additive to promote setting, and although ideal setting times and hardness could be achieved in test mixtures at surface, similar results were seldom achieved in the holes.

As a result of the generally adverse cementing conditions, the worst caving areas in the Muskox South and East holes, which fortunately occurred in the upper sections, eventually had to be sealed off by casing. At greater depths, where casing was impractical, repeated cementing in a given cave area generally sealed off the walls sufficiently to allow drilling to proceed, even though caving was commonly only partly stopped.

Fuel Consumption

No. 1 winter grade diesel oil was used in all motors and heating units with the exception of the motor vehicles and generators used for radio batteries, which used gasoline.

The fuel consumption for the project was difficult to estimate in advance, because of uncertainty regarding the duration of the project and heating required for the drilling water. Estimates by various tenderers ranged from 7,000 to 33,000 gallons. The Geological Survey placed 25,000 gallons at the drill site and about 19,300 gallons were actually consumed, or slightly less than 3 barrels per day. Consumption was kept to a minimum by completion of the project before freeze-up, and by being able to use unheated lakewater as a drilling fluid during part of the season.

An approximate breakdown of the fuel oil consumption is given in Table 5.

Table 5

Fuel Consumption Distribution

D-4 tractor (mainly airstrip construction)	450	gallons
Drills	3,990	"
Coil Heaters	7,000	"
Camp operation (including light plants)	5,980	"
Pumps and other accessory motors	870	"
Fuel used in holes	600	"
Miscellaneous and loss	410	"
Total	19,300	"

The distribution of fuel consumption between drills and heaters is based on an estimated rate of consumption over the drilling period rather than an actual count. However, the figures are considered to represent a good approximation.

Drilling Records

Drilling records have been analyzed to determine whether correlation exists amongst such factors as bit footages, rates of advance, and rock properties. Although some generalizations may be made, detailed interpretations suffer from the lack of sufficiently

precise data. Performance records are influenced by a great number of variables, and the necessary instruments to record such variables accurately was not available.

Bit Records

A total of 210 J.K. Smit medium round nose, bevel wall BX coring bits were used on the three holes. The average bit footage for individual holes was

Muskox South	-	43.0 feet/bit	(92 bits)
Muskox North	-	49.2 feet/bit	(73 bits)
Muskox East	-	55.5 feet/bit	(45 bits)

The range in bit footages obtained while drilling the various rock units of the Muskox Intrusion is summarized in Figure 10. Within each rock type there is a considerable range of bit footages, with the exception of the hard sandstone and gneiss units. The range of footages for each rock unit indicates that rock type alone does not control the resultant bit footage. Other factors, such as bit pressures, fluid pressures, bit R.P.M., bit design, and other physical properties of the rock units are involved. The first three of these factors were not recorded. The bits used were all of the same design, so this factor does not enter into an interpretation of the data. In a few cases there is correlation between bit footage and changes in rock properties within the same unit. This is illustrated by the histogram for serpentinized dunite (Fig. 10A) where the peak concentration of low bit footages (4 - 8 feet) reflects drilling in highly fractured and altered (post-serpentine) zones in the rock. Also, in the olivine gabbro-diabase histogram, the small grouping of low footages (4 - 16 feet) represents the influence of the hard, dense chill zones of diabase dykes.

The average bit footages are related to a calculated rock hardness in Figure 10. The harder rocks—sandstone and gneiss—have the higher hardness numbers, and the softer serpentinized peridotite and dunite have lower hardness numbers. Neglecting other factors which control hardness, such as degree of fracturing and alteration, the theoretical hardness is calculated by the formula

$$H_R = \Sigma A_m H_m$$

where H_R = theoretical rock hardness

A_m = abundance of individual minerals

H_m = hardness of individual minerals according to Moh's scale.

Thus the hardness of a pure quartz sandstone is 100 x 7 or 700. Figure 10 shows a general decrease in average bit footage related to

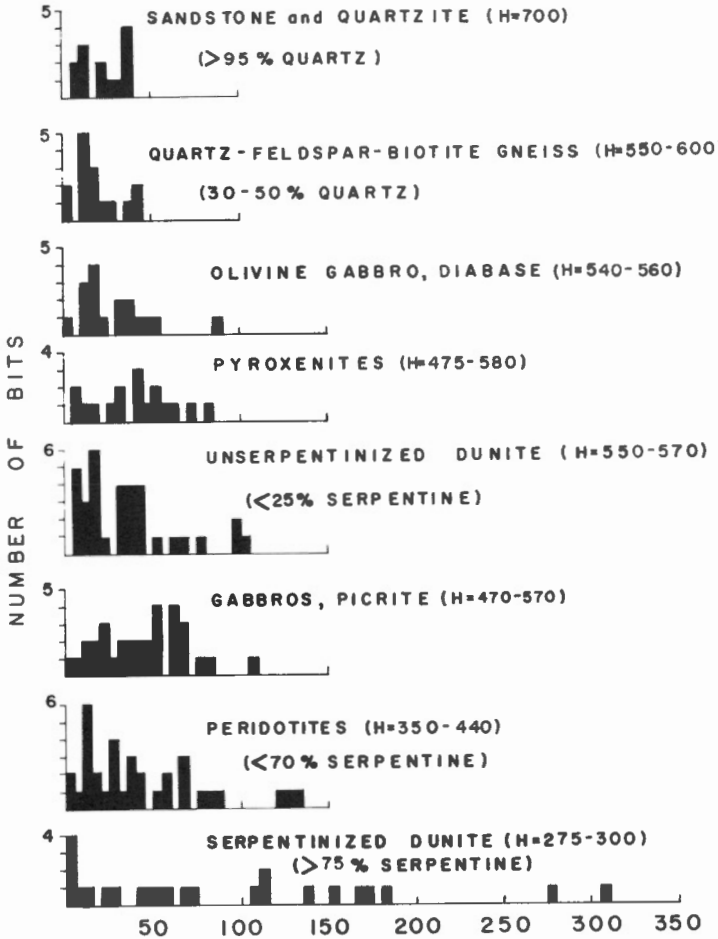


Fig. 10A

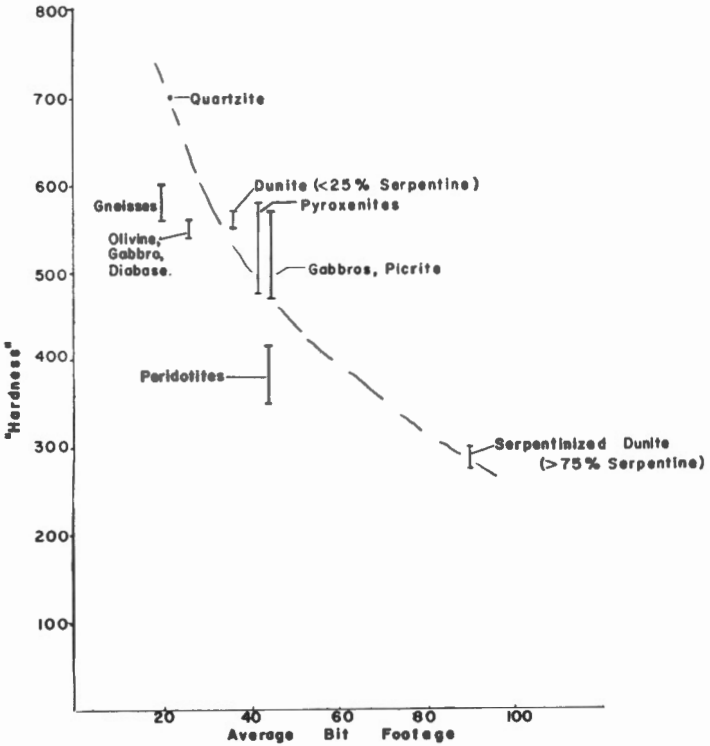


Fig. 10B

Figure 10. Correlation between bit footage data and rock types.

increasing rock hardness. The scatter of points about the hardness curve is probably related mainly to alteration and fracturing within the various rock units, since the hardness number represents an average value in each case. Thus gabbros tend to give better footages than their calculated hardness might indicate, owing to the alteration of plagioclase to softer secondary minerals.

Rates of Advance Data

Rates of advance data derived from shift records are summarized in Table 6. The time lost in pulling and setting rods has been subtracted to determine the average penetration rate. The time lost increased with depth, being greatest in the Muskox South hole, but was also related to differences in efficiency of drills and crews.

Table 6

Rate of Advance Data

Hole	Average penetration rate (ft./hr.)	Rate of advance including pulling and setting rods (ft./hr.)
Muskox South	3.77	2.75
Muskox North	2.80	2.27
Muskox East	3.40	3.30

The ranges of penetration rates in different rock types are summarized in Figure 11. The range in each rock type is large, owing to changing physical properties. For example, low penetration rates (less than 1 ft./hr.) in diabase were obtained in the hard chilled contacts of the dykes. The penetration rates show little correlation with "hardness". The best penetration rates were obtained in fresh dunite (average 4.9 ft./hr.), due partly to its uniform, massive character. In its serpentinized equivalent, a rate of 3.9 ft./hr. was obtained. Diabase gave the lowest average rate of advance, of 2.0 ft./hr.

Time Distribution Data

The time distribution data summarized in Table 7 illustrate many of the reasons for differences in the overall performance records

of the three holes. The Muskox North hole had the best overall performance record as 69.5 per cent of the total time was spent in drilling. One-third of the time on the Muskox East hole was spent in cementing and reaming, because of the fractured nature of the upper horizons. Time losses due to mechanical delays are high partly because of the remoteness of the area and the resultant time required to obtain replacement parts. The high time loss at Muskox North mainly represents a single delay caused by the need to fabricate a part not available from manufacturer's stock. The relatively high figure (5 per cent) for recovery operations on the Muskox South hole reflects the difficulties experienced with the BW series rods used in this hole (see page 35).

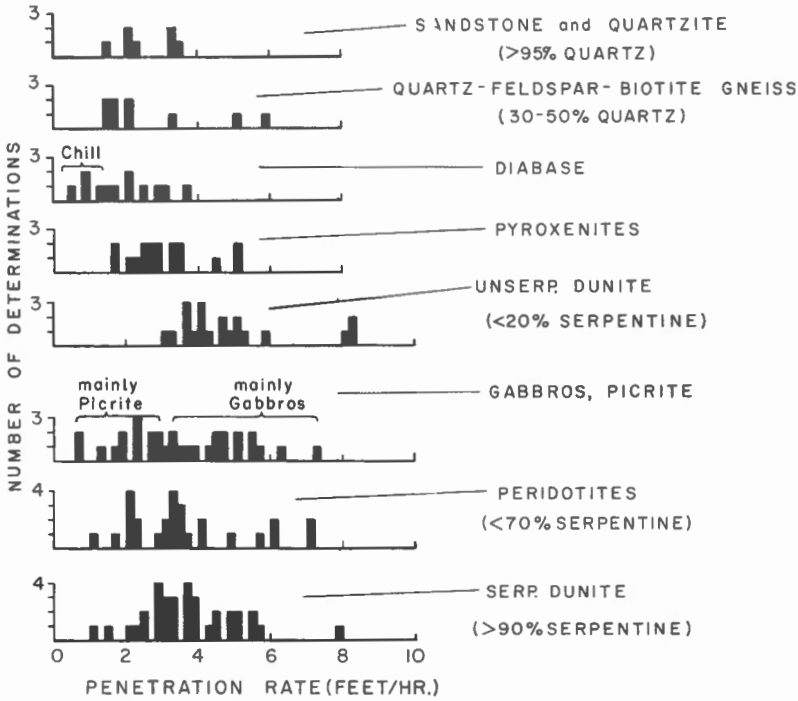


Figure 11. Penetration rates in different rock types.

Table 7

Time Distribution Data

	Muskox South		Muskox North		Muskox East	
	Time (hours)	% of total time	Time (hours)	% of total time	Time (hours)	% of total time
Overburden Penetration	92	3.5	16[1]	0.7	—	—
Drilling	1,478	56.4	1,578	69.5	865	57.7
Reaming #	188	7.2	—	—	175	11.7
Cementing	167	6.4	92	4.0	325	21.7
Repairs and Mechanical delays	540	20.6	553	24.3	25	1.7
Fishing and Recovery Operations	132	5.0	8	.4	8	.5
Acid Tests	23	.9	25	1.1	19	1.3
Setting Up ##	—	—	—	—	56	3.7
Well Logging ###	—	—	—	—	25	1.7
Total.....	2,620	100.0	2,272	100.0	1,498	100.0

[1] Starter casing.

- Includes setting casing.
- Refers to setting up BBS-4 rig over the Muskox East hole at depth of 1,175'.
- Logging of the Muskox South hole was carried out after drilling was completed: Muskox North was not logged, except for a temperature profile, which was measured after drilling was finished.

Chapter VI

CORE SAMPLING AND PROCESSING

This chapter describes the procedures established for handling, processing, and sampling of drill cores in the field, prior to shipment to Ottawa and the distribution of samples to the various laboratories. To expedite the flow of samples through the laboratories, as much sample preparation work as possible was done in the field. This included: cutting of preliminary slices for thin and polished sections with a portable diamond saw; determination of specific gravities of cores; preliminary crushing of samples for chemical and mineralogical studies; and the cutting of geophysical samples into segments of the approximate required dimensions for electrical conductivity, thermal conductivity, seismic velocity, and palaeomagnetic studies.

After sampling, the remaining cores were boxed and shipped to Yellowknife on the return parts of supply flights. They remained there until October, when they were trucked to Ottawa in a single load weighing 27,000 lbs.

Processing Procedures

The preliminary processing of drill cores in the field involved:

1. Visual logging of cores, and recording of pertinent geologic and drilling data.

2. Washing of cores, and checking for correct orientation and sequence in the boxes.

3. Labelling of cores and boxes.

4. Measurements of specific gravity of cores.

5. Sampling and cutting samples into various segments for geochemical and geophysical studies.

Routine core-logging procedures were followed, and all pertinent geologic data were recorded in duplicate on geological log forms, one copy of which was forwarded to Ottawa. In addition, visual drill-hole logs, such as are reproduced in Figure 14, were drawn up as each hole progressed. Day to day records of pertinent drilling data—footage, drilling time, rates of advance, etc.—were entered on drilling log forms in duplicate.

PLATE X. C.H.S. 2-1-63
Washing drill cores prior to sampling. The cardboard boxes are 2 feet long and contain 10 feet of BX core.

After visual logging, which was generally done at the drill-site, the core was transported to camp by Bombardier for further processing and sampling. Cores were first scrubbed clean with cold water, dried, then replaced in boxes (Plate X). This was necessary to remove chloride solutions and mud prior to sampling for chemical studies. As noted previously, in the early stages of drilling the crews had trouble adjusting to the short 2-foot lay-outs of the cardboard core boxes and mixed cores were common. Thus, after washing, cores were checked for proper orientation and sequence, and to ensure that the core ends between successive boxes matched. Commonly this was

a tedious procedure, and in a few instances of badly mixed core, required an inordinate amount of time.

At two places in each box, usually as close to the ends as practical, footages were marked on core with india ink on white or orange enamel backgrounds. The direction toward the top of the hole was indicated on the core with an arrow. Where geophysical or geochemical samples were taken from the boxes, wooden plugs marked with the footage and sample numbers were inserted. On the outside of the box, both on the top and ends, the footage interval, box number and hole name (Muskox South, North, or East) were recorded.

Specific gravity determinations were made on the cores and are summarized in the geologic logs. These measurements proved particularly useful in estimating the amount of serpentine in the core, which, in the south drill hole, decreases with depth.

Sampling Methods

The main purpose of field sampling was to provide initial material for detailed geophysical, petrographic, mineralogic, chemical, and isotopic studies for the various laboratories in Ottawa, with a minimum amount of delay. To this end, the field and laboratory programs were scheduled so that laboratory results from samples submitted during the field season would be available before the drilling was completed. Thus, the usual time-lag between the end of field work and the availability of analytical results could be kept to a minimum.

The preliminary field sampling was intended to provide representative average values and variations in each layer; more detailed sampling across layer contacts and through heterogeneous sections containing fine layering was left until the core arrived in Ottawa, and after results from the preliminary samples had been obtained.

Individual samples fall into two categories, geochemical and geophysical, with each sample being composed of several segments.

Geochemical Samples

Sampling Interval — The sampling interval for geochemical purposes was kept as uniform as possible, but varied according to the thickness of individual layers. The following guide was used in preliminary determination of sample intervals:

Layer Thickness	Sampling Interval
<10'	1 sample (middle of layer)
10-30'	3 samples (middle, plus middle of resultant halves)
30-100'	7 samples (middle of layer, then middle of resultant halves, then middle of resultant quarters)
>100'	Samples at 20-foot intervals starting at sufficient distance past contacts so that core is homogeneous.

In practice, the intervals were frequently varied to obtain representative samples and avoid obvious changes in mineral composition, grain size, or textures within a layer. From a total of nearly 10,000 feet of core 619 samples were taken, resulting in an overall average sample interval of slightly over 16 feet.

Sample Numbering System — The footage from the collar of the hole, expressed to the nearest 10th of a foot served as the sample number. The footage number was prefixed by S, N, or E for hole identification (South, North, or East). For example; sample E 10875 is from the Muskox East hole, at a depth of 1,087.5 feet.

Make-up of Sample — Each geochemical sample consisted of five segments (Fig. 12). A 150-gm sample was broken for chemical analysis and mineral separations. Thin section chips were cut at right angles to the core axis (horizontal orientation) and parallel to the core axis (vertical orientation). The remaining chips were used for a polished section and a reserve reference sample. The various parts were obtained from a core section approximately 4 inches long.

Sampling Procedure — Core sections for samples were selected, marked for orientation reference with grease pencils, then removed from the core box. A piece approximately 1 1/2 inches long was broken off with hammer and cold chisel for chemical analysis (Fig. 12). This was crushed to 1/16"-1/8" size with a mortar and pestle and placed in a heavy polyethelene bag labelled with the sample number. Bags were closed securely with fibre adhesive tape. The remainder of the core sample was then sawn into the other required segments. A portable Felker Di-Met Model DH-1 cut-off saw with 8-inch Rimlock diamond blades gave good service in sawing the cores. The chips were marked with sample numbers in india ink on an enamel background, with arrows indicating the top of the hole, and then were placed in individual paper envelopes bearing the sample number.

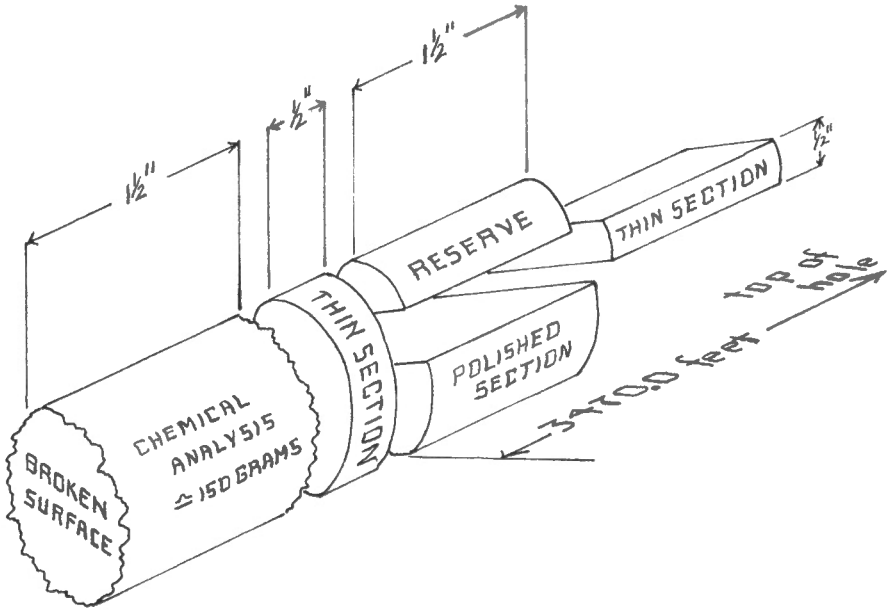


Figure 12. Sampling procedure for geochemical studies.

