A PETROLOGICAL STUDY
OF THE MUNRO ASBESTOS 'A' OREBODY
MATHESON, ONTARIO

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the Degree of Master of Science.

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FRONTPIECE.

Main ramp leading into pit at west end mine, with plant and dump in background.

Munro mine. June 1953.

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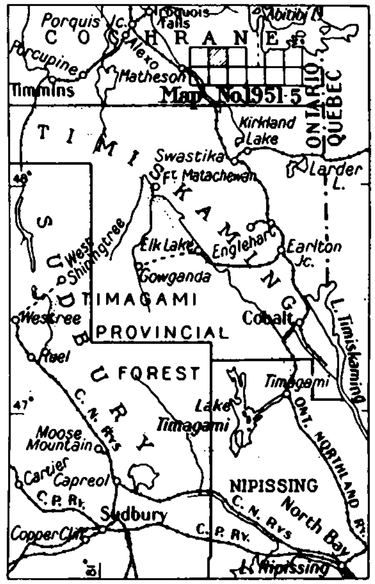


Key map showing the location of Munro township, District of Cochrane. Scale, 1 inch to 60 miles.

CHAPTER I

INTRODUCTION

The Munro "A" asbestos orebody is located in Munro Township, 13 miles east of Matheson in the district of Cochrane, Northern Ontario. Matheson is 206 miles by rail north of North Bay. It is also served by Highway #11 (Ferguson Highway,) being 321 miles north of Toronto, and also by Highway #101, which will eventually run from Timmins, through Matheson, to the Quebec border. This road is metalled and in good condition from Matheson to the Munro Mine turn-off.

Canadian Johns-Manville Corporation holds 45 claims in Munro and Beatty Township. The Munro "A" orebody is in lot 10, concession II, Munro Township.

The original outcrop of asbestos-bearing serpentine was first recorded by Hopkins in 1915 and later by Knight, Ross and Satterley. Henry (1951) has given a detailed description of the history, geology and development of the orebodied of the Munro Mine. The occurence in lot 10, concession II, was brought to Hendry's notice in 1948 by Alex Heffen of Swastika, Ontario, and after an examination by K.V. Lindell, Manager of Canadian Johns-Mainville's Jeffrey mine in the Eastern Townships, Quebec, the company acquired claims and started drilling.

Exploration by diamond drilling on what is now the "A" orebody commenced on March 25, 1949 together with a magnetometer survey of the company's claims. A total of 21,394 feet of drilling was carried in outlining the body in addition to 65,800 feet more in tracing the serpentinised sill westwards in Munro and Beatty Townships. A 314 feet shaft was sunk and 2,972 feet of cross-cutting were done on the "C" orebody two miles west of "A" orebody in 1951, and a bulk sample of 11,000 tons was milled at the Munro mine. A plane table survey was carried out on the "A" orebody in 1951 and Henry brought out the first detailed map (scale 1 inch-200 feet of the orebody in 1951. Since exposures around the orebody were initially limited to two large outcrops at the west ends of the body, no further work was done until September 1953, when open-pitting had reached a depth of nearly 200 feet and exposed most of the rock types.

During this date a detailed map on a scale of 1 inch-50 feet was completed by means of a plane table. The mine survey points and a 1 inch - 50 feet development plan were used as a control for the mapping.

SCOPE AND AIM OF THESIS

The 50' scale map, prepared by the author, (Fig.4) has revealed a number of unusual features in the rock types and structure of the "A" orebody overlooked by previous workers. This thesis presents a revision of current ideas on the general structure and petrology of the orebody.

The detailed structural relations of the rocks, although plotted on the map, have not been fully out worked out due to lack of time while in the field, but are presented in a general fashion. A study of the detailed relations between serpentinite, asbestos veins and magnetite is being undertaken by the present mine geological staff, thus, attention was concentrated on the contacts of the various rock types and on the distribution of the major shears and slips in the orebody.

A suite of specimens representative of the general rock types present has been studied. Another suite, representing the rocks from the top of the sill down into the underlying volcanics, has also been studied to find out the mode of intrusion of the sill composite.

Conclusions, based on this study, are drawn as to origin of the rock types and their subsequent alteration.

PREVIOUS GEOLOGICAL WORK

Munro Township was mapped first in 1911 by A.G. Burrows and by Hopkins and Greenland in 1914. Knight, and others, presented a report on the various mining properties. Martin presented a paper to a meeting of the Prospectors and Developers Association on the Porcupine area in 1946. Satterley described the geology of Munro Township and presented a detailed map in 1951, and details of the Munro mine are given in a report by D.F. Hewitt and Satterley in 1953. Hendry gives the history, development and detailed geology of the mine in 1951.

CHAPTER II

TOPOGRAPHY AND DRAINAGE

The surface features of Munro Township are largely controlled by the Pleistocene glacial and glaciofluvial deposits. Most of the township is underlain by clays deposited on the bottom of glacial lake Ojibway-Barlow, the shore of wich extended north-south through the centre of the township. The Precambrian rocks projet through these deposits. These rocks formed islands in the lake and around them beaches and bars of sand and pebbles are preserved.

The eastern third of the township is covered by outwash glacio-fluvial deposits which form eskers, undrained depressions, kettles and two large lakes. The glacio-fluvial deposits have been reworked by wind to give sand dunes and sand plains. Movements of ice was from 26° - 43° E (Satterley 1951).

Recent deposits consist of extensive accumulations of peat in the swamps.

The general elevation of the area is 1000 feet above sea-level, the swampy areas and depressions in the sand deposits being generally lower and the rock outcrop higher than this elevation. The highest isolated hill is Centre Hill, to the northeast of Munro mine, with an elevation of 1,273 feet above sea-level.

The height-of-land on Munro Township is formed by the glacio-fluvial deposits on the east side of the township with the main drainage to the lowlands in the west, but also some to the north and south. The streams have cut deeply into the deposits.

GENERAL GEOLOGY

REGIONAL

Munro township forms part of the Abitibi Peridotite belt which extends from Reaume Township in the west to Halloway Township in the east, a distance of 80 miles. The bedrock formations of the township are all Precambrian in age.

The oldest rocks are sediments and volcanics, the sediments occuring in the southwest corner of the township. These sediments and volcanics have not been termed Keewatin or Temiskaming since the sediments were found to be interbedded with volcanics in Guibord township to the south by Prest (1951), and areseperated from the volcanics by a strike fault in Munro township.

The volcanics and sediments are cut by four ages of intrusives. The intrusives are basic and ultrabasic sills and sill-like bodies. Since the age of the sediments and volcanics has not been established it is unknown whether untrusives are post-Keewatin and pre-Temiskaming or post-Temiskaming.

Small bodies, sills and dikes of dioritic and lamprophyric composition have been called Algoman(?). Numerous north-south dikes of diabase have been assigned to Matachewan (?) age, while a quartz diabase dike is placed in the Keweenawan. The following is a table of formations taken from satterley's report (1951).

TABLE OF FORMATIONS

CENOZOIC

	RECENT	Windblown sand (dunes), stream deposits, peat.
	Pleistocene	Sand, gravel, boulders, boulder clay, varved clay (?), silt, windblown sand (dunes).

GREAT UNCONFORMITY

PRECAMBRIAN

Keweenawan	(?)	Quartz diabase
Matachewan	(?)	Quartz diabase, diabase
Algoman	(?)	Quartz diorite, felspar porphyry, felsite, lamprophyte
Haileyburian	(?)	Diorite, diabase, gabbro, peridotite, dunite (serpentinised), pyroxenite

INTRUSIVE CONTACT

VOLCANICS — Rhyolite, rhyolite agglomerate and tuff, andesite, basalt, pillow lavas, diabasic lavas, spherulitic lava, fragmental lava (flow breccia), talc-chlorite schist, carbonate-chlorite schist, actinolitised and chloritised lavas.

FAULTED CONTACT

SEDIMENTS — Graywacke, argillite, arkose, conglomerate

SEDIMENTS

The sediments, considered to be the oldest rocks in the township, are mainly well-banded or very fine-grained graywacke with interbeds of argillite, arkose and rarely conglomerate. Owing to the large scale faulting the beds have been moderately to intensely carbonatised or sericitised in places.

VOLCANICS

The volcanics are well exposed in two belts trending N 50° - 70° W across the southern half of the township and are separated from each other by the northwesterly trending Munro fault zone. There is a general progressively increasing acidity of the lavas from the volcanics sediment contact toward the Munro sill, and spherulitic basalt flows are followed by a belt of basic to intermediate pillow lavas showing excellent flow breccia tops. A band of rhyolite follows and trends northwest into Beatty township, where it interfringes with the basic flows. The Munro "A" orebody is underlain to the south by lavas indentified as dacites, and overlain by basic types. The band of volcanics to the north of the Munro fault zone may or may not represent a continuous series with the band to the south. This band consists of basic and intermediate types showing good pillow structures and flow breccia tops. At the Munro mine a band of sheared graphitic slate on the north side and a reddish-brown slate into the sill on the south side seem to indicate that there are narrow or discontious bands of sediment interbedded with these volcanics, and that these bands were favourable horizons for theintrusion of the peridotite sills.

Rock types derived from the basic lavas by tresses associated with strike faulting or by contact metamorphisim by the intruding basic and ultrabasic sills include talc-chlorite or chlorite-carbonate schist, and the development of radiating masses of actinolite adjacent to flow contacts or in blocks included in the sills. Much of the diabase associated with the sills has also developed actinolite or hornblende.

INTRUSIVES

Satterley (1951) described the basic and ultrabasic sills as follows:

"Large and small lenticular, discontinuous sill-like bodies of ultrabasic and basic intrusives of Haileyburian type cut the volcanics and are cut by Algoman (?) dikes, and Matachewan (?) and Keweenawan (?) diabase dikes. The intrusives range in composition from dunite through peridotite, pyroxenite, diabase or gabbro, to possibly diorite. Intrusive evidence is limited, since most of the bodies are sills, but was found in several places; a block of basic and acid volcanics in the diabase; tongues of diabase projecting into the pillow lava, and the diabase chilled against the lave for 20 feet; diabase intrudes flow breccis; peridotite contains inclusions of actinolitised lave up to 10 inches across; inclusions of acid lava from 1 to 20 feet across in pyroxenite. Inclusions of rhyolite agglomerate were noted frequently in basic intrusives adjacent to bands of that rock.

The intrusives are massive and show little or no shearing. Some of the peridotites are shears and fractures but much of this is thought to be due to the process of serpentinisation.

The peridotites and dunites are fine to medium-grained, dark grey, green, greenish-black to black rocks which may weather earth-brown, reddish-brown, greyishwhite or white. The surfaces of many exposures are very soft, since many of the rocks are largely or completely altered to serpentine. Many fractures or slips contain veinlets of chrysotile or picrolite. The original olivine is now largely altered to a mass of antigorite fibres and magnetite veinlets and dust. Pyroxene is present in variable amounts, there being all gradations of rock from dunite to peridotite.

The pyroxenites are massive fine to medium-grained pale-green rocks. They are particularly well exposed in the Centre Hill Complex.

The basic intrusives are identified as quartz diabase, enstatite diabase or gabbro, and possibly diorite. They are typically brown to reddish-brown weathering, massive fine to medium-grained rocks which are dark-green to grey-green on fresh surfaces. In thin section under the microscope they are found to be moderately to intensely saussuritized, amphibolitised or chloritised. These diabases are so similar to the coarse flows of the volcanics, and even to the Matachewan dikes, that individuel exposures showing no relations may be unidentifiable.

Small pods or lenses of sulphides occur along the contacts with the lavas."

Algoman intrusives, consisting of a few small masses and a large number of dikes and sills of felsite, porphyry and lamprophyre, cut the volcanics, sediments and basic and ultrabasis intrusives. They are in turn cut by dikes of diabase or quartz diabase assigned to Matachewan (?) age. A large dike of quartz diabase thought to be of Keweenawan age strikes north-northeast across the northern third of the township.

Alteration:

Carbonitisation and sericitisation are common secondary alteration effects which affect all the Precambrian rocks except the Metachewan and Keweenawan diabases. Most carbonate bodies are found associated with the large strike faults in the township. These metasomatic effects are attributed by Satterley to the action of solutions derived from the same magma which produced the Algoman intrusives.

STRUCTURAL GEOLOGY

The interpretation of structure in the township is based on the determination of tops by means of pillows in volcanics. Also off-setting of contacts of the basic and ultrabasic sills and the differentation of these sills supply useful information. Drilling and geophysical surveys provide additional data. Bodies of carbonate rock are commonly associated with faults. Topographic features, gullies, swamps, scarps are also used to put in faults

Folding: The basic and ultrabasic rocks in the northern half of the township are part of a large synclinal fold known as the McCool Hill syncline.

An anticlinal and synclinal axis are indicated in the volcanics between these rocks, and the Munro fault zone to the southwest. The sill to the south of the Munro fault zone on which the Munro mine is located dips to the northeast.

Faulting: The major strike faults trend N 50° W- 70° W and are vertical as far as is known. No information is as yet available about the displacement along the faults. They are branches of the main regional Porcupine-Destor fault which is in turn associated with the large Cadillac break. From southwest to northeast the faults are known as the Contact, Munro,Camrose, Centre Hill and Potterdoal faults. The Munro mine lies between the Contact and Munro faults.

