THE PETROLOGY OF THE SERPENTINE BODIES

in the

MATHESON DISTRICT,

ONTARIO

by

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Submitted in partial fulfillment of the requirements for the

Degree of Doctor of Philosophy, McGill University, February 1955.

ABSTRACT

East of Matheson, District of Cochrane, Ontario, a group of basic and ultrabasic rocks, classified as Haileyburian (?) in age, intrude Early Precambrian volcanic rocks. In most places they are sills but in a few localities are discordant plutons. Both rock types are folded together.

Strike faults, trending easterly, and cross-faults, trending northerly, are common in the area.

Two lithologic associations are present in the Haileyburian (?) rocks: Type I· Quartz gabbro-diabase, gabbro-diabase and interbanded peridotite and pyroxenite. Type II Quartz gabbro-diabase, gabbro-diabase and dunite or peridotite with minor amounts of pyroxenite. In a few places gabbro-diabase, dunite or peridotite are present without the other rock types. In both types the basic rocks lie stratigraphically above the ultrabasic rocks.

The contacts between the Haileyburian (?) rocks and the volcanic rocks are sharp and there is no thermal metamorphism of the host rocks.

Within the Haileyburian (?) rocks there are no convincing intrusive relationships, nor are there any chill contacts. Contacts are commonly sharp but some are gradational. The bands range from 1 foot to 300 feet in thickness. In some of the gabbro-diabase the plagioclase crystals are oriented parallel to the intrusive contacts.

The banding in the ultrabasic rocks is attributed to flow of a crystal aggregate and the same process was probably responsible for the banding in the basic rocks. However, if the volcanic rocks were horizontal when the intrusive rocks were emplaced, some of the banding in the basic rocks may be due to gravity stratification. Although proof is lacking, the volcanic rocks were probably inclined during the intrusive period.

The gabbro-diabase has a basaltic source and the ultrabasic rocks an ultrabasic source, probably the earth's peridotite shell. The pyroxenite is probably derived from the peridotite by a filter pressing action. The residual material is the dunite.

The superposition of the gabbro-diabase is attributed to prior intrusion. The interval between the intrusion of the basic and ultrabasic materials is geologically short. The intrusions probably occurred early in the orogenic history of the area and in each case consisted of a crystal aggregate with only sufficient liquid to permit mobility.

Serpentinization is confined to the peridotite and the dunite and the olivine of these rocks, with the exception of a few grains, has completely altered to serpentine. The serpentinization probably occurred before the emplacement of the peridotite and dunite masses. Water required for this reaction may have been acquired, at least in part, from the wall rocks.

Chrysotile fibres of which there are two types, cross-fibre and slip fibre, are present in some of the peridotite and dunite.

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INTRODUCTION

The present study is concerned with the description and petrogenesis of a group of basic and ultrabasic intrusive rocks in the District of Cochrane, Ontario. It includes descriptions of localities where exposures are good or considered to be petrogenetically significant and petrographic descriptions of the intrusive rocks. Comparisons are made with other basic and ultrabasic rock occurrences.

Mapping, 1 inch = 800 feet, was carried out under the direction of Dr. J. Satterly during the summers of 1949, 1950 and 1951 in Harker, Munro and McCool townships, while employed by the Ontario Department of Mines. Some localities were mapped in greater detail. Mapping was done by conventional traversing and on aerial photographs. Examination of critical localities throughout the area and the collection of rock specimens was made during 1951.

LOCATION

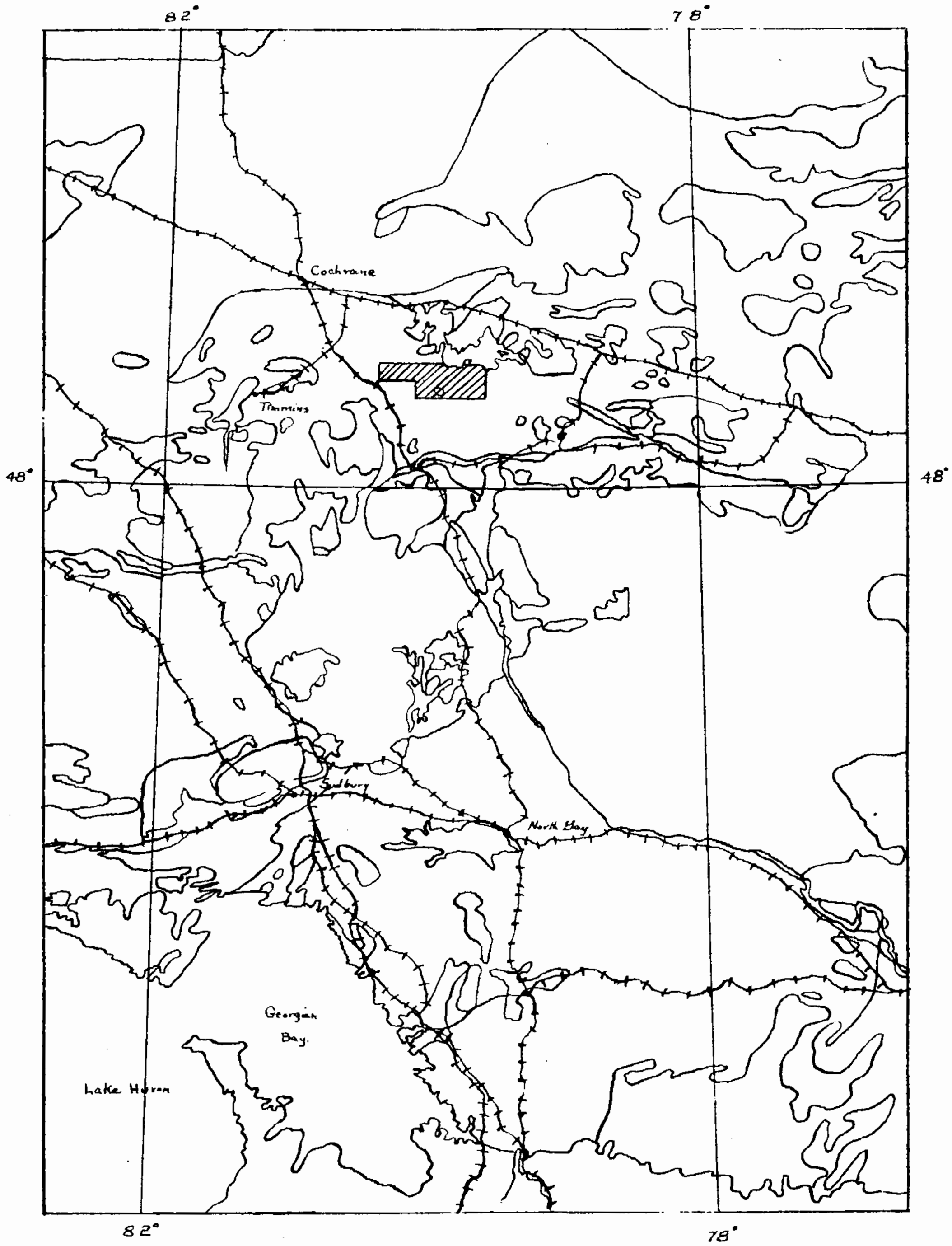
The region dealt with in this report extends eastward from the town of Matheson, Ontario almost to the Quebec border, a distance of 43 miles. Within this region the basic and ultrabasic intrusive rocks occur in a rectangular area bounded by latitudes 48°27'N and 48°36'N and by longitudes 79°40'W and 80°25'W. Known outcrops are chiefly in Beatty, Munro, Warden, McCool, Garrison, Harker and Holloway townships.

ACCESS

The area is easily reached by a railway and several roads. The town of Matheson is on the Ontario Northland Railway 206 miles north of North Bay and on Provincial Highway No. 11, 430 miles north of Toronto. A gravel highway, No. 101, extends eastward from Matheson to halfway across Holloway township. The eastern extension of the intrusive belt can also be reached by a road in the Province of Quebec that extends as far west as the Ontario-Quebec boundary line.

Gravel roads branch from Highway No. 101 at irregular intervals. Many narrow winding roads, suitable for auto transportation, occur where the surface deposits are sandy, but where the surface deposits consist of lake clays, roads are fewer and impassable for most vehicles. There are also a few tractor roads in the clay areas. All these roads are shown on maps of the Ontario Department of Mines. The scarcity of lakes and navigable streams necessitates overland foot travel where roads are absent.

PLATE I



1 inch = 60 miles

Location of the area.

PREVIOUS GEOLOGICAL WORK

The history of geological investigation in the area dates back to 1908 when Baker (1909) made a reconnaisance survey of Lake Abitibi and described the rocks south of that lake. Baker was the first to mention the presence of ultrabasic rocks in the region. Burrows (1912) mapped Guibord township and a part of Munro township. In 1911 and 1915 Hopkins (1915) mapped Beatty, Munro, parts of Warden and Coulson townships on a scale of 1 inch to 1 mile. He reported the presence of serpentine in several places within the map-area. It is interesting to note that he described an occurrence of chrysotile in lot 11, concession II, Munro township and recommended (p.176) that: "This area might be worthy of investigating as a source of asbestos". Over thirty years passed before active exploration for asbestos was undertaken in the area.

All early prospecting in the area was for gold. Several showings were discovered in 1914 in Munro and Guibord townships. One of these prospects was developed into the famous Croesus gold mine in lot 10, concession I, Munro township. The spectacular native gold in this mine was soon mined out. In 1919, a report on the many small gold prospects in the area was made by Knight and others (Knight et al, 1919). Knight's report and map (1 inch = 2 miles) included the entire are of the present study. Knight and his associates were the first to make any systematic study of the rocks of the area.

Gold showings were discovered in 1924 in Harker and Holloway townships. The increase in activity, stimulated by these discoveries, resulted in two further geological investigations, one by Knight (1924) and the other by Gledhill(1925). However, neither of these men studied the basic and ultrabasic intrusive rocks in detail.

Activity lagged until 1946 when Martin (1946) postulated an eastward extension of the Procupine fault through Michaud and Garrison townships and proposed a subdivision of the Early Precambrian sedimentary and volcanic rocks of the district. As a result of Martin's work, large areas were staked and much diamond drilling was undertaken, particularly in Garrison township. Because of the renewed interest in the gold occurrences of the district and the widespread staking, the Ontario Department of Mines began a mapping program in 1944 in Beatty township.

Six townships have been mapped at 1 inch to 1000 feet and reports and maps have been published for the following townships: Beatty (Satterly and Armstrong, 1947), Michaud (Satterly, 1948), Garrison (Satterly, 1949), Harker (Satterly, 1951a), Munro (Satterly, 1951b), and McCool (Satterly, 1952).

Asbestos failed to attract any interest until 1949 when Canadian Johns-Manville Company Limited developed the Munro mine on a group of claims in Munro township. The success of this operation led to much prospecting for asbestos from Beatty township eastward to Holloway township.

ACKNOWLEDGMENTS

The writer is indebted to Dr. J. Satterly of the Ontario Department of Mines for much assistance and encouragement in the field. Dr. Satterly also made available many thin sections for study.

Thanks are extended to Mr. N. W. Hendry and H. L. Garvie of Canadian Johns-Manville Company, Limited for permission to examine drill core and rock exposures on company property in Garrison township. Mr. R. V. Ransom of Asbestos Corporation, Limited kindly permitted examination of company drill core in McCool Township.

Mr. Nelson Hogg, formerly resident geologist for the Ontario Department of Mines in Timmins, graciously loaned the writer several thin sections and drill cores.

The writer is grateful to the staff of the Department of Geological Sciences of McGill University and especially Dr. J. S. Stevenson for advice and constructive criticism during the preparation of this thesis.

Dr. E. R. W. Neale and Mr. T. O. H. Patrick read the manuscript and gave much valuable advice.

TOPOGRAPHY

The topographic features of the district have been extensively modified by glacial and post-glacial events. Most of the area is covered by varved clay. This clay-covered area is part of the "clay belt" of northern Ontario and Quebec. The clay was deposited in Lake Barlow-Objibway, the great pro-glacial lake which covered a large part of Ontario and Quebec in late Wisconsin time. The rock outcrops in this vast clay plain probably existed as a archipeligo in glacial Lake Barlow-Objibway. This is suggested by old shorelines that surround many of the outcrops. These shorelines are composed either of boulders and cobbles, or of gravel characteristic of rock outcrops with which the shorelines are associated. Some of the shorelines are very close to the tops of the more prominent hills proving that some of the outcrops were once covered by lake waters.

There are several north trending eskers in the area. They occur in Garrison, Michaud, McCool, Munro and Beatty townships. Commonly the eskers disappear under outwash sands but reappear on strike a mile or so away. Most of these eskers extend many miles north of the map-area.

Outwash sands are extensive in the district. They are particularly widespread in the eastern quarter of Munro township, the western third of McCool township, and the northern half of Michaud township. Smaller areas of outwash sands are present in Harker, Garrison, and Beatty townships. The larger outwash plains are "pitted" and show typical kame and kettle topography. Nearly

PLATE II

View from Hwy. 101 toward the Ghost Range fire tower showing the general flatness of the area.

all of the lakes in the district occupy kettles. In many places broad basins, irregular ridges and low hills are the most characteristic surface form of the outwash plains. Small "unpitted" outwash areas are dotted with large erratic boulders. These boulders are commonly granitic.

The outwash deposits, particularly those in Munro, McCool and Michaud townships, have been extensively worked by wind. Dunes were formed and subsequently stabilized by forest growth, principally jack pine. Some of the dunes have small lakes or muskeg areas on the concave sides.

In 1916 a fire destroyed most of the vegetation of the district leaving the sandy areas void of a protective covering. During the summer months renewed wind action modified some of the dunes. Recent regrowth of blueberries, sweet fern and relatively small jack pine has almost stopped the erosion.

Glacial striae are rare, those found being confined to valley areas. The trend of the striae observed is between 150° and 185° and averages 170°.

Several comparatively high rock hills occur in the area. The most prominent is the Ghost Range, elevation 1576 feet at the summit, on the Harker-Lamplugh township boundary. This land mark, which is over 500 feet above the surrounding territory, is almost five miles long and one mile wide. Several other hills, for example Centre Hill, Warden Hill and McCool Hill, are 250 to 300 feet above the average altitude of the area. The general flatness of the area is apparent when seen from the top of any one of these hills.