Field data relating to the geochemical samples was recorded in field note books and summarized on sheets, copies of which were forwarded with the samples.

Processing of Samples — After preparation in the field, samples were packed in small cardboard boxes (generally about 15-20 complete samples per box), bound securely with fibre tape, and shipped via air and rail express to the Geological Survey. There the samples were processed as follows: -

1. The geochemical sample was ground in a Bico pulverizer using ceramic grinding discs. It was then rolled and a 20-gram sample removed for chemical analysis. The remainder was used for the preparation of mineral concentrates.

2. The mineralogical portion was screened to remove the -150 + 200 fraction and the remainder bottled and stored as a reserve sample. The -150 + 200 fraction was separated with bromoform into light and heavy fractions for use in X-ray and optical studies of the properties of constituent minerals.

3. The chemical portion was remixed and ground in a "paint shaker assembly" holding 6 mullite vials for one-half hour to a minus 200 mesh size. The proposed analytical procedure for these samples is:-

a - X-ray fluorescence method	- Si, Al, Fe (total) Ca, Mg, K, Mn, Ti
b - Optical spectrograph	- Cu, Ni, Co, V, Ba, Sc, Sr
c - Flame photometer	- Na
d - Wet chemical	- P, Fe^{+2}
e - Dithizone	- Cu, Pb, Zn

4. Standard size thin sections (48 mm X 28 mm) were prepared without cover slips, and the polished section chips were polished on their flat surface and left unmounted.

Geophysical Samples

Sampling for geophysical studies was of a preliminary nature to allow measurement of a range of physical properties. Further sampling will be done from the stored cores as studies proceed. Twenty preliminary samples were taken from the Muskox South and North cores to provide representative samples of each rock type.

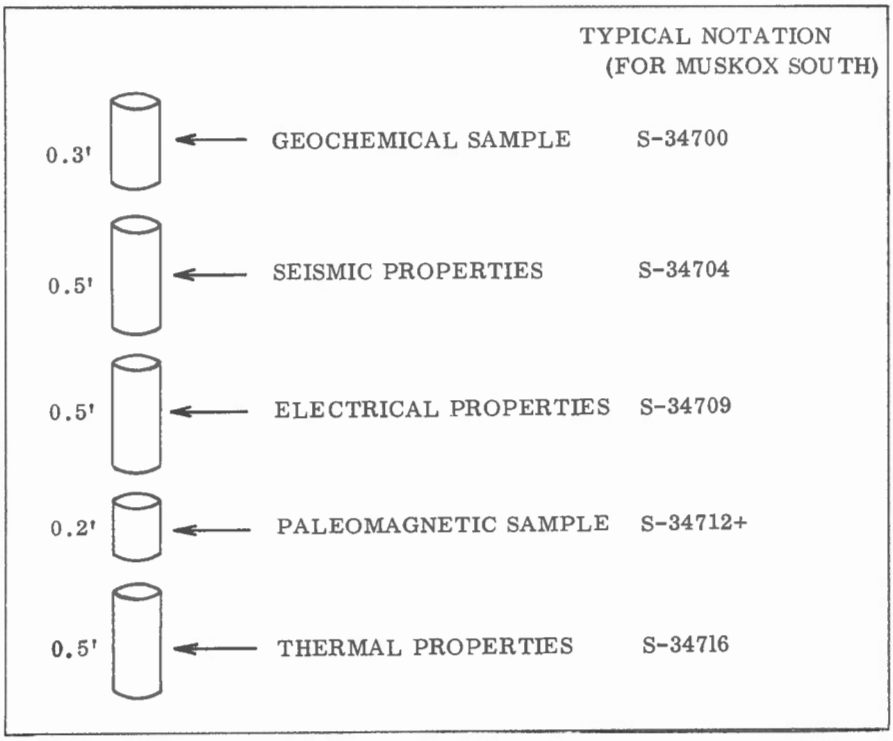


Figure 13. Sampling procedure for geophysical studies.

The grouping of each geophysical sample is shown in Figure 13. Each sample consisted of 5 segments, one of which was for geochemical study. The four geophysical segments were chosen from core free of visible fractures, alteration, or other evidence of heterogeneity. The samples for elastic constants, thermal and electrical conductivity were sawn in 6-inch lengths and for palaeomagnetic study in 2-3 inch lengths. Each sample was labelled according to the footage method used on geochemical samples, wrapped in paper and the pertinent data recorded on special forms. When a suitable number were prepared, they were shipped to the scientists involved in their detailed study.

Chapter VII

FURTHER SCIENTIFIC STUDIES AND CONCLUSIONS

The principal aim of the drilling project was to obtain cores for laboratory studies, in order to determine the origin and cooling history of the intrusion. The reader is referred to Appendix C for detailed megascopic descriptions of the cores and to Figure 14 showing the correlation between drill holes. This chapter indicates the nature of studies underway on the cores to achieve these objectives.

The correlation of layers between drill holes (Fig. 14) and with surface geology (Smith, 1962) is extremely good. This is strikingly shown by the continuity of thin chromite horizons. Certain changes in layer thicknesses and facies changes within layers can be noted, however. These indicate that in general the gabbroic units tend to thicken slightly up-dip along the axis of the intrusion and that the amount of granophyre tends to increase toward the limbs or margins of the intrusion. The latter tendency was also evident in surface mapping.

The drill hole thicknesses of the rock units, combined with the data from surface mapping, are being used to calculate the relative abundances (volumes) of rock units within the intrusions (cf. Smith and Kapp, 1963). This calculation provides an estimate of the total bulk composition of the intrusion independent of the commonly accepted method of analyzing the chilled norite margin. Quantitative mineralogical and chemical determinations are then interpreted within this framework.

Petrographic, Mineralogic, and Chemical Studies

Petrographic studies involve the examination and description of about 1,500 thin and polished sections from the cores, and an equivalent number from surface exposures. The modal composition of the rocks, determined by point counting, is used for correlation with chemical data and, in conjunction with the volumetric data from mapping, to calculate the mineral abundances in the various layers and the intrusion as a whole. Studies of rock textures in different parts of the intrusion indicate the local cooling conditions as the intrusion solidified. Grain size and sorting characteristics of minerals in the layered series are measured on enlarged photomacrographs to provide explanations for the formation of local layering characteristics such as the development of chromite concentrations.

Mineralogical studies being undertaken consist of the determination of changes in mineral composition throughout the intrusion. Mg/Fe ratios in 500 olivine samples have been determined by X-ray powder methods (Jambor and Smith, 1964). Pyroxene variations are being determined by optical (refractive index and 2V) methods supplemented by chemical analyses. X-ray and oil immersion methods are used to study the changes in composition and structural state of plagioclase feldspars. X-ray and chemical studies of the oxide minerals - chromite, magnetite and ilmenite - have been started. The abundance and mineralogy of the sulphide minerals is being determined by standard metallographic methods, supplemented by X-ray and electron probe determinations.

Chemical analyses of rock specimens are being completed to define the composition of individual layers and the whole intrusion, and to interpret the variations in concentration of elements, in both solid and fluid parts of the intrusion, during cooling.

The determination of S^{32}/S^{34} ratio in 366 samples from various parts of the intrusion and surrounding area have been completed. They show a range in values from -5 to +24, expressed in per mil difference of S^{34}. The significance of these variations is being studied.

The petrographic data, together with that on mineral chemistry, is necessary to define the order of mineral crystallization and the reaction series (continuous and discontinuous) that have been characteristic of the Muskox magma. The petrography is also needed to define the mechanical processes that accompanied crystallization of the magma, particularly those operative during differentiation of the feeder dyke and marginal group, and formation of the layered series. This type of information is essential to the understanding of the causes of chemical differentiation and is a necessary background before realistic models can be set up to estimate trends of liquid composition. The nature of liquid variation is of interest, for example, with regard to processes of ore concentration, and on evaluation of the role of fractional crystallization in the geochemical evolution of magmas. The whole of the information gathered on the Muskox intrusion should provide an excellent case history on the formation of large igneous intrusions, and a basis of comparison for ultramafic intrusions that are not so well exposed. The intrusion is an excellent testing ground in which to study processes such as isotopic fractionation during fractional crystallization.

The mineralogical data is necessary to establish or confirm the physical-chemical conditions under which the Muskox intrusion crystallized, e.g. temperatures, pressure, and the partial pressures of water, oxygen, and sulphur. Once these have been defined, then

extra meaning can be attached to other of their relations (e.g. distribution coefficients for various elements) for broader application in the study of the earth's crust and mantle. The interrelation of silicates, sulphides, and oxides is of interest in reference to derivation of ores from igneous intrusions; and the distribution of sulphides in the layers and marginal group rocks is significant in the same respect.

Geophysical Studies

Geophysical surveys were carried out to assess the usefulness of various instruments in mapping the physical properties of igneous rocks *in situ*. Others were made to provide data on seismic velocities and heat flow in igneous rocks.

Downhole Geophysical Studies

Gamma ray, neutron, self-potential, resistivity, and seismic velocity surveys were conducted in the south and east holes. The north hole collapsed at a shallow depth before logging equipment was available at the site. All surveys were done under contract by Birdwell, a division of Seismograph Service Corporation. Some correlations have been made but others remain to be made when the rock cores have been studied in detail. These will be recorded in a later report.

The downhole tools were of standard design and lowered into the hole on the same head adapter by means of a cable-hoist unit capable of logging to 5,000 feet with 6-conductor cable 5/16 inch in diameter (Plate XIA). This unit alone weighed 1,500 lb and was powered by a 7.5 hp gasoline engine. All tools were 1 1/2 inches in diameter except the neutron tool, which was 1 3/4 inches in diameter (Plate XIB).

The surveys were conducted from bottom to top of the holes except for the seismic velocity survey. Serious slumping of material in the holes did not permit any two surveys to be made from identical depths in the holes. The gamma ray and neutron logs were run separately because of the unusual strength of the neutron source. Logging speed was 20 feet per minute.

Gamma Ray Log — The gamma ray sonde carries a Geiger Meuller detector, which detects the presence and relative amounts of natural radioactive elements in the borehole. The resulting log records this information as a function of depth.

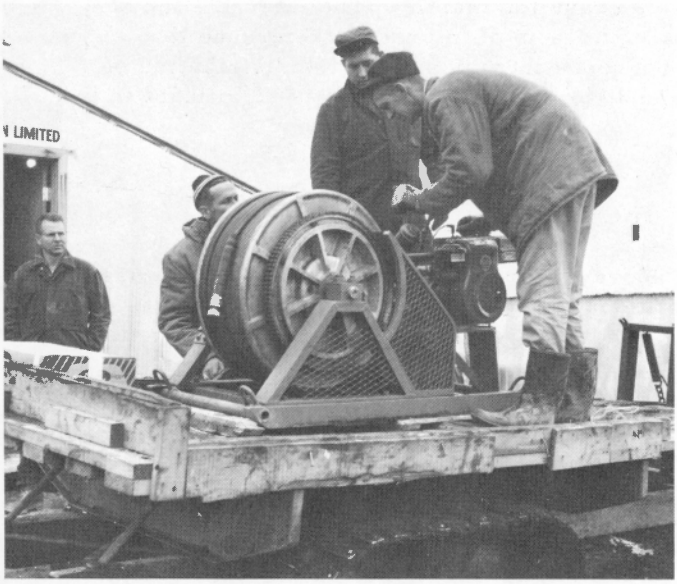


PLATE XI A.

Hoist used for geophysical well logging.

D. C. F. 10-4-63

PLATE XI B.

Small diameter (1 1/2") in-hole probe for geophysical surveys.

D. C. F. 10-5-63

The east hole is, on the average, about four times as active as the south hole on the gamma ray logs. The average count in the south hole was about 1K counts per minute with very few peaks on the log. The east hole gamma ray log exhibits a general level of 4K counts per minute with numerous peaks to 10K counts per minute. A few peaks occur in dunite sections, which are not normally radioactive. R. A. Washington examined cores from the areas of these peaks using a portable geiger counter (thin end-window type) and a single channel gamma-ray spectrometer. These showed only normal backgrounds. It is possible the radioactivity occurs as a fracture filling, which was not recovered in the core; further studies are planned.

Neutron Log — The neutron log is a measure of gamma rays released by the bombardment of hydrogen atoms in the wallrocks by the neutron source. The gamma ray counts recorded on the neutron log increase with decreasing porosity or hydrogen content. A radium beryllium source was used with a measured neutron output of 4.3×10^6 u per second.

The gamma ray count from both holes is very high, up to 68K counts per minute through gabbroic rocks. In the south hole the upper portion, above 1,550 feet, gave low counts through the altered serpentine sections but increased with depth as the serpentine changed to unaltered dunite; the counts changed from 8K counts per minute to 32K counts per minute. The high counts in the gabbros are due in part to the low porosity of these sections. The high counts in unserpentinized dunite reflect its low water content.

Self Potential Log — The self potential logs show considerable variation. Activity in the east hole is more than twice that in the south hole, possibly due to the east hole having been more recently drilled. The depth of permafrost in the south hole was indicated by the log to be at 660 feet.

Resistivity Log — Both 16-inch and 64-inch normal logs were run in the south and east drill holes. Heavy grease from the drill rods in the east hole adversely affected the 16-inch log. High resistivities were encountered in both holes and full scale deflections were common. The transition from serpentinite to fresh dunite in the south hole was well indicated.

Seismic Velocity Survey — A conventional velocity survey was made because a tool is not currently available to run a continuous velocity log in a 2 3/8-inch hole. The downhole geophone was a number of 14-cycle, vertically oriented elements connected in a series-parallel arrangement. Observations were made at frequent intervals in both holes to the extent that in some cases too much detail was obtained beyond the resolving power of the method itself. Computations

over larger geologic sections will probably give more consistent interval velocity data.

The average velocity in the south hole to a depth of 3,433 feet is 16,873 feet/second. In the east hole, the velocity to a depth of 2,400 feet is 18,511 feet/second. There is more serpentine in the south hole than in the east hole.

Interval velocities at a depth of 2,800 ft. in the south hole are as high as 22,700 feet/second in serpentinized dunite (approximately 20% serpentine). In the east hole an interval velocity of 24,300 feet/second was observed in gabbro at a depth of 200 feet.

Heat Flow - A temperature profile was obtained from the north drill hole for the interval from 550 to 3,400 feet. During withdrawal the probe became stuck at 550 feet, and froze into the hole. The thermistor was not recovered for recalibration. Temperature measurements have not been made in the other holes, which were left with casing and filled with fuel oil to allow future temperature measurements.

The mean temperature gradient over the last 1,500 feet of the north drill hole was approximately 7.3°C per thousand feet. The highest temperature measured was 17.35°C at 3,400 feet. These measurements were made 12 days after completion of drilling. A. E. Beck believes the gradient is not too far from the undisturbed temperature gradient. However, this north hole is now blocked and any future measurements will have to be made in the other holes.

Thermal conductivity measurements on the drill cores are being made at the University of Western Ontario.

Drill Core Studies

Electrical Resistivity — D. C. electrical resistivity measurements have been completed on 20 core samples and show a range from 2-6 ohm-m in serpentinite to 6×10^7 ohm-m in olivine gabbro. These are the range of changes measured by the downhole resistivity survey where, as noted above, the high values were off scale with the equipment used.

Paleomagnetism — Measurements of the direction of magnetism are being made from 25 core samples in addition to surface samples from the Muskox Intrusion and surrounding area to determine the magnetic pole position during emplacement. Thermal and alternating magnetic field tests are made to remove secondary magnetic fields unrelated to the time of cooling. The core samples

from layers in the intrusion that could not be sampled at the surface are being used to check the inclinations and stability data obtained on surface. Preliminary interpretations, based on surface samples, indicate that the palaeoclimate at the time of emplacement was tropical (Robertson, in press).

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— APPENDICES —

Appendix A

SPECIFICATIONS FOR DIAMOND DRILLING OF THE MUSKOX INTRUSION, COPPERMINE RIVER AREA, NORTHWEST TERRITORIES

I. General Information

This is the second invitation to tender on diamond drilling of the Muskox Intrusion - a phase of the Canadian Contribution to the International Upper Mantle Project. The first results showed that the estimated costs for a 10,000 foot hole in this area were too high. There was an extremely wide spread in estimated drilling costs between individual tenders. We propose to reduce costs with this invitation to tender by:

(a) Drilling 2 holes, each 5,000 feet deep, in place of the original 10,000 foot hole. Consideration will be given to drilling 3 shorter holes, approximately 3,300 feet each, in place of the 2 holes if there is an appreciable saving in cost. Contractors are therefore asked to tender on the basis of 2 alternate drilling programs.
(b) Postponing the commencing date to 1963 so as to allow the contractor more time for planning, and moving supplies by cheaper means.
(c) Supplying the diesel fuel at Speers Lake.
(d) Suggesting that the holes be drilled simultaneously during the summer of 1963 so as to avoid the costs of a winter operation.

The primary purpose of this program is to obtain drill cores for geologic study. Maximum core recovery is essential to achieve the objectives of the drilling. The responsibility for using proper up-to-date or new drilling methods for optimum drilling efficiency is that of the contractor.

Location:

The drilling area is located 315 miles north of Yellowknife (see enclosed map[1]). The northern hole location is near the stream draining from Transition Lake to All Night Lake. The southern hole is located near the shore of Speers Lake. If a third hole is drilled, it will be near the shore of McGregor Lake.

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[1]A map somewhat like Figure 1 of this report was supplied with each copy of the specifications sent out.

Accessibility:

The area is accessible by chartered aircraft from Yellowknife. Ice strips can be prepared on McGregor or Speers Lakes for larger aircraft. Transition and All Night Lakes can be used by Otter aircraft during periods of open water (July-September) provided wind conditions are suitable.

Heavy equipment is best transported to the area before break-up. This may be done by Bristol Freighter or DC6 from Yellowknife.

Geographic factors:

The area is located north of the tree line. It has low relief and is easily crossed by tractor.

The depth of the permafrost near the drill site is not known.

There are no inhabitants in the area although Eskimo labour may be available from Coppermine, 50 miles to the north. The Canadian Nickel Company has a base camp on McGregor Lake, and in the past years has drilled a total footage of the order of 50,000 feet in the district. The deepest hole was just over 1,000 feet.

Geological conditions:

Table 1 is an abbreviated log of the rock types expected in drilling. No coring problems are anticipated in the gabbros or pyroxenites. The dunites are serpentinized, but generally core well except near local slip zones.

The holes will start in bedrock or close to bedrock so that overburden will not impose a problem.

The rocks vary in magnetic intensity from weak to very strong, and methods of azimuth measurement in the drill hole, using a magnetic needle, will not be of value.

Approximate log of proposed drill holes. The northern hole will cut the upper part of the section, the southern hole the lower part. If 3 holes are drilled they will be equally spaced through the section.