Numerous cross faults which are indicated by scarps, gullies, valleys, rows of vegetation on outcrops and displaced contacts, occur roughly at right angles to the strike faults. They generally displace the strike faults. The nature of the movement is generally rotational.

MINE GEOLOGY

GENERAL

The Munro "A" orebody is developed in part of a differentiated basic to ultrabasic sill which starts in the southeast corner of Munro Township and extends for 3½ miles in a direction N 65° W - 70° W into adjoining Beatty Township. The sill is 900 feet thick at its east end and thickens to about 1,000 feet in the vicinity of the Munro-Beatty township boundary. At the "A" ore-body it is about 650 feet thick.

On the north and south the sill is bounded by intermediate and basic volcanic rocks. They are dacitic to andesitic on the south and andesitic on the north. The south contact is well exposed, but due to more intense shearing of the volcanics on the north there has been deeper scour by ice and a thick covering of drift obscures contact relations.

In the drilling programme carried out by Canadian Johns-Manville in 1949-50 none of the holes drilled northwards was extended to penetrate the volcanics on the north contact of the orebody and the dip of the sill was taken from borehole data on the serpentinite-dacite contact on the south side of the sill. Hendry (1) states that the dip is steeply to the south, but replotting of drill hole data has shown the sill to have a steep dip to thenorth. Fig. 5a & b). Pillows in the dacite to the south of 'B' orebody show tops north, thus confirming a northerly dip.

The sill consists from north to south of a gabbroic band followed by a discontinuous band of coarse-or medium-grained pyroxenite,and this is succeeded by a band of moderately serpentinised pyroxenite in which crystals of pyroxene are visible in a dense, black serpentinised groundmass.

In an outcrop on thenorthwest side of the orebody where the gabbro band is thickest, a sheared graphitic slate is present between the gabbro and a dense dark-green sheared amphibolitised andesite to the north. This andesite in thin section shows an intergranular texture, and consists of green pleochroic actinolite, plagioclase laths, which are largely altered to zoisite, and small patches of radiolitic chlorite. To the north of this andesite a tongue of quartz gabbro and pyroxenite of thickness occurs. These rocks are medium-grained red-weathering and contain angite and pigeonite, rimmed with needles of actinolite, plagioclose and chlorite, and a granophyric intergrowth of quartz and albite. And the contact with the altered andesite a 15 foot band of finer-grained pyroxenite is present. It consists of pyroxene rimmed with actinolite and large crystals of chlorite set in a groundmass of fine needles of actinolite and serpentine. The quartz gabbro and altered pyroxenite are considered to be a tongue of the sill which was squeezed into the andesite during intrusion of the sill, and that this tongue subsequently differentiated into the more basic pyroxene-rich rock and quartz gabbro.

The ultrabasic highly serpentinised portion of the sill to the south of these bands consists of black or greenish-black serpentinite which is fine to medium-grained. This band varies in width from320 feet to 580 feet and is bounded on the west by a cross fault locally known as the John's fault, and on the east by a half-moon shaped body of talc-carbonate rock which thickens in depth. This rock passes by stages unaltered serpentinite. The shape of this talc-carbonate body is similar to the form of talc-carbonate rocks associated with the ultrabasic intrusives near Rochester, Vermont.

In the centre of the sill is a body of light-green granular serpentinite in which most of the asbestos mineralisation occurs. A smaller body of the light serpentinite buhs up against the John's fault on the western side of the orebody. There is no matching portion of this light serpentinite in the "B" orebody on the other side of the fault.

A narrow bands of pyroxenite and moderately serpentinised pyroxenite is present between the serpentinite and dacite on the southest part of the orebody. Also included in this portion of the sill is a xenolith of dacite which has been metasomatically altered the serpentinising solutions to give hybrid rock types which will be dealt with in more detail later.

Discontinuous pyroxenite dikes, now largely altered to prehnite, trend in a north-south direction through the orebody. They are contorted and pinch and swell considerably along strike. (Plate I) Later shearing offsets them in orebody. They vary from a few inches up to about 6 feet wide.

Two discontinuous diabase dikes, one 3 feet wide

PLATE I

Prehnite dike in medium serpentinite. 915' level, south side pit, west end. Note contorted nature of dike. Nov. 1953.

PLATE II

Two diabase dikes on the 915' level, north side pit. Note shear on right. Nov. 1953.

PLATE III

Diabase dike (12') wide) in talc-carbonate rock on 950' level, north side pit. Shows alteration zone in the talc-carbonate rock. View looking north. Nov. 1953.

PLATE IV

Porphyritic lamprophyre, 950' level north side pit. Large phenocryst of actinolite in a groudmass of actinoli te and plagioclase (twinned). Crossed nicols X 40.

and the other 15 inches, pass through the centre of the orebody in a northerly direction. (Plate II) They are considerably faulted and sheared in the middle of the orebody, both with change in dip and strike. A 12 feet wide diabase dike cuts through the talc-carbonate rock on the east side of the pit and has baked this rock for a distance of about 18 inches on either side of the contact. (Plate III) The pyroxene in the central diabase dikes is pigeonitic (2V-42° V) while in the larger dike all the ferromagnesian minerals have been converted to serpentine.

Cutting through the xenolith of altered dacite on the south of the sill is a porphyritic lamprophre dike consisting of an intergranular groundmass of plagioclase and actinolite in which are scattered large phenocrysts of actiniolite some partially or wholly chloritised and showing excellent 'sieve structure'. (Plate IV) Calcite is present sparingly. This dike, which is 6 feet wide, and is displaced small amounts by strike faults, was not traced into the orebody, but a random specimen taken in line with the strike of the dike on the opposite (north) side of the orebody showed that it is present here also but is sheared and shattered by faulting in the orebody and is thus not seen there, The diabase, prehnitised pyroxenite and lamprophyre dikes are extremely difficult to trace in the serpentinite, and many of the smaller ones may have been missed while mapping.

Veins of calcite occur liberally in all the rocks of mine, but are especially concentrated near some of the larger shears and also near the talc-carbonate rock on the eastern side of the orebody. In the gabbro the carbonate veins are essentially horizontal and have an 'asbestiform' structure. (Plate V) This is believed to be due to peculiar stress conditions operative at the time of formation of the calcite veins. A series of quartz-amphibole veins assume the same in the gabbro in the north central part of the orebody. The peculiar 'asbestiform' structure of these and calcite veins is considered by the author to be of significance in any theory concerning the origin of asbestos. In the Woman River area 90 miles southwest of Timmins the presence of 'asbestiform' calcite, Quartz or epidote veins in volcanics was used by the auther as a first guide to localising favourable areas in which to prospect for asbestos deposits. Any serpentinite found in such areas contained asbestos. Where the veins were massive in the surrounding rocks no asbestos was developed in the serpentinite. There is no evidence on the Munro mine or in any of the rocks of the Woman River area that this is a replacement phenomena.

A resinous light-green serpentine is present along all the joints and shears in the serpentinite. This is known as 'slip serpentine'. In thin section it is seen to be composed of a aggregate of chrysotile and some antonite which shows contortion and faulting due to post-

PLATE V

'Asbestiform quartz veins in medium-grained gabbro. 950' level, north side pit, central. View looking NW. Nov. 1953.

consolidation movement along the slips and shears. Associated with this mineral to some extent is a light green or greenish-blue fibrous mineral of the serpentine group called picrolite.

In the north central part of the orebody many of the shears have a coating of sulphides pyrite and chalcopyrite occassionally on the shear faces, the pyrite in well crystallised idiomorphic crystals. Chalcopyrite is present sparingly. A fragment of the medium serpentinite near the south contact of the sill was found to contain small quantities of garnierite. Most specimens of serpentinite when crushed and run through the Vreeland spectroscope showed lines for chrome.

On the northeast side of the sill irregular patches of amphibolitised pyroxenite hornblendite are present in the pyroxenite. It is impossible to say whether this band of rock, which is in immediate contact with the gabbro, is a fine-grained intrusive rock or a recrystallised volcanic rock. Most of the pyroxenes are pigeonitic which would favour a volcanic type rock, as Hess (1) has shown that rapid cooling favours the development of pigeonite, but pigeonite may also occur in quickly cooling plutonic rocks. In the field the pyroxenite was separeted from the gabbro on the basis of visible plagioclase, but after thin section study it is found that much of the rock labelled pyroxenite on the map contains a good deal of

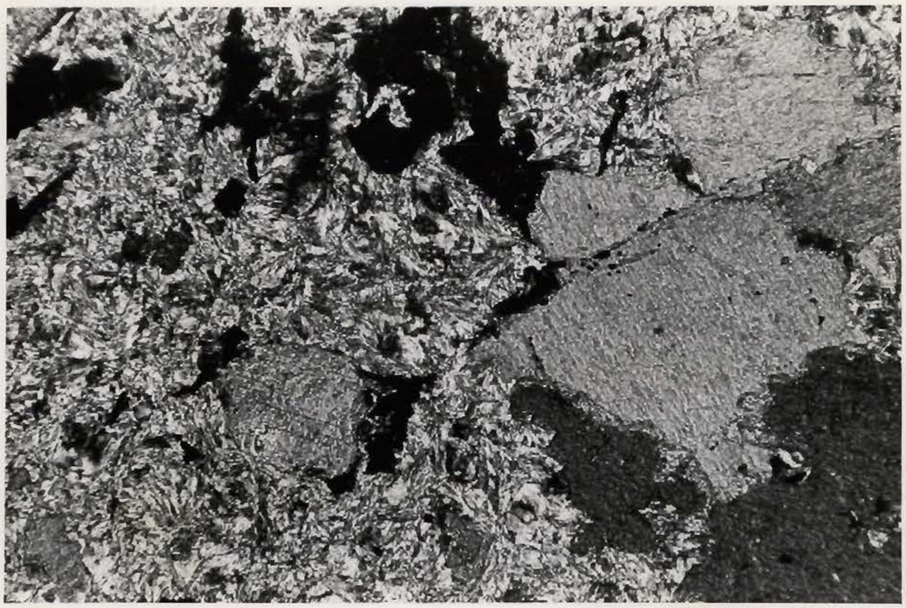


PLATE VI

Pyroxene altering to serpentine (dark) and actinolite (meshlike mineral). 980' level, north side pit, east central end. Crossed nicols X 10.

plagioclase and the two rocks are thus gradational. The pyroxenes are moreover of similar composition as determined from 2V measurements on the serpentinite and the pyroxenite grades into the gabbro they must be consanguinous and the pyroxenite will be designated as part of the sill. The amphibolitisation of the pyroxenite produces a hornblendite, which in the field is practically indistinguishable from a peridote. The small irrehular areas of peridotite shown in the north-east part of the map, have been found as a result of thin section study, to be hornblendite. The rock consists of an interlocking mesh of actinolite and brown hornblende with a sprinkling of magnetite dust. (Plate VI) The gabbro in this region also shows a marked degree of saussuritisation with all the plagioclase converted to a radiolitic chlorite with a little zoisite, and other pyroxene crystals converted mainly to serpentine and a little amphibole. (1) Superimposed on this saussuritisation which is contemporaneous with serpentinisation as will be shown later, is the later steatitisation and carbonitixation, and small clusters and flecks of brightly polarising talc and masses of magnesium carbonate replace the earlier minerals. Small areas of micro pegnatitic quartz are also present but are unaffected by alteration.

The dacites on the south contact of the orebody show very little thermal or hydrothermal alteration expept for the xenolith and one other small outcrop where a narrow zone of talc shist is developed at the serpentinite-volcanic contact. This is due to the phenomenon of metamorphic differentiation described by Phillips and Hess (1936 p. 337, which is a natural consequence of the chemical potential difference sut up when ultrabasic and silicious rocks come into contact. Talc and chlorite develop at low temperatures and actinolite and biotite at higher temperatures. A necessity for such metamorphic differentiation is a free channelway for migrating hydrothermal solutions which is pro vided either by a highly sheared rock or by an undulation in the contact between the two types. Where no channelway is present no alteration occurs due to the low temperatures prevailing in an ultrabasic intrusion. No talc is developed on the southern contact of "B" orebody with the dacites but there are patches of this rock on the north contact, a phenonenon which os nowhere seen on the north contact of the "A" orebody portion of the sill.

STRUCTURAL GEOLOGY

Under this heading will be described the salient features of the orebody in relation to the deformation which it has suffered with explanations for some of the features observed.

(Fig. 4)

Faults: A study of the map (Fig. 4) will show the host of faults, joints and shears which divide the serpentinite into innumerable blocks and slabs. Dips vary from vertical to nearly horizontal. Fault traces are relatively straight or strongly curved. During the mapping only the more obvious and stronger shears were put in and those shown are by no means representative of the faults actually present. The dividing up of the orebody is further completed by a system of joints; vertical, horizontal and inclined.

As elsewhere in Munro Township the major recognisable faults are those which trend across the strike of the formations and which displace marker horizons. No idea of the magnitude of displacement is obtained from intensity of fracturing of the serpentinite. A fault may pass from a single fault plane by stages into numerous closely spaced shears extending over a zone and then bifurcate into a series of shears which gradually diverge and die away. It is thus extremely difficult to trace any fault into the serpentinite with any degree of certainty. In many instances, along an apparently strongly sheared zone, no displacement of marker horizons has occurred. Most of the larger faults die out rapidly in passing from serpentinite into volcanics or gabbro. Thus faults with large displacements appear as thin and apparently weak shears when traced into the surface outcrops of country rock around the edge of the pit.