GENERAL GEOLOGY

All the bedrock of the district is of Precambrian age. The oldest rocks are sedimentary and volcanic rocks whose age relationship to one another has not been definitely established. In Beatty and Munro townships where the best exposures are available, the contact between the sedimentary and volcanic rocks is along a major strike fault that partially obscures their age relationship. Structural data show the sedimentary rocks south of the fault and volcanic rocks north of the fault both face north. This suggests that the volcanic rocks are the younger of the two

The sedimentary and volcanic rocks are cut by four groups of intrusive rocks. The oldest consists of a series of basic and ultrabasic rocks that have been assigned to the Haileyburian (?) by Satterly and Armstrong (1947) because of their cutting relationships and lithologic features. The sedimentary rocks, volcanic rocks, and basic and ultrabasic rocks are cut by lamprophyres, porphyries, syenite, granite and other silicic intrusives that have been classified as Algoman (?) by Satterly (1948). All of these have in turn been intruded by quartz diabase and diabase dikes of Matachewan (?) age. The latest intrusions are olivine diabase, quartz diabase and diabase dikes of Keweenawan (?) age. These dikes have a general northeast trend.

TABLE OF FORMATIONS

Cenozoic		
Pleistocene:	Post-glacial:	Peat, wind-blown sand.
	Glacial:	Sand, gravel, boulders, till, varved clay.
Unconformity		
Precambrian		
Keweenawan (?):		Quartz diabase, diabase, olivine diabase.
Matachewan (?):		Quartz diabase, diabase.
Algoman (?):		Granite, syenite, feldspar porphyry, quartz-feldspar porphyry, felsite, lamprophyre.
Haileyburian (?):		Gabbro-diabase, quartz gabbro-diabase, peridotite, dunite, pyroxenite, serpentine.
Volcanic Rocks:		Rhyolite, fragmental rhyolite; Andesite, basalt, fragmental basalt, tuff, chert, talc-chlorite schist.
Sedimentary Rocks:		Greywacke, arkose, quartzite, conglomerate, iron formation

PRECAMBRIAN

Sedimentary Rocks

The sedimentary rocks, probably the oldest in the area, consist chiefly of well-banded, interbedded, greywacke, quartzite, and arkose. Some pebble conglomerate has been found in drill core in Garrison township. A few narrow bands of iron formation outcrop also in Garrison township.

Greywacke sections include bands of quartzite and slate or argillite, 1 to 2 inches thick. There is no sharp division between the quartzite and slate, but rather a grain-size gradation from sand to clay.

The arkose beds, ranging in thickness from a few inches to 50 feet, are intercalated with the greywacke and the quartzite. The arkose consists of fragments of quartz, feldspar, sericite, chlorite and carbonate. The carbonate content varies considerably, especially close to and within fault zones.

Volcanic Rocks

Volcanic rocks are well-exposed in various parts of the area. Their general distribution is shown on the accompanying map. In the western part of the area the broad bands of volcanic rocks have an east-southeast trend that gradually changes to a trend slightly north of east in eastern Harker township.

The volcanic rocks are chiefly basic to intermediate in composition and commonly consist of a series of diabasic basalt flows. Most of the volcanic flows range in thickness from a few feet up to 200 feet and the average flow is about 100 feet thick.

Pillowed flows occur in some parts of the area. In some places very wide selvages, 3 to 4 inches wide, are formed around the pillows, whereas in other places the selvages are narrow and not so apparent.

Many good exposures of prominently spherulitic basalt flows occur in Beatty and southwestern Munro townships. A few scattered exposures are found elsewhere in the district. All the flows are not spherulitic throughout, some showing abrupt changes from a non-spherulitic rock at the bottom of the flow to spherulitic at the top. The spherulites average about $\frac{1}{4}$ of an inch in diameter, with many smaller and a few as large as 2 inches. They are greyish white on weathered surfaces and grey to greyish green on fresh surfaces. A gradation in size of spherulites from large at the bottom to small at the top of the flow was seen in Munro township.

Amygdaloidal textures are found in some pillowed flows and at the tops of some massive flows. Flow breccias are commonly well-preserved and serve to verify top determinations based on pillow structures.

A few porphyritic flows have been observed in Michaud, Garrison and Harker townships. The phenocrysts in these flows consist of yellowish white plagioclases from $\frac{1}{2}$ inch to 1 inch in diameter. Satterly (1949, P. 9) states that:

> " ***** it would appear that the feldspar crystals had accumulated either by "streaming" of intratelluric crystals or by some process such as fractionation during the crystallization of the flow."

The silicic volcanic rocks consist of rhyolite, rhyolite fragmentals and spherulitic rhyolites. They are green, white, grey, yellow and, in a few localities, black. They are very fine-grained, especially the spherulitic types. The fragmental rhyolites may be in part agglomerates. In some places, notably in Beatty township, the silicic and basic volcanic rocks interfinger.

Thin beds of chert are sporadically intercalated with the basic flows. These well-banded cherts are of various colours, the most common are white and green. They seldom extend for more than a few hundred feet.

Tuff and cherty tuffs have a restricted occurrence in Garrison township.

Haileyburian (?)

The basic and ultrabasic rocks of Haileyburian(?) age outcrop in several places in the area. The best exposures are in Munro, McCool, Garrison, northern Harker and southern Lamplugh townships. The rocks in this group include dunite, peridotite and their serpentinized equivalents, and pyroxenite, gabbro, diabase, and quartz-diabase or quartz-gabbro. Diorite had been reported from a few drill holes. The diabase intrusives of Haileyburian (?) age is very similar in appearance to the diabasic flows of the early Precambrian and it is possible that some small outcrops of diabase have been mapped as Haileyburian (?) rather than as volcanic rocks.

The Haileyburian (?) rocks are chiefly concordant, sheetlike bodies and, hence, may be classified as sills. In a few localities, however, they form discordant plutons and the term "sill" is not applicable. The contacts between the basic and ultrabasic intrusives and the volcanic rocks are commonly concealed by overburden. Where exposed, they are usually sharp. Metamorphism of the host rock is rare.

The basic and ultrabasic rocks occur in two distinct petrologic associations. One is quartz-gabbro or diabase with interbanded pyroxenite and serpentinized peridotite; the other is quartz-gabbro or diabase and serpentinized dunite or peridotite with very minor amounts of pyroxenite.

The best exposures of the first type occur on Centre Hill, Munro township and on the Warden-Munro township boundary in lots 5 and 6. Good examples of the second type are known in lot 6, concession V, Munro township and in both northern Garrison and Harker townships.

Detailed description of the occurrence and petrography of these rocks is given on pages 22 to 67 of this report.

Algoman (?)

Algoman (?) intrusives are not common in the western part of the area and the largest occurrences of these rocks are in the eastern part of the area in Michaud, Garrison and Harker townships. They consist chiefly of stocks of granite and syenite. Small dikes of feldspar porphyry, quartz-feldspar porphyry and felsite, probably related to the silicic stocks, are present throughout the area.

Lamprophyre dikes within the map-area have also been assigned to the Algoman (?) (Satterly, 1948).

Matachewan (?)

Quartz-diabase and diabase dikes that trend north or north-east are classified as Matachewan (?). These dikes are particularly abundant in Munro township. Here, their cutting relationships suggest three or more distinct periods of intrusion. However, similarity of lithology and structural trend suggests that all the dikes are closely related in absolute age.

The dike rocks are very similar megascopically to the Haileyburian (?) diabase and the diabasic lava flows. Chilled border zones are common. Aerial photographs show that many of these dikes occupy distinct valleys in outcrop areas. Others can be recognized on the photographs by their shades of grey in the lighter coloured outcrops. They vary in width along the strike from a few feet up to 400 feet, but most of them are about 100 feet wide. A rectangular joint pattern is common in the dikes. The joints are parallel and normal to the dike walls. In some dikes large plagioclase phenocrysts are present close to the dike walls.

The rock is either fine or medium-grained depending on the thickness of the dike.

Keweenawan (?)

Several diabase dikes trending approximately 70^{o} are mapped as Keweenawan (?). They cut the northerly trending dikes and are the youngest rocks in the area. These dikes range from a known maximum thickness of 600 feet to a minimum thickness of 75 feet. Some of the Keweenawan (?) dikes consist of olivine diabase and others are quartz diabase.

In some places narrow dikelets, from 4 to 12 inches wide, of fine-grained silicic rock, are found within the diabase. This rock probably represents a late silicic differentiate of the diabase. Microscopically, it consists of a micrographic intergrowth of quartz and feldspar. (Satterly and Armstrong, 1947, p. 14).

II

STRUCTURAL GEOLOGY

GENERAL

Although the widespread cover of glacial drift and the absence of key horizons within the exposed bedrock are obstacles to a detailed solution of the structural problems of the area, the broad structural features of the area are readily revealed by combination of geophysical, drill hole, and surface data. Attitudes of beds and flows exposed at the surface have been determined with the aid of brecciated flow tops, pillows, and grain size gradation.

FOLDING

Folds are common in the area. A large faulted syncline extends from northern Beatty township southeasterly into central Munro township. In Beatty township the axis of this fold is slightly north of Painkiller Lake. The volcanic rocks in northern Munro township face southward and are probably part of the north limb of the same syncline. Several smaller synclines and anticlines occur within the major syncline in both Beatty and Munro townships. Cross-faults have offset the smaller folds in several places.

Centre Hill and McCool Hill are underlain by folded basic and ultrabasic rocks. Top determinations on pillow lavas northeast of Centre Hill suggests an anticlinal structure in this region which plunges 70° to the northwest. Structural determinations at McCool Hill show a closed syncline plunging approximately 50° to the northwest. The relationship of these folds to the regional structure is not known.

A northwest trending syncline and anticline occur within a belt-like area of volcanic rocks in eastern McCool township. The limbs of these folds dip vertically.

FAULTING

The area has been broken into a great number of blocks of various sizes by complex faulting. Many of these faults are closely spaced so that only the more prominent ones are shown on the accompanying map. Greater detail is available from the township maps of the Ontario Department of Mines.

Two types of faulting are distinguished: strike faulting and cross-faulting. The strike faults form an east trending group. They are cut and offset by north trending cross-faults which have also displaced and offset formational contacts. Offsets are usually with the east side blocks moved northward.

Strike Faults

The major strike fault of the area is the Destor-Porcupine fault zone which extends from southwestern Beatty township across northern Michaud, Garrison and Harker townships. Its location has been principally determined by drilling and geophysical data supplemented by a few small outcrops of carbonatized zones in Garrison township. Extensive drilling in Garrison township shows that the fault zone consists of several parallel faults with blocks of unsheared material between them. Toward the eastern half of Garrison township the Destor-Porcupine fault zone may split into two zones with a block of sedimentary rocks between the two. The northern fault zone if probably a parallel strike fault. It is suggested that the two zones converge in eastern Harker township. The fault zone is up to 400 feet in width. The dip varies between 65° and 73° to the north. The amount and direction of movement on the Destor-Porcupine fault zone is not known. From scanty evidence in Garrison township, Satterly (1949, p. 15) suggests that the north side moved eastward with respect to the south side.

The fault zone material is chiefly green carbonate rock with associated quartz, but in some places it is talc-chlorite schist.

Another strike fault, roughly parallel to the Destor-Porcupine fault zone, forms the contact between the sedimentary rocks and the volcanic rocks in Beatty and Munro townships. The volcanic rocks are not deformed, but the sedimentary rocks are crumpled, crenulated and drag folded. Fractures, drag folds and crenulations suggest that the north side moved eastward with respect to the south side. The dip is probably vertical. The fault zone material is carbonatized sedimentary and volcanic rocks.

Strong shearing and carbonatization in the volcanic rocks of Beatty and Munro townships mark the position of a strike fault which trends northwestward across the two townships. This fault has been named the Painkiller-Munro fault (Satterly and Armstrong, 1947, p. 17; Martin, 1946). Satterly and Armstrong (1947, p. 17) state:

> "The fault surface is reported to dip 80°N. Observations underground by Hopkins show the latest displacement along the fault to have been about 800 feet, the movement being essentially horizontal. The north block moved southeast relative to the south block."

A possible extension of this fault through Perry Lake is suggested by drilling in Michaud and Garrison townships. It probably joins the Destor-Porcupine fault zone in Garrison township.

Cross-faults

Evidence for cross-faulting in the area is the offset of marker beds and formational contacts. The cross-faults are commonly expressed topographically by linear valleys, gullies and rows of bushes or trees. Most trend northeastward, but a few trend northwestward. The strike separations range from a few feet to 700 feet. Most of the cross-faults are vertical or nearly so, but a few have dips as low as 45° to either east or west.

III

DESCRIPTIVE GEOLOGY OF THE HAILEYBURIAN (?) ROCKS

As stated above (p.15), there are two distinct associations of basic and ultrabasic rocks.

Type I Quartz gabbro-diabase, gabbro-diabase and inter-banded pyroxenite and peridotite.(1)

Type II Quartz gabbro-diabase, gabbro-diabase and dunite or peridotite with minor amounts of pyroxenite. In some localities gabbro-diabase, dunite or peridotite are present without the other rock types.

These two distinct lithologic associations are treated separately below.

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(1) In this report the following definitions are used:

Dunite: a rock composed of at least 90 percent olivine, the remainder consisting of pyroxene, amphibole, and plagioclase and accessory minerals.

Peridotite: a rock consisting of 75 to 90 percent olivine with the remainder predominantly pyroxene or amphibole and accessory minerals.

Diabase: a rock composed of calcic plagioclase, pyroxene, amphibole and accessory minerals, characterized by an ophitic to sub-ophitic texture.

Gabbro: a rock composed of calcic plagioclase, pyroxene, amphibole and accessory minerals, characterized by a hypidiomorphic granular texture.

Gabbro-diabase: a rock intermediate in texture between a diabase and a gabbro and of the same composition. As most of the basic rocks are in this category, this term is frequently used.

TYPE I

(Quartz gabbro-diabase, gabbro-diabase and interbanded pyroxenite and peridotite).

The gabbro-diabase consists of a variable rock within the gabbro clan which may be fine- or coarse-grained. The finer grained varieties occur near the contact with the overlying volcanic rocks. Within the gabbro-diabase zone there are bands of hornblende-rich rock alternating with narrow bands of feldspar-rich rock. A zone of banded, amphibolitized diabase is present next to the underlying pyroxenite.

Beneath the gabbro-diabase, a series of interbanded pyroxenite and peridotite rocks are present. The pyroxenite in each band is similar except that feldspar is present in the band bordering the gabbro-diabase.