Rock Type	Possible Thicknesses (ft.)
Sandstone	25
Breccia (well cemented)	10
Granophyre	100
Gabbro	400
Picrite (gabbro + 30% olivine)	50
Gabbro	400+
Pyroxenite	50
Gabbro	65
Pyroxenite	50
Gabbro	125-
Pyroxenite	150
Peridotite (serpentinized)	275
Anorthosite	15
Pyroxenite	50
Dunite and peridotite (serpentinized)	600
Pyroxenite	20
Dunite (serpentinized)	100
Pyroxenite	25
Peridotite (serpentine)	150
Peridotite and pyroxenite (alternating layers)	1,600
Gabbro (with serpentine layers)	350
Peridotite and pyroxenite layers	3,200
Granite gneiss	--

The vertical drill holes will intersect these layers at an angle of about 85°. The total thickness of igneous rocks is estimated between 7,800 and 9,000 feet.

Information required from drill contractor:

The contractor must supply the following information with his tender. This information will be treated as confidential.

1. Hole design and operating procedure.
2. Drilling equipment to be used.
3. Previous experience in deep drilling. Diamond drilling experience below 3,500 feet is a prerequisite for tendering on this program.
4. Personnel to be assigned to the drilling operation and their deep drilling experience.
5. Plans for drilling through the permafrost.
6. Proposed transportation methods to site.
7. Method for testing hole inclination and azimuth.
8. Time estimate to complete holes.
9. Estimate of fuel oil requirements.

Failure to supply satisfactory data in connection with the above may adversely affect the tender.

Additional information:

For further information regarding the specifications the contractor should contact the:

Geological Survey of Canada,
601 Booth Street,
Ottawa 4, Ontario.
Attention: Dr. C.H. Smith

II. Specifications and Conditions

1. Location:

The holes are to be drilled 50 miles south of Coppermine, N.W.T. in the area shown on the accompanying map and at exact sites to be selected by the Geological Survey of Canada during the summer of 1962.

2. Diamond Drills:

The Contractor is to supply diamond drilling equipment capable of drilling to 5,000 feet, with the necessary men and supplies to carry on the work, to operate 24 hours per day 7 days per week, and to pay all expenses of the work not otherwise provided for in the agreement. It is preferable that 2 or more drills operate simultaneously in order to complete the drilling during the summer of 1963.

3. Footage:

The Contractor is to sink by core drilling two holes to a depth of not more than 5,000 lineal feet, although the drilling of 3 holes to shorter depths will be considered.

4. Inclination of Hole:

The holes are to be vertical. When they deviate from the vertical by 4° then they will be wedged at the discretion of the Departmental representative.

5. Size of Core:

The core diameter is to be no less than BX size (1 5/8" diameter) at the bottom of the holes. The core size at the top of the holes is left to the Contractor's judgement as to a proper hole design under the permafrost and bedrock conditions expected.

6. Price per Foot for Penetrating Overburden:

The price per foot for penetrating overburden is to be quoted at 25 foot intervals to a depth of 100 feet.

7. Pipe Casing:

The cost of all material left or lost in holes while driving pipe or drilling is to be borne by the Contractor. However, should the Department instruct the Contractor to leave any pipe or casing in the holes, the Department will pay for same at cost per foot F. O. B. drill site.

8. Price per Foot for Core Drilling:

The price per foot for core drilling to 5,000 feet is to be quoted at a flat rate per foot at 500 foot intervals to 1,000 feet, then at 1,000 foot intervals to 5,000 feet. The price to include all contingencies not otherwise specified.

The price per foot for core drilling to 3,500 feet, is to be quoted at similar intervals. If this drilling plan is adopted, 3 holes will be drilled.

9. Water Supply:

The Contractor is to supply all water to the drill site at no charge to the Department. The northern drill hole will be within 3,000 feet of water for drilling, and the southern drill hole will be on the shore of Speers Lake. If a third hole is drilled, it will be located near the shore of McGregor Lake.

10. Surveying of Holes:

The Contractor is to supply equipment and take tests for azimuth and dip angle as required by the Department; the charge per test is to be quoted in 1,000 foot intervals. Costs for azimuth tests are to be quoted separately from dip tests.

11. Other Tests in Holes:

Heat flow or other measurements not related to surveying the hole may be required by the Department. The Department will be expected to supply the instruments and the Contractor to lower them in the hole. The charge for these tests is to be quoted on an hourly basis.

12. Wedging of Holes:

The Contractor will orient and/or set the wedge to insure proper deflection of the hole. If trouble arises traceable to a wedge, and not due to Contractor error, the cost of cleaning the hole to allow drilling to proceed will be borne equally by the Department and the Contractor. The Contractor will furnish the correct wedges, wedge bits and shells, and lowering tools. The cost of wedging (including assembly and installation) is to be quoted in 1,000 foot intervals. Separate costs should be stated for directional and non-directional wedging.

13. Cementing:

If a hole requires cementing due to loss of water or rock cave the drilling may be stopped to permit cementing, but such stoppage shall be only with the consent of the Departmental representative. The cost of cement and cementing to be quoted at 1,000 foot intervals, based upon 6 bags per job.

14. Difficulty in Penetration:

Should a cavity or loose and caving material be encountered which cannot be overcome by normal methods of casing, cementing, or wedging, the Contractor does not guarantee to drill holes at any specified depth but will drill as is practical under existing conditions and the Department will pay for the effective depth drilled.

15. Extra Footage:

If redrilling is necessary due to carelessness or error on the part of the Contractor, such drilling will be at the Contractor's expense until the hole arrives at the depth previously turned in to the Department.

16. Core Recovery:

Maximum core recovery is essential as scientific studies are planned on the complete section of drill core. This is the principal purpose in drilling holes. It will be necessary that the Contractor's

foreman cooperate to maintain as high a core recovery as due diligence will allow.

17. Core:

The core is to be stored in boxes provided by the Contractor and the Contractor will cover, wire, and transport the core from the drill site to Yellowknife at no cost to the Department. The core is to be transported on the return leg of service flights chartered by the Contractor and the Department will not require special aircraft charters from Yellowknife for this purpose.

18. Transportation:

The Contractor is to pay the cost of all transportation of diamond drilling equipment, men, and supplies to and from the drilling site. A fixed lump sum price is to be quoted. Transportation of Departmental representatives between Yellowknife and the site will not be the Contractor's responsibility.

19. Drill Moves:

In the event that it is not considered practical to continue drilling in any hole, it is agreed that the Contractor will move his equipment to another site to be selected by the Department, and there drill a hole for the footage remaining under this agreement at the prices specified. The Contractor therefore agrees to move his equipment up to a distance of two miles for a lump sum of 750.00 dollars and any additional distance at the rate of 250.00 dollars per mile. The calculation of distance will be measured along the route of travel rather than directly. The Department will agree to pay for the cost of moving camp should this be considered advisable, or will pay the Contractor's employees for normal walking time in excess of one mile.

20. Buildings:

The Contractor is to supply buildings and cookery for the drilling operation.

21. Board:

The Contractor is to board one Departmental representative at no charge to the Department, and any seasonal or temporary Departmental representative at the rate of $3.00 per day. The Department will keep such temporary representatives to a minimum so as to avoid interfering with the conduct of the drilling operation by the Contractor.

22. Recording of Drilling Data:

The Contractor will be required to record, with the assistance of the Departmental representative, and to supply to the Department all technical data relating to the conduct of the drilling operation. This data is to be supplied in full within 6 months of completion of the project, and will be available for distribution to the diamond drilling industry.

23. Daily Reports:

The Contractor is to give the Departmental representative carbon copies of all daily reports, daily.

24. Radio Communication:

The Department will provide base radios at the drill site for the purpose of aiding the drilling operation at no cost to the Contractor.

25. Laws and Regulations:

The Contractor shall conform at his own expense with all local and Provincial regulations and laws including those pertaining to labour conditions and Workmans Compensation Board requirements.

26. Liability:

The Contractor shall save harmless the Department of Mines and Technical Surveys from and against all claims, suits, and damages of whatever nature arising out of this contract.

27. Drill Results:

The Contractor will not give out any information regarding drill results or permit access to any drill core to any person other than the accredited representatives of the Department except upon specific permission of responsible representatives of the Department.

28. Arbitration:

Interpretation of the specifications and requirements is to be the prerogative of the Departmental representative. In case of failure to meet mutual agreement, arbitration by a recognized professional engineer not in the employment of either party may be sought and his decision will be final and binding.

29. Payment for Work:

The Department will pay the Contractor the agreed prices, payment to be made on or before 25th day of each month for work done during the preceding month, and settlement in full when the drilling is completed satisfactorily.

III. Form of Tender

Firm prices are to be given under the following headings:

1. Mobilization and transporation of all necessary equipment, personnel, and materials to site and return to Contractor's premises. Alternate prices are to be given, based on a) 2 holes to 5,000 feet and b) 3 holes approximately 3,500 feet each.

2. Cost per foot for core drilling; a) to 5,000 feet, at 500 foot intervals to 1,000 feet and then at 1,000 foot intervals; b) to 3,500 feet at similar intervals. These prices to include all contingencies not otherwise specified in this quotation.

3. Cost per foot for penetrating overburden to bedrock. Quote at 25 foot intervals to 100 feet.

4. Cost of wedging (cost of assembly plus placing in hole). Quote at a flat rate, at 1,000 foot intervals, for both directional and non-directional wedges.

5. Cost of cementation of hole where necessary. Quote at a flat rate for 1,000 foot intervals based upon 6 bags per job.

6. Cost of surveying hole where necessary. Quote at a flat rate at 1,000 foot intervals. Costs for dip tests is to be quoted separately from azimuth test.

7. Cost of other tests in the hole. Quote on an hourly rate.

Appendix B

EQUIPMENT USED ON THE MUSKOX DRILLING PROJECT

A. Drilling Equipment

1. Drills

Muskox South - Boyles Bros. BBS-3 Model 44 with 112 H. P. Perkins diesel motor. Longyear 44NW hydraulic swivel head. Hydraulic pump - 20 gal/min variable volume Racine, 0-1,000 psi. Weight of complete unit - 6,700 lb. Rating - 5,000 feet with B equipment. (See Plate VA.)

Muskox North - Boyles Bros. BBS-4 with 88 H. P. Hercules diesel motor. Boyles H friction feed swivel head with feed gears 600, 450, 300, and 200 T. P. I. (turns per inch). Weight of complete unit - 7,820 lb. Rating - 5,000 feet with B equipment.

Muskox East - Inspiration INS-3 with 50 H. P. Waukesha diesel motor, and twin disc fluid coupling. Inspiration Mark 3 hydraulic swivel head. Weight of complete unit - 5,000 lb. Rating - 3,500 feet with A equipment. (See Plate VB.)

2. Towers

Muskox South - Fabricated 52-foot sectional tubular steel tower with centre mounted single sheave wheel. Construction of 3" pipe and 1 1/2" angle iron. Erected in 4 sections of 18', 15', 11', and 8', plus 1-foot cap. Maximum length of pull - 40 feet. (See Plates I and VIA.)

Muskox North - Tubular steel 65 foot derrick, pinned to base of drill and raised by hoist and gin-pole. Maximum length of pull - 50 feet. (See Plate VIB.)

Muskox East - Original tower was a wooden tripod made from three 35-foot poles, giving a 20-foot pull. At a depth of 1,175 feet, the BBS-4 drill and derrick were moved from Muskox North drill site to complete the hole.

3. Pumps

Supply - Smart and Turner 1,000 gal/hr double-acting positive displacement duplex pumps. Chain driven by Petter PAZ-1 3 H.P. diesel motors.

Pressure - Bean Royal Model 420 single-acting triplex pumps, 20 gal/min capacity. Belt driven by Onan DJ-60 diesel motors developing 14 H.P. at 2,400 R.P.M.

In addition to the above pumps, a larger 30 gal/min Oliver single-acting triplex pump driven by a Waukesha Model 180 diesel motor developing 36 H.P. at 2,400 R.P.M. was used intermittently as a pressure pump on all three holes, when excessive mudding conditions required higher fluid pressures and volumes.

4. Hoisting Cables

3/4" and 7/8" flattened strand, non-rotating type.

5. Foot Clamps

Bull Dog and Wommer clamps.

6. Rods

Muskox South - BW series; 2 1/8" O.D., 1 13/16" I.D.; Upset ends, 3 threads per inch. Twenty foot lengths. Weight approximately 75 lb/20 foot length.

Muskox North and East - B standard series; 1 29/32" O.D., 1 1/4" I.D.; parallel wall; 3 threads per inch. Ten foot lengths. Weight approximately 60 lb/10 foot length.

7. Core Barrels

Double tube, rigid type, X series; 2 9/32" O.D.; core diameter 1 5/8". Stainless steel inner tubes. Fifteen and twenty foot lengths.

8. Reaming Shells

J.K. Smit and Sons spiral type; 2.360" O.D.

9. Coring Bits

J.K. Smit and Sons medium round nose bevel wall; 2.345" O.D.; 1.655" I.D. Approximately 40-60 stones/carat; approximately 6-7 carats/bit.

10. Core Lifters

Standard split type.

11. Ancillary Equipment and Supplies

Coil Heaters

Inspiration coil stoves; fuel oil burning; 1 gal/hr nozzle. Heat rise 30°F at 400 gal/hr. Chain driven by Petter 3 H.P. diesel motors.

Core Boxes

Water repellant treated cardboard; 26 1/4" x 9 3/4" x 2"; holding 10 feet of BX core.

Cement

60 bags Ciment Fondu; all consumed.

Calcium Chloride

14,000 lb in 100 lb bags; all consumed.

Fuel Oil

25,000 gal. No. 1 Winter Grade in 45 gal drums. 19,300 gal used.

B. Vehicles

1. Bombardier "Muskeg" tractor with tracked trailer.

2. Bombardier "J-5" tractor with tracked trailer.

3. Caterpillar D-4 tractor equipped with blade shoes and grousers for airstrip construction on ice. Loaned by Canada Department of Transport, Yellowknife, N.W.T.

4. Bombardier "Ski-Doo", track driven, ski-equipped 3-man personnel carrier.

C. Communications

1. Two, Spilsbury and Tindall MRT 600, 60-watt, 6-channel transmitter-receiver sets. 24V, D.C. power supply. Normal transmitting distance - 320 miles.

2. Two, Humble P-12, 1.8 watt, single-channel, battery-operated transceivers. Working frequencies were 4,982 kc (Department of Mines and Technical Surveys) and 5,536.5 (Wardair Canada Ltd., Yellowknife).

D. Camps

(at north and south drill sites)

1. One 36' x 20' aluminum-sheeted insulated combination cookhouse and bunkhouse.

2. One 16' x 20' aluminum-sheeted insulated office building.

3. One 12' x 10' heavy duck house tent on aluminum frame and plywood floor. For core processing and storage.

4. One 16' x 12' x 4' house tent on wooden frame for storage of drill equipment and supplies (Speers Lake camp only).

5. Extra tents; - two 12' x 10' house tents; three Mt. Logan 8' x 10' x 2.2' double-walled tents. Used according to demand at all camps.

6. Light plants - three 3kw Onan Model 3DSL diesel powered 115-120 V plants. One at each camp; one spare.

E. Core Sampling

One Felker Di-Met Model DH-1 diamond cut-off saw, driven by 3/4 H. P. electric motor.

Appendix C

GEOLOGICAL LOGS OF THE DRILL HOLES[1]

1. Muskox North Drill Hole

Latitude:	67°05'30"N	Date drilled:	May 10 - August 13, 1963
Longitude:	115°16'30"W	Size:	BX
Collar Elevation:	1,682.8 ft.	Casing:	10' BX, 4' NX
Depth:	3,593 ft.		

Depth (feet)	Description
	Hornby Bay Group (Map-unit 8)[2]
0 - 202.8	Grey to grey-white, fine- to medium-grained, massive sandstone grading downward into quartzite toward roof contact of the Muskox Intrusion. Transition between sandstone and quartzite is irregular and discontinuous, but below about 137-140 feet rock is mainly quartzite. Recrystallization is marked by appearance of bluish, glassy quartz patches, giving a spotted cast to the rock. Basal part of the unit (187'-202.8') is darker due to green chlorite. Unit is highly fractured. Specific Gravity: 2.63 gm/cm^3 (21 determinations, range from 2.59 to 2.64).
202.8	Roof contact of the Muskox Intrusion.
	Upper Border Zone
	Contact Breccia (Map-unit 28)

[1]See Figure 14 for a diagrammatic representation and correlation of the drill holes.

[2]Map-unit numbers referred to on the following pages are those shown on the Geological Survey's coloured map of the Muskox Intrusion (in press).

Depth (feet)	Description
202.8 - 208.8	Green to greenish grey, fine-grained altered (chloritic) gabbroic matrix containing irregular quartzite fragments up to 2" - 3". Amount of quartzite decreases from top to bottom of section. Quartzite fragments commonly fractured and re-cemented. Chalcopyrite and pyrite occur in thin veinlets in both matrix and fragments. Local concentrations of sulphides to 5% over a few inches.

Granophyric Gabbro

(Map-unit 25)

208.8 - 251.9	Dark green to greenish grey rock varying from medium to pegmatitic in grain size. Subophitic texture. Erratically distributed zones contain coarse granophyric aggregates. Upper part of unit (208.8 - 213.3) is a dark 'hybrid' fine- to medium-grained massive gabbro with scattered granophyric patches up to 1 inch in size. Hornblende is common and there is minor disseminated pyrite. The base of the unit is characterized by 1 1/2 feet of pegmatitic gabbro.

Composition:

Clinopyroxene	10-15%
Hornblende	15-25
Plagioclase	35-40
Potassium feldspar	10-20
Quartz	10
Biotite	2
Opaques (magnetite and ilmenite)	4

Specific Gravity:

2.91 gm/cm^3 (4 determinations, range from 2.90 to 2.93).

Top of Layered Series

Granophyre-bearing Gabbro

(Layer 35, map-unit 24)

Depth (feet)	Description
251.9 - 269	Granophyre-bearing gabbro. Dark grey, fine-grained massive gabbro containing hornblende and iron oxides. Change to overlying granophyric gabbro is gradational over 1-2 inches.
269 - 278.2	Granophyric gabbro pegmatite. Dark greenish grey, pegmatitic gabbro containing coarse amphibole and pyroxene and abundant quartz and potassium feldspar in granophyric intergrowth. Contact with granophyre-bearing gabbro above not exposed due to broken core.
278.2 - 315.1	Granophyre-bearing gabbro. Dark grey, fine- to medium-grained massive gabbro containing hornblende. Contact with overlying unit is sharply defined.
315.1 - 324.6	Granophyric gabbro pegmatite. Greenish grey pegmatitic gabbro containing coarse amphibole and granophyric patches. Contacts with enclosing units are sharply defined and perpendicular to core axis.
324.6 - 372.8	Granophyre-bearing gabbro. Greenish grey, fine-grained (in places medium-grained) equigranular granophyre-bearing gabbro. Local sub-pegmatitic zones. Texture subophitic. Granophyre content less than 10%. Biotite is a common accessory. Chloritic alteration common. Contact with granophyric gabbro above is gradational.

Composition:

Clinopyroxene	25-35%
Orthopyroxene	5-10
Plagioclase plus alteration products	45-50
Biotite	1-2
Opaques (magnetite, ilmenite)	2-3
Potassium feldspar	0-3
Quartz	4-7
Hornblende	<1

Specific Gravity:

2.90 gm/cm^3 (5 determinations, range from 2.79 to 2.97).