<u>Cross fractures:</u> During the initial geophysical survey and diamond drilling programme cross fractures

with strikes varying from north to northeast and displacements ranging from 50 feet to 600 feet were indicated according to Hendry (1951). The plane table survey showed that there are 7 major cross faults on the north side of the orebody and that some of the faults on Hendry's map are mislocated. Fault zones which appear strongly developed along the edges of the orebody could not be traced into the orebody itself due to their habit of 'faming' out in the serpentinite. In a few cases these zones were correlated with similar zones on the opposite side of the orebody but it was generally considered inadvisable to do so.

Movements and slip components on the faults are difficult to define due to many recurrent movements since the inception of the faults. Slickensides, crag-and-tail, mullion structure and plucking are sommonly present on most of the shears, but only indicate the last slip component along the shear. Drag folds are associated with two faults; the fault which defines the western end of the orebody (Johns'fault) and the northeast trending fault in the centre of the orebody. In this latter fault drag is developed in the pyroxenite on the hanging wall of the fault on the 950 feet level and indicates that the hanging moved directly up the dip i.e., the fault is a reverse fault. (Plate VII) Drag is a good criterion for difinition of absolute movement along a fault but is so rarely developed that it could

PLATE VII

A northeast trending cross fracture 915' level, north side pit. Sheared pyroxenite left (light-grey), peridotite right. Note drag folds in the pyroxenute. Hanging wall has moved directly up the dip.
(Length of section approx. 20')

Photo Nov. 1953.

not be used generally. Displacement of calcite or asbestos veins was used occasionally. Displaced calcite veining in the gabbro was found useful to work out directions of movement.

The diabase, prehnitised pyroxenite and lamprophyre dikes were intrude at a later stage into these cross fractures. Since the large dike on the eastern side of the orebody bakes the talc-carbonate rock, it must be post-steatitisation and hence post-fibre formation as Hess (1933 p 637) has shown that steatitisation always succeeds serpentinisation. On this premise the two diabase dikes in the central part of the orebody are post-serpentinisation.

The lamprophyre dike on the southwest side of the orebody has produced steatitisation of the peridotita. This may be due to a process of metamorphic differentiation due to a difference in composition between the dike and the peridotite.

The prehnitised pyroxenite dikes are autoinjections of basic material into the partially consolidated sill as is evidenced by their nature of pinching and swelling and contortion, moreover their north-south strike is an indication that the stress distribution which gave rise to the present fracture pattern was already established at this time. The serpentinite for about 1 inch on either side of these dikes is converted to a dense, dark apparently colloidal material which is similar to that

PLATE VIII

View from dacite xenolith on surface on SW side of sill looking NE. Shows a strike fault in the medium serpentinite. On the floor of the pit (840') level is light granular serpentinite. to the left of the trucks on the level above (880') is medium grained gabbro (light) and to the right is medium serpentinite.

Nov. 1953.

observed by Cook (1937a p 82) associated with felspathic dikes in the Eastern Townships.

Strike Fault: Faults or fault zones trending with the length of the orebody are numerous, but in only one was the displacement measurable. This shear, on the northeastern side of the orebody displaces the diabase dike 30 feet and is a right-handed fault. In passing into the serpentinite it 'fans' out into a maze of shears which are lost in the orebody.

In a zone extending 500 feet west of 0+00 on number 2 baseline and 50 to 200 feet north of this line, a number of the larger strike and cross faults intersect and there is extreme shattering, contortion and grinding of the serpentinite, This zone is coincident with a notable decrease in the tenor of the asbestos.

The inclusion of altered dacite on the southwest side of the orebody acted as a buttress during the faulting and is a mass of intense shearing and fracturing, the faults curving round the block in a definite pattern up to 250 feet north and east of the block. (Plate VIII)

A strongly developed shear zone on the southeast side of the orebody could not be traced for any distance and no idea of the magnitude of the displacement is available.

Joints: The serpentinite body and associated rocks to the north, are fractured by a well developed joint system. The stronger joints trend N 70° with the length of the orebody and dip vertically, but a less conspicuous set is developed at right angles to this. The surfaces of the joint planes are straight in distinction to the curved surfaces of the shears. (Plate IX) Joints are also developed in other directions and have variable dips. The strike of the joints changes in passing from one rock type to another as is exemplified by the dike on the east side of the orebody where the jointing changes strike in passing from the serpentinite into the dyke

There has been slight movement along many of these joints as shown by slickensiding and displacement of asbestos veins.

Age of Faults and Joints: The faults are of two ages--

(1) Pre-Ore — The fault filling is tightly cemented to the walls. The faults are thus 'closed'.

(2) Post-Ore — The shear planes are open and slickensided. These faults are termed 'open'.

(3) Joints are all post ore and post 'open' faults as they cut across all the existing faults.

Many of the 'closed' type pre-ore faults have had recurrent movement along them and have changed to the 'open' type. Thus most of the faults are compound in origin and combine features of both (2) and (1) above.

The cross and strike faults appear to be of the same age and the one set of fracture is not displaced by the other.

Asbestos Veins: A detailed statistical study is at present being carried out on the Munro mine by the geo-

PLATE IX

Highly sheared medium serpentenite
View looking south, 915' level, east
end pit. Note the curved nature of
the shears. Nov. 1953.

logical staff to establish distribution and trend of fibre veins. During the course of preparing the map a relation between size of vein and trend was noticed.
(1) Veins of 1/8 inch and less mainly trend N 70^{o} with the orebody and dip vertically with a less well-developed set at right angles to this.
(2) Veins of 1/8 inch or greater are predominantly horizontal or have low dips.

These are the major sets of veins. There are many variations to this pattern and veins may trend in any direction and have any attitude.

A well developed 'ribbon zone' of horizontal veins is present in a small area of the light serpentinite on the extreme northeast tip of this body.

Asbestos veins are of the one fibre or the two or more fibre types. The two types are evenly distributed through the orebody. The break or breaks may occur along the centre or on either side of the veins and are continuous or irregular. The partings are filled with magnetite or serpentine.

The magnetite occurs in 4 principal ways:
(1) As well crystallised grains, often in nearly perfect octahedra evenly distributed through the fibre and cutting it.
(2) As small, usually well defined undulatory sheets which cut the fibre horizontally. In addition there are loose magnetite grains scattered on either side of these sheets and diminiching away from the sheets.
(3) In some cases there is a concentration of fine-grained

magnetite on one side of the vein diminishing away from the vein. On the opposite magnetite-free side the fibres have a sharp contact with the host rock.
(4) As solid veins of granular magnetite of limited lateral extent occuring with the asbestos veins.

Vermaas (1952 p. 222) has postulated that fibre growth takes place from the magnetite-free towards the magnetite-bearing side, and the growing fibres tend to expel magnetite away from the direction of growth. This would mean for example, that in the two fibre type of vein growth of fibre took place from both walls inwards, expelling magnetite towards the centre. More complex conditions hold for the three or more fibre types.

CHAPTER III

PETROGRAPHY

PYROXENITE

Three bands of pyroxenite are associated with the sill.
(1) A northern band of unknown thickness which pinches out against the John's fault on the western side of the orebody. This band is thickest in the central part of the sill where the serpentinite is thinest and where the maximum amount of faulting occurs. Its thickness may be due to repetition by faulting. It is probably a lenti-

PLATE X

Talc schist at contact between dacite (at hammer head) and serpentinite (black). View looking east on 915' level, south side pit, east central end. Note sharpness of contacts. Nov. 1953.

cular body as deduced from the limited exposures available.

(2) A narrow lenticular band of partially serpentinised pyroxenite extends 500' east from the John's fault and is separated from the northern band by gabbro. This band averages 10 feet in width. Associated with it is a fairly highly serpentinised part which has been called 'peridotite' on the map. East of the second large cross fault serpentinite is in direct contact with gabbro and the pyroxenite is absent, Near the eastern of the ore-body irregular lenses of pyroxenite in the gabbro probably represent this same horizon. The grain size of this band is variable, and the pyroxenes may be over 1 inch in length. The rock is generally friable and Williams (1890 p. 35) has cited this as suggestive of the origin of the crystals by settling in connection with the pyroxenites associated with gabbro in Maryland.

(3) A narrow lenticular band of partially serpentinised pyroxenite on the south contact of the sill with dacite. This extends from the John's fault approximataly 400 feet east and is about 5 feet thick. South of the dacite xenolith irregular narrow bands of pyroxenite are present in the serpentinite to the north of this band. East of the xenolith the band was traced for about 80 feet until it disappeared beneath sand. It may possibly extend a few hundred feet more to the east. At a contact between the serpentinite and dacite 400 feet east of the last outcrop of pyroxenite, talk schist takes the place of the pyroxenite.
Plate X

PLATE XI

Felspathic pyroxenite, 980'level, north side pit, east central end. Shows pyroxene (dark-grey, rough surfaces) with interstitial plagioclase. Note slight undulose extinction of pyroxene grain in centre. Crossed nicols X 22.

Description: The rock is eqigranular hypidiomorphic with euhedral crystals of pigeonite, angite and enstatite in a serpentine, chlorite, actinolite and occasionally plagioclase (An 35) base.(Plate XI) Small amounts of magnetite occur as segregations along the pyroxene cleavages and as disseminations in serpentine (bastite)crystals. The amount of plagioclase is variable and gradations through felspathic pyroxenite to gabbro occur.

The average pyroxenite has a grain size of 0.7 mnn and is thus medium-grained. A modal analysis everage for three slides gives.

Pyroxene	65%
Amphibole	22%
Serpentine	7%
Chlorite	5%
Plagioclase, magnetite	1%
Total	100%

Pyroxene: The pyroxene belongs to the clinoenstatite diopside series, and there are 3 prominent types as determined on the universal stage:

1. Pigeonite with 2V-44°
   Z>C-34°

this corresponds to an approximate composition of diopside 56%, clinoenstatite 44% (Winchell '933, p. 223)

2. Augite with 2V -54%
   Z-C- 36%

approximate composition is diopside 74%, clinoenstatite 20%

These two types are distinct and there are no varieties with intermediate 2V's.

3. Enstatite with 2V - 74° and parallel extinction which contains approximately 6% of the ferrosilite molecule.

The great majority of the pyroxenes are twined, contact twins being common with occasional polysynthetic twins. Enstatite is rare, probably due to the fact that it would be the first mineral to alter to serpentine.

Alteration: The alteration of the pyroxenites is associated directly with the serpentinisation of the sill. The mode of alteration and the attendant end products are dependent on the original composition of the pyroxenes and the temperature conditions prevailing at the time The extent of alteration has been governed by availible channelways for migration of hydrothermal solutions.

In process of serpentinisation and steatitisation Hess (1933 a and b) recognises two types of alteration of the ultrabasic rocks and the surrounding rocks.

1) In a closed system the presence of solutions merely facilitates the recrystallisation of the rock to minerals stable at the prevailing tempāretures.

2) In a open system the solutions attack the ultrabasic mass along the contacts and fractures causing local alteration to a talc-carbonate rock. A part of the material will turn into solution and be redeposited in the

neighbourhood (solution principle of Escola).

A typical succession of characteristic minerals, with talc as the end product, may be found. Starting with olivine and pyroxene the following succession of minerals, leading to soapstone, is found: hornblende-- actinolite-- chlorite-- talc--carbonate. This alteration may stop at any stage and repersents minerals formed at progressively decreasing temperatures. Addition of silica from outside sources is necessary. Daly (1933) has shown, by the average composition of the igneous rock, that no ultrabasic rock types, even dunite, is entirely free from calcium. In the scheme presented by Hess, if the rock has passed the hornblende stage, actinolite (tremolite) will form in the presence of a calcium content. If al 203 is present also, and it invariably is in pyroxenes, chlorite will form.

A study of thin sections of pyroxenite from various parts of the mine has revealed all stages of alteration up to the chlorite stage, and in special cases (near fractures and contacts) up to the talc-carbonate stage. None of the pyroxenite is entirely free from alteration.

The mode of alteration has been of either the closed system or open system type.

Closed system: this is the pervasive type of alteration affecting the pyroxenite generally and leading to rocks with varying amounts of actinolite, chlorite, serpentine and hornblende.

PLATE XII

Talc-tremolite schist. From dragfolded pyroxenite. 950' level, north side pit central portion. Talc(roughened white areas) and tremolite (smoth white areas) are set in serpentine (dark)
Crossed nicols X 22.

a. The initial stage is characterised by small needles of actinolite(tremolite) growing off the pyroxene crystals with small areas of chlorite and serpentine between the pyroxenes.

b. In the final stage and almost pure hornblende rock consisting of pseudomorphs of hornblende after pyroxene is developed. The name hornblendite is proposed for this rock which forms isolated odd-shaped bodies in the pyroxenite north of the gabbro band. On the map the rocks marked as 'peridotite' on the N.E. side of the sill have been found to be hornblendite. The general name Perknite as used by H. W. Turner is thus appropriate for the pyroxenite and associated hornblendite.

Open system: near large shears where solutions have circulated freely the pyroxenite has been altered to a sheared talc-carbonate or talc-tremolite (actinolite) rock. (Plate XII) Wik (1953 p. 45) has given equations which illustrates the conversion of pyroxene to talc and tremolite, and the affect of carbonitisation on such a rock.