The peridotite of each band is also very similar, although grain size varies slightly in some bands. The basal band of peridotite is slightly darker weathering than the others.

Distribution

Type I occurs only in two areas. The greater part of each area is located in Munro township. The best exposure is on Centre Hill and has been called the Centre Hill Complex (Satterly, 1951, p. 19). This exposure forms a hill 300 feet above the general altitude of the area.

The only other exposure is along the Warden-Munro township boundary. The similarity of rock types in these exposures is unmistakeable. The Warden-Munro boundary outcrop area is not a prominent topographic feature. This may, in part, be due to the sequence of the rock types. On Centre Hill the gabbro-diabase is on the north edge of the outcrop area and the relatively soft ultrabasic rocks on the south side. On the Warden-Munro boundary the rock sequence is reversed, the ultrabasic rocks are on the north side of the outcrop and the gabbro-diabase is on the south side. Possibly, the advancing ice sheets of the Pleistocene eroded the Warden-Munro ultrabasic rocks more readily than the Centre Hill ultrabasic rocks which were protected by the gabbro-diabase.

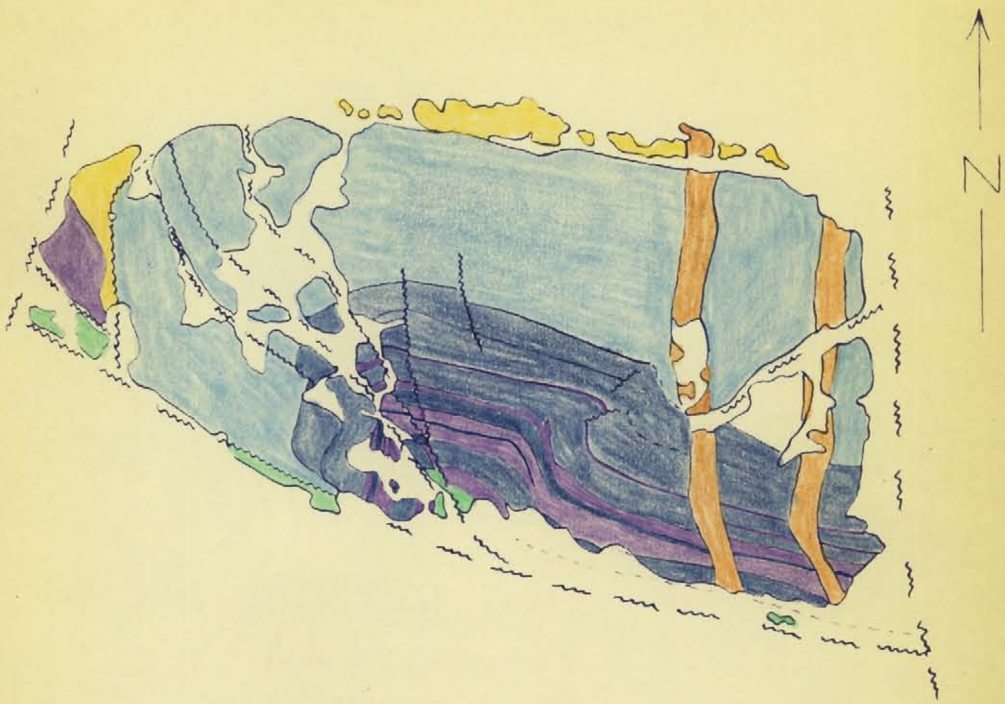
Centre Hill Complex

The Centre Hill Complex is exposed for 1,700 feet at the widest part and is 1,650 feet thick if the dip is 78° as it is along the pyroxenite-gabbro-diabase contact. The complex is folded and bounded on the north by rhyolite and on the south by basalt. Pillow structures in the basalts 400 feet northeast of the main outcrop prove that the fold is a west plunging anticline.

Most of the rocks exposed strike 110°. Dips of the various contacts show a gradual decrease from nearly vertical in the southernmost 500 feet to a minimum of 78° between the pyroxenite and gabbro-diabase, 677 feet from the south boundary of the complex. A similar variation is shown in the dip of the banding which occurs at various horizons. The lowest dip of the banding is 75°, 650 feet from the rhyolite-gabbro-diabase contact. The dip of the rhyolite-gabbro-diabse contact is not obtainable.

A section of the complex was chained along a picket line

PLATE III



Centre Hill Complex
Munro Township

Geology by J. Satterly, 1950 — 1" = 800'

Legend

- Diabase
- Gabbro - Diabase } Haileyburian (?) Rocks
- Pyroxenite } Haileyburian (?) Rocks
- Serp. Peridotite } Haileyburian (?) Rocks
- Basaltic Lavas
- Rhyolitic Lavas

400 feet east of the 6-7 lot line. The following sequence of rocks and their apparent thicknesses follows:

CENTRE HILL COMPLEX FROM SOUTH TO NORTH

Distance		Apparent Thickness	Approx. Actual Thickness	Rock Type	Contact
From	To				
-	--	-	-	Basalt	Sharp
0	1	1'	1'	Pyroxenite - fine-grained	Gradational
1	73	72'	72'	Peridotite - med. to coarse-grained	Gradational
73	181	108'	108'	Pyroxenite - fine-med.gr., foliated	Shart
181	223	42'	42'	Peridotite - coarse-grained	Sharp
223	235	12'	12'	Pyroxenite - medium-grained	Sharp
235	299	64'	62'	Peridotite - coarse-grained	Sharp
299	351	52'	50'	Pyroxenite - medium-grained	Sharp
351	382	31'	30'	Peridotite- med-coarse gr., banded	Sharp
382	503	121'	116'	Pyroxenite - medium-grained	Sharp
503	507	4'	4'	Peridotite - med-coarse grained	Sharp
507	677	170'	164'	Pyroxenite - med.-gr., feldspathic	Sharp
677	681	4'	4'	Gabbro-diabase - med.-grained	Gradational
681	765	84'	81'	Gabbro-diabase - foliated, some hbl-rich bands	Gradational
765	820	55'	53'	Pyroxenite - amphibolitized,chloritized	Gradational
820	1,139	319'	311'	Gabbro-diabase - coarse-grained	Gradational
1,139	1,240	101'	98'	Gabbro-diabase - med-coarse gr.	Gradational
1,240	1,339	99'	96'	Gabbro-diabase - med-grained	Gradational
1,372	-			Rhyolite	Sharp

The contacts between the intrusive complex and the intruded rock do not show any thermal effects of intrusion. The country rock is not "baked" and thin sections show no apparent change in the basic volcanic rocks. The rhyolites were not examined microscopically. Megascopically, they do not differ from other rhyolites of the area.

Two types of rock contacts characterize the Centre Hill Complex: gradational contacts and sharp contacts. The gradational contacts occur in the upper and lower parts of the complex, whereas the sharp contacts are common in the central part.

The contact between serpentinized peridotite and pyroxenite 73 feet from the bottom of the complex shows, on the weathered surface, a change in colour from pale reddish-brown to a very dark reddish-brown as the pyroxenite is approached. From the contact with the volcanic rocks to that with the pyroxenite, there is a continuous increase in grain-size. Maximum grain size is $\frac{1}{4}$ inch. A decrease in the content of reddish-brown weathered olivine is apparent in the colour of the pyroxenite which is normally a dark greyish colour. The average grain size of the pyroxenite is 1 mm. The contact is gradational over 6 feet. From south to north a gradual increase in the olivine content of the pyroxenite is apparent. This causes an increase in reddish-brown colour on the weathered surface.

A well-defined banding in the olivine-bearing pyroxenite is present at 157 feet from the base of the complex. The olivine content increases from approximately 10 percent to 75 percent at 181 feet. The banding in the pyroxenite continues for 6 feet into the peridotite. Veinlets of serpentine, up to 1/8 inch wide and 2 feet long are present in the peridotite.

The grain size of the serpentinized peridotite is variable but most commonly it is a coarse-grained rock. The serpentinized peridotite is characterized by a groundmass of serpentinized olivine grains within which there are scattered large grains of pyroxene. The pyroxene grains which are up to 1 inch in longest dimension, contain grains of olivine similar to those in the groundmass.

The contact at 223 feet is very different from the two beneath it. Here, the contact is sharp between the serpentinized peridotite and grey-green pyroxenite. There is no chill zone associated with either rock nor are there any intrusive characteristics. Similar contact relationships exist between other pyroxenite and serpentinized peridotite bands.

Some of the pyroxenite and serpentinized peridotite is banded. The banding is always parallel to the contact.

The pyroxenite at 507 feet is feldspathic and the feldspar content increases as the gabbro-diabase is approached. The change from feldspathic pyroxenite to gabbro-diabase is abrupt. No chilling is apparent and no intrusive characteristics noted. The rock is essentially a medium-grained diabase. In some places it is gabbroic in character.

The gabbro-diabase from 681 to 765 feet is foliated and a fluxion texture is common within it. The rock is chiefly light coloured and, therefore, dark bands composed essentially or hornblende stand out markedly. These bands are never more than 1 foot thick and are always parallel to contacts with the pyroxenite. A small amount of pyrite and quartz occurs as irregular veins within the foliated gabbro-diabase.

The pyroxenite from 765 to 820 feet is considerably altered and now consists almost wholly of chlorite. The original rock was probably a feldspathic pyroxenite which was amphibolitized and later chloritized. A few fragments of plagioclase (ca. An 48) are present. There is about 30 percent hornblende. Chlorite, most of it as radiating dark green bunches, forms 60 percent of the rock. Both the upper and lower contacts are gradational. Whether the contacts were gradational before chloritization is not known.

The remainder of the Centre Hill Complex consists of gabbro-diabase which varies from coarse- to fine-grained. The fine-grained varieties are close to the rhyolite contact. In places the texture is diabasic and elsewhere it is hypidiomorphic granular with all variations between the two. Changes in grain-size and texture are gradational.

Warden-Munro Complex

The Warden-Munro Complex lies across the boundary between Warden and Munro townships and is centred about lot 6. The complex is 1,500 feet thick and is similar to the Centre Hill Complex.

The south boundary of the Warden-Munro Complex is chiefly with rhyolite or rhyolite breccia, but in some localities, with basalt. Along this boundary typical gabbro-diabase is in contact with the volcanic rocks. Northward from the contact the rock changes quickly from fine-grained to coarse-grained. The coarse-grained rock has patches of feldspar- and hornblende-rich rocks within it. Two hundred and ninety feet from the contact the rock is foliated. The first evidence of banding within the gabbro-diabase occurs at this locality. The banding is the result of crystal segregation within the coarser grained gabbro-diabase. The bands show sharp boundaries with the surrounding rock. More banding, together with fan-like concentrations of hornblende in the gabbro-diabase, occur for an additional 100 feet northward. Individual grains within the hornblende fans are up to 18 inches long.

The southernmost band of pyroxenite is feldspathic and very similar to that on Centre Hill. Its contact with the gabbro-diabase is sharp and slightly more sinuous than the Centre Hill contact. There are no chill zones. This band of feldspathic pyroxenite is about 480 feet thick and within it are four narrow diabase bands or sills up to 3 feet wide. The diabase bands each consist of coarse-grained diabase with individual grains of feldspar and hornblende up to $\frac{1}{2}$ inch long. There are no chill zones within these narrow diabase bands. They are characterized by having coarse-grained zones near the walls and fine-grained near the core. In the northernmost band small inclusions of pyroxenite are present within the diabase. Toward the base of the pyroxenite band there is a feldspar-free zone for a short distance and then reversion to the more common feldspathic pyroxenite.

Beneath the feldspathic pyroxenite there are 7 bands of serpentinized peridotite and pyroxenite. A summary of their thicknesses is shown in the following table:

Pyroxenites and Peridotites of Warden-Munro Complex,
South to North

Thickness in feet	Rock Type	Contact Relations
30	Peridotite - medium-gr.	Sharp
2	Pyroxenite - medium-gr.	Sharp
110	Peridotite - med.- to coarse-grained	Shear 7 feet wide in peridotite.
80	Pyroxenite - medium-gr.	Sharp
200	Peridotite - medium-gr.	Sharp
5	Pyroxenite - medium-gr.	Sharp
200	Peridotite - medium-gr.	Sharp
	Basalt	Not seen

Modified after J. Satterly (1951b)

The pyroxenite and serpentinized peridotite in each place is similar to that exposed on Centre Hill. The basal contact was not seen. The total thickness of the Warden-Munro Complex is approximately 1,500 feet. The bands within the complex are variable in apparent thickness, partly because of cross-faulting. The true thickness varies also along the strike of any band.

Chrysotile veins are more common in the serpentinized peridotite of the Warden-Munro Complex than at Centre Hill. In the northwest corner of lot 5, concession VI, Munro township, these veins are both parallel and normal to the contacts with the pyroxenite and have vertical dips. The longest vein is 2 feet. The longest chrysotile fibres are in veins parallel to the contact. Fibres are commonly bent and split; they may be bordered by serpentine or may themselves border serpentine veins. The fibre is commonly quite harsh and brittle. Most of the chrysotile is between 1/16 and 1/8 inch in length. Very little magnetite is present in this locality.

TYPE II

The basic and ultrabasic rocks here described as Type II consist of quartz gabbro-diabase, gabbro-diabase and dunite or peridotite with minor amounts of pyroxenite.

The rock sequence in Type II is characterized by a sill of diabase of varying thickness, with a minimum thickness of 50 feet, overlying dunite or peridotite. Varying amounts of pyroxenite are commonly present between the dunite or peridotite and the gabbro-diabase.

The gabbro-diabase is similar to that in Type I and is commonly banded with feldspar-rich and hornblende-rich bands. The dunite is quite variable but a white weathered variety is the most typical. Dunite, brown on weathered surfaces, is also common and the two dunites grade into each other. The peridotite is not as distinctive as that in the Type I sequence. The pyroxenes in this Type II peridotite are neither as large nor as abundant as those in the Type I peridotite. The pyroxenite is only locally present, and where present lies between the dunite or peridotite and the gabbro-diabase. The interbanded pyroxenite and peridotite of Type I is not known to exist.

In some places gabbro-diabase bodies occur without associated ultrabasic rocks. Similarly, sills of dunite or peridotite may have no associated gabbro-diabase.

Distribution

Several outcrop areas of the Type II ultrabasic rocks are known. Perhaps the best-known area is in the vicinity of the Munro mine. The other well-known areas are in northern Garrison township (the Bird Group), and in northern Harker township (the Ghost Range). The McCool Hill exposure and a group of ultrabasic exposures in lot 2, concession IV, McCool township, also belong to Type II. With the exception of the Munro mine area, the writer examined all the above areas in varying degrees of detail.