Depth (feet)	Description

Details:

347 - 348.6	Sub-pegmatitic phase in granophyre-bearing gabbro. Grain size change from fine to coarse is abrupt over 1/2" - 1".
365.0 - 367.0	Darker, feldspathic websterite zone. Cut by thin (1/8" - 1/4") veins of white siliceous material.

Picritic Websterite

(Layer 34, Map-unit 14)

372.8 - 420.8 An altered, fractured unit with overall picritic composition, but containing zones rich in olivine. A distinctive feature is the presence of a zone of quartzite breccia (405-408.2). The layer contains many thin quartz-carbonate and serpentine-carbonate veinlets and stringers. Contact with overlying gabbro is not visible due to broken core, but is apparently sharp or sharply gradational over less than 1" - 2".

Composition: Variable, but an approximate range is:

Olivine	10-25%
Serpentine (from olivine)	2-8
Magnetite (from olivine)	1-2
Clinopyroxene	30-45
Orthopyroxene	5-15
Plagioclase	20-30
Opaques (magnetite, ilmenite)	1-2

Specific Gravity:

2.70 gm/cm^3 (5 determinations, range from 2.65 to 2.79).

Details:

373 - 386	Picritic websterite, cut by numerous quartz veinlets in the upper 5 feet.

Depth (feet)	Description
386 - 395	Serpentinized peridotite cut by quartz stringers at 20° - 25° to the core axis.
395 - 395.5	Brecciated and altered peridotite (?).
395.5 - 397	Serpentinized peridotite.
397 - 405	Picritic websterite (serpentinized) with irregular quartzite fragments up to 15%.
405 - 408.2	Quartzite breccia zone. Lower contact at about 20° to core axis. Upper contact brecciated and irregular.
408.2 - 420.8	Highly altered picritic websterite cut by frequent asbestos stringers and white carbonate veinlets.

Gabbro

(Layer 33, Map-unit 22a)

420.8 - 704.7 Variable unit, but mainly grey to greenish grey, fine- to medium-grained gabbro. Local sub-pegmatitic bands and zones are common. In places, crude feldspathic layering at high angles to the core axis (80°) is present. Foliation due to preferred orientation of plagioclase crystals at angles from 30° to 50° to the core axis is common in parts of the section. Rare disseminated pyrrhotite and chalcopyrite.

Composition:

Clinopyroxene	25-40%
Orthopyroxene	10-20
Plagioclase, plus alteration products	45-55
Biotite	<1
Opaques (magnetite and ilmenite)	5-1
Potassium feldspar	<2
Quartz	1-3
Apatite	<1
Hornblende	<2

Depth (feet)	Description
	Specific Gravity:
	2.97 gm/cm^3 (28 determinations, range from 2.91 to 3.16).
	Details:
420.8 - 426.6	Fine-grained gabbro.
426.6 - 427.5	Coarse-grained gabbro.
427.5 - 429.1	Fine-grained gabbro.
429.1 - 467	Gabbro becomes coarse-grained and locally pegmatitic. From 445'-460', crude foliation due to orientation of plagioclase and clinopyroxene grains. Poorly defined feldspathic banding at 451.5 and 458.9 at about 80° to core axis. Feldspathic bands are up to 4" thick and contacts with normal gabbro are gradational over 1".
469 - 513	Discontinuous foliation at 40°-60° to core axis, average about 55°. Feldspathic bands at 501.1, 501.3, 505.1, and 505.6 ft.
524.1 - 560.9	Fine-grained gabbro containing numerous, thin (0.1" - 0.6") bands of coarse-grained, sub-pegmatitic gabbro.
560.9 - 591.1	One-half inch band of pegmatitic gabbro with 5 per cent disseminated pyrrhotite and chalcopyrite.
591.8 -	One-eighth inch wide veinlet of chalcopyrite.
595 - 654	Pegmatitic gabbro bands ranging from 1" to 6' in thickness. Attitude of bands range from perpendicular to core axis to about

Depth (feet)	Description
	35° to core axis. Contacts with normal gabbro are sharp or sharply gradational over less than an inch.
688.6 - 695.3	Pegmatitic gabbro zone.

Picritic Websterite

(Layer 32, Map-unit 19)

704.7 - 772 Grey, fine-grained, massive websterite with minor olivine at top, increasing to a maximum of 20% near the base of the layer. Cumulate texture with orthopyroxene forming large poikilitic plates. Disseminated pyrrhotite and chalcopyrite, locally to 5% over 1 foot. Contact with the overlying gabbro is sharp, but a supra-contact gradation is present in the gabbro, shown by a decrease in plagioclase and increase in orthopyroxene and clinopyroxene.

Composition:

Olivine	5-20%
Serpentine and magnetite (from olivine)	1-5
Clinopyroxene	30-70
Orthopyroxene	10-20
Plagioclase plus alteration	15-50
Biotite	<1
Opaques (magnetite and ilmenite)	1
Potassium feldspar	0-2
Quartz	0-1

Specific Gravity:

3.19 gm/cm^3 (7 determinations, range from 3.10 to 3.22).

Details:

704 - 710	Picritic websterite is more feldspathic and olivine content decreases upward.
710 - 722	Disseminated pyrrhotite and chalcopyrite to 1%.

Depth (feet)	Description
764 - 772	Olivine plus serpentine content averages 15-20% over this section. 768.8 - 768.9 has 10% sulphides.

Feldspathic Websterite and Melanogabbro

(Layer 31, Map-unit 18b)

772 - 1054.2 A unit composed of 188 feet of feldspathic websterite with bands of melanogabbro underlain by 94 feet of melanogabbro. Greenish grey rocks, fine to medium grained with cumulate textures. Top of sequence is composed of melanogabbro in sharp contact with overlying layer. Contacts within the layer are gradational over 1-2 inches.

Composition:	Feldspathic websterite	Melanogabbro
Clinopyroxene	60-75	40-60
Orthopyroxene	10-20	10-25
Plagioclase	12-16	25-35
Biotite	<1	<1
Opaques	<1	<1

Specific Gravity:

Feldspathic websterite - 3.18 gm/cm^3 (14 determinations, range from 3.11 to 3.22). Melanogabbro - 3.13 gm/cm^3 (5 determinations, range from 3.00 to 3.21).

Details:

772 - 786	Melanogabbro. Disseminated pyrrhotite and chalcopyrite up to 2-3%.
786 - 790.4	Websterite.
790.4 - 795.1	Interbanded melanogabbro and websterite.
795.1 - 799.5	Websterite.
799.5 - 804.6	Pegmatitic gabbro.

Depth (feet)	Description
804.6 - 828.2	Greenish grey fine- to medium-grained websterite.
828.2 - 839.5	Melanogabbro.
839.5 - 908.8	Websterite.
908.8 - 912.9	Melanogabbro.
912.9 - 916.9	Websterite.
916.9 - 921.8	Melanogabbro.
921.8 - 932.6	Websterite.
932.6 - 936.3	Melanogabbro.
936.3 - 937.1	Websterite. Upper contact gradational over 1/2 inch and 75° to core axis.
937.1 - 937.7	Melanogabbro. Band inclined at 75° to core axis.
937.7 - 941.8	Websterite. Sharp contacts inclined 75° to core axis.
941.8 - 950.0	Gabbroic websterite.
950.0 - 950.5	Websterite.
950.5 - 952.5	Melanogabbro.
952.5 - 960.3	Websterite. Upper contact gradational over 1/2 inch and 80° to core axis. Irregular in detail.
992 - 1,000	Crude foliation at 80-85° to core axis.
1,000 - 1,016	Irregular, feldspathic zones less than 2" wide in the gabbro.

Depth (feet)	Description
1,016 - 1,053	Melanogabbro with frequent thin (1/4"-1/8") green chlorite-carbonate alteration bands at 30°-40° to core axis.
1,053 - 1,054.2	Feldspathic websterite. Plagioclase decrease to 15%.

Gabbro

(Layer 30, Map-unit 22a)

1,054.2 - 1,164.9 A light grey, fine to medium-grained gabbro, foliated at angles of 70°-85° to the core axis. Transition to overlying feldspathic websterite is sharply defined and inclined at 80°-85° to core axis. Very minor disseminated pyrrhotite is present.

Composition:

Clinopyroxene	30-40%
Orthopyroxene	5-15
Plagioclase (in part altered)	50-55
Opaques	<1
Quartz	<1

Specific Gravity:

3.09 gm/cm^3 (5 determinations, range from 3.07 to 3.12).

Details:

992 - 1,000	Crude foliation at 80°-85° to core axis.
1,054.2 - 1,076	Gabbro with local thin (1/4"-1/2") pyroxene bands at 75°-80° to core axis. Minor disseminated pyrrhotite at 1,057.6 and 1,061.
1,076 - 1,094	Gabbro; slightly more feldspathic than above. Plagioclase 50%.

Depth (feet)	Description
1,094 - 1,096.6	Coarse pegmatitic gabbro zone. Orthopyroxene (poikilitic) and clinopyroxene crystals up to 1".
1,121.6	1 1/2" pegmatitic gabbro band at 70° to core axis. Basal contact is knife edged, and pegmatite shows sharp decrease in grain size toward contact.
1,129.9	Pegmatitic (3") band as above. Contacts sharp at 80-85° to core axis.
1,158 - 1,164.8	Gabbro becomes pyroxenitic.
1,164.8 - 1,164.9	Coarse-grained slightly pegmatitic gabbro.

Websterite - Orthopyroxenite

(Layer 29, Map-unit 17a)

1,164.9 - 1,218.5 A paired layer consisting of 38 feet of websterite underlain by 14 feet of orthopyroxenite. The websterite (layer 29B) is greenish grey, medium grained, and commonly very altered to chlorite. Its upper contact is marked by a 4-inch zone of coarse, recrystallized pyroxenite-rich material in relatively sharp contact with slightly pegmatitic gabbro. The orthopyroxenite section (layer 29A) is chloritized and sheared between 1,204-1,214 feet. The remainder is unaltered, medium grained, and massive. The bottom 4 feet contains up to 5% disseminated chromite and 3-4% combined pyrrhotite and chalcopyrite.

Composition:	Websterite (29B)	Orthopyroxenite(29A)
Clinopyroxene	70-75	5-10%
Orthopyroxene	20-25	70-80%
Plagioclase (altered)	5-8	10-15%
Opaques	<1	1%

Depth (feet)	Description

Specific Gravity:

3.17 gm/cm^3 (5 determinations, range from 3.12 to 3.26).

Details:

1,169 - 1,182	Shear zones with thin serpentine-chlorite veinlet at 30° to core axis.
1,203 - 1,204	Light, 2-inch aphanitic dyke at 25° to core axis.
1,208.6	Disseminated chromite.
1,214.2	1 1/2 inch band of heavy disseminated chromite. Pyroxene is fine-grained, well oriented, in places coarse and recrystallized.
1,214.3 - 1,218.2	Local minor disseminated chromite to 5% and erratic pyrrhotite and chalcopyrite to 5% in places.

Feldspathic Peridotite and Chromitite

(Layer 28, Map-unit 13)

1,218.2 - 1,222.0 A narrow band of medium to coarse-grained feldspathic peridotite, which is partly recrystallized to coarse clinopyroxene and plagioclase. Upper contact gradational over 2-3 inches. Within the band are three narrow chromitite layers as well as scattered coarse pyrrhotite and chalcopyrite.

Composition:	Feldspathic peridotite	Chromitite
Olivine	<1%	<1 %
Serpentine and Magnetite (from olivine)	40-60	5
Clinopyroxene	12-40	30-40
Orthopyroxene	10-15	15-25
Plagioclase	5-15	5

Depth (feet)	Description		
	Chrome Spinel	1-2	25-50
	Sulphides	1-2	1-2

Specific Gravity:

3.23 gm/cm^3.

Details:

1,218.2 - 1,218.5	Recrystallized peridotite.
1,218.5 - 1,218.8	Chromite-rich (40%) zone, 1/2 inch massive band at base. Up to 5% coarse pyrrhotite and chalcopyrite.
1,218.8 - 1,219.8	Recrystallized peridotite.
1,219.8 - 1,220	Highly concentrated chromite with sulphide blebs.
1,221 - 1,221.5	Up to 5% pyrrhotite and chalcopyrite.

Websterite - Orthopyroxenite

(Layer 27, Map-unit 17a)

1,222 - 1,280.2 A paired layer consisting of 36.5 feet of websterite (layer 27B) underlain by 22 feet of orthopyroxenite (layer 27A). The upper part is greyish green, medium grained, and altered to chlorite in places. The contact with overlying peridotite (layer 28A) is relatively sharp, but preceded by appearance of 5-15% olivine in upper foot of pyroxenite. The orthopyroxenite is grey to greenish grey, fine to medium grained, and contains several thin feldspathic bands. The contact with overlying websterite is apparently gradational over 2-3 feet and the contact with underlying chromitite (26B) is gradational over 6 inches with increasing olivine content.

Depth (feet)	Description

Composition:	Websterite (27B)	Orthopyroxenite (27A)
Clinopyroxene	55-65%	2-5%
Orthopyroxene	25-35	80-85
Plagioclase	8-10	10-15
Opaques	<1	<1

Specific Gravity:

Websterite 3.22 gm/cm^3 (4 determinations, range from 3.20 to 3.24).
Orthopyroxenite 3.17 gm/cm^3.

Details:

1,260.9	One inch coarse feldspathic band, normal to core axis.
1,271 - 1,279.5	Several thin feldspathic bands at 60°-70° to core axis.

Feldspathic Peridotite and Chromitite

(Layer 26, Map-unit 13)

1,280.2 - 1,342.4 Green to greenish black, fine- to medium-grained rock with blotchy appearance due to irregular distribution of poikilitic orthopyroxene and plagioclase. Top contact is marked by a 3/4-inch band of massive chromite inclined at 50° to core axis.

Composition:	Feldspathic peridotite	Chromitite
Olivine	1-5%	5%
Serpentine (from olivine)	50-60 }	5
Magnetite (from olivine)	5-20 }	
Clinopyroxene	10-20	20-30
Orthopyroxene	2-7	5-10
Plagioclase	5-15	25-35
Chrome spinel	1-5	20-40

Specific Gravity:

2.79 gm/cm^3.

Depth (feet)	Description

Details:

1,280.3 - 1,280.4 Pegmatitic zone beneath chromite layer contains 25% coarse feldspar and up to 5% sulphide minerals.

Olivine Clinopyroxenite

(Layer 25, Map-unit 16b)

1,342.4 - 1,352 Greenish grey, medium-grained rock with large poikilitic orthopyroxene grains. Upper contact with layer 26 is gradational over 4 inches.

Composition:

Olivine Serpentine (from olivine)	5-10%
Magnetite (from olivine)	<1
Clinopyroxene	65-75
Orthopyroxene	10-15
Plagioclase	5-15
Chrome spinel	<1

Specific Gravity:

3.20 gm/cm^3.

Feldspathic Peridotite

(Layer 24, Map-unit 13)

1,352 - 1,508.3 Greenish black, medium grained, and serpentinized, similar to layer 26A. Lower 4 feet is higher in pyroxene, marking the transition to underlying websterite. Upper contact is not exposed due to ground core.

Composition:

Olivine	1-5%
Serpentine (from olivine)	50-60
Magnetite (from olivine)	5-20
Clinopyroxene	10-20
Orthopyroxene	2-7
Plagioclase	5-15
Chrome spinel	1-5

Depth (feet)	Description

Specific Gravity:

2.79 gm/cm^3 (21 determinations, range from 2.68 to 2.84).

Details:

1,502	- 1,508.3	Several thin serpentine shear zones at 25-30° to core axis.

Websterite

(Layer 23B, Map-unit 17b)

1,508.3 - 1,541 A greyish green, fine- to medium-grained rock with chloritic alteration in places. Upper contact is gradational over 1" to 2" into feldspathic peridotite and is inclined at 40° to the core axis. On surface the websterite is overlain by an anorthositic gabbro unit (layer 23S, Map-unit 29), which was not encountered in the drill hole. The basal orthopyroxenite member (layer 23A), 19.8 feet thick in the east hole, was not found.

Composition:

Olivine Serpentine (from olivine)	<1%
Clinopyroxene	65-75
Orthopyroxene	25-35
Plagioclase (altered)	<5

Specific Gravity:

3.12 gm/cm^3.

Details:

1,517	- 1,520	Sheared and chloritized zone at 5° to core axis.
1,527	- 1,529	Sheared and chloritized zone at 5° to core axis.

Olivine Clinopyroxenite and Peridotite

(Layer 22, Map-units 15, 12)

Depth (feet)	Description
1,541 - 1,571.3	The unit comprises 18 feet of greenish grey olivine clinopyroxenite overlying 12 feet of peridotite. Its upper contact with layer 23 grades over 1"-2". The pyroxenite shows an increased content of olivine downward; its contact with peridotite is marked by a 1-inch band of coarse recrystallized pyroxene inclined at 80° to the core axis. The peridotite consists of serpentinized olivine grains and a heavy concentration of coarse, poikilitic pyroxene.

Composition:	Olivine Clinopyroxenite		Peridotite
Olivine Serpentine (from olivine)	5-30	to	55-65%
Magnetite (from olivine)	<4	to	5-10
Clinopyroxene	55-70	to	15-25
Orthopyroxene	5-10		5-10
Plagioclase (altered)	2-3		<3
Chrome spinel	<1		2-3
Sulphide minerals			<3

Specific Gravity:

Olivine clinopyroxenite 2.91 gm/cm^3.
Serpentinized peridotite 2.78 gm/cm^3.

Details:

1,541 - 1,550	Serpentine plus olivine content is 15-20%.
1,550 - 1,559	Serpentine plus olivine content is 35-40%.
1,559 - 1,560	Serpentine plus olivine content is 20-25%.
1,560 - 1,560.1	One inch band of coarse recrystallized clinopyroxene with 1-2% disseminated pyrrhotite and chalcopyrite. Transitional to peridotite.

Depth (feet)	Description
1,564 - 1,571	Content of poikilitic pyroxene drops from 40-50% to 10-15% through this section.

Dunite (Serpentinite)

(Layer 21, Map-unit 11)

1,571.3 - 1,780 Dark green, fine-grained, massive rock containing over 85% serpentine and magnetite from olivine. Numerous thin fractures filled with reddish brown serpentine and hematite. Up to 2% biotite is locally present. Upper contact is gradational over 6 inches and defined by an increase in coarse poikilitic clinopyroxene aggregates.

Composition:

Olivine	-
Serpentine (from olivine)	75-80%
Magnetite (from olivine)	10-15
Clinopyroxene	1-3
Orthopyroxene	1-5
Plagioclase (altered)	1-3
Chrome spinel	1-3
Sulphide minerals	<3

Specific Gravity:

2.62 gm/cm^3 (22 determinations, range from 2.53 to 2.76).

Details:

1,746 - 1,756	Zone of fractured core with numerous thin brown serpentine-magnetite veinlets generally 20° to core axis.
1,762 - 1,780	Scattered poikilitic clinopyroxene grains, in places up to 3%.

Peridotite

(Layer 20, Map-unit 12)

Depth (feet)	Description
1,780 - 1,948.9	Dark green to greenish black, fine- to medium-grained, locally blotchy serpentinized peridotite. Layer has overall peridotite composition, but pyroxene content is variable (<5 - 20-25%) and dunite zones of varying thickness are present. Biotite is a common accessory (<2%) and the layer contains unevenly disseminated sulphides (mainly pyrrhotite with subordinate chalcopyrite) rarely over 2%. Texture is cumulate. Contact with overlying dunite (layer 21A) is gradational.