(1) mg26 Fe10 Ca4 (Si03)10 + H20

3 Mg6 Si8 020 (OH) 4 + 2 Ca2 Mg4 Fe Si8 022
(Talc) (Tremolite)

(OH) 2 + 8 FeO (1)

(2) Ca2 Mg5 Si8 022 (OH)2 + 7 CO2 2 Ca Mg (CO3)2 +
(Tremolite) Dolomite)

3Mg Co3 + Si02 + H20 (2)
(Magnesite)

The irregular proxenite band to the south of the gabbro has undergone an alteration of a different kind and details of this will be presented when describing the medium serpentinite.

GABBRO

The gabbro forms a band averaging about 100 feet in width between the pyroxenites, for 600 feet east of the John's fault. After this it either contacts the serpentinite directly but an irregular band of moderately serpentinised pyroxenite (called peridotite on map) sometimes intervenes. In the centre of the orebody the band thins or is absent due to elimination by faulting. Another probability is that the percentage of pyroxene increase to such an extent that the rock was called pyroxenite instead of gabbro in the field. There is a gradation from pyroxenite to gabbro however, and it becomes impossible, in the field, to distinguish a gabbro with a low percentage of plagioclase from a pyroxenite with a low percentage of plagioclase. The rock in the north central part of the orebody resembles the pyroxenite more closely than the gabbro and has thus been designated pyroxenite.

a. Description: The texture of the gabbro is extremely variable and ranges from medium-grained (<0.2mm) to coarse-grained (>1.0mm) and from hypidiomorphic to typically diabasic. In the field it was possible to seperate coarse gabbro from medium gabbro on the basis of grain size. 'Diabasic gabbro' would, in general, be the

PLATE XIII

Coarse-grained diabasic gabbro. 950' level. Boulder lying directly below face.

PLATE XIV

Diabasic gabbro. 950' level, north si-
de pit west end. Shows a large crystal of augite (light) ophitically intergrown with turbid plagioclase (dark-grey). Small area of micropegmatite (mp) in lower right corner.
Crossed nicols X22

best name for the rock (Plates XIII - XIV).

A model composition for the rock gives:

Plagioclase (An 35)	51%
Pyroxene	39%
Amphibole	9%
Micropegmatite	0.5%
Accessories	0.5%
Total	100.0%

Accessory minerals are secondary magnetite, and very rarely eubedral crystals of sphene.

Pyroxene: The pyroxenes are similar to those in the pyroxenite, and comprise pigeonite and augite from the clinoestatite-diopside series and occasional crystals of enstatite.

Alteration: In plain, polarised light the pyroxenes show a brown turbidity due to a mass of minute secondary cleavages. Henry (1942 p 188) goes into great detail about fine lamella structure in pyroxenes and ascribes it to deformation during crystallisation. He does not state anywhere, however, that such a structure produces a brown turbidity in the pyroxene in plain polarised light, and the structure he describes may thus not be the one seen in the Munro thin sections. This structure is present in both ortho- and clinopyroxenes but Henry only mentions it in orthopyroxenes, A fine lamelle structure is also produced in the pyroxenes in the initial period pf serpentinisation. This would be a secondary alteration phenomenon but must have been controlled by initial cleavages in the pyroxene. Henry (op.cit. p. 187) observes that this fine lamella structure is not produced in volcanis rocks and that 'conditions of crystallisation in an ordinary plutonic basic magma allow the best development of lamella structure'. It has been noted also that pyroxenes which develop this lamella structure do not show undulose extdnction, a strain effect, whereas many of those without it show the effects of strain. This structure thus develops to relieve applied stresses.

Contact twins are always present and occasionally polysynthetic twins.

Most of the pyroxenes are rimmed by needles of actinolite, or else altered completely to serpentine (bastite) and actinolite. In a few cases pseudomorphs of magnetite after pyroxene develop. Magnetite also occurs along cleavages.

In general the alteraion is similar in all respects to that described for the pyroxenites.

On this premise we may thus assume that since the structure is due to deformation it requires conditions of slow cooling, and that such conditions abtained during consolidation of the Munro sill to produce this structure in the pyroxenes. Indiredtly, this eliminates some of the doubt about the gabbro and pyroxenite being coarse portions of a volcanic flow.

Plagioclase: Most of the original plagioclase (2V- 78^{o}) has been replaced by zoisite and secondary albite

PLATE XV

Coarse-grained gabbro. Ø50' level, north side pit, east central end. Shows corroede crystals pf pyroxene (py) in a matrix of zoisite and serpentine (dark areas), with occassional blebs of micropegmatite (mp). Crossed nicols X22

PLATE XVI

Well-crystallised zoisite. Zoisite (dark-grey) and actinolite lath with secondary albite (dark). Crossed nicols X45

PLATE XVII

Quartz vein with growth of fibrous tremolite in medium-grained gabbro. 950' level, north side pit, east central end. Crossed nicols X45.

PLATE XVIII

Micropegmatite in diabasic gabbro, 950' level north side pit, west end. Crossed nicols X45 has developed. (Plate XVI) The zoisite is in general granular and shows andinalous blue and yellow interference colours under crossed incols. In rare cases the zoisite preserves the original lath shape and carlsbad twinning of the replaced felspar. Wedge-shaped crystals also occur. The zoisite is porbably very Fe-free and is unusual in that it sometimes occurs so well crystallised (Plate XVI) Zoisite occasionally develops from pyroxene

Long thread-like needles of tremolite (actinolire) very often form radiating clusters in the secondary albite giving it a 'cracked ' appearance, or else bomb-shaped crystals of actinolite occur in initimate association with the zoisite. The same thread-like tremolite develops at right angles to the walls of fractures filled with quartz and this probably gives rise to the 'asbestiform' veins described previously. (Plate XVII)

Chlorite is only rarely developed and is then in radiolitic aggregates which show a peculiar olive-green colour under crossed nicols. It was not possible to isolate any of this chlorite for refractive indice determinations and its composition is thus unknown. It is different to the normal penninite which shows anomalous 'Berlin blue' interference colours.

<u>Micropegmatite:</u> In all the thin sections of the diabasic gabbro a micrographic intergrowth (Holmes) p. 343) of quartz and albite or quartz and zoisite, when the plagioclase is altered, is present interstitially to the plagioclase and pyroxenes.(Plate XVIII) This micropeg-

matite is developd in varying amounts in the various thin sections, but is always present. A.C. Lane (1892) asserted that interstial micropegmatite in diabase dikes in Michigan is the last product of the basic magma and not a secondary material as others had claimed, In the tholeitic (olivine-free) diabases the place of micropegmatite is taken by galss and F. Walker (1935 p. 155) has shown that such a glassy residue has the composition of a granite and thus could not be of secondary origin. Its presence in the gabbro is taken as convincing proof that differentiation took place in the sill. Since the micropegmatite is also present in small blebs in the pyroxenite to the north of the gabbro it shows the consanguinity between the two rock types and the pyxenite is thus also part of the sill rather than a coarse part of an extrusi se flow a Satterley (1951) has suggested may be the case. The presence of the micropegmatite is also indirect evidence that olivine was not present in the pyroxenite or gabbro as W.Q. Kennedy (Shand 1949 p. 263) has stated that the tholenitic type diabase is the type which gives granitic residue.

In 70 thin sections, representing all the different rock types on the mine, except serpentinite, no sign of olivine was found in any, and there are no relic structures in the secondary minerals suggestive of the former presence of olivine. The 'mesh' structure of the serpentine towards the centre of the orebody has been taken as indicative of the presence of olivine, but even this is conclusive. With this lack of clues it was decided that the madium serpentinite, at least, was not derived from an olimine-bearing rock. This point will be elaborated on in the section dealing with the origin of the serpenti- nites.

3. METAGABBRO:

The concentration of fracturing roung the xenolithic inclusion of dacite in the southeast part of the sill provided unique ppptunity for the circulation of hydrothermal solutions derived from the cooling sill. The physical and chemical potential difference between the hot ultrabasic rock of the sill and the cool acidic volcanic rocks initiated a metasomatic exchange of ions according to the principles of metamorphic differentation postulated by Eskola (1935 p. 68-77), with the recrystallisation of dacite ti a gabbroic-like rock and development of small amounts of talc in the ultrabasic portions of the sill (Plate XIX) Read (1934) p. 519-540) considers this process to have taken place at one stage, but Phillips and Hess (1936 p. 348) beleive that a considerable length of time alapsed betwen the formation of successive minerals in the different stages of metamorphicsdifferentiation.

A series of specimens taken from the south of the metagabbro for a distance of 20 feet in a northeasterly direction towards the centre of xenolith shows.

1) A 3 foot wide band of coarse-grained metagabbro seperated from the 'peridotite' by a shear. This rock consists

of large turbid crystals of angite (generally > 2.0 mm) with corroded boundaries which are sometimes wholly altered to serpentine (bastite) and in which small needles of tremolite (actinolite) occasionally remain. The pyroxenes are mostly untwinned but occasional contact or polysynthetic twins are seen. The pyroxenes are set in a granular groundmass of zoisite, which represents alteres plagioclase, and some carbonate. (Plate XX) Small radiolitic mass of a dark olive-green polarising chlorite are present sparingly. A dark-brown istropic spinal forms anbedral interstial crystals or occurs as coatings round magnetite grains.

2) This band is followed by 5 feet of a medium-grained metagabbro in which the intergranular textureoof the original dacite (Plate XXI) may be recognised. The mineral assemblage is the same as that of the coarse gabbro but the constituents rarely exceed 1 mm in size. Zoisite grains after plagioclase is exclusively present and no plagioclase relics were seen.

3) With the gradual appearance of plagioclase, the rock passes into a dacite, but zoisite is always present, even in the central part of the xenolith. The minerals are augite, plagioclase, zoisite, magnetite and spinel and average 0.07 mm in diameter.

There can be little doubt that this gradational change of rock from a coarse-grained metagabbro into relatively fresh dacite has been produced by metasomatic changes asso-

PLATE XIX

Coarse-grained metegabbro developed at contact of serpentinite and dacite. Surface, south side sill, west end. View looking NW.
Nov. 1953.

PLATE XX

Coarse-grained metagabbro. Pyroxene right, granular zoisite left. Crossed nicols X22.

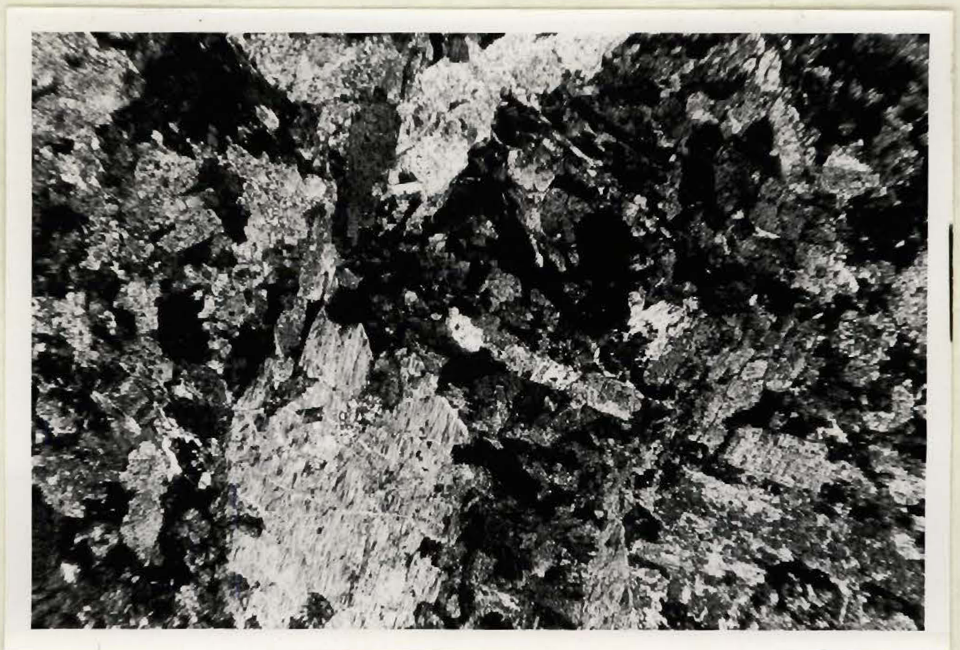


PLATE XXI

Medium-grained metagabbro. 6' from contact with serpentinite. Pyroxene (light-grey) in a groundmass of granular zoisite (dark-grey). large crystal (Ba) is bastite. Crossed nicols. X45 ciated with intrusion of the sill and facilitated by the structural control of permeability offered by the localising of shears round the xenolith which acted as a buttress during deformation.

PERIDOTITE :

South of the middle pyroxenite band, and southoof the dacite xenolith, irregular lenticulat bodies of a medium-grained moderately serpentinised rock in which pyroxene crystals are distinctly visible, are developed. In the field, similar looking rocks to the north of the gabbro band and bordering some of the larger shears in the pyroxenite, were identified as peridotite, but have been found on examination of the thin sections, to be hornblendites. As stated previously, the absence of any direct evidence for the occurrence of olivine makes it difficult to pigeonhole a rock with serpentine and pyroxene, as it may either be an original peridotite or a moderately serpentinised pyroxenite. For the purposes of this discussion however, the name peridotite, originally given the rock in field, will be adhered to.