Usually gabbro-diabase forms the most prominent part of the outcrop area. McCool Hill and the Ghost Range are essentially gabbro-diabase with more basic rock-types at the base of the hills. Much of the derpentinized dunite and peridotite is drift- or outwash-covered. Exposures of serpentinized dunite and peridotite are commonly limited to very small outcrops adjacent to the gabbro-diabase. Diamond drilling and geophysical surveys have provided much of the information on the serpentinized dunite and peridotite areas.

McCool Hill

In McCool township the contacts between pyroxenite, gabbro-diabase and serpentinized dunite are well-exposed along the base of McCool Hill, especially on the southern side. The complete series of rocks was not studied in detail but the contacts were examined for structures that could be used to establish relative ages of these intrusive rocks.

On the eastern end of the hill, the contact between gabbro-diabase and pyroxenite is exposed over a distance of 325 feet. This contact is characterized by tongue-like projections of pyroxenite into gabbro-diabase and gabbro-diabase into pyroxenite. This suggests the parent magmas of these two rock-types existed simultaneously,

PLATE IV

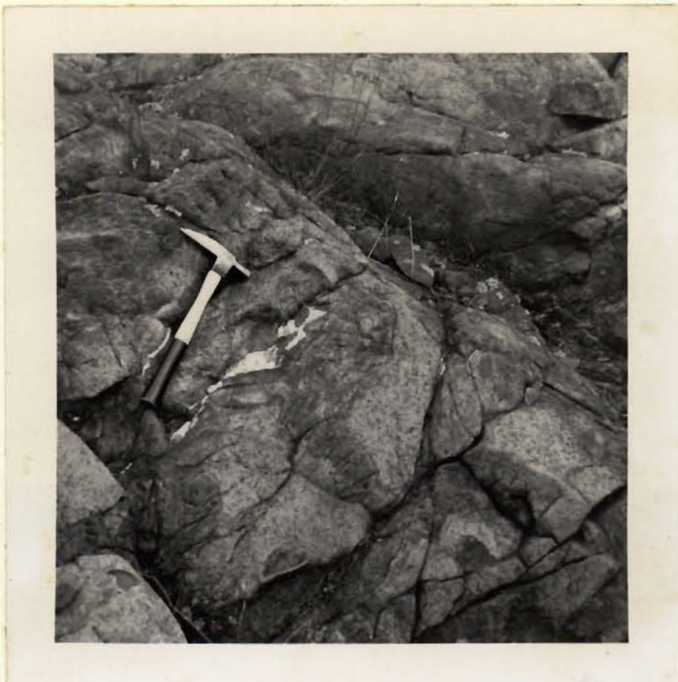


Fig. 1 Intertonguing pyroxenite, background, and serpentinized dunite. Note the tongue of pyroxenite to the right of the hammer. South side of McCool Hill, McCool township.

Fig. 2 Irregular contact between pyroxenite, background, and serpentinized dunite. South side of McCool Hill, McCool township.

PLATE V

Fig. 1 Serpentinized dunite with white weathered surface. Black spots are clots of magnetite. South side of McCool Hill, McCool township.

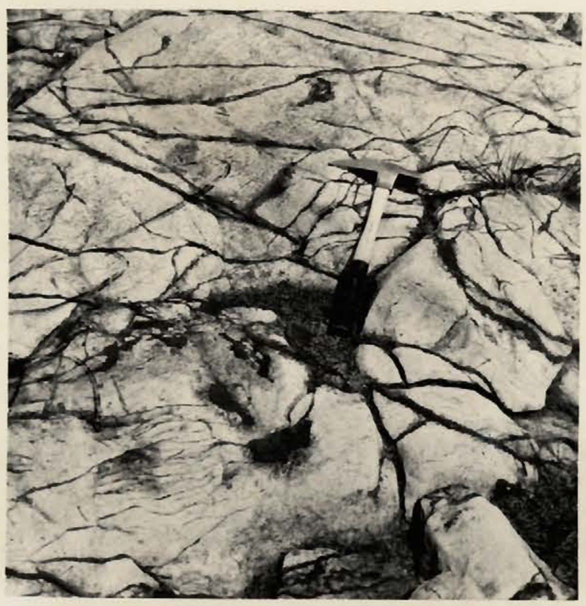


Fig. 2 Serpentinized dunite with white weathered surface. The veins are magnetite. South side of McCool Hill, McCool township.

at least in the contact zone.

Examination of thin sections of rock specimens taken across the contact shows the following grain-size relationships: (1) The pyroxene anhedra in the gabbro-diabase increased in size toward the contact, whereas the size of the plagioclase subhedra remains constant. (2) The pyroxene grains in the pyroxenite near the contact do not differ in size from those elsewhere in the pyroxenite.

The plagioclase (An 30) is identical in both. The specimens of pyroxenite taken within 10 feet of the contact contain approximately 10 percent plagioclase, whereas those specimens more remote from the contact less than percent plagioclase.

Slightly less than a mile farther west, the contact between the pyroxenite and a white weathered serpentinized dunite is exposed intermittently for a few hundred feet. This contact is very similar to the pyroxenite-gabbro-diabase contact with tongue-like projections of one rock into the other. There is no chilled border phase in either rock. A thin section across the contact shows the contact to be very sharp. It does not suggest that there was a transfer of material from one rock to the other. There are a very few serpentinized olivine grains in the pyroxenite. However, the pyroxenite normally contains small amounts of olivine.

Lot 2, Concession IV, McCool Township

In lot 2, concession IV, McCool township, the contact between pyroxenite and serpentinized dunite is well-exposed for 900 feet. A shear zone, 1 foot to 3 feet wide in the serpentinized dunite locally marks the contact. This shear zone does not extend into the pyroxenite.

The shear zone material is a schistose rock consisting of serpentinized dunite fragments in serpentine matix. Some of the dunite fragments are rounded. The serpentine is slickensided and the attitudes of the slickensides box the compass so that the direction of movement could not be determined.

Veinlets of serpentine are common. Most of them are normal to the shear zone or contact. One veinlet of serpentine extends from the serpentinized dunite into the pyroxenite for 4 feet.

Adjacent to the shear zone the serpentinized dunite is greyish white on weathered surfaces. It contains serpentinized olivine grains averaging 1/8 inch in length. On fresh surfaces, the rock is very dark green with a few grains of pale green serpentinized olivine scattered throughout. This rock occurs in a zone 3 to 5 feet wide adjacent to the contact or shear zone. A few veins of chrysotile, up to 4 feet long, are present parallel to the contact. Serpentine veins are much more common. They are commonly parallel to the contact, but some form 30° to 60° angles to it. The next zone in the dunite is from 15 to 20 feet wide and very similar to the rock at the contact except for a higher magnetite content. The magnetite is present as streaks on the white surface of the rock and causes a "ribboned" appearance. The grouping together of serpentinized olivine grains into clots or bunches gives the rock a mottled appearance on weathered surfaces. Veins of chrysotile and serpentine are less common in this zone.

Farther from the contact, the rock is almost pure white on

PLATE VI

Fig. 1 Scalloped contact between pyroxenite, on the left, and serpentinized dunite. Lot 2, concession IV, McCool township.

Fig. 2 Irregular contact between pyroxenite, in the foreground, and serpentinized dunite. Note the pyroxenite almost completely encircled by the serpentinized dunite. Lot 2, concession IV, McCool township.

weathered surfaces. Chrysotile veins are absent, although a few serpentine veins are present. Individual serpentinized olivine grains can be seen on weathered surfaces of the rock. On fresh surfaces, the rock is indistinguishable from that adjacent to the contact. Veins of serpentine are very scarce and chrysotile is absent. The serpentine veins are, in some places, bordered by magnetite and, in other places, magnetite forms the core of the vein.

The pyroxenite at the contact is white on weathered surfaces and is quite rich in serpentinized olivine. About 20 feet from the contact the rock has a faint brown hue on weathered surfaces because the olivine here weathers reddish brown instead of white. Eighty feet from the contact a band of pyroxenite, 20 feet thick, consists almost wholly of pyroxene and only a small amount of serpentinized olivine.

The contact between the serpentinized dunite and pyroxenite, where it is not sheared, does not show any consistent intrusive relationship of one rock into the other. At one locality, a circular-shaped body of pyroxenite has been partially stoped off by the serpentinized dunite. Elsewhere along the contact, the pyroxenite apparently intrudes the serpentinized dunite. Chilled border zones are not in evidence and, therefore, the intrusive relationship, if any, could not be established.

Garrison Township (Bird Group)

The basic and ultrabasic intrusive rocks of the Bird Group; of clains were mapped at 1 inch = 200 feet by J. Satterly and the writer in 1951. This detailed mapping brought out the following features:

(1) The thickness of the gabbro-diabase varies from 80 to 120 feet. The apparent thickness varies from 80 to 300 feet. The thin part is in a faulted zone and the thickness is probably controlled in part by faulting.

(2) The contact with the overlying volcanic rocks is sinuous and irregular, partly due to cross-faulting. The chill zone between the volcanic rocks and the gabbro-diabase is very narrow or non-existent. The volcanic rocks show no contact metamorphism.

The gabbro-diabase is a medium-grained rock which has a spotted rusty appearance on weathered surfaces. Eighty feet of gabbro-diabase bordering the volcanic rocks is characterized by quartz, some of it vuggy. The rock is coarse-grained in places with pyroxene subhedra up to 2 inches in length. Bands of finer-grained rock are present within the coarse-grained areas. There are no chill zones between any of the fine-grained and coarse-grained bands.

Some of the bands of varying grain-size also show changes in mineralogy. Some bands are very rich in hornblende or pyroxene and others are rich in plagioclase.

The gabbro-diabase is more uniform in appearance close to the serpentinized dunite or peridotite contact. This contact is commonly sheared, but where there is no shearing the contact is sharp and shows no intrusive characteristics.

Most of the ultrabasic rock is serpentinized dunite. No unaltered dunite was seen. Serpentinized peridotite is very scarce and confined to the area near the gabbro-diabase contact. Whereas most of the contact rock is serpentinized dunite, a small amount is serpentinized peridotite. The two rocks apparently grade into one another.

The ultrabasic rocks are outwash-covered and their distribution is known only by a few scattered outcrops and the results of diamond drilling. Drilling on the Bird Group revealed a body of serpentinized dunite which extends 2,200 feet south of the gabbro-diabase contact.

The serpentinized dunite is the white weathered variety. It is granular in texture and varies from dark green to pale apple green. Chrysotile veins are moderately abundant.

The southern contact is entirely covered by outwash and the limits of the serpentinized dunite body are only known from drilling. The contact here is very poorly marked, as extensive carbonatization has taken place. The serpentinized dunite has been replaced by a grey, in places slightly green, carbonate which is very massive and fine- to medium-grained. The carbonate retains the texture and the grain size of the serpentinized dunite. Chrysotile is apparently more resistant to replacement than the serpentinized dunite because the veins of chrysotile occur in the carbonate.

Ghost Range Intrusives

The Ghost Range consists primarily of gabbro-diabase with associated mafic and felsic phases. The northern limit of the intrusive mass is not known, but it extends for at least 4,000 feet north of the Harker-Lamplugh township boundary. The southern limit is the contact of the serpentinized peridotite and dunite with rhyolite.

The ultrabasic rocks are not abundant in Harker township but farther east, in Holloway township, drilling disclosed the presence of a large mass of serpentinized peridotite. The ultrabasic rocks include both serpentinized peridotite and dunite which, from observation of poor, scattered exposures, apparently grade into each other. The serpentinized peridotite is more abundant than the serpentinized dunite.

The serpentinized peridotite is a green rock which is reddish-brown on weathered surfaces. Well-developed crystals of pyroxene, up to $\frac{1}{2}$ inch long, are quite common.

The serpentinized dunite is a dark green to greenish-black rock which is dark brown on weathered surfaces. It is very similar to other dunites in the district. Chrysotile may be present in either the serpentinized peridotite or dunite.

A small amount of pyroxenite occurs intermittently along the contact of the serpentinized peridotite or dunite and the gabbro-diabase. The pyroxenite is very similar to that in McCool township, consisting almost entirely of pyroxene with small quantities of chlorite. The pyroxenite does not form a continuous horizon. Its boundaries with the serpentinized peridotite or dunite and the gabbro-diabase are sharp wherever observed.

The contact between the gabbro-diabase and the ultrabasic rocks is poorly exposed. In some places it is the locus of a weak shear zone and elsewhere it is sharp showing neither intrusive or gradational phenonema.

The gabbro-diabase is very similar to that known elsewhere in the district with both fine- and coarse-grained varieties of normal mafic and felsic phases. Bands of coarse-grained gabbro-diabase cut the finer-grained varieties of this rock in some of the outcrops of the Ghost Range. The coarse-grained rock is characterized by fans of pyroxenes up to 3, and exceptionally, 5 inches across. A more complete description of the gabbro-diabase is given in the section on Petrography.

PETROGRAPHY OF THE HAILEYBURIAN (?) ROCKS

DUNITE AND SERPENTINIZED DUNITE

The dunites are fine- to medium-grained rocks of varying shades of green to black which weather to dark brown, grey or white. In some places the colour of the weathered surfaces grades from white to very dark brown although the white and brown weathered surfaces are not common in a single outcrop. The rock is soft on exposed surfaces and this is especially true of the brown weathered varieties.

Fresh surfaces of the dunites vary in colour from pale apple green to very dark green or black. The pale green varieties are granular in texture, whereas the dark varieties are commonly dense. Grain boundaries are difficult to distinguish. Conchoidal fracture is very characteristic of these rocks.

In hand specimens only serpentine, serpentinized olivine, pyroxene, magnetite and less commonly plagioclase are visible. Megascopically, the olivine grains are well-formed, commonly green to dark green and semi-vitreous. In some of the pale apple green dunites the olivine grains are much paler than elsewhere. They are very pale yellow or pale greenish-yellow. The pyroxene crystals are characterized by a lighter green than the serpentinized olivine. Their vitreous cleavage surfaces are very distinctive against the serpentine groundmass. Pyroxene is present only in the dark dunites. Magnetite can be easily seen in most specimens and in some places it is present in small veins, commonly parallel to the strike of the intrusive rock. Most commonly the magnetite forms minute grains between serpentinized olivine grains. In a few exposures, some feldspar is present in the dunites and is very distinctive on fresh surfaces. Wherever seen, the feldspar occurs on the upper edges of the intrusive rocks.