Composition:

Olivine	<1%
Serpentine (from olivine)	60-70
Magnetite (from olivine)	5-15
Clinopyroxene	5-20
Orthopyroxene	2-5
Plagioclase (altered)	3-10
Opaques (chrome spinel, magnetite, ilmenite)	1-4
Sulphides (pyrrhotite, chalcopyrite)	<1

Specific Gravity:

2.74 gm/cm^3 (15 determinations, range from 2.68 to 2.78).

Details:

1,823 - 1,824	Dunite zone; pyroxene <5%.
1,853.1 - 1,853.3	2-inch band of gabbroic pegmatite at 65° to core axis.
1,856 - 1,868	Rock is strongly sheared at 10°-40° to the core axis.
1,878 - 1,888	Dunite zone; pyroxene averages 4-5%, but distribution is erratic.
1,888 - 1,919	Frequent fractures nearly parallel to core axis containing serpentine-magnetite veinlets. One-quarter inch veinlet from

Depth (feet)	Description
1,888 - 1,919 (con'd)	1,900 to 1,917.6 contains disseminated pyrrhotite and chalcopyrite (minor).
1,919 - 1,944	Rock in this zone is peridotite-dunite with pyroxene content erratic, but averaging about 10%.

Websterite - Orthopyroxenite

(Layer 19, Map-unit 17)

1,948.9 - 1991.4 A paired layer consisting of an upper websterite member (layer 19B) and a thin basal orthopyroxenite member (layer 19A). Both contain olivine. Websterite is greenish grey, fine to medium grained, massive, in places containing chlorite alteration. It has a cumulate texture. The orthopyroxenite is similar in appearance. Upper contact is sharp and inclined 40° to core axis.

Composition:	Websterite (19B)	Orthopyroxenite (19A)
Olivine Serpentine (from olivine)	<1-5 to	15-20%
Clinopyroxene	60-75 to	5-10
Orthopyroxene	15-30 to	65-75
Plagioclase	5-8 to	3-5
Opaques	<1	

Specific Gravity:

Websterite - 3.19 gm/cm^3.
Orthopyroxenite 2.87 gm/cm^3.

Details:

1,974 - 1,984	Intensely sheared, brecciated, chloritized rock.

Depth (feet)	Description

Peridotite
(Layer 18, Map-unit 12)

1,991.4 - 2,081.1 This layer has an overall composition of serpentinized peridotite, but in detail contains poorly defined alternating peridotite and dunite zones. The upper 25 feet of the layer is mainly dunitic, with minor peridotite bands; the central and lower parts are mainly peridotitic with subordinate dunite zones. The rocks are dark green to greenish black, fine to medium grained, and are locally coarsely blotchy owing to poikilitic pyroxene aggregates. Textures are cumulate modified by serpentinization effects. The contact with overlying olivine-bearing orthopyroxenite (layer 19A) is gradational over 2-3 inches. An 8-foot olivine clinopyroxenite layer of limited lateral extent, exposed in this unit on surface, was not intersected in the hole.

Composition:

Olivine Serpentine (from olivine)	65-85%
Magnetite (from olivine)	5-15
Clinopyroxene Orthopyroxene	5-20
Plagioclase (altered)	3-5
Opaques (chrome spinel, magnetite, ilmenite)	<2

Specific Gravity:

2.77 gm/cm^3 (9 determinations, range from 2.66 to 2.83).

Details:

1,991.4 - 2,017	Mainly serpentinized dunite with a few peridotitic zones. Two inch coarse-grained feldspathic pyroxenite at 1,992.5.

Depth (feet)	Description
2,017 - 2,057	Peridotite with 10-20% pyroxene. Four inch clinopyroxenite band, normal to core axis, at 2,018.4.
2,057 - 2,079	Mainly dunite.
2,079 - 2,080.9	Peridotite with 10-15% pyroxene, and well defined gradational contacts at 40° to core axis.
2,089.9 - 2,081.1	Dunite.

Olivine Clinopyroxenite

(Layer 17, Map-unit 16)

2,081.1 - 2,119.8 Greenish grey, fine- to medium-grained rock with blotchy appearance due to irregular dark serpentine patches. Olivine content increases from 2% at the top to 30% at base of unit. Contact with overlying peridotite is sharp and 60° to core axis.

Composition:

Olivine	0-5%
Serpentine (from olivine)	1-25
Magnetite (from olivine)	<1-8
Clinopyroxene	70-98

Specific Gravity:

3.11 gm/cm^3 (3 determinations, range from 2.99 to 3.26).

Dunite - Peridotite

(Layer 16, Map-units 11, 12)

2,119.8 - 2,173 The layer is a composite sequence composed of (from top to bottom): dunite; poikilitic peridotite; dunite; and rhythmically layered peridotite with thin dunite and olivine-bearing clinopyroxenite

Depth (feet)	Description
2,119.8 - 2,173 (cont'd.)	bands. The rocks are dark green to greenish black, fine to medium grained, and serpentinized. Change to overlying pyroxenite occurs within two inches but contact is not exposed due to lost core. Interval contacts are gradational over a few inches to sharp.

Composition:

Olivine Serpentine (from olivine)	65-85%
Magnetite (from olivine)	5-20
Clinopyroxene	5-20
Plagioclase	1-5

Specific Gravity:

2.76 gm/cm^3 (6 determinations, range from 2.69 to 2.82).

Details:

2,119.8 - 2,136	Serpentinized dunite. In places pyroxene up to 5%.
2,136 - 2,148.9	Poikilitic peridotite. Contact with overlying dunite gradational over 6".
2,148.9 - 2,163.2	Serpentinized dunite with with sporadic thin poikilitic peridotite bands at angles from 20°-50° to core axis.
2,163 - 2,173	Peridotite with thin dunite and olivine pyroxenite bands. Plagioclase content up to 5%. Bands at angles from 65° to 70° to core axis.

Olivine Clinopyroxenite

(Layer 15, Map-unit 16)

Depth (feet)	Description
2,173 - 2,260.8	Greenish grey, medium-grained rock containing about 10% relatively unaltered olivine at top (2,173-2,210 feet), increasing gradually to 40% altered serpentine at the base. Contact with overlying peridotite is sharp, and at 80° to core axis.

Composition:

Olivine	5-15%
Serpentine (from olivine)	0-35
Magnetite (from olivine)	0-5
Clinopyroxene	75-95
Plagioclase	2
Biotite	1

Specific Gravity:

3.11 gm/cm^3 (8 determinations ranging from 2.87 to 3.30). Basal peridotite is 2.87 to 2.99 gm/cm^3.

Details:

2,202 - 2,210	Sheared core.
2,219 - 2,232.5	Frequent fractures with thin serpentine veinlets. 1/4-inch chrysotile vein from 2,219.1 - 2,222.3.
2,249.6 - 2,260.8	Darker coloured zone with higher content of serpentinized olivine.

Dunite (Serpentinite)

(Layer 14, Map-unit 11)

2,260.8 - 2,334.7	Greenish black, fine-grained massive serpentinized dunite with pyroxene increasing erratically toward base. A 1-foot zone containing 20-25% pyroxene occurs at the base. Contact with overlying pyroxenite (layer 15) is sharp and 15° to the core axis. Layer contains 1% disseminated pyrrhotite and chalcopyrite.

Depth (feet)	Description

Composition:

Olivine Serpentine (from olivine)	75-85%
Magnetite (from olivine)	10-15
Clinopyroxene Orthopyroxene	2-10
Plagioclase	-
Opaques	-

Specific Gravity:

2.74 gm/cm^3 (7 determinations, range from 2.60 to 3.00).

Details:

2,315 - 2,333.8	Scattered poikilitic clinopyroxene, locally up to 10%.
2,321.2 -	3/4-inch band of heavily disseminated chromite.
2,333.8 - 2,334.7	Peridotitic zone. Clinopyroxene up to 25%.

Olivine Clinopyroxene

(Layer 13, Map-unit 16)

2,334.7 - 2,364.6 Greenish grey, fine to medium grained cumulate similar to layers 15 and 17. Olivine (serpentinized) content is 15% at the top, increasing to 55% at the base. Contact with overlying dunite is gradational over 1 foot and marked by slight banding.

Composition:

Serpentine (from olivine)	10-55%
Magnetite (from olivine)	0-10
Clinopyroxene	45-90

Specific Gravity:

2.94 gm/cm^3 (3 determinations, range from 2.88 (basal zone) to 3.10 (top)).

Depth (feet)	Description

Details:

2,347	- 2,354	Rock shows a gradual increase in olivine (serpentine) content (from 15% to 40%) through this zone and corresponding decrease in grain size.
2,354	- 2,364.6	Basal peridotitic zone. Olivine (serpentine) content up to 55%.

Dunite (Serpentinite)

(Layer 12, Map-unit 11)

2,364.6 - 3,271

A thick serpentinite layer cut by two diabase dykes. Below 2,172 feet the rocks intersected in this hole correlate with the top of the Muskox South hole. The lower ultramafic units in this hole remain heavily serpentinized to the bottom, unlike the change to less serpentinized rocks noted in the south hole. In addition, layer 12 in this hole appears to contain more pyroxene than in the Muskox South core.

Throughout most of the layer, the rock is greenish black, subaphanitic to fine grained, heavily serpentinized, with poikilitic clinopyroxene up to 10% in places. Biotite and altered plagioclase are common accessory minerals. Close fracturing is common, and the fractures frequently contain thin serpentine-magnetite veinlets. Contact with overlying pyroxenite is sharp and 10° to the core axis.

Composition:

Serpentine (from olivine)	75-80%
Magnetite (from olivine)	10-15
Clinopyroxene (altered)	5-10
Plagioclase (altered)	1-3
Biotite	1-2
Chrome spinel	1-2

Depth (feet)	Description

Specific Gravity:

2.71 gm/cm^3 (23 determinations, range from 2.66 to 2.82).

Details:

2,367 - 2,387	Dunite without visible pyroxene. Minor biotite (<1%). A few thin brown randomly oriented serpentine-magnetite veinlets.
2,387 - 2,411	Erratic clinopyroxene to 5-10%; biotite 1-2%.
2,411 - 2,443	Dunite, no visible pyroxene.
2,443 - 2,461	Peridotite/dunite. Poikilitic clinopyroxene 10%. Plagioclase 2%.
2,461 - 2,622.9	Dunite with erratic clinopyroxene up to 5%; scattered altered plagioclase (hibschite) (2%), and accessory biotite (1%). Many fractures with thin (1/8" - 3/8") brown serpentine-magnetite veinlets and in places white carbonate.
2,622.9 - 2,640	Diabase dyke. Medium grey, fine-grained, hard dense diabase. Upper contact not visible in core; lower chilled contact at 10°-15° to core axis. Minor disseminated sulphides along lower contact.
2,640 - 2,657	Strongly sheared and broken dunite with abundant serpentine veinlets.

Depth (feet)	Description
2,657 - 2,839.9	Diabase dyke. Grey, fine-grained, massive leucocratic rock, which is locally strongly sheared and fractured, and contains several zones of chloritic and siliceous alteration. Upper contact with dunite is sharp and about 35° to core axis. Minor brecciation is visible along the contact. Lower contact is sharp and about 30° to core axis. (Start of core overlapping with Muskox South hole sequence).
2,839.9 - 2,845.2	Serpentinized dunite as before. Frequent thin (1/8" - 1/4") brown serpentine-magnetite stringers in shear and fracture zones. Stringers have varying attitudes, but are commonly 25°-40° to core axis.
2,845.2 - 2,847.6	One quarter inch magnetite stringer with disseminated pyrrhotite.
3,036.4 - 3,039	Shear zone with rotated and slickensided core fragments. Frequent heavy green serpentine veinlets inclined about 50° to core axis.
3,039 - 3,062.3	Dunite with irregular patchy biotite-chlorite aggregates. Rare finely disseminated pyrrhotite.

Depth (feet)	Description
3,062.3 - 3,070	Zone of sheared and brecciated dunite; with 5-10% disseminated pyrrhotite.
3,070 - 3,271	Serpentinized dunite with frequent brown serpentine-magnetite stringers and less common green-white serpentine-carbonate veinlets.

Feldspathic Olivine Clinopyroxenite-Troctolitic Peridotite-Dunite

(Layer 11, Map-unit 19)

3,271 - 3,322

A composite layer consisting of olivine gabbro at the top (3,271 - 3,273.5) grading downwards through well-banded feldspathic olivine clinopyroxenite (to 3,299') and layered troctolitic peridotite (to 3,309') and dunite (to 3,322'). The sequence is generally similar to that in the Muskox South hole, and the total thickness of the unit is about the same. The upper part has well-defined rhythmic layering consisting of alternating feldspathic and pyroxene-olivine bands ranging from 1/4" to 6" in thickness. Layering is nearly perpendicular to the core axis, but dips vary in sections containing structures resembling cross-bedding. The dunite is massive. The contact of the unit with overlying dunite (layer 12) is sharp and about 35° to the core axis.

Composition: Variable due to layering, but an approximate average is:

	Feldspathic Olivine Clinopyroxenite	Troctolitic Peridotite	Dunite
Olivine Serpentine (from olivine)	25-50	65-80	90
Clinopyroxene	30-50	5-30	<5
Plagioclase (altered)	15-25	20-25	<5

Depth (feet)	Description
	Details:
	3,271 - 3,273.5 Greenish grey, medium-grained olivine gabbro. Olivine 20%; plagioclase 40%; clinopyroxene 40%.
	Feldspathic Peridotite
	(Layer 10, Map-unit 13)
3,322 - 3,399	A heterogeneous olivine-rich unit, predominantly feldspathic peridotite in composition. The unit is bounded by two feldspathic olivine clinopyroxenite layers and includes two thin olivine-rich gabbro layers. The sequence is similar to that encountered in the south drill hole.
	Composition: (Only an order of magnitude due to layered nature of the unit).

Olivine	5-10%
Serpentine (from olivine)	40-60
Magnetite (from olivine)	3-10
Clinopyroxene	20-30
Orthopyroxene	<1
Plagioclase	10-20

Details: Unit is subdivided as follows:

3,322 - 3,326	Dark green to black feldspathic olivine clinopyroxenite.
3,326 - 3,357	Blotchy feldspathic peridotite. Three inch gabbroic pegmatite zone at 3,326.8 feet.
3,357 - 3,374	Feldspathic peridotite.
3,374 - 3,379	Olivine gabbro.
3,370 - 3,390	Feldspathic peridotite. 3% plagioclase.

Depth (feet)	Description
	3,390 - 3,394.3 Olivine-rich gabbro.
	3,394.3 - 3,399 Feldspathic olivine clinopyroxenite.

Olivine Gabbro

(Layer 9, Map-unit 20)

3,399 - 3,403.2 This thin (4') olivine gabbro layer has decreased in thickness from 107 feet in the Muskox South hole. The rock is light grey, medium grained, with a spotted appearance due to darker olivine-serpentine patches. Change to overlying peridotite (layer 10) occurs within 1 inch but contact lost due to ground core.

Composition:

Olivine	5-10%
Serpentine (from olivine)	3-10
Magnetite (from olivine)	-
Clinopyroxene	35-55
Plagioclase	35-45

Olivine Clinopyroxenite

(Layer 8, Map-unit 16)

3,403.2 - 3,479.9 A typical olivine clinopyroxenite layer showing a gradational increase in olivine (serpentine) content with depth, from 10% at the top to 40% at the base. The rock is light to medium greenish grey, fine to medium grained, massive, and has a cumulate texture. Contact with overlying olivine gabbro is gradational over a few inches.

Composition:

Olivine	1-3%
Serpentine (from olivine)	3-30
Magnetite (from olivine)	1-10
Clinopyroxene	60-85
Orthopyroxene	2-5
Plagioclase	3-7 (in upper part)

Depth (feet)	Description

Details:

3,404	- 3,404.2	Two inch zone with 10% pyrrhotite.

Dunite (Serpentinite)

(Layer 7, Map-unit 11)

3,479.9 - 3,593 (end of hole)

Typical dark green to greenish black, subaphanitic to fine-grained very serpentinized dunite. Section contains up to 5% erratically distributed subrounded clinopyroxene grains. Brown serpentine-magnetite alteration in fractures is common. Contact with overlying pyroxenite (layer 8) is sharp but irregular. Its average inclination is 35° to the core axis.

Composition:

	- %
Olivine	
Serpentine (from olivine)	80-90
Magnetite (from olivine)	5-15
Clinopyroxene	3-5
Plagioclase (altered)	1-2
Chrome spinel	1-2

Details:

3,590	- 3,593	Lost core.
3,593		End of hole.

2. Muskox South Drill Hole

Location: Lat. 67°00'30"N, Long. 115°13'W

Collar Elevation: 1,759.6 ft. Depth: 4,000 feet

Date drilled: May 14 - September 1, 1963

Size: BX

Casing: 550' BX, 413' NX

Depth (feet)	Description
	Overburden
0 - 45	Sand, gravel, and boulders.
	Dunite (serpentinite)
	(Layer 12, Map-unit 11)
45 - 490.1	Dark green to greenish black, aphanitic to medium-grained serpentinite with mesh textures visible in coarser zones. Commonly closely fractured at variable angles to core axis. Waxy green serpentine veinlets, generally less than 1/4 inch wide, with soft white carbonate selvages are common. The lower contact of unit is knife-edged and inclined at 70° to core axis.

Composition:

Serpentine (from olivine)	75-80%
Magnetite (from olivine)	10-15
Clinopyroxene (altered)	6-8
Plagioclase (altered)	1-2
Chrome spinel	1-2

Specific Gravity:

2.57 gm/cm^3 (41 determinations, range from 2.47-2.64).

Depth (feet)	Description

Details:

73.7	- 74	Small fault at 30° to core axis. Left hand displacement.
76.5	- 78	Close parallel shears at 45° to core axis.
118.5	- 128	Strong shear zone containing minor serpentine.
141	- 149	Fault zone containing breccia and gouge.
326	- 327.5	Breccia zone.
328.5	- 331	Strong fracture zone; minor breccia.

Feldspathic Olivine Clinopyroxenite-Troctolitic Peridotite-Dunite

(Layer 11, Map-unit 19)

490.1 - 547.2 A layered sequence starting with 6 inches of olivine gabbro passing downward through layered feldspathic olivine clinopyroxenite (to 517') and troctolitic peridotite (to 530.8') and dunite at the base. Green, white, and black rhythmic layers from 1/2" to several inches thick at 75°-80° to core axis but locally steeper (crossbedded). Lower contact is well defined.

Composition: Variable, due to layering. A rough average is:

	Feldspathic Olivine Clinopyroxenite	Troctolitic Peridotite
Olivine	10-20%	8-10%
Serpentine (from olivine)	25-40	50-60
Clinopyroxene	35-45	10-15
Plagioclase (altered)	15-20	25-30

Depth (feet)	Description

Feldspathic Peridotite
(Layer 10, Map-unit 13)

547.2 - 586

A heterogeneous ultramafic sequence composed predominantly of feldspathic peridotite, bounded by two feldspathic olivine clinopyroxenite bands and including one thin gabbroic band. Unit contains more olivine and less feldspar than overlying layer. Lower boundary is well defined.