Description: The compositon and the grain size of the peridotite is variable. From north to south progressively increased serpentinisation occurs until the rock passes into a medium-grained serpentinite. The constituent minerals are:

Serpentine (antigorite and chrysotite)

Pyroxene (augite or pigeonhole and rarely an ortho-

PLATE XXII

Typical banded medium serpentinite, 915' level north side pit east central end. Antigorite (dark), chrysotile (light). Crossed nicols X22

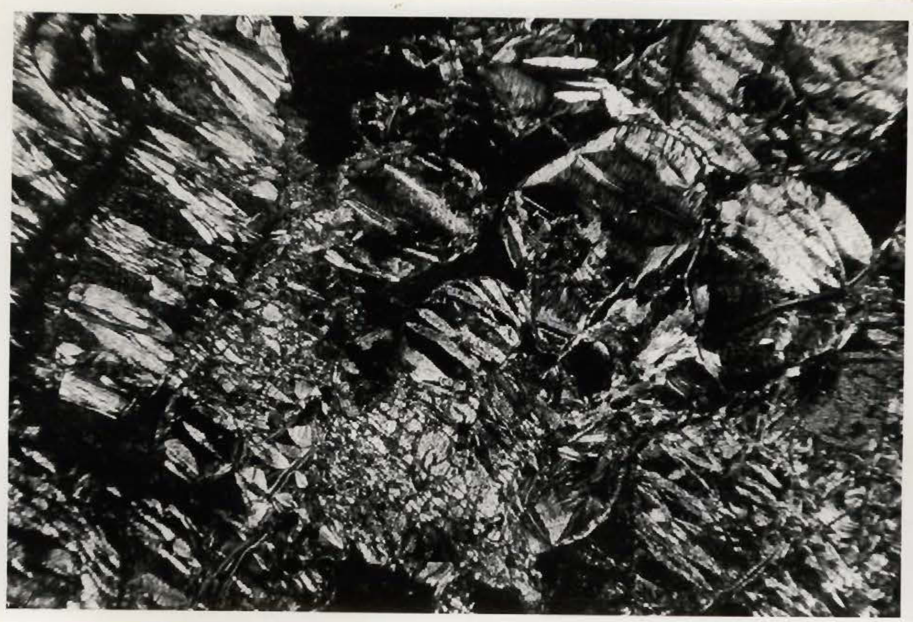


PLATE XXIII

Fractured pyroxene altering to serpentine. Shows pyroxene (Py) with veins of chrysotile Surrounded by banded serpentine. Crossed nicols X22 pyroxene)

Amphibole (actinolite tremolite) and occasionally hornblende)

Chlorite (penninite)

Magnetite.

Serpentine: The serpentine developed is of two types, antigorite and crysolite, which can be distinguished optically on the basis of structure. Nagy (1953 p. 591) and Nagy and Bates (1952)p. 1285) found that serpentine is either chrysotile or antigorite or a mechanical mixture of these two minerals. The same two authors (1952) find evidence that one mode of formation of antigorite may involve the recrystallisation of chrysotile which is less stable than antigorite under stress conditions. Sobolev (1945 p. 1455-456), Hess, Smith and Dengo (1952 p. 68-75) also find evidence for change of chrysotile to antigorite under dynamothermal conditions.

The serpentine developed in the peridotite is of these two types, or mixtures of them. In thin section under crossed nicols:-

1) The chrysotite appears as bonders on rounded grains of antigorite or as lamella cutting through the grain. It is unusual in that the lamillae throughout the section show a parallelism giving rise to a distinctly banded structure. (Plate XXII - XXIII) The fibrous nature of the chrysotite bands is obvious and they show sweeping extinction. The fibres grow at right angles to the walls in most ceses but may be inclined at high angles. Elongation is positive.

2) Between the laminae dark areas or areas which show only faint birefringence under crossed nicols mark the antigonite or the mixture of antigonite and chrysotile respectively. This type of serpentine produces various structures which are generally fern-like or leaf-like and have been given names such as Kluft antigorit, Facherantigonit etc., by Angel (1930 p. 113) but which are considered to be of relatively little genetic significance.here.

Serpentine of types (1) and (2) is present in approximately equal amounts.

In connection with type (1) Magy (1953 p. 596) states that recrystallisation of chrysotile into antigorite may be more common than is generally regarded, since a careful study of fibre veinlets penetrating larger antigorite grains has shown that the fibres are antigorite which resembles chrysotile present in similar veinlets. These can only be distinguished optically with great difficulty. He states moreover that 'one gets the impression that the antigonite was derived from chrysotile'.

Accepting these findings, the massive serpentine will henceforth be called antigonite and the fibrous serpentine chrysotile merely to clarify their difference structurally, even through the 'chrysotile' may be antigorite in many cases, which is of small moment since it was probably originally chrysotile.

Where serpentine grains are in contact with relic pyroxenes the chrysotile laminae extend into cracks or cleava-

PLATE XXIV

Hypidiomorphic gabbro with fractured pyroxene. Surface, 150' north of graphic shear. Crossed nicols X 22.

ges in the pyroxene without change of direction showing that the banded structure was produces by directed stress which fractured the pyroxene if its atomic planes were not directed parallel to the stress (Plate XXIV) or produced secondary cleavage if the atomic planes were arranged favourably to the stress.

The name 'bastite' has been used to describe a mixture of chrysotile and antigorite which forms large crystals obviously derived from a pyroxene.

<u>Pleochroic Serpentine:</u> Most of the serpentine in the peridotite is slightly to fairly strongly pleochroic from light yellow-green to yellow-brown. This plaeochroism becomes distinctly weaber in specimens nearer the centre of the orebody, but is present very faintly even in the light-green granular serpentinite in the core. Bonney and Raisin (1905 p. 690) state that a tint and pleochroism are accidental rather than essential charecteristics of the vatiety of the mineral serpentine named antigorite, while Hess (1933 p. 650) prefers to call a pleochroic and coloured mineral 'chlorite' rather then serpentine. According to him a pleochroic 'chlorite' will form rather than serpentine because of much Al and Fe in the original rock. Reed (1950 p. 121) noted pleochroic serpentine in the Mossburn district of New Zealand and called it 'bowlingite' after Winchell (1933 p. 437). Since chlorite (penninite) forms as a seperate mineral in the presence of excess Al and Fe, however, it is felt that Bonney and Raisin are

PLATE XXV

Incipient serpentinisation of twinned pigeonite along secondary cleavages. 950' level, north side pit east centralend Crossed nicols X10 correct in stating the pleochroism to be an accidental characteristic, and that this pleochroism is due to the serpentine itself, the mineral is not a chlorite. There is no structural difference between the pleochoic and non-pleochroic serpentine, while all the chlorite present is easily recognised due to a distinctive structure.

Pyroxene: The pyroxenes occur as corroded highly fractured remnants in which contact twins are sometimes seen. Many of them have a brown turbidity in plain polarised light due to secondary twinning which has produced a series of minute cleavages spaced very closely together; The turbidity is increased if some serpentinisation has occurred along these cleavages. (Plate XXV) If the pyroxene is unfractured or does not exhibit a turbidity due to twinning it invariably shows an undulose strain extinction, which is not present in fractured or turbid grains, showing that the fracturing and twinning which developed relieved the stress. Serpentine may eat into the pyroxenes or appears as centres in some of them.

Alteration: The mode of alteration of the pyroxenes and the structure developed in the resulting serpentine is well illustrated in the series of sections taken across the orebody and is the only clue as to the original rock from which the serpentinites were derived. The peridotites are thus the only link in which the probable sequence of events, leading to an ultimate pure serpentinite, may be studied.

PLATE XXXVI

'Sieve' structure in pyroxene. 915' level, north side pit, east central end. Shows crystal of augite (dark-grey) being altered to actinolite (lighter grey), and small specks of pyroxene (grey-white). Crossed nicols X45.

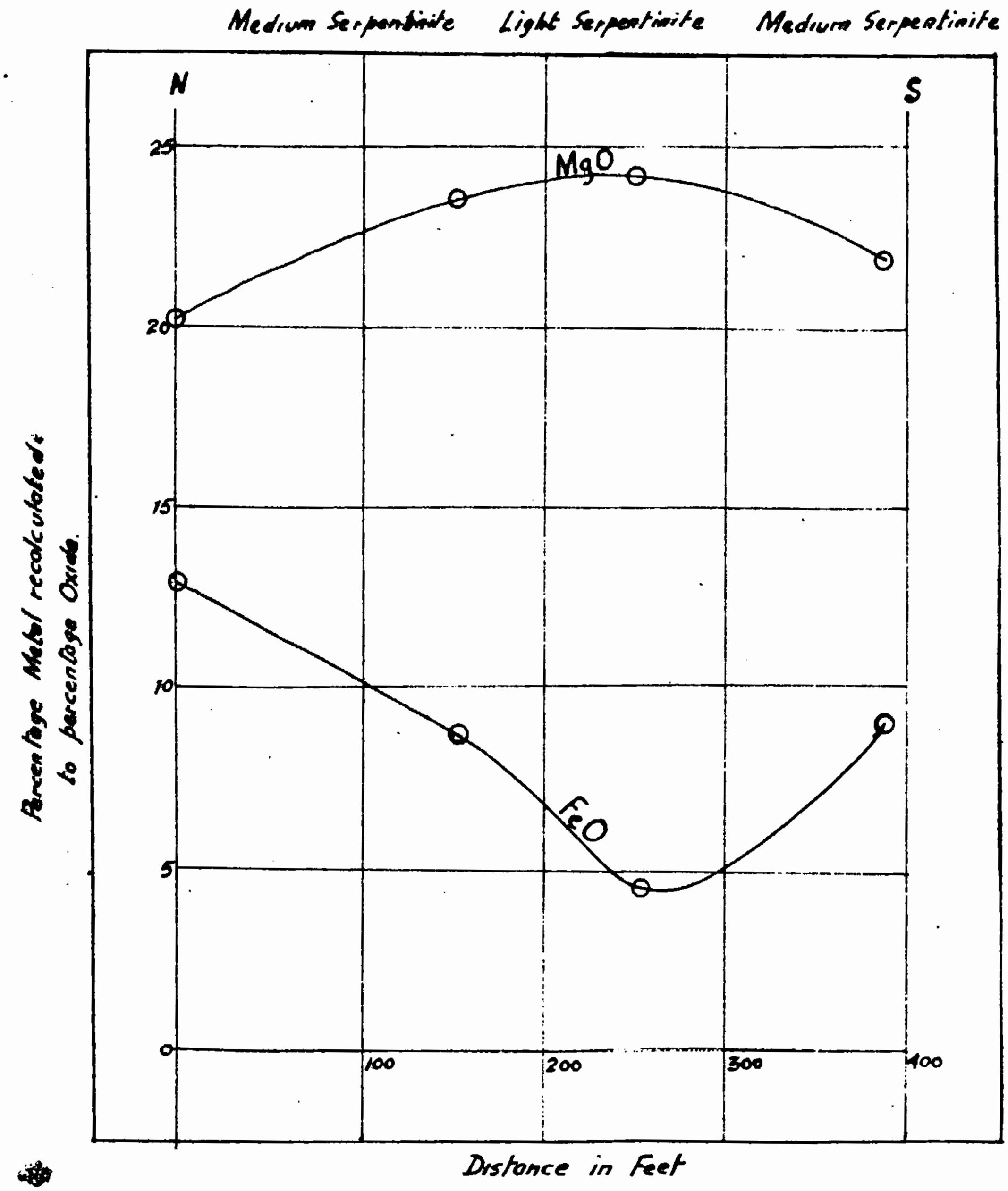
Progressing from north to south the following changes are noticed in the pyroxenes:-

1) As previously described, the first sign of alteration is the development of a very fine closely-spaced cleavage in the (100) and (010) directions or else along a dome face such as (104), which gives a cleavage at right angles to those on (100) or (010). A similar type of gliding along a dome face has been described by Bucking (1883 p. 502) ffom the bronzites of Ultenthal in the Tyrol. Fractures develop when the crystal was not favourably oriented for gliding.

2) The next stage is the inception of alteration along the cleavages and fractures. In its initial form the alteration produces a micrographitic texture in the pyroxene which resembles fishscales under crossed nicols. (Plate XXVI) Rosenbusch-Wulfing (1927 p. 345) mentions a lamella intergrowth of monochinic and orthorhombic pyroxene which gives rise to a microperthitic structure common in some igneous rocks. This is a primary structure. The micrographic texture here described is secondary however as the two components forming it are pyroxene and an amphibole, probably actinolite. The term 'sieve structure' is more appropriate and descriptive than micrographic. The most advanced stage of this type of replacement is the development of 'bastite' in which a complete pseudomorphous replacement of pyroxene and amphibole by serpentine occurs while preserving the 'sieve structure'.