Microscopically, the same minerals are recognized. Also present are minor amounts of hematite, chlorite, talc and calcite.

The olivine crystals are invariably serpentinized. Relic grain boundaries are easily distinguished by the minute magnetite grains which outline their peripheries. Magnetite is also commonly present along fractures. Many minute chrysotile veinlets cut across or follow the fractures of the original olivine grains. This chrysotile is entirely the cross-fibre type. These altered olivine grains are uniform in size and range from 1 to 2 mm.

Antigorite is the most common alteration of the olivine. It occurs in bladed, lamellar and fibrous forms. In some thin sections the antigorite blades lie in a plane parallel to the "c" axis of the olivine. More commonly, the antigorite blades have no preferred orientation with respect to the crystal outlines. However, they commonly radiate from the corners of the fractures within the altered olivine grains.

Chrysotile veins and veinlets are abundant in the dunites over short distances. However, most of the dunites lack commercial amounts of chrysotile. The longest fibres are 1 inch long. In the area of the Munro mine the greatest number of veins contain fibres that average less than 1/3 inch in length.

Examination of the magnetite in thin section confirmed the above statements as to its character. Most of the magnetite is probably secondary having been formed during the period of serpentinization. Some of the interstitial magnetite may be primary, particularly the larger grains. Some of these larger grains may have increased in size during the serpentinization period.

Pyroxene, a diopsidic variety, is present in only small amounts in the dunitic rocks. This pyroxene is similar to that of the pyroxenites and is described below.

The original feldspar of the feldspathic varieties of dunite is extensively altered to a very opaque matte which is primarily sericite and minor clinozoisite. The original feldspar was plagioclase, as determined by relic twinning, but no further information is available.

The accessory minerals include talc, chlorite, biotite, hematite and possibly brucite. Talc is especially common along grain boundaries where it is fibrous and finely laminated. Chlorite is pleochroic in bright greens, and shows anomalous blue interference colours. Most of the chlorite is interstitial. Small quantities of interstitial brown biotite are rarely present. Is is commonly altered to chlorite.

Drill cores from a sheared part of the dunite of the Bird Group, in Garrison township, contain a colourless fibrous mineral with fibres at least 3 inches long. This mineral is brucite, variety nemalite. It has been previously described by Berman (1932) from specimens obtained in the Thetford district of Quebec. The mineral is biaxial positive ($+2V$ ca. 70°), length fast and the N_x refractive index is 1.585, a value which coincides with that determined by

PLATE VII

Fig. 1 Photomicrograph of typical serpentinized dunite composed almost entirely of antigorite after olivine. McCool township. Nicols crossed, X 40.

Fig. 2 Photomicrograph of typical pyroxenite showing euhedral diopside grains. McCool township. Nicols crossed, X 25.

Berman. Some of the very fine-grained fibrous interstitial material in the dunites may be brucite.

PERIDOTITE AND SERPENTINIZED PERIDOTITE

The rock is commonly slightly varying shades of dark green. The texture is typically porphyritic with comparatively large pyroxene grains in a groundmass of serpentinized olivine. Phenocrysts of subhedral pyroxene vary from $\frac{1}{4}$ inch to 1 inch in diameter. Volumetrically they form between 10 and 15 percent of the rock. The pyroxene commonly contains grains of serpentinized olivine. The grains of serpentinized olivine both in the groundmass and in the pyroxene are much smaller and average 1 to 2 mm in length. The serpentinized olivine grains are well-formed and grain boundaries easily distinguished, The serpentinized olivine comprises approximately 70 to 80 percent of the rock. Minor magnetite is commonly visible, especially where it forms veins. Chrysotile is present in some exposures.

Microscopically the groundmass consists primarily of serpentinized olivine with a fairly uniform grain size averaging 2 mm. The serpentinized olivine consists of antigorite in bladed, lamellar and fibrous forms. It is similar to that in the serpentinized dunites. Rarely small amounts of unaltered olivine are present. Only six of twenty-seven thin sections of peridotite studied contained any fresh olivine. Only two of these contained a sufficient quantity to permit further identification. In both the olivine is colourless, has high birefringence, + 2V ca. 95°, $N_x = 1.643$, $N_y = 1.662$, and $N_z = 1.680$.(1) According to Winchell (1951, p. 500) the composition is Fo_{96} Fa_4.

The pyroxene is diopsidic and similar to that in the pyroxenites described on page 52 of this report. It is colourless to very pale green in thin section. Commonly it is largely altered to amphibole. Two varieties of this amphibole were identified. An early-formed amphibole is pleochroic in brown and $Z \wedge c = 20°$. A second, later-formed amphibole is pale green to colourless. It occurs as a rim around the brown amphibole, particularly in sections normal to the "c" axis. This second amphibole has absorption qualities similar to the brown amphibole, but $Z \wedge c = 16°$. This form of pyroxene alteration is apparent in nearly every thin section examined. Some of the larger pyroxene grains contain serpentinized olivine grains within their boundaries.

The accessory minerals are magnetite, chlorite, biotite, calcite, altered plagioclase, talc and brucite. Magnetite is the most widespread accessory. It is present interstitially and in veinlets similar to the magnetite in the serpentinized dunites. The other accessory minerals, with the exception of calcite and plagioclase, are also similar to those in the dunites.

The calcite in the serpentinized peridotites occurs interstitially and is very fine-grained. It is most common in a few thin sections of rocks from McCool township. The plagioclase

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(1) Refractive index determinations given in this report are within limits of error of ± 0.002.

PLATE VIII

Fig. 1 Photomicrograph of typical serpentinized peridotite showing antigorite after olivine and diopsidic pyroxene. A minor amount of magnetite is also present. Garrison township. Nicols crossed, X 25.

Fig. 2 Photomicrograph of peridotite showing unaltered olivine, high relief, with pale green hornblende and minor chlorite. Centre Hill, Munro township. Nicols crossed, X 25.

in the peridotites has been completely altered to chlorite, clinozoisite and sericite. No further identification of the plagioclase was possible.

Brucite was identified on basis of optic sign, crystal habit and low birefringence.

PYROXENITE

The pyroxenite, all of which is very similar, is a grey-green to green, fine- to medium-grained rock with fairly uniform crystalline texture. Megascopically, they consist of approximately 85 percent pyroxene and varying amounts of olivine, plagioclase, hornblende and accessory magnetite. The pyroxene crystals, 2 to 5 mm in greatest dimension, are euhedral, vitreous and fresh in appearance. Crystal outlines and surfaces are easily identified.

Microscopic study shows that the pyroxenite consists of a holocrystalline groundmass of uniform grain size averaging 2 mm. It is composed almost entirely of short, tabular euhedral crystals of pyroxene. The mineral has the following optical properties: $Z \wedge c = 40^{\circ}, +2V = 57^{\circ}, N_x = 1.663, N_z = 1.684$. The axial angle was determined with the aid of a universal stage. According to Winchell (1951, p. 411) the mineral is diopside. Twins on the 100 plane are common.

Relatively small amounts of interstitial material is present consisting of chlorite in fibrous bunches, antigorite either bladed or lamellar, and a small quantity of magnetite.

In the pyroxenite of McCool Hill and Centre Hill small amounts of plagioclase (An 45) are present interstitially. It is fairly fresh in most thin sections examined, but alteration to sericite and clinozoisite has occurred in some plagioclases.

Hornblende subhedra form 10 percent or less of the pyroxenite. They are pale brown to pale green, commonly fresh but locally chloritized. Most of the hornblende is primary and only a small quantity has formed through uralitization of pyroxene.

Small quantities of euhedral olivine are present in some specimens taken near more ultrabasic contacts. The olivine is typically fresh, but some grains are altered to antigorite. Where determined the olivine proved similar in composition (Fo 96) to that in the peridotites.

Talc is a rare constituent of these rocks. It was identified in only two thin sections.

In several specimens from McCool Hill a pale green isotropic mineral is scattered throughout the matrix of the rock. Tentatively, this mineral is identified as spinel.

Bastite is rare and occurs only in two thin sections. Antigorite after diopside and olivine is so scarce that none of them can be classified as serpentinized.

GABBRO-DIABASE

The gabbro-diabase is the most widely distributed rock-type of the Haileyburian (?) group of rocks. Its areal extent is shown on the accompanying map.

The rock is dark green to light grey. Its colour is due to the varying amounts of individual minerals present. The most common mineral is a prismatic, subhedral, grey to pale green plagioclase. In the basic bands, subhedral hornblende is dominant and, locally, feldspar is present in very small amounts. Some felsic bands consist almost entirely of feldspar. Minute quantities of interstitial quartz are locally present, especially near the top of the intrusive masses. Chlorite is quite common. Some gabbro-diabase specimens, particularly from basic bands are extensively chloritized.

The rock texture is diverse. It ranges from diabasic to equigranular and, in places, pegmatitic. In the medium-grained phases the texture is commonly diabasic. On the Ghost Range, where feldspars up to 4 inches long are quite common, pegmatitic texture is very well-developed.

The grain size varies as greatly as the texture. Medium-grained rocks are most common, but fine-grained and coarse-grained rocks are present in nearly all exposures.

The gabbro-diabase is reddish-brown on weathered surfaces. These surfaces are commonly pitted and spotted due to the ferromagnesian minerals eroding much faster than the feldspars.

In western McCool township and in parts of the Centre Hill Complex some of the gabbro-diabase has a flow-like texture in which the feldspars are oriented parallel to the contacts of the intrusive bodies. Mineralogically, the rock is similar to the gabbro-diabase which occurs elsewhere.

In most places the texture is equigranular and diabasic. The textures grade into one another over short distances across the strike. Parallel to the strike they are fairly consistent.

The term gabbro-diabase is used because much of the rock is intermediate in texture between the diabasic texture and equigranular texture.

In thin section, medium-grained varieties of gabbro-diabase have a groundmass of plagioclase laths, 2 mm in average length. Much of the plagioclase is altered to sericite, clinozoisite and albite, but very commonly the alteration minerals are so fine-grained that individual minerals cannot be identified. Where fresh plagioclase is present, the composition varied from An 32 to An 45. The mean composition is An 42.

The more basic phases are composed chiefly of green hornblende together with some plagioclase (An 35). The hornblende grains vary greatly in size, from 1/8 inch to 4 inches in length. Commonly they are randomly oriented, but in some specimens, especially from McCool township, there is a parallel orientation of the hornblende and feldspar.

Most, and perhaps all, of the hornblende is secondary after diopsidic pyroxene. Evidence of uralitization is common in thin section. Relic pyroxene occurs as small islands within the hornblende grains. Alteration of the hornblende to chlorite is common. The chlorite, penninite, is also common interstitially as radiating bunches.

Quartz, in those specimens which contain it, is invariably in myrmekitic intergrowth with plagioclase. Much of the quartz shows strain shadows and anomalous biaxiality.

The accessory minerals include sphene, ilmenite, magnetite and apatite. Sphene and apatite are not abundant. They are present in only a few of the 39 thin sections studied. Ilmenite and magnetite are ubiquitous. Magnetite is more abundant than ilmenite.

PLATE IX

Fig. 1 Photomicrograph of typical quartz gabbro-diabase from near the top of the intrusive body. Garrison township. Nicols crossed, X 25

Fig. 2 Photomicrograph of gabbro-diabase from McCool township showing parallelism of altered plagioclase crystals. Nicols crossed, X 25.

CHEMICAL COMPOSITION OF THE HAILEYBURIAN (?) ROCKS

The chemical compositions of the Haileyburian (?) Rocks have been determined by Rosiwal analysis. Thin sections considered as most representative of the various rock types were used.

CHEM. COMP. OF SERP. DUNITE CALCULATED FROM THE MODE (ACTUAL MIN. COMP.)

	Antigorite	Magnetite	Diopside	Chlorite	Calcite	Talc	Totals
SiO_2	39.56		1.63	0.32			41.51
Al_2O_3				0.18			0.18
Fe_2O_3		4.04					4.04
Fe O		1.81		0.26			2.07
Mg O	38.58		0.55	0.21			39.34
Ca O			0.76		0.22		0.98
H_2O	11.57			0.13			11.70
CO_2					0.18		0.18
Totals	89.71	5.85	2.94	11.0	0.40		100.00

SERPENTINIZED DUNITE

Mineral	Vol. %		S. G.			Wt. %
Antigorite	93.0	x	2.62	=	243.66	89.71
Magnetite	3.1	x	5.13	=	15.90	5.85
Diopside	2.4	x	3.33	=	7.99	2.94
Chlorite	1.1	x	2.72	=	2.99	1.10
Calcite	0.4	x	2.72	=	1.08	0.40
Talc	Tr	x	2.73	=	----	----
					271.62	100.00

S. G. of the rock = 2.72.

CHEMICAL COMP. OF THE SERP. PERIDOTITE CALCULATED FROM THE MODE (ACTUAL MIN. COMP.)

	Antigorite	Diopside	Hornblende	Magnetite	Chlorite	Biotite	Calcite	Talc	Totals
SiO_2	33.96	5.30	2.28		0.37	0.18			42.09
Al_2O_3			0.65		0.21	0.10			0.96
Fe_2O_3			1.00	3.56					4.56
FeO			1.36	1.60	0.39	0.05			3.40
MgO	33.11	1.80	0.51		0.25	0.03			35.70
CaO		2.50	0.36				0.16		3.02
K_2O						0.05			0.05
H_2O	9.93				0.15	0.01			10.09
CO_2							0.13		0.13
Totals	7.70	9.60	6.16	5.16	1.27	0.42	0.29		100.00

SERPENTINIZED PERIDOTITE

Mineral	Vol.%		S. G.			Wt. %
Antigorite	81.8	x	2.62	214.31	=	77.00
Diopside	8.1	x	3.33	26.97	=	9.69
Hornblende	5.3	x	3.24	17.17	=	6.17
Magnetite	2.8	x	5.13	14.36	=	5.16
Chlorite	1.3	x	2.72	3.53	=	1.27
Biotite	0.4	x	2.95	1.18	=	0.42
Calcite	0.3	x	2.72	0.81	=	0.29
Talc	Tr	x	2.73	----	=	----
				278.33		100.00

S. G. of the rock = 2.78.

CHEM. COMP. OF PYROXENITE CALCULATED FROM THE MODE (ACTUAL MIN. COMP.)