Composition: Variable, due to layering. An approximate average is:

	Feldspathic peridotite
Olivine	0-15
Serpentine (from olivine)	45-70
Magnetite (from olivine)	0-10
Clinopyroxene	5-25
Orthopyroxene	1
Plagioclase	5-15
Chromite	1

Details: Unit can be subdivided into following zones -

547.2	- 551	Feldspathic olivine clinopyroxenite.
551	- 569	Blotchy feldspathic peridotite. Includes 1 1/2 inch gabbroic pegmatite at 553 ft.
569	- 574	Dunite and peridotite.
574	- 575.3	Olivine-rich gabbro.
575.3	- 584	Feldspathic olivine clinopyroxenite.
584	- 586	Alternating olivine gabbro and dunite bands.

Depth (feet)	Description

Olivine Gabbro

(Layer 9, Map-unit 20)

586 - 693

Pale green, medium-grained, massive olivine gabbro. Subrounded olivine-serpentine grains in plagioclase-clinopyroxene matrix. Clinopyroxene occurs as small anhedral-subhedral grains poikilitically enclosed by larger plagioclase plates. Much of plagioclase is altered. Cumulate texture. Section is fairly homogeneous, but olivine-serpentine content increases locally toward layer margins (from 10% to 15-20%). Local feldspathic layers from less than 1 inch to 1 foot thick, at 75°-78° to core axis.

Composition:

Olivine	3-5%
Serpentine (from olivine)	7-15
Clinopyroxene	35-55
Plagioclase (altered)	35-45

Details:

600	- 601	Anorthositic band.
601	- 680±	Local feldspathic layers up to 1 1/2" thick at 75°-78° to core axis. Some irregular feldspathic zones up to 1 foot thick; attitudes not constant.

Olivine Clinopyroxenite

(Layer 8, Map-unit 16)

693 - 779.3

Greenish grey, fine- to medium-grained generally massive olivine clinopyroxenite with cumulate texture. Local fluctuations in olivine abundance cause faint banding at approximately 85° to core axis. Contact with overlying olivine gabbro gradational over 6".

Depth (feet)	Description

Composition:

Olivine	3-8%
Serpentine (from olivine)	12-22
Magnetite (from olivine)	3-10
Clinopyroxene	65-75
Chrome spinel	<1
Plagioclase (in upper part of layer)	<3

Dunite (serpentine)

(Layer 7, Map-unit 11)

779.3 - 1,091.9

Dark green to greenish black, aphanitic to medium-grained rock containing 80-85% serpentine. Local zones of 3-4% white alteration products of plagioclase (hibschite) are common. Infrequent zones with 2% altered poikilitic clinopyroxene plates. Pale green mottled and blotchy serpentine-chlorite-tremolite alteration veins associated with fracture zones are fairly common. Normal texture of the rock is granular, with serpentine mesh structures visible in coarser zones. Contact with overlying olivine clinopyroxenite is knife-edged at 45° to core axis.

Composition:

Olivine	-
Serpentine (from olivine)	80-90%
Magnetite (from olivine)	5-15
Clinopyroxene	1-3
Plagioclase alteration products	<1-3
Chrome spinel	1-2

Specific Gravity:

2.62 gm/cm^3 (10 determinations, range from 2.58-2.69).

Details:

780.7	3-inch zone of scattered plagioclase altered to hibschite.

Depth (feet)	Description
788.2 - 799	Mottled green serpentine-chlorite-tremolite alteration zone, with sharp, irregular contact with serpentinized dunite (35° to core axis).
804 - 805.9	Fracture with alteration zone as above.
815.3 - 842.5	Alteration zone with remnant serpentinite patches. Irregular upper contact with serpentinized dunite nearly parallel to core axis. Altered rock locally contains coarse (1"), sub-radiating chlorite plates.
862 - 903.1	Frequent fracture and alteration zones. Sections of lost and broken core up to 4 feet in length.
903.1 - 941	Scattered white plagioclase alteration products (hibschite) up to 2%.
941 - 1,091.9	As above with local erratic poikilitic clinopyroxene plates up to 1/4" (2%). Plagioclase (altered) and clinopyroxene reach maximum concentration at about 948-951 where they total 4-5% of the rock.

Olivine Clinopyroxenite

(Layer 6, Map-unit 16)

1,091.9 - 1,122.5 Mottled green and black, fine- to medium-grained, olivine clinopyroxenite. Local crude streaky foliation or lineation due to elongation of olivine-serpentine aggregates. Foliation is 85° to core

Depth (feet)	Description
1,091.9 - 1,122.5 (cont'd.)	axis. Texture crudely foliated to subpoikilitic. Contact with overlying serpentinized dunite is gradational over 3" - 4" through a zone consisting of alternating serpentinite and olivine pyroxenite layers.

Composition:

Olivine	-
Serpentine (from olivine)	25-40%
Magnetite (from olivine)	3-8
Clinopyroxene	55-65
Plagioclase	1
Chrome spinel	<1

Specific Gravity:

2.89 gm/cm^3 (3 determinations, range from 2.82-2.95).

Details:

1,117.5 - 1,122.5	Numerous thin (1/16 - 1/8") veinlets at variable angles to core axis, composed of serpentine and in places tremolite.

Dunite (serpentinite at top)

(Layer 5, Map-unit 11)

1,122.5 - 2,236.6

Serpentinite after dunite in upper part of layer, changing to dunite (60% olivine) at depth. Transition from serpentinite to dunite is gradational over about 110 feet (1,580-1,690'). Upper part (serpentinite) - 1,122.5-1,580 Dark green to greenish black, fine- to medium-grained, granular serpentinite. Mesh structures common. Frequent local zones containing small white plagioclase alteration products to 3-4%, and less commonly, poikilitic clinopyroxene to 3-5%. Contact with overlying olivine pyroxenite is knife-edged, but irregular. General attitude is about 50° to core axis. Zones of fracturing and alteration (post-serpentine?) are common (see below).

Depth (feet)	Description

Composition:

Olivine	1-2%
Serpentine (from olivine)	75-90
Magnetite (from olivine)	3-5
Clinopyroxene	3-5
Orthopyroxene	<1
Plagioclase plus alteration products	1-4
Chrome spinel	1-3

Specific Gravity:

2.59 gm/cm^3 (43 determinations, range from 2.52 - 2.70).

Details:

1,194.7	Thin (1"-1') bands contain 5-10% plagioclase alteration products (hibschite).
1,196.3	Thin (1"-1') bands contain 5-10% plagioclase alteration products (hibschite).
1,204.2	Thin (1"-1') bands contain 5-10% plagioclase alteration products (hibschite).
1,206	Thin (1"-1') bands contain 5-10% plagioclase alteration products (hibschite).
1,239 - 1,294.5	Layers from 2"-6" thick, generally 2-3 feet apart, contain 10-15% plagioclase alteration products.
1,331 - 1,343	Core fractured and crumbly. Possible fault zone.
1,367.3	Small fracture at 55° to core axis and soft reddish-brown ferruginous(?) alteration material. Vuggy.

Depth (feet)	Description
1,395 - 1,397	Discontinuous zone of fractured, altered serpentinite with veinlets of red ferruginous(?) alteration material and late waxy serpentine. Small (1/8" - 1/4") pieces of native copper at 1,396.7 and 1,397.1 ft. Isolated thin (1/8") seams of red ferruginous alteration material continue to 1,412 ft.
1,426.2 - 1,426.8	Core fractured, crumbly, with similar red alteration.
1,455 - 1,506	Scattered vuggy zones with red alteration.

Transition from serpentinite to dunite (1,580-1,690')

Serpentinite becomes paler green in colour and more granular in texture. Increase in specific gravity of specimens.

Composition:

Olivine	10-45%
Serpentine (from olivine)	40-75
Magnetite (from olivine)	1-2
Clinopyroxene	3-5
Orthopyroxene	1
Plagioclase alteration products	2-8
Chrome spinel	1-2

Specific Gravity:

2.82 gm/cm^3 (range from 2.70-3.00).

Lower part (dunite) (1,690-2,236.6')

Light green to greenish grey fine- to medium-grained dunite. Texture is distinctly granular. Local feldspathic and poikilitic clinopyroxene- — bearing zones as in upper parts of layer. Erratic distribution of clinopyroxene and plagioclase alteration products.

Depth (feet)	Description

Composition:

Olivine	55-65%
Serpentine (from olivine)	20-30
Magnetite (from olivine)	0-2
Clinopyroxene	3-10
Orthopyroxene	1-2
Plagioclase alteration products	2-8
Chrome spinel	1-3

Specific Gravity:

3.00 gm/cm^3 (49 determinations, range from 2.85-3.15).

Details:

1,804 - 1,857	Frequent thin serpentine-carbonate veins at various angles to core axis.
1,866.9 - 1,867.3	Red ferruginous alteration.
1,867.3 - 1,877	Finely disseminated phlogopite.
1,946.7 - 1,970.6	Probable fault zone. Rock is strongly sheared and contains much serpentine, carbonate, and chlorite. Breccia zones. Bands up to 1 foot wide of pale grey, very fine-grained dyke.
2,136.2 - 2,137.6	Typical reddish brown and white serpentine-carbonate alteration with minor phlogopite. Sheared.
2,193 - 2,197	Fracture and alteration zones 1/4" to 1 1/2" wide at 2° to core axis. Chlorite, serpentine, and white carbonate. Minor phlogopite.

Depth (feet)	Description

Olivine Clinopyroxenite

(Layer 4, Map-unit 16)

2,236.6 - 2,291

Green, medium-grained blotchy olivine clinopyroxenite. Olive + serpentine content increases downward. Local olivine-rich segregations giving crude layering at about 70° to core axis. Contact with overlying dunite is gradational over 3"-4" at about 70° to core axis.

Composition:

Olivine plus serpentine alteration	15-45%
Magnetite (from olivine)	0-5
Clinopyroxene	50-75
Orthopyroxene	1-2

Specific Gravity:

3.15 gm/cm^3 (5 determinations, range from 2.96-3.30).

Details:

2,246.6 - 2,260.5	Primary layering shown by minor serpentine-olivine rich bands, less than 4" thick, at 70° to core axis.
2,260.5 - 2,262	Vein of fine-grained grey cherty material cut by 1/2"-1" vein of white carbonate with coarse phlogopite. Vein shows comb structure arrangement at high angles to vein walls.

Dunite

(Layer 3, Map-unit 11)

2,291 - 2,396.5

Greenish grey to pale green, fine to medium grained granular dunite. Scattered clinopyroxene grains, locally up to 10%. Contact with overlying olivine pyroxenite is gradational through a peridotite zone about 7 feet thick (2,284 to 2,291).

Depth (feet)	Description

Composition:

Olivine	55-65%
Serpentine (from olivine)	30-35
Clinopyroxene	2-5
Oxides	5

Specific Gravity:

3.03 gm/cm^3 (range from 2.79 to 3.18).

Details:

2,323.5 - 2,328 Alteration zone containing grey, hard feldspathic material and minor white xonotlite and phlogopite.

Olivine Clinopyroxenite

(Layer 2, Map-unit 16)

2,396.5 - 2,422.5 Greenish grey, fine to medium grained olivine-rich clinopyroxenite with cumulate texture. In places rock is peridotite. Contact with overlying dunite is gradational over 2 feet.

Composition:

Olivine	0-6%
Serpentine (from olivine)	35-55
Magnetite (from olivine)	4-11
Clinopyroxene	20-40
Orthopyroxene	3-8
Plagioclase plus alteration products	5-10
Biotite	1
Chrome spinel	1

Specific Gravity:

3.25 gm/cm^3 (range from 3.23-3.27).

Dunite

(Layer 1, Map-unit 11)

Depth (feet)	Description
2,422.5 - 3,103	Greenish grey, fine- to medium-grained granular dunite. Poikilitic clinopyroxene occurs erratically in amounts ranging from 3-10%. Contact with overlying olivine clinopyroxenite is gradational over 1-2 feet.

Composition:

Olivine	60-70%
Serpentine (from olivine)	20-25
Clinopyroxene	3-10
Accessory minerals (including magnetite, chrome spinel, plagioclase, biotite)	5-10

Specific Gravity:

3.17 gm/cm^3 (66 determinations, range from 3.00-3.27).

Details:

2,571.2	2 inch white serpentine alteration zone with phlogopite.
2,580 - 2,590	Interstitial biotite up to 5%.
2,592.5 - 2,598.2	Alteration zone containing serpentine, red alteration, and coarse phlogopite.
2,669 - 2,669.6	As above.
2,748 - 2,749	As above.
2,894 - 2,895.7	Fractured core with alteration as above.
2,935.2 - 2,936.2	Serpentine-phlogopite band.
3,052 - 3,058	Peridotite zone. Pyroxene 10%.
3,064.8 - 3,066	Steep fracture containing red alteration, at 7° to core axis.

Depth (feet)	Description
	3,066 - 3,100 Rock is locally peridotitic, containing 10% clinopyroxene.
3,103	Marginal Zone of the Muskox Intrusion

Peridotite

(Marginal Zone, Map-unit 12)

3,103 - 3,176

Greenish black, fine- to medium-grained poikilitic peridotite. Local feldspathic zones contain up to 5-7% plagioclase. Contact with overlying dunite is gradational over 10 feet.

Composition:

Olivine	5-15%
Serpentine (from olivine)	45-65
Magnetite (from olivine)	5-10
Clinopyroxene	10-15
Orthopyroxene	2-10
Plagioclase	2-3

Specific Gravity:

2.97 gm/cm^3 (6 determinations, range from 2.84-3.04).

Feldspathic Peridotite

(Marginal Zone, Map-unit 13)

3,176 - 3,340 (approx)

Green to greenish black, medium-grained rock with poikilitic clinopyroxene and plagioclase. A crude orientation of clinopyroxene at approximately 45° to the core axis, and a local, poorly defined lamination due to thin serpentine bands at 30°-40° to the axis. Contact with peridotite above is gradational over 10-20 feet.

Composition:

Olivine	35-55%
Serpentine (from olivine)	5-15
Magnetite (from olivine)	1-5
Clinopyroxene	10-15

Depth (feet)	Description
	Orthopyroxene 5-10 Plagioclase 5-20 Biotite 1-2 Specific Gravity: 3.05 gm/cm^3 (15 determinations, range from 2.94-3.11). Details: 3,228 - 3,229 Soft, serpentine-chlorite zone. 3,229 - 3,231.8 Light grey to white feldspathic band. Lower contact with feldspathic peridotite contains thin (1") selvage of serpentine and fibrous xonotlite. 3,287 - 3,340 Serpentine-olivine lamination or banding at 30°-40° to core axis. Olivine plus serpentine content gradually decreasing with depth (50%); rock becoming lighter coloured and poikilitic clinopyroxene and orthopyroxene grains are prominent. Zones contain scattered biotite (<3%) and locally, minor disseminated pyrrhotite with rare chalcopyrite.
	Picrite (Marginal Zone, Map-unit 14)
3,340 (approx)-3,365	Greenish-grey, fine-medium grained poikilitic picrite. Differs from feldspathic peridotite above in lighter colour and higher plagioclase content. Poikilitic orthopyroxene grains are common. Contact with overlying feldspathic peridotite is gradational over 5-10 feet.

Depth (feet)	Description

Composition:

Olivine	10-20%
Serpentine (from olivine)	15-35
Magnetite (from olivine)	2-5
Clinopyroxene	15-20
Orthopyroxene	10-15
Plagioclase plus alteration products	20-25

Specific Gravity:

3.11 gm/cm^3 (3 determinations, range from 3.10-3.14)

Olivine Bronzite gabbro

(Marginal Zone, Map-unit 21)

3,365 - 3,479

As picrite above, except for increase in plagioclase content and decrease in olivine content. Rock is lighter-coloured than picrite, and poikilitic. Biotite is a common accessory (up to 3%) and the section contains local zones of disseminated pyrrhotite to 2-3%. Contact with picrite above is gradational over several feet.

Composition:

Olivine } Serpentine (from olivine) }	20%
Clinopyroxene	20-30
Orthopyroxene	10-15
Plagioclase plus alteration	25-30
Others (including secondary magnetite, biotite, pyrrhotite)	5-10

Specific Gravity:

3.10 gm/cm^3 (10 determinations, range from 2.88-3.17).

Details:

3,391.5 - 3,403.5 Fractured and altered rock with bands of white, fibrous xonotlite up to 3" wide.

Depth (feet)	Description
	3,412 - 3,412.5 Disseminated pyrrhotite to 3%.
	Picrite
	(Marginal Zone, Map-unit 14)
3,479 - 3,653	Greenish grey, fine- to medium-grained, poikilitic picrite. Olivine content is variable, and in places the rock approaches feldspathic peridotite. Local crude lamination due to black serpentine-rich bands inclined 35°-45° to the core axis. Biotite is a common accessory (up to 3-4%) and core contains minor disseminated pyrrhotite with rare chalcopyrite. Contact with olivine bronzite gabbro above is gradational over about 10 feet, through zones of variable olivine content. Plagioclase increases in abundance downward.
	Composition:
	Similar to picrite (3,340'-3'365')
	Specific Gravity:
	3.01 gm/cm^3 (14 determinations, range from 2.72 to 3.13).
	Details:
	3,525 - 3,558 Prominent ovoid poikilitic orthopyroxene grains to 1/4". Many black serpentine stringers giving lamination at 35°-45° to core axis.
	3,558 - 3,571 Discontinuous alteration zone. Soft, green, serpentine alteration.
	3,571 - 3,571.4 Disseminated pyrrhotite with rare chalcopyrite (<2%)

Depth (feet)	Description
3,573 - 3,577	Discontinuous disseminated sulphide zone in altered picrite. Mainly pyrrhotite with a few grains of chalcopyrite, sulphides locally concentrated to 3-4% over 2"-3".
3,583 - 3,590	Soft, locally gougy, serpentine alteration zone.
3,595.5 - 3,601	Disseminated pyrrhotite with minor chalcopyrite. Estimated to be 5% over 6".
3,601 - 3,614	Olivine-serpentine rich zone. Rock is feldspathic peridotite. Biotite (2-3%) and sporadic disseminated pyrrhotite to 2 -3%.
3,614 - 3,619.5	Serpentine alteration zone; with 3-4% scattered coarse phlogopite.

Bronzite gabbro

(Marginal Zone, Map-unit 21)

3,653 - 3,674.8 Light to medium grey, fine- to medium-grained, fairly equigranular gabbro. Subophitic texture. Olivine content increases upward. Biotite is a common accessory and the unit contains erratic pyrrhotite with minor chalcopyrite. Sulphides occur both in finely disseminated form, and as coarse (up to 1/2") patchy aggregates.

Composition:

Olivine Serpentine (from olivine)	0-15 %
Clinopyroxene	20-25
Orthopyroxene	20-25
Plagioclase plus alteration	35-40

Depth (feet)	Description
	Others including oxides, biotite, sulphides 5-10
	Specific Gravity:
	3.10 gm/cm^3 (2 determinations, 3.05, 3.14).
	Details:
	3,653 - 3,673 Erratic coarse patchy pyrrhotite with minor chalcopyrite; also fine disseminated pyrrhotite. Overall sulphide content of section is about 3%.
	3,664.5 One-inch band of massive pyrrhotite.
	3,673.5 - 3,674.8 Gabbro shows patchy irregular chlorite alteration. Disseminated pyrrhotite blebs up to 3/8".
3,674.8 - 3,677	Intrusion Wall
	Contact zone is fine-grained bronzite gabbro containing irregular quartz fragments with alteration rims and patches of altered country rock gneiss. Gabbro matrix is finer grained than normal; probably in part chilled. Zone contains scattered pyrrhotite blebs up to 3/8".
	Quartz-Plagioclase-Biotite Schist with Paragneiss Bands (Basement Rocks, Map-unit 5)
3,677 - 4,000 (end of hole)	Greenish grey to grey, fine- to medium-grained (locally coarse) quartz-plagioclase-biotite schists and gneisses. Local variations in the sequence include; a fine-grained contact hornfels; a garnet-bearing zone; and patches and bands of granitic gneiss. Foliation attitudes (gneissosity and schistosity) range from 55°-80° to the core axis. Erratically disseminated pyrrhotite with minor chalcopyrite are present to about 3,800 feet.