PLATE XXVII

Grid structure development in altered pyroxene. 915' level north side pit east central end. Shows a mesh of actinolite crystals (light) in antigorite (dark) developing from a pyroxene (dark-grey). Crossed nicols X10



Medium Serpentinite
Light Serpentinite
Medium Serpentinite
N
S
MgO
FeO
25
20
15
10
5
0
100
200
300
400
Percentage Metal recalculated to percentage Oxide.
Distance in Feet

FIG. 6

3) With more complete serpentinisation the pyroxene breaks down a stage further and the components of the replacement, i.e. serpentine and actinolite or tremolite are seperated clearly distinguishable as entities. A grid structure is the result and it comprises short, usually wedge-shaped crystals of actinolite, arranged in a rectangular mesh, set in a groundmass of serpentine. (Plate XXVII) In the breakdown of a pyroxene with Ca, Mg and Fe in the molecule, the addition of water would lead to the formation of serpentine, amphibole and iron oxide a closed system, but would give talc, amphibole and iron oxide in an open system. In a pervasive type serpentinisation in a closed system either a pure hornblende rock would form from a pyroxenite, or in this case the formation of tremolite would provide enough mg for the formation of serpentine instead of tying it up in the hornblende molecule. If the pyroxene was initially enstatite it would all be converted to serpentine and talc. Enstatite is rare on the north side of the sill but Fig. (6) shows that there is a progressive increase of Mg towards the centre of the sill with a corresponding decrease in Fe. This may be due to an increase in original forstetite, but it is suspected to be due to an increase in enstatite relative to Ca-and Fe-bearing pyroxenes. This means an increase in the amount of serpentine in relation to amphiboles and chlorite, from the contacts inwards. Serpentinisation proceeds from core outwards (Hess 1933 p. 649)

and the serpentinisation is complete in the centre of the sill.

The grid structure is especially well developed near the north contact of the peridotite with the pyroxenite. As the serpentinite proper is approached a different structure develops. Here the pyroxene is irregularly fractured the centre of the fracture being occupied by serpentine, and extending off this fracture many small needles of tremolite (actinolite. Some of the original pyroxene may be preserved as a core. (Plate XXVIII) This structure finally gives rise, where directed stress was operative, to the beginnings of the banded serpentinite and bands of chrysotile alternate with bands of antigorite. Needles of tremolite (actinolite) are scattered haphazardly in some of these bands. (Plate XXIX) Finally all trace of amphibole disappears and a nearly pure banded serpentine rock results. Turner (1948 p. 130) found that in the absence of a volume change in serpentinisation it is necessary to expel a large amount of material (SiO_2, CaO and MgO) from the rock being serpentinised. Since most of the Mg is stabilised in the serpentine minerals, the serpentinisation of a pyroxene to give a nearly pure serpentinite would involve the removal of Ca and SiO_2. Amphibolitisation, which is essentially the result of the addition of line, is thus more liable to occur along the margins of a sill which is serpentinised from the centre outwards. The preferential development of hornblende instead of serpentine at the margins of the sill, and

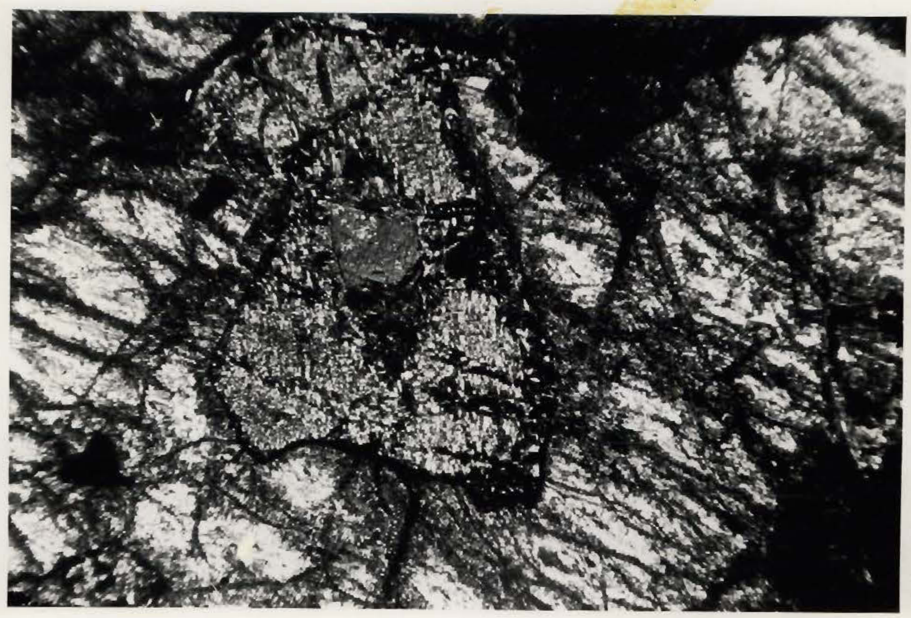


PLATE XXVIII

Advanced serpentinisation of pyroxene. Spec. from moderately serpentinised peridotite 950' level, north side pit east central end. Dark lines serpentine, white areas tremolite.
Crossed nicols 22

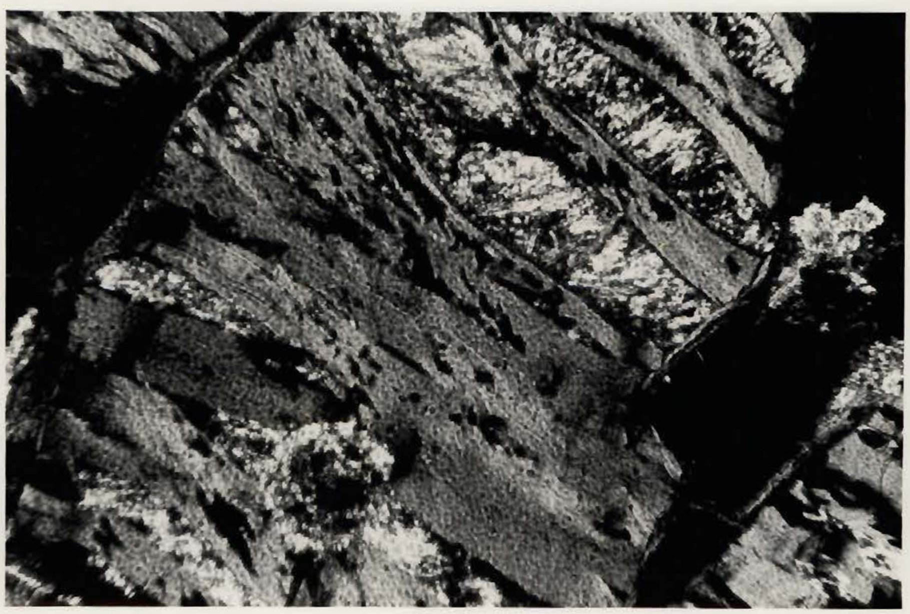


PLATE XXIX

A grain of banded serpentine (dark-grey) with randomly oriented tremolite needles (white) in some of the bands. 950' level, north side pit.
Crossed nicols X45

also near large fractures, is thus due to the addition of lime from the serpentinised portion of the sill and also to the presence, initially, of lime in the pyroxene molecule. That lime was not completely driven out to the edges of the sill is shown by the presence in all the thin sections of serpentinite, whether light or dark, of irregular shreds of hornblende.

Chlorite: Radiating clusters of penninite are present sparingly. They probably represent the mineral into which excess Al was incorporated during the alteration.

Magnetite: The excess Fe in the pyroxene is converted to magnetite during alteration, and the magnetite to a certain extent delineates the fractures and cleavages present in the pyroxene. It may also occur as a secondary replacement of chrysotile or antigotite in the banded serpentine and preserves the structure of these minerals in a general way. It also occurs disseminated or as idiomorphic grains. Only in very special cases can it be used as an indicator of the structure of the mineral from which it was derived.

5. MEDIUM SERPENTINITE

The ultimate product of serpentinisation of the pyroxenite is a granular, medium-grained to blank serpentinite, which an average grain size of 0,5 mm. The term 'serpentinite' was originally used by Lodochnikov (1933 p. 119-144). This rock represente the bulk of the sill. With more detailed work further subdivisions, based on grain size and colour, could be made.

Description: The most striking feature of the serpentinite to the north of the granular core is the microscopic banding formed by alternation bands of antigotite and chrysotile. The characteristics of these bands have been fully described in the previous sections.

The medium serpentinite on the south of the core shows only rudimentary banding , this banding being produced by the elongation of the serpentine grains. Each grain is bounded by a brightly polarising rim of chrysotile fibres which grow parallel to the grain borders. The centre of the grain is filled by a mesh, often rectangular, of antigorite. Each grain is generally bordered by magnetite, which is either massive or in small trains, the grain being about .005 mm in diameter, The centres of the grains are free of magnetite. 'Bastite' crystals are occasionally present. Apart from serpentine and magnetite small shreds of a brown pleochroic hornblende is present between some of the serpentine grains.

LIGHT SERPENTINITE

Two irregular bodies of light-green granular serpentinite occupy the middle of the sill. The larger body, 1000feet long and 150 feet wide, is in the centre and a smaller body 200 feet by 200 feet butts against the John's fault on the west.

Description: The green colour of the rock is due to the paucity of magnetite in the serpentine. Here the magnetite is in descrete idiomorphic crystals averaging

0.05 mm in diameter. Magnetite rimming serpentine grains is scarce.

A rough banded appearance is also typically developed and is due to elongation of the grains. In both the madium and light serpentinite the banding may be near certain of the shears.

The centres of the grains consist of mixtures of antigorite and chrysotile and show a sweeping extinction similar to the sweeping across the field of an isogyre from an optic figure. An 'hour glass' structure is also common in some of the grains (See Selfridge p. 485 fig. 2, plate II).

An occasional fleck of brown hornblende may be seen.

Origin of Banding and Graularity

The almost universal presence of the banded structure and the granular appearance of the serpentine are important criterian for the evaluation of the mode of origin of the serpentinite.

The granules of serpentine are of secondary origin and do not represent the shape and size of original constituents

Pyroxenite, Gabbro, Peridotite, Medium Serpentinite.

Progressive granulation of pyroxene grains can be studied starting from unaltered pyroxenite into serpentinite. A large pyroxene crystal, if it does not develop secondary cleavage, will become fractured across the cleaveges until an eventual granular rock with roughly even grain size results. This granulation does not increase evenly into the orebody but is developed more intensely in certain zones. These zones become more frequent as the serpentinite is approached. In certain zones the fractures are closely spaced and resemble a pseudocleavage.

This type of granulated rock provided passage to hydrothermal solutions and replacement of the pyroxene by serpentine along the fractures and cleavages eventually produces the banded rock.

Light Serpentinite: In this rock the banding is not produced by alternating bands of chrysotile and antigorite, but by alongation of the grains. The structure of the serpentine from this rock is thus distinctly different from that of the medium serpentinite, The marked increase of Mg in this body (see fig. 6) also shows a change in chemical composition between the rocks. Due to lack of evidence to the contrary it has conventionally been assumed that this core represents an original dunite and that the serpentine was derived from an olivine. Its granular nature is, however, secondary, and is due to granulation of originally larger olivine grains.

Although no petrofabric work was done it is quite obvious that the universal banding is due to the operation of directed stresses. Such a study would reveal interesting information as to stress directions. Fairbairn (1943 p. 1320) shows that tensile stress would tend to favour conversion of antigonite to chrysotile, i.e.a. form with more open structure. In a mass of rock undergoing serpen-

serpentinisation the fractures and cleavages represent areas of low stress, and hence chrysotile would tend to develop such cleavages and fractures in preference to antigorite. During this stage also the grains would be alongated at right angles to the stress, If the rock mass had been moving at this stage the elongation could have been produced by rolling of the grains producing a B-tectonite type rock. The directions of banding and elongation of grains are in all probability parallel to the length of the sill.

Relation of medium serpentinite to light serpentinite , Development of Asbestos

Hess (1948 p. 432) states: "Peridotite intrusions in mountain built belts are an important tool because of their histoties of loci and intrusion. Peridotites of the ultramafic suite occur in all Alpine mountain systems and nowhere alse. They occur in two great belts about 50 miles on either side of the original tecto-gene axis and less commonly in the area between the two balts. They are intruded during the first great deformation of the belt, probably during buckling of the crust, and later deformations of the same belt are not accompanied by intrusions of peridotite."

Satterly's map of the Abitibi peridotite belt shows the relationship of the various ultrabasic intrusions to the main fault trends of the region. The elongation of these intrusion is parallel to the strike of the faults, and many are cynclinal in shape. The lineation of the Arains of serpentine in the serpentinite is suggestive of intrusion of the sills into an active zone of thrusting similar to the ophiolite intrusions of the Alps. Dips of the major faults in the area are not stated in reports and it is quite probable that further investigations would reveal that thrusting was operative on a large scale, and that some of the sills are typidal ophiolite intrusions. The synchinal belts may even represent folded thrusts.

The emplacement of the Munro sill is disualised as follows:

1) Initial intrusion of a pyroxene-rich magma along a thrust zone and fracturing of the rock as it solidified. Auto-metamorphism of the pyroxenite by solutions derived from cooled magma. While cooling, gravitative differentiation of the magma took place to give the gabbroic bands above pyroxenite this initial intrusion could not have been at a very high temperature as there is a noticeable lakk of any metamorphism in the volcanics, except where fracturing provided channelways for movement of solutions. Since there are no granitic masses near the orebody the source of the hydrothermal solutions causing the metamorphism is regarded as the magma itself. This autometamorphic origin for the serpentine follows the principle that the 'ultrabasic stews in its own juice' own advocated by Benson (1918). Bowen and Tuttle (1949 p. 457) state that the solutions originates from acid intrusives and this view ia also held by Du Rietz (1935)

for the serpentinised masses in northern Sweden, Wiik (1953 p. 36) sums up the various views for the origin of the solutions by saying "Geologists represent either the one or the other opinion depending on the presence or lack of acid intrusives in the area investigated by them".

The extent of this initial serpentinisation in mot known but was probably not greater than say 50%, as the magma could not have contained sufficient water to effect total serpentinisation. Cooling of this initial phase would start from the margins inwards.