	Diopside	Chlorite	Antigorite	Magnetite	Albite	Anorthite	Hornblende	Talc	Spinel	Totals
SiO_2	48.58	0.55	0.60		0.61	0.32	1.94			52.60
Al_2O_3		0.31			0.17	0.28	0.55			1.31
Fe_2O_3				1.73			0.85			2.58
MgO	16.25	0.37	0.58				0.43			17.63
FeO		0.44		0.77			1.16			2.37
CaO	22.54					0.15	0.30			22.99
Na_2O					0.10					0.10
K_2O										
H_2O		0.22	0.18							0.40
CO_2										
Totals	87.37	1.89	1.36	2.50	0.88	0.75	5.23			99.98

PYROXENITE

Mineral	Vol. %		S. G.				Wt. %
Diopside	86.1	x	3.33	=	286.71	-	87.37
Chlorite	2.3	x	2.72	=	6.25		1.90
Antigorite	1.7	x	2.62	=	4.45		1.36
Magnetite	1.6	x	5.13	=	8.20		2.50
Albite	1.1	x	2.63	=	2.89		0.88
Anorthite	0.9	x	2.75	=	2.47		0.75
Hornblende	5.3	x	3.24	=	17.17		5.23
Talc	Tr	x	2.73	=	----		----
Spinel	Tr	x	3.55	=	----		----
					328.14		99.99

S. G. of rock = 3.28.

CHEMICAL COMP. OF GABBRO-DIABASE CALCULATED FROM THE MODE

	Albite	Anorthite	Hornblende	Diopside	Chlorite	Magnetite	Ilmenite	Sphene	Apatite	Totals
SiO_2	18.75	8.92	11.01	3.86	2.43			0.07		45.04
Al_2O_3	5.29	7.57	3.12		1.37					17.35
Fe_2O_3			4.85			2.86				7.71
MgO			2.47	1.29	1.62					5.38
FeO			6.57		1.93	1.28	1.28			11.06
CaO		4.15	1.73	1.79				0.07		7.74
Na_2O	3.21									3.21
K_2O										
H_2O					0.97					0.97
CO_2										
TiO_2							1.42	0.09		1.51
Totals	27.25	20.64	29.75	6.94	8.32	4.14	2.70	0.23		99.97

GABBRO-DIABASE

Mineral	Vol. %		S. G.			Wt. %
Albite	30.8	x	2.63	81.00	=	27.25
Anorthite	22.3	x	2.75	61.32	=	20.64
Hornblende	27.3	x	3.24	88.45	=	29.76
Diopside	6.2	x	3.33	20.64	=	6.94
Chlorite	9.1	x	2.72	24.75	=	8.33
Magnetite	2.4	x	5.13	12.31	=	4.14
Ilmenite	1.7	x	4.72	8.02	=	2.70
Sphene	0.2	x	3.52	0.70	=	0.23
Apatite	Tr	x	3.20	----	=	----
				297.19		99.99

S. G. of rock = 2.97.

COMPOSITIONS OF THE HAILEYBURIAN (?) ROCKS

	Serp	Dunite	Serp Perid.	Pyrox.	Gabbro-Diabase
$Si O_2$		41.51	42.09	52.60	45.04
$Al_2 O_3$		0.18	0.96	1.31	17.35
$Fe_2 O_3$		4.04	4.56	2.58	7.71
Fe O		2.07	3.40	2.37	11.06
Mg O		39.34	35.70	17.63	5.38
Ca O		0.98	3.02	22.99	7.74
$Na_2 O$		----	----	0.10	3.21
$K_2 O$		----	0.05	-----	----
$H_2 O$		11.70	10.09	0.40	0.97
$Ti O_2$		----	----	----	1.51
$C O_2$		0.18	0.13	----	----

Mg/Fe Molecular ratio			
	12.4	8.5	6.6

PETROGENESIS OF THE HAILEYBURIAN (?) ROCKS

Before entering into a general discussion of the origin of the Haileyburian (?) rocks, it is to be noted that all the Haileyburian (?) rocks, whether classified as Type I or Type II, show many features common to both. The most outstanding features are age relationship, rock sequence, conformability and general rock types. It is reasonable, therefore, to assume that any theory of origin and history of the Haileyburian (?) rocks must be applicable to all the intrusive bodies and the processes involved are, in general, the same for each. Any varieties, such as Type I and Type II, are believed to be minor when the entire area is considered.

BANDING

The most outstanding feature of the Haileyburian (?) rocks is the banding. Banding in intrusive rocks is quite common and several theories have been proposed to explain it. The two most prominent are:

(1) Gravitational settling of crystals in a liquid; a concept derived from the study of banded sedimentary rocks.

(2) Flowage of mineral constituents resulting in flow lines similar to those observed in volcanic rocks and along the margins of granitic batholiths.

Several other theories have been proposed. These include liquid immiscibility, a phenomenum not applicable to silicate melts, and various rhythmic cycles of crystallization of different components. The latter requires pulsatory conditions of heating and cooling or peculiar and improbable mechanisms which are not borne out by field evidence. The repeated injection of new magma, to cause new cycles of crystallization to commence, relies upon so many factors such as position of feeders, depth of chamber, tilting or other deformation, possible volcanic draining of the magma chamber, varying temperature and pressure conditions, that the likelihood of a repetition of all these factors being coordinated in the same manner several times during one major intrusive period is so remote that further consideration is not warranted.

Gravity Banding

Several excellent examples of gravitative stratification exist; perhaps the best known are the Bushveld and Stillwater Complexes of Africa and Montana, and the Skaergaard intrusions of Greenland. These masses exhibit prominent banding with sharp contacts between various bands, similar to those in the Haileyburian (?) rocks. Peoples (1933) cites an illustration of banding in the Stillwater Complex which is very similar to the banding in the Haileyburian (?) rocks on Centre Hill. Dr. J. Satterly, who has seen both the Stillwater and the Centre Hill Complexes, has remarked, on several occasions, of the great similarity of the banding in the two exposures (oral communication).

The formation of bands by gravitational settling relies, in its simplest form, upon the difference in the specific gravity of the mineral constituents and the residual liquid. For example, the banding in gabbros relies on a difference in specific gravity of calcic plagioclase (S.G. = 2.68 - 2.73) and augite (S.G. = 3.2 - 3.6).

The generally accepted concept is similar to that proposed by Coats (1936, p. 412.)

> "If two sorts of crystals of differing densities are settling in a liquid, the density of which is but slightly less than that of the lighter sort of crystal, both varieties will settle toward the bottom. As these two kinds of crystals approach the bottom, the proportion of crystals to liquid will increase. When a certain limiting value is reached, since the sinking of the heavier crystals tends to displace the adjacent fluid upward, this liquid because of its viscosity, and the slow rate of settling of the lighter crystals, carries them upward. There is thus produced a layer rich in the lighter crystalline constituent, over one rich in the heavier. Crystals of the heavier variety, continuing to fall upon the loose mesh of the lighter crystals, will slip through the interstices of the mesh until by the settling of the lighter crystals relative to the liquid, this mesh becomes too tight to permit the passage of any further crystals of the heavier variety. The process then repeats itself, another layer of the heavier crystals being formed on the top of the layer of the light crystals."

The theory above is not applicable, however, to the ultrabasic zones of the Haileyburian (?) intrusive rocks. The specific gravity of diopside (3.33) differs only by one one-hundredth from that of forsterite (3.32). It is inconceivable that such a small difference in specific gravity could bring about a separation as complete and on such a scale as exists in the Haileyburian (?) rocks. If the olivine was serpentinized before the separation, its specific gravity would be only 2.62, a value sufficiently different from 3.33, the specific gravity of diopside, that separation by gravity settling is a possibility. For structural reasons however, this possibility is eliminated because the dunite and peridotite lie beneath the pyroxenite, especially in Type II, a sequence exactly reversed from that which would be produced by gravity settling of serpentinized olivine and diopside.

One of the prime reasons for the use of the gravitational settling theory for the Bushveld Complex is the evolution in chemical composition. A similar chemical evolution was shown to exist in the Skaergaard intrusions of Greenland by Wager and Deer (1939). There is no evolution in chemical composition in the ultrabasic zone of the Haileyburian (?) rocks. The variation in rock type is mineralogically quantitative rather than chemical. The lack of evolution in chemical composition suggests that the ultrabasic zones were formed as units and not by crystal accumulation.

In considering the entire area, if gravity settling were the method of separation, it is reasonable to expect that all the intrusive bodies would be similar in lithologic sequence. In other words, rock sequences such as Type I and Type II would not be expected but rather either Type I or Type II.

It is concluded therefore, that the banding of the ultrabasic rocks cannot be satisfactorily explained by theories based upon gravitational crystal settling in place. Whereas the banding within the gabbro-diabase is on a more limited scale, it is not unreasonable to expect that it was formed by the same method as that which produced the banding in the ultrabasic rocks. However, gravitational settling may be the process which produced some of the thinly banded portions of the gabbro-diabase.

Flow Banding

Flow structures in volcanic rocks are well known and fully described. Similar flow structures have been described as occurring in plutonic rocks of several types ranging in composition from granitic to ultrabasic. Balk (1937, p. 15) defines flow layers as follows:

> "Flow layers may be said to be tabular disk-like rock bodies composed essentially of those minerals that build up the surrounding rocks, but in different proportions. The boundaries of flow layers may be gradational or sharp. Within individual flow layers, the relative proportion of minerals is fairly constant. Thickness and length of layers range widely; they may be straight, curved or folded. Adjacent layers may be parallel to each other, or, more rarely, may truncate each other. Crystals in flow layers in granitic rocks may lie with their largest faces parallel to the plane of the layer; whereas, the crystals that compose flow layers in gabbroic rocks tend to be oriented at random. Synonyms are "foliation" and "fluxion banding"."

Williamson (1941) developed similar features experimentally by the deformation of plastic material. Balk (1925, p. 689) in a paper describing primary structures in granite wrote:

> "The granite of the Riesengebirge is characterized by platy flow bands which in places are so perfectly developed as to give the rock a stratified appearance."

In describing the internal structure of the Mariposa granodiorite of California, Cloos (1932, p. 299) comments:

> "The arrangement of the flow structures within the intrusive depends entirely on the form of the space which was available for the intrusion. The elements are oriented parallel to the contact planes. The planes of mineral parallelism follow the contacts in strike and dip, and the flow lines coincide with the dip of the contact planes.

****

> The intensity of the flow structures in the granodiorite does not increase on approaching the contact. Apart from the flow lines, only an elusive platy parallelism is noted a few yards from the southern contact."

The role played by stress is well summarized by Zavaritsky (1932, p. 177).

> "There is no doubt that the whole of the Rai-Iz massif was formed as a single geologic unit, and the apparition of the banded structure might most probably be ascribed to the stress which acted upon a nearly crystalline mass of olivine grains having contained a small residual acid solution. Under the influence of stress it was irregularly distributed in bands in the mass of the crystallizing rock, and on its definitive consolidation this irregularity led to the formation of the banded structure. It is notable that the banding is developed also in the adjacent gabbro-amphibolites."

The banding seen in the outcrops, especially that of Type I, is known to exist only in two dimensions. If a three-dimensional view is envisioned, the banding may occur as shown in Fig. A rather than that shown in Fig. B which is a more conventional interpretation.

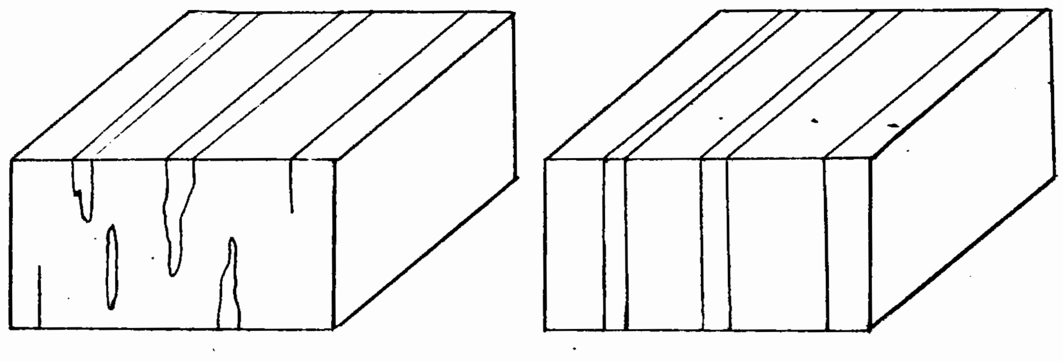

Fig. A Fig. B

If the banding is irregular and non-continuous, as shown in Fig. A, then flowage is a more readily acceptable concept and gravity stratification less adaptable.

The use of a flow process for the emplacement of ultrabasic material consisting of substantially solid masses of olivine crystals was proposed by Bowen (1917, p. 237). Bowen and Tuttle (1949, p. 245) suggest:

> "It may be that an olivine aggregate is more capable of flow in the crystalline state than other common anhydrous rock-forming minerals, because its crystals are built up of SiO_4 groups without any chain, double chain, sheet, or space linkages - i.e., sharing of O atoms by Si atoms."

The flowage of partially crystalline rock-forming material should result in some tendency toward a preferred orientation of the crystal constituents. Some of the gabbro-diabase, particularly in McCool township, does contain feldspar crystals aligned parallel to the sill contacts. No attempt was made to study the grain orientation of the Haileyburian (?) ultrabasic rocks. However, other workers have noted that in banded dunites there is a tendency for the olivine grains to be oriented so that their long axis "c" is in the plane of the banding (Turner, 1943, and Guild, 1947).

It is here suggested that the banding in the Haileyburian (?) rocks is a flow feature resulting from the intrusion of magmatic material consisting of a crystalline aggregate with only enough liquid to permit mobility. This process is believed to account for:

(1) The absence of thermal metamorphic effects in the host rocks. The intrusive material would be sufficiently cooled at the

time of the intrusion so that the thermal metamorphic effect is small.

(2) The lack of intrusive relations between the various bands. The temperature of the intrusive material was uniform and therefore, chilling impossible. The flowage along the various contacts would tend to smooth out or obliterate any large scale tendency for diking. Sheared contacts may be, in part, residual flow lines.

(3) The flow-like features which are present in the gabbro-diabase in McCool township.

(4) The interbanded pyroxenite and peridotite of Type I and the banding in the gabbro-diabase.

(5) The fact that some contacts are gradational and others are sharp.