Depth (feet)	Description
3,677 - 4,000 (cont'd)	Local sulphide concentrations up to 3-5% occur, particularly near the intrusive contact. Below 3,800 feet, sulphides are rare, and consist only of pyrite-chalcopyrite. Specific Gravity: 2.71 gm/cm^3 (23 determinations, range from 2.57-2.86). Details: 3,677 - 3,681 Contact hornfels: grey, fine-grained quartz-plagioclase-biotite hornfels with random coarse quartz-feldspar aggregates and dark grey, soft, argillaceous bands, which follow shear directions parallel to the intrusive contact (40°-45° to the core axis). Scattered pyrrhotite in irregular blebs and patches (generally less than 1/4"). Minor chalcopyrite occurring as discontinuous rims around pyrrhotite grains, and as isolated small grains. Total sulphide content of contact hornfels zone is about 3-5%. 3,681 - 3,684 Garnet-bearing hornfels: as above, but with thin, irregular garnetiferous bands. Garnet is pale red, and erratically distributed in ovoid grains and clusters up to 1/4". Rock is crudely banded due to dark argillaceous zones dipping 70°-75° to core axis. 3,683.5 1 inch band of milky quartz.

Depth (feet)	Description
3,684 - 3,694.5	Garnet (Sp_{45} Py_{25} Al_{30})-bearing schist: Greenish grey, fine- to medium-grained banded quartz-plagioclase-biotite schist with coarser granitic zones and bands. Local, irregularly distributed garnet-bearing bands up to 5"-6" thick. Disseminated pyrrhotite with minor chalcopyrite in places forming 3% of the core.
3,694.5 - 3,703	Quartz-plagioclase-biotite schist and gneiss: dark grey, fine- to medium-grained, irregularly banded schist, locally gneissic in structure. Biotite is commonly chloritized giving a greenish cast to the rock. Minor disseminated pyrrhotite to 2-3%.
3,703 - 3,737	As above, with a coarse irregular and locally contorted gneissic structure. Crude segregation banding due to alternating light quartz-plagioclase, and darker biotite-chlorite zones. Minor pyrrhotite in streaky lenticular bands (1/8" thick) at 75°-80° to core axis (parallel to gneissosity). Sulphides are commonly concentrated in darker, chloritic bands.
3,737 - 3,745	Granitic gneiss: greenish grey, medium-grained, quartz-orthoclase-plagioclase-chlorite gneiss.

Depth (feet)	Description
3,745 - 4,000 (end of hole)	Quartz-plagioclase-biotite gneiss: frequent coarser white quartz-plagioclase-rich bands. Irregular gneissosity at 55°-70° to the core axis. In places, the rock is finely banded and regular in structure due to thin, biotite-rich bands.

3. Muskox East Drill Hole

Location: Lat. 67°06'45"N, Long. 115°11'45"W.

Collar Elevation: 1,893.5' Depth: 2,496 feet

Date drilled: July 24 - September 25, 1963

Size: BX

Casing: NX 0-40'
Gap 40'-130'
BX 130'-700'

Depth (feet)	Description
	Quartz-mica Schist and Quartzite (Map-unit 1)
0-52	Greenish grey to dark grey, impure quartzite and quartz-biotite schist with frequent irregular granitic zones, commonly containing xenoliths of quartzite or schist. Schistosity attitudes from 30°-55° to core axis. Erratic pyrite and chalcopyrite, locally in concentrations of 5-10% over lengths up to 6 inches. Specific Gravity: 2.71 gm/cm^3 (6 determinations, range from 2.61-2.88). Details: 0 - 5 Medium grey, fine- to medium-grained impure quartzite. Quartz - 60-80%; biotite, chlorite, epidote(?) - 20-40%. 5 - 15.7 Pale pink granitized quartzite. Quartz 40%; orthoclase 40%; dark minerals 20%. Distribution of orthoclase is erratic through the zone.

Depth (feet)	Description
15.7 - 25	Quartzite with irregular zones of granitic material.
25 - 31.5	Quartzite and quartz-mica schist patches and xenoliths in granitic matrix. Composition erratic. Minor disseminated pyrite.
31.5 - 37.8	Quartz-biotite schist with disseminated pyrite to 3%.
37.8 - 41.5	Impure quartzite.
41.5 - 50.1	Interbedded quartz-biotite schist and greenish quartzite. Schistosity and bedding at about 30° to core axis. Finely disseminated pyrite to 5-10%, mainly concentrated in schist.
50.1 - 52	Quartzite with granitic material.

Contact Breccia

(Map-unit 28)

52 - 58.7	Quartzite pieces in a dark grey to greenish grey altered gabbroic matrix. Disseminated pyrite.

Granophyre

(Map-unit 27)

58.7 - 60.3	Red to pink, medium- to coarse-grained rock composed of about 60-70% granophyric material and up to 30% plagioclase. Minor disseminated pyrite. Well defined upper contact inclined 30° to core axis. Apparently an offshoot from Muskox granophyre.

Quartzite

(Map-unit 1)

Depth (feet)	Description
60.3 - 91	Greenish grey altered biotite quartzite with irregular fine granophyric patches in places up to 20%. Specific Gravity: 2.67 gm/cm^3. Details: 70 - 77 Lost core. 89 - 91 Dark, hybrid rock, containing abundant chlorite.

Roof contact of the Muskox Intrusion

Upper Border Zone

Granophyre

(Map-unit 27)

91 - 99.3	Fine-grained pink granophyre, becoming darker upward as mafic content increases toward upper contact, which is inclined at 10° to core axis. Small inclusions of roof rocks are present.

Mafic Granophyre

(Map-unit 26)

99.3 - 135.7	Pegmatitic rock composed of coarse pink granophyre in excess of long dark green amphibole laths. Granophyre content decreases downward. Specific Gravity: 2.89 gm/cm^3. Details: 103.9 - 104.7 Diabase dyke. Chilled margins. 105.1 - 107.1 Diabase dyke. Chilled margins.

Depth (feet)	Description

Diabase

(Map-unit 29)

135.7 - 149.2 Grey, fine-grained intrusive, massive diabase. Upper contact not visible due to broken core. Lower contact is knife-edged, chilled, and inclined at 20° to core axis.

Specific Gravity:

3.04 gm/cm^3.

Granophyric Gabbro

(Map-unit 25)

149.2 - 186.5 Coarse-grained diabasic gabbro containing 20-30% granophyre. Upper contact not exposed due to younger diabase dyke.

Composition:

Clinopyroxene	0-15%
Plagioclase	25-35
Potassium feldspar	15-20
Quartz	10-15
Hornblende	15-35
Opaques	3-8

Specific Gravity:

2.99 gm/cm^3 (5 determinations, range from 2.97-3.02).

Details:

165	- 166	Fine-grained granophyre-bearing gabbro.

Top of Layered Series

Granophyre-bearing Gabbro

(Layer 35, Map-unit 24)

Depth (feet)	Description
186.5 - 290.4	Granophyre-bearing gabbro (ilmenite-magnetite zone). Grey, fine- to medium-grained gabbro distinguished by magnetite and ilmenite disseminated in about equal amounts totalling 15-20%. Magnetite forms equant grains; ilmenite occurs as thin, blade-like crystals, 1/8" - 1/4" in length. The rock shows weak to moderate foliation at 45°-70° to the core axis due to orientation of ilmenite, plagioclase, and pyroxene. Contact with the overlying gabbro is gradational over 1 foot and is marked by upward coarsening and decrease in Fe-oxides.

Composition:

Clinopyroxene plus alteration products	25-35%
Orthopyroxene	0-10
Plagioclase and alteration products	40-50
Biotite	<1
Magnetite	7-10
Ilmenite	10-12
K-feldspar	5
Quartz	5
Apatite	1
Hornblende	5-15

Specific Gravity:

3.06 gm/cm^3 (11 determinations, range from 2.98 to 3.12).

Details:

188.2		1 1/2-inch diabase dykelet.
267.1	- 262.0	Slightly coarser zone.

290.4 -338.7 Granophyre-bearing gabbro (magnetite zone). (Map-unit 24). Grey, fine to medium grained gabbro with 10-15% disseminated equant grains of magnetite. Weak to moderate foliation due to parallelism of plagioclase and pyroxene grains. Contact with overlying zone is defined within a few inches by the upward appearance of discrete ilmenite grains.

Depth (feet)	Description

Composition:

Clinopyroxene	25-35%
Orthopyroxene	5-10
Plagioclase	40-50
Magnetite plus minor ilmenite	10-15
Apatite	1-2
Biotite	1
Hornblende	1-2
K-feldspar	2-3
Quartz	2-5

Specific Gravity:

3.10 gm/cm^3 (5 determinations, range from 3.05-3.14).

338.7 - 555.7

Granophyre-bearing gabbro. Grey to greenish grey, fine- to medium-grained gabbro with local coarser pegmatoid zones. The unit contains visible interstitial Fe-oxides throughout. It generally coarsens slightly upward, and the granophyre content increases appreciably above 465' but is <10%. Foliation is weak at 50° to the core axis; it is due to planar alignment of plagioclase and pyroxene. The upper contact is defined within inches by the upward appearance of equant magnetite grains.

Composition:

Clinopyroxene	30-35%
Orthopyroxene	10-15
Plagioclase	40-50
Biotite	1-2
Fe-oxides	2-3
K-feldspar	2-3
Quartz	3-5
Apatite	1
Hornblende	1-2

Specific Gravity:

2.90 gm/cm^3 (21 determinations, range from 2.63 to 3.01).

Depth (feet)	Description

Details:

338 - 343	Broken and altered core.
345.5 - 346.3	Coarse-grained granophyric gabbro. Granophyre content is 20-25%.
364	1 1/2" veinlet of granophyric material at 35° to core axis.
396.7 - 401.2	Coarse-grained granophyre-bearing gabbro.
431 - 437	Slightly coarser granophyre-bearing gabbro.
465 - 481	Altered granophyre-bearing gabbro.
487 - 523	Altered with numerous chloritized fractures.

Picritic Websterite

(Layer 34, Map-unit 19)

555.7 - 643.3 Greenish grey, medium to medium fine-grained picritic websterite with 10-20% olivine serpentine and 10-25% plagioclase. A central blotchy olivine clinopyroxenite zone contains olivine serpentine to 30% and has <5% plagioclase. Layer is cut in two places by diabase (584.8 - 591, 595 - 600). Contact with overlying gabbro is sharp but irregular at 50° - 60° to core axis.

Composition

Olivine	10-25%
Serpentine (from olivine)	2-10
Magnetite (from olivine)	1
Clinopyroxene	35-55
Orthopyroxene	10-20
Plagioclase	15-25
Biotite	1
Opaques	1

Depth (feet)	Description

Specific Gravity:

2.91 gm/cm^3 (9 determinations, range from 2.70 to 3.15).

Details:

555	- 584.8	Picritic websterite; locally poikilitic, olivine to 20%.
585.6	- 591	Diabase dyke. Upper and lower contacts sharp at 30°-40° to core axis.
591	- 595	Picritic websterite; partly chloritized.
595	- 600	Diabase dyke. Upper contact 40° to core axis. Lower contact not well defined, but probably about 45° to core axis.
600	- 605.2	Picritic websterite as above.
605.2	- 620	Peridotite containing 25-40% granular pyroxene.
620	- 625.4	Picritic websterite.
625.4	- 628.8	Pyroxene-rich peridotite, as above.
628.8	- 629.4	Picritic websterite.
629.4	- 630	Pyroxene-rich peridotite, as above.
630	- 637.5	Picritic websterite.
637.6	- 637.8	Gabbro band. Contact with websterite above is 70° to core axis.
637.8	- 643.3	Chloritized picritic websterite.

Depth (feet)	Description

Gabbro

(Layer 33, Map-unit 22a)

643.3 - 866.3

Light to medium grey, medium-grained gabbro. Section is locally closely fractured and altered (chloritized). Contains minor zones of darker, websteritic rock. In places, a crude foliation due to alignment of plagioclase grains is present. Contains minor gabbroic pegmatite lenses. Section is cut by several thin diabase dykes, and bottom part of layer is missing due to presence of thick diabase dyke. Contact with overlying websterite is sharp at about 50° to core axis.

Composition:

Clinopyroxene	25-35%
Orthopyroxene	10-15
Plagioclase	50-60
Biotite	1
Opaques (magnetite, ilmenite)	1-2
Potassium feldspar	0-2
Quartz	1-3

Specific Gravity:

2.89 gm/cm^3 (20 determinations, range from 2.71 to 3.03).

Details:

643.3	- 647.1	Altered dark grey gabbro. Crude foliation at 60° to core axis.
647.1	- 647.6	Brecciated material as in 648.1-649.2 below.
647.6	- 648.1	Altered gabbro, as above.
648.1	- 649.2	Brecciated coarse-grained leucocratic material, intensely altered and of uncertain origin. Either feldspar-rich gabbroic

Depth (feet)	Description
648.1 - 649.2 (cont'd.)	pegmatite or a replaced inclusion of country rock.
649.2 - 652.9	Dark grey altered gabbro.
652.9 - 653.2	Diabase dyke.
653.2 - 653.8	Altered gabbro.
653.8 - 654.1	Diabase dyke.
654.1 - 663.5	Altered feldspathic websterite. Olivine-bearing?
663.5 - 726	Altered gabbro, medium to coarse grained. Locally poikilitic, altered ortho-pyroxenes give rock a blotchy texture.
726 - 778.0	Finer grained normal gabbro. Locally highly fractured and altered. At 740.6 - 3" x 1/4" dis-continuous chalcopyrite stringer.
778.0 - 779.3	Diabase dyke. Core broken. Lower contact at 35° to core axis.
779.3 - 785.1	Gabbro containing small white feldspar bleb or "eye".
785.1 - 788.2	Diabase dyke. Core broken and contact attitudes not known.
788.2 - 796.1	Light grey, normal gabbro.
796.1 - 797	Coarse-grained gabbroic pegmatite. Lower contact has 1/4" mafic reaction rim.

Depth (feet)	Description
797 - 866.3	Gabbro; locally altered but becoming fresher and more uniform over basal 20 feet. Local weak foliation due to alignment of plagioclase approximately normal to core axis.
822.9 - 823.2	Coarse-grained pegmatite segregation.
823.2 - 835	Rare plagioclase lenses and "eyes" 1/2" to 1" in length; aligned approximately normal to core axis.

Diabase Dyke

(Map-unit 29)

866.3 - 1,001.5 Grey, fine-grained diabase containing rare altered gabbro inclusions. Upper contact of dyke is sharp at about 10° to core axis; lower contact not visible due to broken core. Basal 4 feet of dyke (997 - 1,001.5) are chilled.

Specific Gravity:

3.00 gm/cm^3 (14 determinations, range from 2.61 to 3.08).

Picritic Websterite

(Layer 32, Map-unit 19)

1,001.5 - 1,057.7 Dark green, medium-grained, blotchy rock whose olivine content decreases from 20-25% to <10-15% in basal 5 feet of layer, as the contact with underlying gabbros is approached. Layer is cut by a thin diabase dykelet at 1,035.2.

Composition:

Olivine	0-25%
Serpentine (after olivine)	0-10
Clinopyroxene	40-60

Depth (feet)	Description

Orthopyroxene	10-20
Plagioclase	15-25
Biotite	1-2
Opaques	1-2

Specific Gravity:

2.96 gm/cm^3 (5 determinations, range from 2.92 to 3.00).

Details:

1,001.5 - 1,035.2	Picritic websterite; locally blotchy-textured.
1,035.2 - 1,036	Diabase dyke. Contacts about 30° to core axis.
1,036 - 1,049.5	Picritic websterite.
1,049.5 - 1,057.7	Olivine content decreases to 10-15%. Transition zone toward underlying gabbroic websterite.

Feldspathic Websterite (with Minor Melanogabbro)

(Layer 31, Map-unit 18)

1,057.7 - 1,191.7 Grey, medium grained, feldspathic websterite (103 feet thick) is the main component of this unit. It is overlain by 17 feet and underlain by 8 feet of melanogabbro. Layer is locally fractured and altered (chloritized) and is cut by a diabase dyke at 1,081.9 - 1,093.7. Contact with overlying picritic websterite is transitional over several feet.

Composition:

Variable, but an approximate mean is:

	Feldspathic websterite	Melanogabbro
Clinopyroxene	60-70%	45-55 %
Orthopyroxene	10-20	10-20

Depth (feet)	Description		
	Plagioclase	12-16	25-35
	Biotite	1	1
	Opaques (magnetite, ilmenite)	1	1

Specific Gravity:

3.06 gm/cm^3 (12 determinations, range from 2.97 to 3.09).

Details:

1,057.7 - 1,074.8	Melanogabbro, approximately 30% plagioclase. Erratic olivine-serpentine patches at top of zone. At 1,061 core is cut at 20°-25° by a thin (3") diabase dykelet.
1,074.8 - 1,081.9	Feldspathic websterite; rock is darker than above and contains less plagioclase. Frequent coarse, ragged chlorite patches after orthopyroxene give a spotted appearance to the rock.
1,081.9 - 1,093.7	Diabase dyke. Upper contact irregular at about 35° to core axis.
1,093.7 - 1,115	Feldspathic websterite with spotty chloritic alteration as above.
	1,104 - 1,106 - broken core; some fragments are diabase.
1,115 - 1,140	Unaltered websterite.
1,140 - 1,178	Altered websterite.

Depth (feet)	Description
	1,178 - 1,183 Feldspathic websterite, grading toward gabbro below.
	1,183 - 1,191.7 Core is badly broken and altered.

Gabbro

(Layer 30, Map-unit 22a)

1,191.7 - 1,217.2 Greenish grey, medium-grained, altered gabbro. Contains frequent chlorite seams and stringers. Contact with overlying melanogabbro is probably gradational over several feet, but change is not visible due to broken core.

Composition:

	Gabbro (30A)
Clinopyroxene (plus chlorite)	25-35%
Orthopyroxene	10-15
Plagioclase	45-55

Specific Gravity:

2.88 gm/cm^3 (3 determinations, range from 2.84 to 2.91).

Details:

1,191.7 - 1,206	Highly altered gabbro.
1,206 - 1,207	Lost core.
1,207 - 1,213	Fresher gabbro; scattered green chlorite plates.
1,213 - 1,217.2	Altered gabbro.

Websterite-Orthopyroxenite

(Layer 29, Map-unit 17a)

Depth (feet)	Description
1,217.2 - 1,282	A double layer consisting of 39 feet of websterite (layer 29B) underlain by a 25-foot thick orthopyroxenite basal zone (layer 29A). Contact with overlying gabbro is marked by 1 foot of pegmatoid recrystallized websterite. Contact between websterite and underlying orthopyroxenite is gradational over 3-5 feet. The total thickness of this layer increases from 52 feet in the Muskox North hole to 65 feet in the Muskox East hole.