2) While still in the plastic state an olivine-rich fraction was intruded into the central part of the sill as irregular bodies which became serpentinised. Riordan (1952) has stated that the serpentinisation of a dunitic mass enriches the remaining fluid inMgo. This fluid then penetrated cracks in the partially serpentinised pyroxene-rich rock and effected the serpentinisation of the remaining portions not serpentinised initially. The central part of the sill thus remained at a high temperature for a relatively longer period than the margins.

The asbestos veins developed directly as a result of this second phase of serpentinisation accompanying the instrusion of the dunite dores. Riordan (1952 p. CLXIV) has stated that the conversion of antigorite to chrysotile is produced by cooling and contraction of the walls of the veins of serpentine produced during the late stage serpentinisation, and that this contraction produces a relief of stress, the antigorite adjusting itself to the change by converting to chrysotile. This conversion needs an initial high temperature to produce the necessary contraction on cooling to provide the release of stress. It is significant that most of the asbestos in the mine is present either in the light serpentinite or immediately adjacent to the light serpentinite bodies, showing that this portion must have remained at higher temperature longer than the rest of the sill. From the core outwards there is also a decrease in the width of the green serpentine bands immediately adjacent to asbestos veins, and Cook (1937a p. 109) has observed the same condition in the Eastern Townships orebodies. Riordan (1952) cites as this as evidence of lesser temperature conditions prevailing at the margins. In some instances on the south side of the sill there is no zone of secondary alteration round asbestos veins. Nearer the core the proportion of green serpentine to medium serpentine increases until eventually the whole rock becomes green. This is taken as evidence that the hydrothermal solutions producing the secondary serpentinisation and formation of asbestos originated from the granular core and spread outwards.

7. TALC-CARBONATE ROCK

The eastern end of the orebody is occupied by a half-moon shaped body of talc-carbonate rock which plunges under the serpentinite like the keel of a boat. The contacts of this rock with the serpentinite are gradational. A moderately carbonated serpentinite in hand specimen is black with grey areas. Occasionally alternating bands of serpentine, talc and carbonate are produced, the bands being of the order of 1/8" in width. Very minor carbon ation produces no megascopically determinable features in the serpentinite. The rock genetally has a schistose appearance, and is iron stained along fractures. (Plate XXX)

Hendry (1951 p. 52) gives the following analysis for a typical talc-carbonate rock from the east end of the ore-body.

Si 02	31.50%
Fe2 03 + Al2 03	16.00%
Ca 0	Trace
Mg 0	31.95%
Mn 0	0.40%
Loss on ignition	19.30%
Total	99.15%

A modal composition as determined by a Rosiwal count gives---

Talc	47%
Carbonate	44%
Chlorite	9%
Total	100%

Magnetite is present sparingly with occasional concentrations into streaks or bands but is generally less than 1% of the total.

The figures for the chemical analysis given by Hendry agree remarkably well with those given by Riordan (1952p.

PLATE XXX

Talc-carbonate rock. 950' level
looking SW. Note faintly schisto-
se appearance of the rock.
Nov. 1953.

LXXXVI) for the talc-carbonate rock of the various in the Eastern Townships and with certain analyses of soapstones, given by Wiik (1953 p. 48-55) from various parts of the world. Such rocks thus undoubtedly have a similar origin. Wiik (p. 46) has designated a rock consisting of talc + carbonate + chlorite + accessories, a Carbonate Carbonate Soapstone.

Description: In thin section, the rock is seen to contain approximately equal amounts of talc and carbonate with occasional patches of chlorite.

The talc is present in masses consisting of an interlocking mesh of minute (0.01 mm) brightly polarising blades and laths with no stinct preferred orientation. In this, subhedral crystals of carbonate (magnesite and or dolomite) averaging 0.5 mm in diameter are scattered singly or in groups, Only powder diffraction patterns would give the proportions of magnesite to dolomite, but following Riodan the name breunnerite would be most suitable for the carbonate (Winchell 1933 p. 75) The chlorite present was not identified optically but is the same type. as that found in some of the other rocks. It occurs in radiolitic aggregates which polarise with a dark olive-green colour. Wiik (1953 p. 38) has stated that no chemical analyses of chlorites found in soapstones have yet been made, and moever the optical properties of chlorite are not reliable in deciding the chemical composition. There is little doubt, however, that the Al_2O_3 present is tied up in the chlorite molecule. There seems to be no special reason to assume that this aluium, now incorporated in the chlorite structure, has been introduced into the soapstone in the process of steatitisation. The alumium content found in soapstones can be more readily interpreted as beloning to the composition of the original rock was subjected to alteration.

Origin: Serpentine may be converted to lalc and magnesium carbonate by introduction of CO2. Wiik (1953 p. 42) gives the following reaction equation, at constant volume to show conversion of serpentine to talc and carbonate.

2 Serpentine +7 Co2 --> 0.83 Talc + 7 Magnesite +1.33 sio2 (removed) + water

Reaction product:	Talc	52% by weight
	Magnesite	48% by weight

A similar equation--

$$2\ Mg_6Si_4O_{10}(OH)_8 + 6\ CO_2 \rightarrow Mg_6Si_8O_{20}(OH)_4 + 6\ MgCO_3 + 6H_2O$$

(Serpentine) (Talc) (magnesite)

has been given by Turner (1948 p. 132), but the constancy of volume for Wiik's reaction is somewhat more accurate. Steatitisation does not follow the general trends of the reactions strictly, however, due to the presence of Al, but as long as the chemical composition of chlorite in soapstone is not known, the formation of this mineral in the steatitisation process cannot be illustrated by accurate reaction equations.

PLATE XXXI

Moderately carbonated medium serpentinite. 915' level, north side pit east end. Shows seroentine grains replaced margi nally and in the centre by talc (needle-like clusters) and carbonate (rough grey-white). Note that the rock still preserves a banding. Crossed nicols X 45

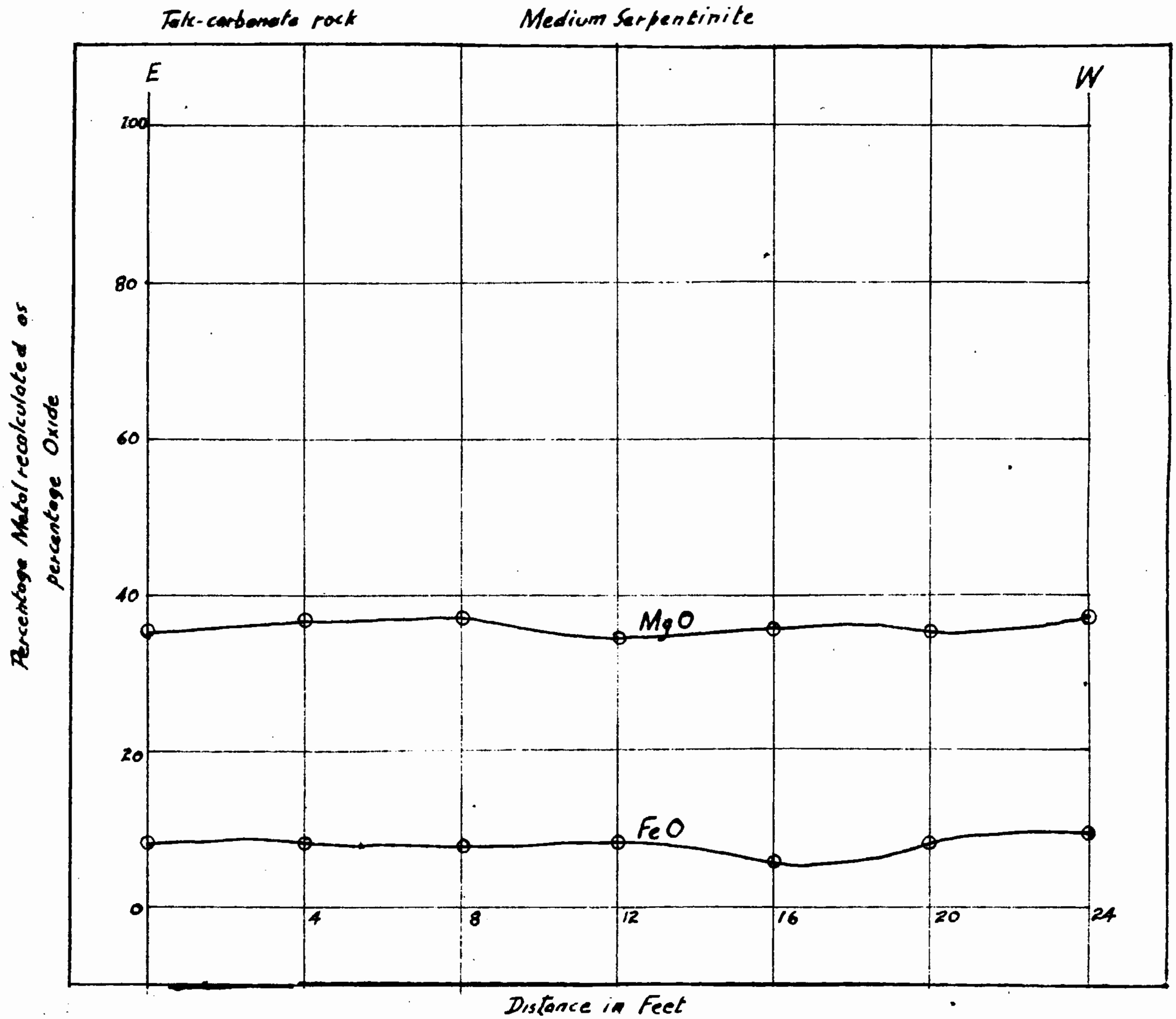

Talc-carbonate rock
Medium Serpentinite
E
W
100
80
60
40
20
0
MgO
FeO
4
8
12
16
20
24
Percentage Metal recalculated as percentage Oxide
Distance in Feet

FIG. 7.

In attempting to trace the chage, or probable, change of composition of a serpentine going over to a talc-carbonate rock, seven specimens taken over a contact between the two rocks on the 915 foot level at the northeastern end of the orebody, were partially analysed for mg, and Fe in the Flame PHotometer. The following is a table of the analyses which are plotted on fig (7) in terms of percentage of oxides of the metals. From top to bottom the sampled were taken from moderately carbonated serpentinite (Plate XXXI) into unaltered serpentinite.

Spec No.	MhO	FeO
40	35.56	8.20
41	36.65	8.60
42	37.38	8.60
43	35.97	8.90
44	36.65	6.00
45	36.14	8.70
46	37.80	9.80

As can be seen from the figure and from the table. there is no significant change in the composition of the rock The equations indicated previously demand that a certain proportion of material be removed from the rock th the conversion of a pyroxene or serpentine to soapstone. The material removed is silice and magnesite (Wiik p. 44 since the amount of magnesite required by the equations is generally higher than that found in the soapstones.

The silica that is removed should be persent somewhere in the form of quartz but was not seen in the talc-carbonate rock. Hess (1933a) has reported clumps of chalcedony in soapstone which may well represent this silica. It is thought by the author that many of the quartz veins in the surrounding volcanics are probably formed from this liberated silica. The removal of silica and magnesium carbonate will make the volume of the rock remain constant during the alteration process.

SUMMARY AND CONCLUSIONS.

In this thesis the serpentinites and associated basic and ultrabasic rocks of the 'A' orebody portion of the southernmost portion of Munro township have been described structurally and petrologically, and ideas on their origin based on thin section study and some chemical analyses have been presented. A description of Munro township and an outline of the geology of the Munro 'A' orebody based on previous reports and on work done on the mine by the writer are included to give the reader a general idea of the regional geology and the mine geology respectively.

The writers conclusions are listed below in tabular form:

(I) The gabbro, pyroxenite and serpentinite of the Munro 'A' orebody are part of a differentiated sill

(II) The sill has a steep dip to the north.

(III) Cross and strike fractures are of two ages; pre-ore and post-ore, which are closed and open respectively.

(IV) The diabase dikes are later than serpentinisation and steatitisation.

(V) Shorter asbestos veins trend with the length of the orebody, larger veins are predominantly horizontal. Veins with intermadiate strikes are subordinate.

(VI) The northern band of pyroxenite is part of the sill due to the presence of micropegmatite.

(VII) Patches of hornblendite have develop in the pyroxenite due to a process of metamorphic differentiation which leads in exreme cases, near fractures, to the formation of a talc-tremolite schist.

(VIII) Where sufficient channelways have been present for migration of hydrothermal solutions, the dacite has altered to matagabbro.

(IX) Most of the plagioclase of the gabbro and metagabbro has alteres to zoisite.

(X) Progressive alteration of pyroxenite to a banded serpentinite has taken place from north to south in the sill. Absence of indications of former olivene in the rocks, has suggested to the writer that the banded medium serpentinite is derived from a pyroxenite and not a peridotite.

(XI) The granular light-green serpentinite core of the sill is assumed convertio nally to have been derived from a dunite.

(XII) The granular appearance and the banding of the medium and light serpentinites are assumed to be due to directed stresses, and it has tentatively been suggested that the sill may represent an ophiolite type intrusion along an active thrust plane.

(XIII) Serpentinisation has been autometamorphic and in two stages. An initial partial serpentinisation associated with concentration of volatiles from the cooling pyroxenite with subsequent fracturing, and a second associated with intrusion of the dunitic core from which solution rich in MgO completed serpentinisation and filled the fractures with antigorite, which on release of stress with cooling reverted to the stable form chrysotile.