The intertonguing and irregular contacts, such as shown in Plate IV , are probably the result of movement of residual juices after the emplacement of the main masses. Bowen and Tuttle (1949, p. 460), in considering these types of intrusives where age indications are contradictory, state:

> "In short our observations suggest that the mutual "intrusion" of ultramafic types in such complexes, often giving contradictory indications of time of "intrusion", is really due to hydrothermal (pneumatolytic) rearrangement of material, taking place largely within the mass itself, though the water and perhaps small amounts of other substances were of extraneous origin.
>
> Such "intrusives" would not extend beyond the borders of the ultramafic complex, and this appears to be the relation observed."

The application of the flow theory, rather than the gravity settling theory, to explain the banding in the Haileyburian (?) rocks eliminates the necessity of the host rocks being in a horizontal position at the time of the intrusions. Whereas there is no evidence available to establish definitely the attitude of the volcanic rocks during the intrusive period, it is reasonable to expect that the intrusions could take place more readily during the period of folding rather than before or after. It is probable, therefore, that the volcanic rocks were inclined at the time of the intrusions, although in some places the flows may have been horizontal or nearly so.

CLASSIFICATION OF ULTRABASIC PLUTONS

As Smith (1952, p.109) points out, there are at least two contrasting types of plutons containing ultrabasic rocks. These are: (1) gravity-stratified sheets (Buddington, 1936), also referred to as lopolithic or sill-like plutons (Hess, 1938), all belonging to the basaltic magma series; and (2) the alpine type (Benson, 1926), or serpentinites associated with orogenic zones (Turner and Verhoogen, 1951), or injected peridotites (Guild, 1947), or members of the ultrabasic magma series (Hess, 1938). Smith (1952, p. 110) uses the terms "basaltic layered pluton" and "ultrabasic pluton":

> "--- to emphasize the essential difference between the plutons, namely that one is composed dominantly of rocks of basaltic composition, while the other is composed of rocks of mainly ultrabasic composition."

These terms will be used here.

More complex ultrabasic plutons, including concentric rings of dunite surrounded by pyroxenite and gabbro, may form another type and be distinct from the two discussed here. Their origin is undoubtedly complex. The kimberlites and mica peridotites are all hypabyssal and can be grouped together as a fourth type. They are not related to the rocks under discussion.

The basaltic layered plutons are well known and have been studied in detail in several places in the world. These include the Bushveld Complex, the Stillwater Complex and the Duluth gabbro. The Palisades diabase and the Nipissing diabase probably also belong to this group. The essential features of the basaltic layered plutons are, according to Buddington (1936, p. 348):

> "Thick intrusive sills of basic or intermediate composition characteristically show a relatively thin basal zone of a composition intermediate between the extreme variations occurring above. The material just above the basal zone is generally more mafic than that of the basal zone and passes upward into more feldspathic or felsic material. Accordingly, in the sheet as a whole, the specific gravity is intermediate at the base and grades from a maximum just above the base to a minimum in the upper part. This gradation may, however, be very irregular. In the lower portion of the thicker sheets there may be ultrabasic segregates and small-scale alternation of more mafic and felsic material or bands of different mineral composition, and the uppermost part may be granite. There may be some minor intrusive relations of one facies to another. Thin sub-basal sills may differ in composition from the normal chill facies of the main mass."

An important characteristic, not mentioned specifically in Buddington's paper, is that basaltic layered plutons are plateau type intrusions. Nowhere are the large-scale masses associated with strongly deformed mountain built belts at the time of their intrusion. A summary of the features of basaltic layered plutons is shown in Table A .

The essential features of the ultrabasic plutons were outlined by Hess (1938) when he proposed a primary peridotite magma. These are:

(1) Large masses of peridotite are present in regions where few if any other igneous rocks of the same age are known. These may be of batholithic proportions such as the Cuban serpentines.

(2) The border facies of the ultrabasic plutons is itself

an ultrabasic rock differing in no way from the main mass.

(3) The metamorphic effects of the ultrabasic intrusives on the wall rocks are much less than by a basaltic intrusive of the same dimensions.

(4) Primary banding is rare.

(5) The Mg/Fe molecular ratio of the ultrabasic plutonic rocks is usually above 7.5.

(6) Ultrabasic plutons occur in orogenic zones during the first great deformation.

Table A

Characteristics of Basaltic Layered Plutons and Ultrabasic Plutons

	Basaltic Layered Plutons	Ultrabasic Plutons
Attitude at the time of intrusion.	Horizontal intrusion.	Inclined.
Rock sequence.	Generally according to specific gravity.	May or may not correspond to S.G.
Metamorphic effects.	Usually marked.	Slight to absent.
Border facies.	Prominent and representative of the magma.	Similar to main mass.
Layering or banding.	Primary banding common.	Primary banding rare.
Other intrusions.	Associated dikes and sills or similar composition common.	Few or no other rock-types of the same age.
Chemical composition.	Basaltic Mg/Fe 7.5	Ultrabasic Mg/Fe 7.5
Distribution in time.	Quiet periods.	Orogenic periods.

Comparison of the Haileyburian (?) Rocks with Basaltic Layered Plutons and Ultrabasic Plutons.

A comparison of the Haileyburian (?) intrusive rocks with the characteristics of basaltic layered plutons and ultrabasic plutons shows there are some similarities with both types. With regard to attitude, the basaltic layered plutons are horizontal at the time of the intrusions. The Stillwater Complex is an excellent example. As previously pointed out (p.76), there is no evidence as to the attitude of the volcanic rocks at the time of the Haileyburian (?) intrusions. The Haileyburian (?) rocks are conformable with and folded with the volcanic rocks, therefore, the Haileyburian (?) rocks may have been in a horizontal position when intruded. If so, structural conditions suitable for gravitational settling existed, but, as already established, gravitational settling in place is certainly not the prime method of separation and absolutely untenable for the ultrabasic rocks.

Metamorphic effects by the Haileyburian (?) intrusions on the host rocks are negligible, a characteristic of ultrabasic plutons. This suggests low temperature intrusion. Experimental work by Bowen and Tuttle (1949) shows that serpentine cannot exist at temperatures above 500°C., a temperature sufficiently low so that metamorphism would not be expected, at least on the basal side of the Haileyburian (?) intrusions. The lack of thermal metamorphic effects bordering the gabbro-diabase suggests that this rock was also intruded at low temperature. It may have consisted of a partially crystallized magma with only enough liquid to provide mobility for emplacement.

Basal chill zones, supposedly the rock most representative of the magma, are an important criterion of basaltic layered plutons. Wherever seen, the Haileyburian (?) rocks do not have basal chill zones, and the lower parts of the sills are not representative of the sills as a whole. Commonly, the basal portions of the Haileyburian (?) intrusions are serpentinized peridotite or dunite, and in a few places, pyroxenite. The basal rock of the Cemtre Hill Complex, for example, is a pyroxenite, suggesting that at the time of the intrusion the lower ultrabasic part of the complex was, in part, if not all, pyroxenitic in composition, but certainly not basaltic.

Primary banding is very common in basaltic layered plutons but rare in ultrabasic plutons. The Haileyburian (?) rocks are well banded in most places and appear to be more closely related to basaltic layered plutons for this reason. It has been shown, however, (p.73) that in those places where banding is most prominent (Type I) it may be the result of intertonguing rather than layering.

The rock sequence in basaltic layered plutons generally corresponds with the specific gravity of the rocks. Whereas the gabbro-diabase, pyroxenite and peridotite do occur in a definite sequence, it has been concluded (p.74) that this sequence was not the result of gravity stratification and must be the result of some other process. It is suggested that the rock sequence corresponds with the sequence of the intrusion, the gabbro-diabase first, the pyroxenite second, and the dunite and peridotite last.

No other intrusive rocks of the same age are known to exist in the area, a characteristic of ultrabasic plutons.

The chemical composition of basaltic layered plutons is, of course, basaltic. The Haileyburian (?) rocks do not have an overall basaltic composition. The composition of the Centre Hill Complex is calculated on the following basis, (assuming that the ultrabasic rocks were unaltered and that the olivine of the peridotite was entirely forsterite):

54% gabbro-diabase

32% pyroxenite

14% peridotite

	Calculated Comp. Centre Hill Complex	Av.% Gabbro Family (Grout, 1932, p. 127)	Haileyburian (?) Gabbro-diabase
SiO_2	46.8	48.24	45.04
Al_2O_3	9.9	17.88	17.35
Fe_2O_3	5.8	3.16	7.71
Fe O	7.2	5.95	11.06
MgO	14.7	7.51	5.38
CaO	12.1	10.99	7.74
Na_2O	1.7	2.55	3.21
H_2O	0.6	1.45	0.97
TiO_2	0.8	0.97	1.51
K_2O	Tr.	0.89	-
MnO	-	0.13	-
Total	99.6%	99.72%	99.97%

A comparison of the calculated composition of the Centre Hill Complex with the average percentages of the gabbro family shows the Centre Hill Complex to be slightly lower in silica, soda and potash, much lower in alumina, and much higher in magnesia. The composition of the Haileyburian (?) gabbro-diabase shows a much better agreement with the average percentages of the gabbro family. This suggests that the gabbro-diabase alone was derived from a basaltic type magma. The ultrabasic part of the pluton must then be derived from an ultrabasic source.

The composition of the ultrabasic part of the Centre Hill Complex is calculated on the following basis, (assuming that the rocks were unaltered and that the olivine of the peridotite was entirely forsterite):

70% - pyroxenite

30% - peridotite

	Calculated Composition of the Ultrabasic Part of the Centre Hill Complex	Average percent of Pyroxenite Family (Grout, 1932, p. 127)
SiO_2	49.4	51.29
Al_2O_3	1.2	3.52
Fe_2O_3	3.5	1.82
FeO	3.0	6.00
MgO	25.7	21.06
CaO	17,2	13.88
Na_2O	0.1	0.30
K_2O	-	0.16
H_2O	0.4	1.20
P_2O_5	-	0.06
TiO_2	-	0.58
MnO	-	0.13
Total	100.8	100.00

The calculated composition of the ultrabasic part of the Centre Hill Complex shows general agreement with an average pyroxenite composition, although lower in alumina and slightly higher in magnesia and lime. This must be considered as further evidence for an ultrabasic origin for the ultrabasic part of the Haileyburian (?) rocks.

The Mg/Fe molecular ratio is considered by Hess (1938) as the most important difference in composition distinguishing basaltic layered plutons from ultrabasic plutons. Hess (1938, p. 341) writes:

> "All of the Mg/Fe ratios of peridotites, dunites, and serpentinites of the ultramafic magma series, so far as the writer was able to find, are above 7.5. The pyroxenites related to this series generally have ratios between 6 and 7. Ultramafics that are crystallization differentiation products of a mafic magma have ratios between 3.5 and 7.5. ***************
> It can be concluded that low ratios, below 6, are almost certainly not members of the primary ultramafic magma series."

The Mg/Fe molecular ratios of the serpentinized peridotite and dunite of the Haileyburian (?) rocks are above 6.0, the lower limit for ultrabasic plutons. The Haileyburian (?) pyroxenite Mg/Fe molecular ratio is 6.6, a figure which agrees remarkably well with Hess' observations.

It is evident, that when considered from a compositional aspect, the ultrabasic Haileyburian (?) rocks are very closely related to ultrabasic plutons and were probably derived from an ultrabasic source. The gabbro-diabase, on the other hand, has a basaltic composition and can be expected to have been derived from a basaltic source.

As the Haileyburian (?) rocks have been folded with the volcanic rocks and are pre-Algoman (?) in age, they are most certainly an integral part of the same orogeny. Hess (1938, p. 333) noted that major mountain systems throughout the world showed serpentine belts in each, and that the peridotites were intruded during the first great deformation. The relationship between mountain building and ultrabasic intrusions is well founded. It is probable, therefore, that the Haileyburian (?) rocks were intruded early in the orogenic history of the volcanic rocks.

In general, the Haileyburian (?) rocks closely resemble ultrabasic plutons. The presence of gabbro-diabase overlying the ultrabasic rocks is not typical of ultrabasic plutons, and therefore, a somewhat different origin must be used.

Smith (1952) suggests that the basaltic layered plutons and ultrabasic plutons are end members of a series of plutons containing ultrabasic rocks. If so, the Haileyburian (?) intrusions are close to the ultrabasic pluton end of the series.

SOURCE OF ULTRABASIC MATERIAL

The source of the ultrabasic material depends upon which of the two chief ultrabasic types of intrusions are considered. The ultrabasic material of the basaltic layered plutons is believed to be, and is generally accepted to be, derived by gravity settling differentiation in place from a basaltic magma. In the past several theories on the source of the material for the ultrabasic plutons have been proposed. The work of Bowen and Tuttle (1949) has eliminated the possible existence of a liquid of serpentine composition at geologically reasonable temperatures and pressures. Previous to this, Bowen (1915) proved that a liquid peridotite magma did not exist. Since 1917, Bowen has advocated the intrusion of masses of olivine crystals to form dunites. Bowen and Tuttle (1949, p. 455) state:

> "Under certain conditions of crustal deformation, apparently involving strong overthrusting, dunitic and related material, coming at times perhaps from a peridotite shell of the earth, at other times from a peridotite mass that has formed as a differentiate of a gabbroid magma, can be intruded in a completely crystalline state into accessible levels of the earth."

Thus there are two generally acceptable theories for the source of the ultrabasic material.

(1) Gravity settling differentiation in place from a basaltic magma.

(2) Dunitic and related material in a completely crystalline state either from the peridotite shell of the earth or as a differentiate of a basaltic magma.

It has been shown (p.69) that the Haileyburian (?) rocks were not formed by gravity settling differentiation in place. Nor is it probable that they are a differentiate of a basaltic magma (p.84) and subsequently intruded separately. The ultrabasic Haileyburian (?) rocks are probably derived from the peridotite layer of the earth.

The association between the ultrabasic intrusions and orogenic movements also suggests that the peridotite layer of the earth is the source of the ultrabasic material. A downbuckle of the earth's crust early in the period of deformation, as pictured by Hess (1938, p. 333), possibly resulted in the partial fusion of the peridotite substratum which would supply sufficient ultrabasic material to form the Haileyburian (?) ultrabasic rocks. The partial fusion of the peridotite substratum would also release sufficient magma of basaltic composition to form the gabbro-diabase. The presence of feldspathic dunite may be a genetic link between the two rock types.