Composition:

	Websterite (29B)	Orthopyroxenite (29A)
Clinopyroxene	55-65%	10-15%
Orthopyroxene	20-30	70-75
Plagioclase	8-12	10-12
Biotite	1	1
Opaques (magnetite, ilmenite)	1	1
Potassium feldspar	1	1
Quartz	1	1

Specific Gravity:

Websterite (29B) - 3.12 gm/cm^3 (4 determinations, range from 3.07 to 3.20).
Orthopyroxenite (29A) - 3.22 gm/cm^3 (2 determinations, 3.19 and 3.24).

Details:

1,217.2 - 1,218	Coarse, pegmatoid recrystallized websterite containing rare pyrrhotite and magnetite. Forming top of websterite layer (29B).
1,218 - 1,257	Medium grey, fine, medium-grained websterite (29B). Locally fractured and altered (chlorite). Rare disseminated pyrrhotite.

Depth (feet)	Description
1,257 - 1,282	Grey, medium-grained orthopyroxenite (29A). Contact with overlying websterite is gradational through 3-5 feet. 1,273 - 1,282 - erratically disseminated pyrrhotite, locally to 3-4%. At 1,274.4, small (11/2" x 1/4") irregular massive chromite bleb.

Feldspathic Peridotite and Chromitite

(Layer 28, Map-unit 13)

1,282 - 1,283.6 A thin layer consisting of greenish black serpentinized feldspathic peridotite extensively replaced by coarse pyroxene containing several thin irregular massive chromite bands with blotchy disseminated pyrrhotite. Main chromite concentration is toward the top of the zone. Contact with overlying orthopyroxenite is gradational over 2"-3". Mineral proportions are variable, and secondary alteration is fairly intense, hence the following composition is only approximate.

Composition:	Feldspathic peridotite	Chromitite
Olivine	1%	1%
Serpentine (from olivine)	0-55	0-10
Clinopyroxene	10-35	10-20
Orthopyroxene plus alteration	20-40	10-20
Plagioclase alteration	10-15	10-15
Chromite	2-10	30-50
Sulphides	2-5	2-5

Specific Gravity:

Peridotite - 2.85 gm/cm^3.

Depth (feet)	Description

Details:

1,282 - 1,282.2	Olivine pyroxenite/ peridotite. Grain size and olivine content increase downward. Minor disseminated pyrrhotite.
1,282.2 - 1,282.3	Chromite band contains about 70% chromite and is inclined at 55°-60° to core axis.
1,282.3 - 1,282.7	Green, serpentinized blotchy feldspathic peridotite with disseminated pyrrhotite blebs to 1-2%.
1,282.7 - 1,282.8	Chromite band contains 60-70% chromite and is inclined at 60°-65° to core axis.
1,282.8 - 1,283.6	Blotchy recrystallized peridotite with disseminated pyrrhotite (2-3%) and minor biotite.

Websterite-Orthopyroxenite

(Layer 27, Map-unit 17a)

1,283.6 - 1,352.8 A double unit similar to layer 29. Unit contains an upper websterite zone (27B) 44.8 feet thick, and a thinner (23.0 feet) basal orthopyroxenite part (27A). Thickness of the unit increases from 58.5 feet in the Muskox North hole to 67.8 feet in the Muskox East hole. The contact with overlying feldspathic peridotite (layer 28) is gradational over 1"-2" at 65°-70° to the core axis.

Composition;	Websterite (27B)	Orthopyroxenite (27A)
Clinopyroxene	55-65	5-15
Orthopyroxene	20-30	70-80

Depth (feet)	Description		
	Plagioclase	10-12	8-15
	Biotite	1	1
	Opaques (magnetite ilmenite)	1	1

Specific Gravity:

Websterite - 3.20 gm/cm^3 (5 determinations, range from 3.17 to 3.23).
Orthopyroxenite - 3.14 gm/cm^3.

Details:

1,283.6 - 1,289	Websterite with disseminated pyrrhotite, occurring as blotchy patches and blebs up to 1/4". Zone averages 3-4% pyrrhotite. At 1,287.4 ft., small (1/2") zone with coarse plagioclase and 1/8 - 1/4" chromite blebs.
1,289 - 1,330	Websterite with 2% disseminated pyrrhotite to about 1,295 feet. Below this depth sulphides are rare. Olivine continues to about 1,300 feet.
1,330 - 1,352.8	Grey, medium-grained orthopyroxenite, locally sheared and altered (chlorite). In general orthopyroxenite is coarser-grained than websterite above. Contact with websterite is gradational over several inches.

Feldspathic Peridotite and Chromitite

(Layer 26, Map-unit 13)

Depth (feet)	Description

1,352.8 - 1,382

Dark green to greenish black blotchy serpentinized feldspathic peridotite containing a thin chromite band near the top. Contact with overlying orthopyroxenite is well defined at 75°-80° to the core axis. Layer decreases in thickness from 62 feet in the Muskox North hole to 28 feet in this hole.

Composition:

Olivine	5-10%
Serpentine (from olivine)	45-60
Magnetite (from olivine)	1-5
Clinopyroxene	10-20
Orthopyroxene	5-15
Plagioclase	5-20
Opaques	2-3

Specific Gravity:

2.79 gm/cm^3 (4 determinations, range from 2.75 to 2.85).

Details:

1,353.2	Chromitite band, 3/4"-1" wide, dipping at 70° to core axis.

Olivine Clinopyroxenite

(Layer 25, Map-unit 16b)

1,382 - 1,384.8

A thin, pale green, medium- to coarse-grained olivine clinopyroxenite layer. Contains coarse poikilitic orthopyroxene grains, partly altered to chlorite. Contact with overlying feldspathic peridotite is gradational and poorly defined. Layer thins from 9.5 feet in Muskox North hole to 2.8 feet in this hole.

Composition:

Olivine Serpentine (from olivine)	15-20%
Clinopyroxene	50-60
Orthopyroxene	10-15
Plagioclase	10-15

Depth (feet)	Description

Feldspathic Peridotite

(Layer 24, Map-unit 13)

1,384.8 - 1,419.5 Blotchy feldspathic peridotite, similar to layer 26. Contact with overlying olivine clinopyroxenite is sharp at about 75° to core axis. Layer shows pronounced thinning toward extremities, from 156 feet in the Muskox North hole to 33.5 feet in the Muskox East drill hole.

Composition:

As layer 26.

Specific Gravity:

2.87 gm/cm^3.

Websterite-Orthopyroxenite

(Layer 23, Map-unit 17a)

1,419.5 - 1,443.7 A thin (4.3 feet) upper websterite zone (layer 23B) underlain by 19 feet of orthopyroxenite (layer 23A). Rocks are similar to those of double-layers 27 and 29. Contact with overlying peridotite is sharp at 70° to core axis. On surface, layer 23B is overlain by the anorthositic gabbro layer 23S, but 23S was not intersected in the drill holes.

Composition:	Websterite (23B)	Orthopyroxenite (23A)
Clinopyroxene	60-65%	10-15%
Orthopyroxene	20-25	75-80
Plagioclase	10-15	8-12

Specific Gravity:

Websterite - 3.16 gm/cm^3.
Orthopyroxenite - 3.23 gm/cm^3.

Depth (feet)	Description

Details:

1,419.5 - 1,423.9	Websterite - contact with underlying orthopyroxenite is marked by a 2"-3" coarse pyroxenite band containing 15-20% interstitial olivine (serpentinized). Band dips at 60°-65° to core axis.
1,423.9 - 1,443.7	Orthopyroxenite - core locally very fractured.

Feldspathic Peridotite

(Layer 22, Map-unit 13)

1,443.7 - 1,497

A double unit consisting mainly of blotchy feldspathic peridotite and peridotite (layer 22A) with a thin (3.2 feet) upper olivine clinopyroxenite zone (layer 22B). Contact with overlying orthopyroxenite is sharp but irregular at about 80° to core axis. Layer 22 thickens from 30 feet in Muskox North hole to 51.5 feet in Muskox East, but olivine clinopyroxenite part (22B), which is 18 feet thick in Muskox North, is not present.

Composition:

Olivine	0-15%
Serpentine (from olivine)	40-50
Magnetite (from olivine)	0-10
Clinopyroxene	5-30
Orthopyroxene	5-10
Plagioclase	5-15
Biotite	1-4
Opaques	1-3

Specific Gravity:

2.81 gm/cm^3 (4 determinations, range from 2.77 to 2.87).

Details:

1,443.7 - 1,447	Green, blotchy recrystallized peridotite. Olivine (serpentinized) increases to 50%

Depth (feet)	Description
1,443.7 - 1,447 (cont'd.)	toward base. Interstitial plagioclase up to 10%.
	1,445 - 1,446 2-3% disseminated pyrrhotite.
1,447 - 1,471	Feldspathic peridotite, locally peridotite containing serpentinite bands up to 4"-5". 2-3% biotite is present.
1,471 - 1,497	Peridotite changing toward underlying dunite (serpentinized) through a gradual but erratic decrease in clinopyroxene from 20-30% to 10% or less at the base of zone. Plagioclase decreases to 3-5%. Basal part of zone contains irregular dunite bands.

Dunite (serpentinized)

(Layer 21, Map-unit 11)

1,497 - 1,725

Dark green to black, aphanitic to fine-grained serpentinized dunite with scattered poikilitic clinopyroxene and minor interstitial plagioclase. Contains minor peridotite zones. A thin chromite band occurs near the base of the layer. Contact with overlying peridotite (layer 22A) is gradational over several feet through zone of alternating peridotite and dunite. 108 feet of diabase was intersected in this section.

Composition:

Olivine	0-5%
Serpentine (from olivine)	60-70
Magnetite (from olivine)	5-15
Clinopyroxene	5-20
Plagioclase	2-8
Biotite (altered)	1-2

Depth (feet)	Description

Specific Gravity:

2.65 gm/cm^3 (8 determinations, range from 2.60 to 2.70).

Details:

1,497 - 1,522	Frequent peridotite zones containing clinopyroxene up to 20% over a few inches.
1,522 - 1,545	Serpentinized dunite with scattered poikilitic clinopyroxene, and plagioclase to 2-3%.
1,545 - 1,589.4	As above with rare visible clinopyroxene. 1,545 - 1,580 - intermittent broken core.
1,589.4 - 1,717.5	Diabase dyke; grey, fine grained, locally fractured and altered (chloritized). Upper contact with dunite is sharp at 25°-30° to core axis. Lower contact not visible due to broken core.
1,717.5 - 1,725	Serpentinized dunite with poikilitic clinopyroxene appearing toward base of zone. Core is broken. At 1,724.1 - 1,724.2 - chromite band; discontinuous; up to 1 1/2" wide, at about 85° to core axis.

Peridotite

(Layer 20, Map-unit 12)

Depth (feet)	Description
1,725 - 1,815.2	Dark green to greenish black, locally blotchy serpentinized peridotite containing dunite zones and bands of varying thickness. A thin chromite band occurs near the base of the layer. Contact with overlying dunite (layer 21) is gradational through 1-2 feet, but core is broken in contact zone. Layer decreases in thickness from 169 feet in the Muskox North hole to 80 feet in Muskox East.

Composition:

Olivine	0-5%
Serpentine (from olivine)	60-70
Magnetite (from olivine)	5-15
Clinopyroxene	5-20
Orthopyroxene	2-5
Plagioclase (altered)	3-10
Opaques (chromite, magnetite, ilmenite)	1-4

Specific Gravity:

2.78 gm/cm^3 (8 determinations, range from 2.69 to 2.92).

Details:

1,725 - 1,758	Poikilitic peridotite, locally feldspathic. Plagioclase and clinopyroxene are erratic in distribution.
1,758 - 1,780	Dunite; aphanitic serpentinite with scattered clinopyroxene, generally 10%. Plagioclase 2-3%.
1,780 - 1,785	Blotchy peridotite.
1,785 - 1,806	Dunite with local blotchy peridotite zones.
	1,793 - 1,795 - broken core.

Depth (feet)	Description	
	1,785 - 1,806 (cont'd)	1,798 - 1,803 - broken core with numerous pale green serpentine stringers.
	1,806 - 1,814	Blotchy peridotite, locally feldspathic.
	1,814	Chromite band; 1/2".
	1,814 - 1,815.2	Blotchy feldspathic peridotite. Plagioclase 10%.

Olivine Clinopyroxenite

(Layer 19, Map-unit 16)

1,815.2 - 1,827.5 Greenish grey, medium-grained, locally blotchy, olivine clinopyroxenite with a central, 1 foot websterite core. Contact with peridotite above (layer 20) is gradational over 6"-8". This 12-foot section is believed to correlate with a 42.5-foot orthopyroxenite-websterite paired layer in the Muskox North hole (see Fig. 14).

Composition:

Olivine Serpentine (from olivine)	5-40%
Clinopyroxene	60-95

Specific Gravity:

3.06 gm/cm^3.

Details:

1,815.2 - 1,821	Olivine clinopyroxenite with irregular bands up to 2" thick containing up to 30-40% clinopyroxene.
1,821 - 1,823	Websterite with gradational contacts defined within a few inches.

Depth (feet)	Description
	1,823 - 1,827.5 Blotchy olivine clinopyroxenite showing a downward increase in olivine content. Contact with dunite below apparently sharp but not recovered due to broken core.

Peridotite and Dunite (Serpentinite)

(Layer 18, Map-units 12, 11)

1,827.5 - 1,946 Greenish black serpentinized peridotite with large patchy pyroxenes. Thin dunite zones present. Upper contact is probably sharp, and is marked by the appearance of small clinopyroxenite grains. Actual contact was lost in ground core. Minor disseminated pyrrhotite.

Composition:

Variable, but an approximate mean is:

Olivine Serpentine (from olivine)	65-75%
Magnetite (from olivine)	5-10
Clinopyroxene	5-25
Plagioclase (altered)	1-5

Specific Gravity:

2.71 gm/cm^3 (9 determinations, range from 2.54 to 2.81).

Details:

1,845 - 1,856	Blotchy peridotites, in places feldspathic; plagioclase up to 10%.
1,856 - 1,866	As above with increase in coarse poikilitic clinopyroxene to 25%.
1,866 - 1,890	Clinopyroxene decreasing to 15% with erratic

Depth (feet)	Description
1,866 - 1,890 (cont'd)	distribution, giving several dunite bands up to several inches thick.
1,890 - 1,903	Blotchy feldspathic peridotite. Biotite is a common accessory. 1,897 - 1,898 - lost core. 1,898 - 1,903 - broken core.
1,903 - 1,946	Peridotite with dunite bands up to several inches thick. Overall decrease in clinopyroxene to 10-15%. Plagioclase 3-5%. 1,903 - 1,905 - broken core. 1,913 - 1,916 - broken core and 1 foot of lost core. 1,922.5 - vertical fracture with serpentine-carbonate coating.

Olivine Clinopyroxenite

(Layer 17, Map-unit 16b)

1,946 - 1,980

Greenish grey blotchy olivine-bearing clinopyroxenite with olivine clinopyroxenite zones. Contact with overlying peridotite (layer 16) is sharp and at about 75° to the core axis. Layer shows little change in thickness between Muskox North hole (39 feet) and Muskox East (33 feet).

Composition:

Olivine Serpentine (from olivine)	5-20%
Clinopyroxene	75-85
Plagioclase (altered)	1-5

Depth (feet)	Description
	Specific Gravity:
	3.17 gm/cm^3 (3 determinations, range from 3.12 to 3.22).
	Details:
	1,946 - 1,948 — Blotchy olivine clinopyroxenite. Olivine-serpentine content 15-20%, but erratic.
	1,948 - 1,980 — Mainly massive olivine-bearing clinopyroxenite. Olivine-serpentine 5-10%; scattered plagioclase up to 5%.
	1,972 - 1,980 - broken core.
	1,976 - 1,977 - lost core.
	1,797 - 1,980 - much soft green and white serpentine-carbonate alteration.
	Dunite and Peridotite
	(Layers 16, 14, 12, Map-units 11, 12)
1,980 - 2,496 (end of hole)	Layer is composed of alternating dunite (serpentinized) and blotchy peridotite. Peridotite sections are locally feldspathic. Overall composition of this layer is borderline between peridotite and dunite; essentially a pyroxene dunite. The section appears to contain more pyroxene than the equivalent parts in the Muskox North and South holes. Contact with overlying pyroxenite (layer 17) is not visible due to broken core. This section is interpreted to include parts of layers 16, 14, and 12, pyroxenite layers 13 and 15 having wedged out. This interpretation is reasonable as the hole is approaching the side of the intrusion.

Depth (feet)	Description

Composition:

Variable; an approximate average is:

Olivine Serpentine (from olivine)	65-80%
Magnetite (from olivine)	5-15
Clinopyroxene	5-20
Plagioclase (altered)	2-10

Specific Gravity:

2.72 gm/cm^3 (51 determinations, range from 2.50 to 2.91).

Details:

1,980 - 2,023.5	Greenish-black blotchy peridotite, locally feldspathic. (Plagioclase to 5%). 1,980 - 1,985 - broken core. 1,985 - 1,987 - lost core. 2,016 - 2,023.5 - clinopyroxene decreasing gradually toward dunite below. 2,022.6 - 2,023.1 - thin (1/8") brown magnetite seams in fractures.
2,023.5 - 2,105.5	Mainly serpentinized dunite with peridotite bands a few inches thick. 2,036 - 2,044.6 - several thin (1/8" - 1/16") reddish-brown oxidized magnetite seams along fractures at 40°-65° to core axis. 2,044.6 - 2,046 - broken core.

Depth (feet)	Description
	2,046 - 2,056 - fractured dunite with several vuggy alteration seams carrying clusters of euhedral magnetite.
2,105.5 - 2,110	Blotchy peridotite with local dunite zones.
2,110 - 2,142	As above, with plagioclase up to 5%. Accessory biotite to 2%.
	2,109.8 - 2,111 - disseminated pyrrhotite to 2%. Coarse poikilitic clinopyroxene grains up to 1".
2,142 - 2,167	Clinopyroxene and plagioclase decreasing and becoming more erratic in distribution. Local dunite zones.
2,167 - 2,279	Blotchy peridotite. Erratically disseminated pyrrhotite to 1-2%. Many dunite zones.
	2,233 - 2,235.6 - disseminated pyrrhotite to 3-5%.
	2,237 - 2,242.5 - plagioclase increases to 10%; pyrrhotite to 5%.
	2,269 - 2,279 - clinopyroxene decreasing toward dunite below.
2,279 - 2,287	Serpentinized dunite with scattered clinopyroxene <10%.

Depth (feet)	Description
	2,284.3 - 2,285 - white carbonate alteration in dunite.
2,287 - 2,322	Peridotite. Scattered pyrrhotite to 1-2%.
2,322 - 2,401	Dunite and pyroxene dunite; clinopyroxene 5-10%. Local disseminated pyrrhotite to 2-3%. Peridotite zones up to 1'-2' wide with clinopyroxene up to 15-20%.
2,401 - 2,416.1	Peridotite, locally feldspathic. Erratically distributed pyrrhotite to 2-3%.
2,416.1 - 2,430	Dunite.
2,430 - 2,496	Peridotite with dunite zones. Contains 1-3% disseminated pyrrhotite.
	2,487 - 2,491 - lost core.