(XIV) The talc-carbonate rock derived from alternation of serpentinite by addition of CO_2 and water from the cooling serpentinite.

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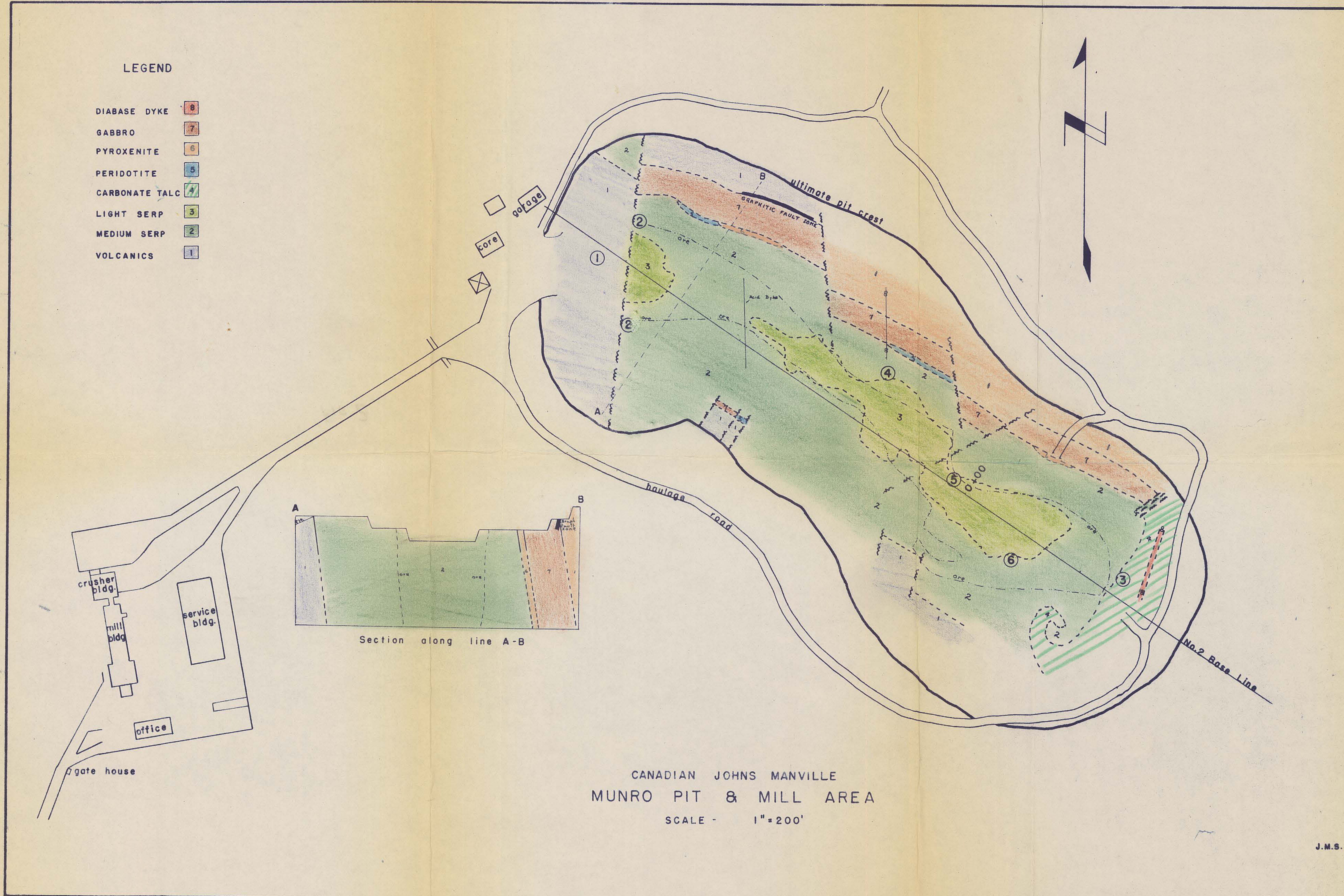
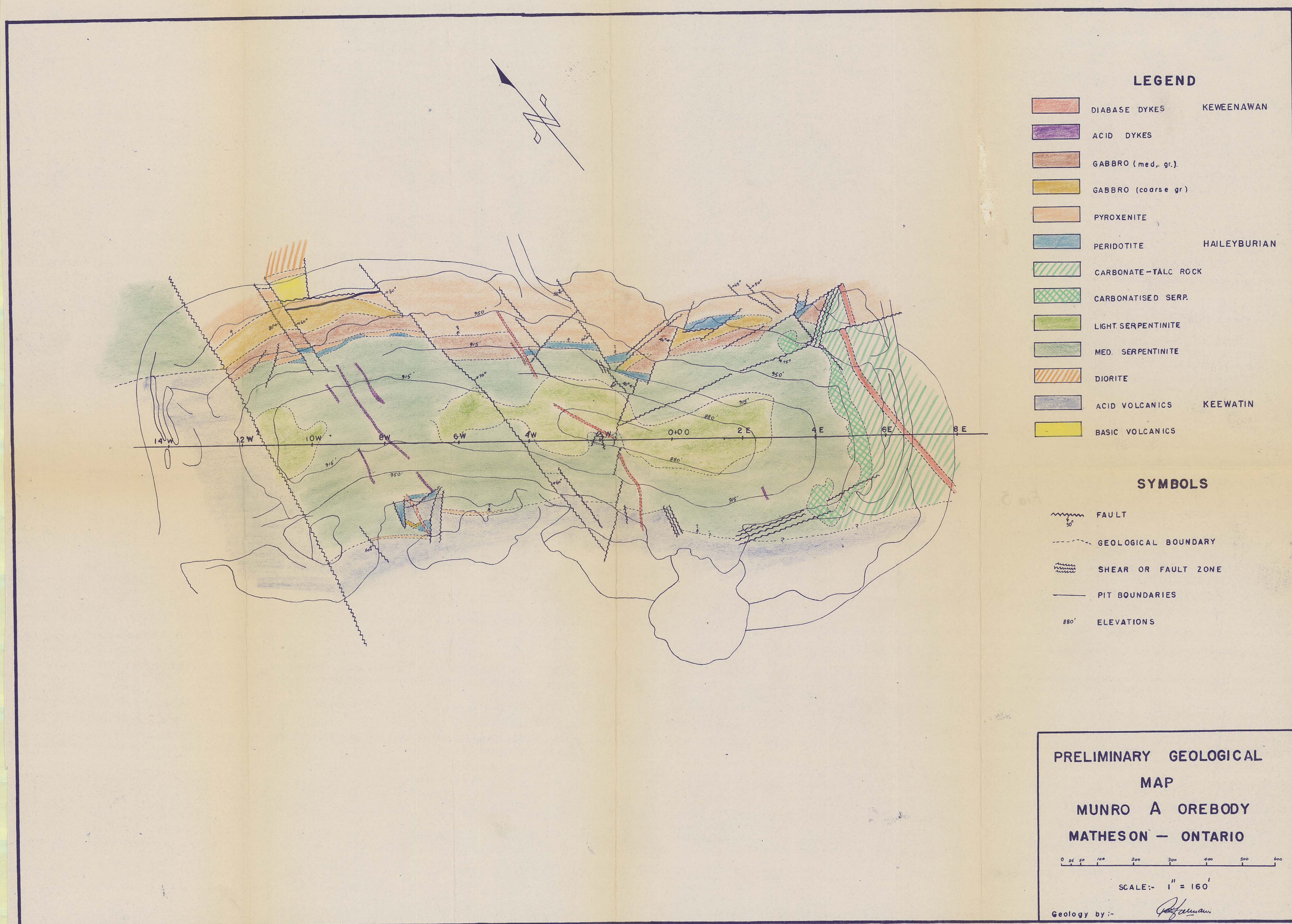


CANADIAN JOHNS MANVILLE

MUNRO PIT & MILL AREA

SCALE - 1" = 200'



LEGEND
DIABASE DYKES
KEWEENAWAN
ACID DYKES
GABBRO (med. gr.)
GABBRO (coarse gr)
PYROXENITE
PERIDOTITE
HAILEYBURIAN
CARBONATE-TALC ROCK
CARBONATISED SERP.
LIGHT SERPENTINITE
MED. SERPENTINITE
DIORITE
ACID VOLCANICS
KEEWATIN
BASIC VOLCANICS
SYMBOLS
FAULT
GEOLOGICAL BOUNDARY
SHEAR OR FAULT ZONE
PIT BOUNDARIES
880' ELEVATIONS
14 W
12 W
10 W
8 W
6 W
4 W
0+00
2 E
4 E
6 E
8 E
950'
915'
880'
PRELIMINARY GEOLOGICAL MAP
MUNRO A OREBODY
MATHESON — ONTARIO
0 25 50 100 200 300 400 500 600
SCALE:- 1" = 160'
Geology by :-

CANADIAN JOHNS - MANVILLE CO. LTD.

GEOLOGY MAP
MUNRO "A" ORE BODY

MUNRO TWP., DISTRICT OF COCHRANE, ONTARIO
SEPTEMBER 1953 SCALE - 1" = 50'

SYMBOLS

- Fault, defined
- Fault, assumed
- Slip
- Shear Zone
- Fibre vein
- Carbonate vein (cb.)
- Lava flow, pillows
- Medium grain (m.)
- Coarse grain (c.)
- Outcrop
- Geological boundary, defined
- Geological boundary, assumed
- Crest of bench (880' 880')
- Plane table station
- Grid Control (10,200 N)

LEGEND

KEWEENAWAN	Diabase Dyke	11
	Acid Dyke	10
	Gabbro	9
	Pyroxenite	8
HAILEYBURIAN	Peridotite	7
	Carbonate Talc Rock	6
	Light Serpentinite	5
	Medium Serpentinite	4
	Diorite	3
KEEWATIN	Acid Volcanics	2
	Basic Volcanics	1

NOTE -
PIT OUTLINE ACCURATE AS
OF OCTOBER FIRST 1953

GEOLOGY - P.V. FREEMAN

PLANE TABLE - J.M. SHARRATT

J.M.S.

MUNRO "A" ORE BODY

GEOLOGICAL CROSS SECTION

at

8+00W No2 Base Line

Scale 1" = 50'

October 1953

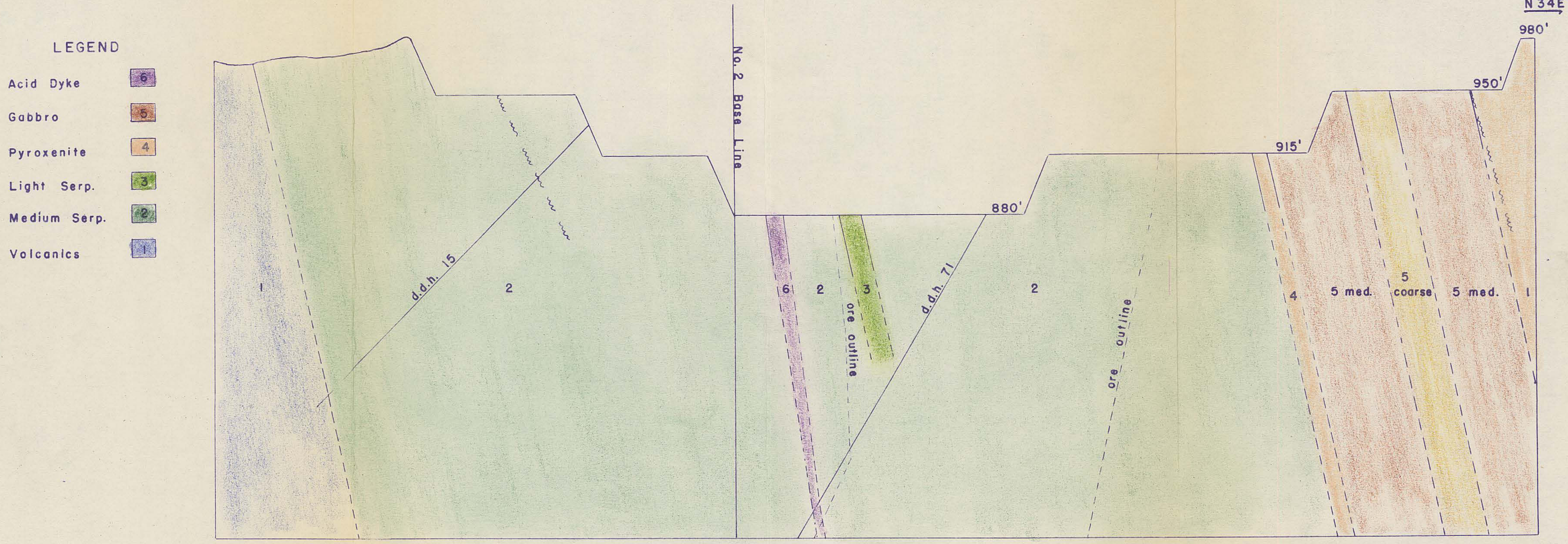


Fig. 5 (a).

j.m.s.

FIG. 5 (b).

LEGEND

Diabase Dyke	7
Gabbro	6
Pyroxenite	5
Peridotite	4
Light Serp.	3
Medium Serp.	2
Volcanics	1

MUNRO "A" ORE BODY

GEOLOGICAL SECTION
at
4+00W No. 2 Base Line

OCTOBER 1953

SCALE 50' = 1"

j.m.s