The superposition of the gabbro-diabase is attributed to prior intrusion. The time lapse between the intrusion of the gabbro-diabase and the ultrabasic material is considered to be very short geologically. In fact, where there are gradational contacts between the ultrabasic rocks and the gabbro-diabase, the two moving masses probably were emplaced one behind the other.

The pyroxenite material is probably derived from the ultrabasic material by a filter pressing action which separated the pyroxene liquid from the olivine crystals. The dunite is the cleanest residuum of this action, whereas the peridotite is probably the most representative of the original material from the peridotite substratum.

SUMMARY OF EVENTS LEADING TO THE FORMATION OF THE HAILEYBURIAN (?) ROCKS

The Haileyburian (?) rocks may have been formed as a result of the following sequence of events.

A partial fusion of the earth's peridotite shell, possibly as a result of a downbuckle of the volcanic rocks early in their orogenic history, released quantities of peridotitic and basaltic material. The basaltic material, because of its superposition, was the first to be emplaced. The amount varied from place to place. As the result of orogenic movements, the host volcanic rocks were probably inclined at the time, but in part, may have been horizontal. The basaltic material consisted of a crystal aggregate with only sufficient liquid and volatiles to permit mobility. It was relatively cool, and therefore, contact metamorphism was kept to a minimum. Any banding within the gabbro-diabase is probably the result of flow. However, if the volcanic rocks were horizontal, minor banding may be due to gravity stratification.

The intrusion of the basaltic crystal aggregate was followed by the intrusion of the peridotitic crystal aggregate. The quantity of the ultrabasic material also varied from place to place. Prior to the emplacement of the peridotite, pyroxenitic material was separated from the main mass by a filter pressing action. This pyroxenitic material was injected to form the pyroxenite. The dunitic residuum and also some of the parental peridotitic material was emplaced shortly after the pyroxenite and the typical Type II sequence was formed.

If the separation of the pyroxenitic material from the peridotitic material was incomplete, peridotitic and pyroxenitic material flowed to the point of emplacement simultaneously. This produced, upon consolidation, a typical Type I sequence of inter-banded peridotite and pyroxenite.

In most places the ultrabasic material was intruded into the same horizons as the basic material and underneath it. However, in a few places the ultrabasic material occupied new horizons. Elsewhere, those horizons occupied by gabbro-diabase were by-passed leaving masses of gabbro-diabase without ultrabasic associates.

This postulated sequence of events accounts for the following facts:

(1) The lack of thermal metamorphic effects in the host rocks.

(2) The variation in quantity of one rock type from one exposure to another.

(3) The presence of isolated masses of gabbro-diabase, peridotite, and dunite.

(4) The gabbro-diabase masses are always stratigraphically above the ultrabasic rocks.

(5) The prominent banding.

(6) The absence of convincing intrusive relationships between the various rock types of Haileyburian (?) age.

(7) The absence of fine-grained or chill contacts in the Haileyburian (?) rocks.

(8) The basaltic composition of the gabbro-diabase and

the ultrabasic composition of the pyroxenite, peridotite and dunite.

(9) The erratic distribution of peridotite and dunite which grade into one another.

(10) The parallelism of the feldspars in some of the gabbro-diabase.

(11) The presence of two lithologic associations, Type I and Type II.

METAMORPHISM

ACTINOLITIZATION

The development of actinolite in volcanic rocks along flow contacts and close to some of the Haileyburian (?) intrusions is quite common, particularly in the northern half of Munro township. The zone of actinolitization varies from several inches to a few feet in thickness from the flow contact, and, in general, the thicker the zone of metamorphism, the larger the actinolite crystals. Most of the actinolite crystals are normal to the contact with relatively few crystals more erratically oriented.

A large part of the actinolitization, particularly that remote from Haileyburian (?) intrusive rocks, appears to be associated with strike faults which are common in Munro township. Very extensive actinolitization is present along the Munro fault zone.

Whether actinolitization results from contact metamorphism due to the intrusion of Haileyburian (?) rocks is not known. Extensive actinolitization of gabbro-diabase in lot 7, concession VI, Munro township suggests, according to Satterly (1951b, p. 15), that the alteration is either post-Haileyburian (?) or the gabbro-diabase was misidentified and is actually a thick diabasic volcanic rock.

In a few places, actinolitized volcanic rock fragments occur in serpentinized peridotite. This may be interpreted in two ways. (1) The actinolitization is, at least in part, pre-Haileyburian (?). (2) The actinolitization is the result of the intrusion.

The formation of actinolite in the volcanic rocks by contact metamorphism resulting from the intrusion of the Haileyburian (?) rocks is not probable. Only a very small part of the volcanic rocks are actinolitized even though Haileyburian (?) and volcanic rocks are in contact in many places. Actinolitization is notably absent along the contacts of some of the most prominent and thickest plutons, such as Centre Hill and in Garrison township.

At least two ages of actinolitization are probable, one before, and one after the Haileyburian (?) intrusive period. Strike faulting is probably the prime cause of the actinolitization. Thermal metamorphism possibly plays a small role.

SERPENTINIZATION

The serpentinization of the dunite and peridotite is the most important metamorphic reaction to have taken place in the Haileyburian (?) rocks. Two theories have been postulated as to the origin of serpentine. The first involves a deuteric reaction brought about by solutions emanating from the magma itself. This theory, most strongly advanced by Hess (1933, 1938), is untenable in the light of the experimental work by Bowen and Tuttle (1949). The second theory involves a reaction between olivine and pyroxene grains and aqueous solutions derived from outside sources. This theory is strongly supported by Bowen.

The derivation of the aqueous solutions is limited to two major sources:

1. The wall rocks through which the mass of olivine grains are moving.

2. Totally extraneous sources.

With respect to the addition of water into a moving crystal aggregate from the wall rocks, Bowen and Tuttle (1949, p. 455) comment:

> "If, as it moves slowly under the deformative forces, the mass comes into a zone of wet rocks, it may acquire water from those rocks, as Hess (1938, p. 331) has suggested. Above 500°, or even above 400° if it is a mass of olivine only, the amount of water that can enter the mass will be merely that which can exist as vapor in the pore spaces and minute fractures of the crystal aggregate which is suffering gliding translations and perhaps also granulation and some major fracturing."

In considering a still-standing mass of ultrabasic rocks the same authors conclude that a totally extraneous source must be called upon to supply the aqueous media inducing serpentinization. They also suggest that a still-standing mass is not as readily serpentinized throughout its mass.

Totally extraneous sources, such as the Algoman (?) granite and syenite stocks, may provide serpentinizing solutions. With regard to the Haileyburian (?) rocks, the field evidence lends little support for an Algoman (?) source as serpentinization is as complete in areas far from Algoman (?) masses as it is in areas close to them. Furthermore, the passage of large quantities of aqueous solutions from the Algoman (?) rocks into and through the Haileyburian (?) dunite and peridotite would, in all probability, leave some indication of their presence, possibly in the form of alteration either in the neighbouring pyroxenite and gabbro-diabase or the volcanic rocks. No evidence of any kind is known. The Algoman (?) masses are all small and perhaps not capable of supplying sufficient solutions. Another difficulty arising, if the solutions are Algoman (?), is that the masses of dunite and peridotite would be still-standing and, therefore, thorough and complete serpentinization much more difficult.

It is probable therefore, that the serpentinization of the Haileyburian (?) dunite and peridotite took place primarily before their emplacement. The precise source of the aqueous solutions which brought about the serpentinization is unknown, but part, if not all, may have come from the wall rocks during the passage of the crystal aggregate from its source to its place of rest.

IV

ECONOMIC GEOLOGY

The only mineral of economic importance in the Haileyburian (?) intrusives is chrysotile. Prospecting for asbestos fibre started in 1949 and has resulted in the finding of several showings in the area. No detailed study was made of the chrysotile showings or of the Munro mine, but a few general observations were made in the course of the field work.

All chrysotile veins are confined to bodies of serpentinized dunite and peridotite. The chrysotile is in narrow lensing veins from one-eighth to one-half an inch wide and from a few inches to several feet long. The veins may be parallel or normal to the ultrabasic contacts. In places the veins are flat lying.

The chrysotile fibres vary in flexibility from soft and pliable to harsh and brittle. The colour is usually greenish-grey. Two types of fibre are present; cross-fibre and slip-fibre. The cross-fibre chrysotile is most common and is oriented normal to the vein walls. The fibres range in length from one thirty-second to about one-half an inch. A few fibres have been reported up to an inch and one quarter in length. The cross-fibre veins may be subdivided into one-fibre and two-or more-fibre veins. In one-fibre veins each individual fibre of chrysotile extends from one vein wall to the other wall, whereas in the two-or more-fibre veins there is a distinct break between the fibres extending from one wall and the fibres extending from the other wall. The break or breaks between the fibres may be in any part of the vein, which results in fibres of different lengths in one vein. The break between the fibres is commonly filled with magnetite or massive serpentine or both. One-fibre and two-or more-fibre types may be present in the same vein.

The slip-fibres are oriented parallel to the walls of the "vein". They are confined to small slips and shears. The lengths of the slip-fibre vary considerably, but short soft fibres are the most common. Disseminated magnetite is a common associate.

It was noted in several places, especially in Munro township, that asbestos fibre is more common where the ultrabasic bodies are cut by Matachewan (?) diabase dikes. An examination of the map of Munro township (Satterly, 1951b, Map No. 1951-5) shows that diabase dikes are so numerous that it is almost impossible not to have a diabase dike close to any asbestos fibre occurrences. Satterly (1951b, p. 35) states:

> "It is suggested that this association is structural rather than genetic, being related to pre-Matachewan movements on the fracture that now contains a diabase dike."

The present author agrees with this statement.

In general asbestos fibre is more common in those areas where fractures and cross-faults are common.

The history, development, and description of the geology of the Munro asbestos mine, the only producing mine in the area, is given by Hendry (1951).

Nickel and chromium are common constituents of ultrabasic rocks. Satterly (1951b, p. 57) reports that in six assays of peridotite and dunite, the nickel content ranges from 0.16% to 0.30% and the chromium content from 0.13% to 0.50%.

Because of the relatively high magnetite content of the ultrabasic rocks, geophysical surveys employing magnetic principles are particularly adaptable for outlining the ultrabasic zones in drift-covered areas. Magnetometers and dip needles have been used with success in the area.

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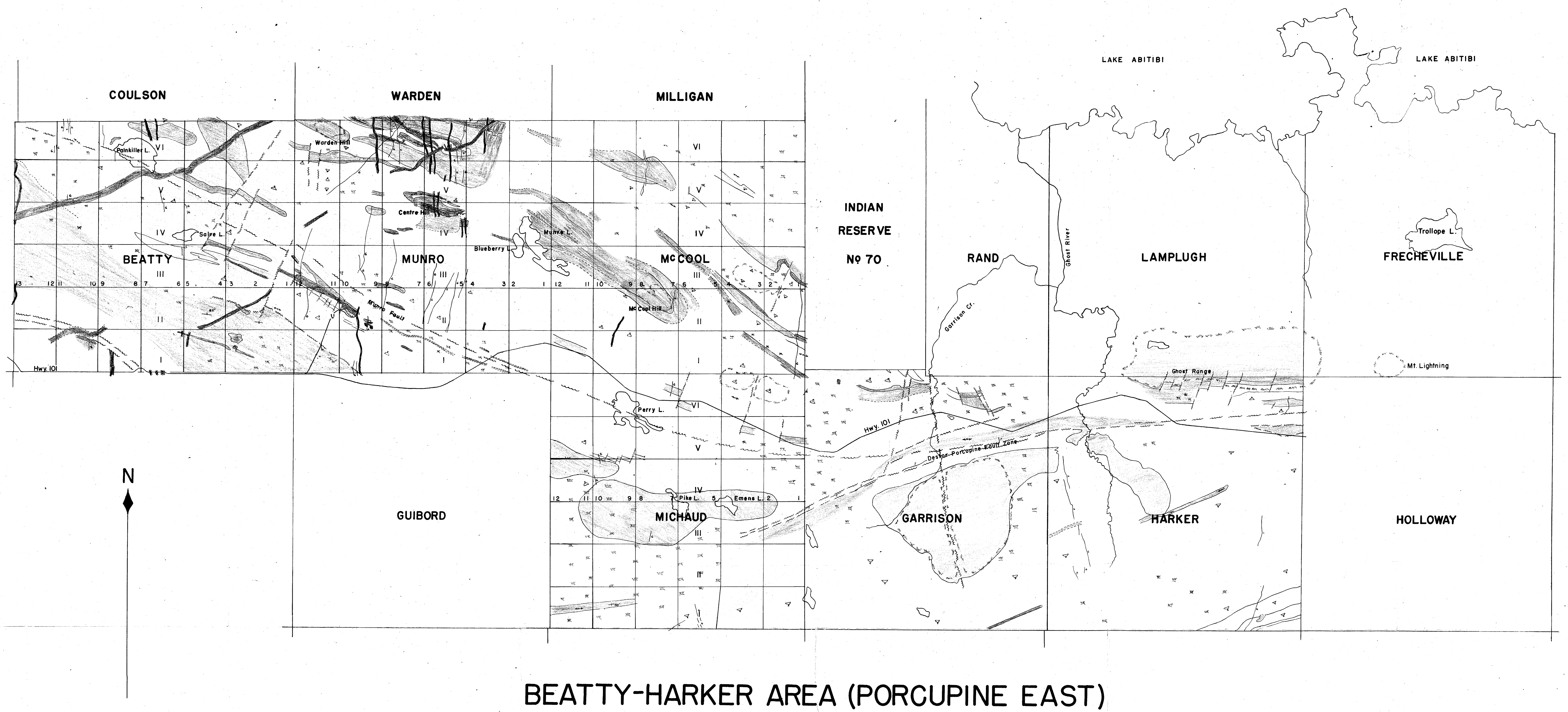

BEATTY-HARKER AREA (PORCUPINE EAST)

DISTRICT OF COCHRANE, ONTARIO

Scale: $\frac{1}{63,360}$ or 1 Inch to 1 Mile

1 0 1 2 3 4 5

SYMBOLS

- Hill or higher ground
- Muskeg or swamp
- Highway, with number
- Geological boundary, defined*
- Geological boundary, approx. based on geophysical data
- Strike and dip of beds
- Strike of vertical beds
- Strike and dip of schistosity
- Strike of vertical schistosity
- Fault, defined
- Fault, assumed
- Tops of lava flows as indicated by pillow shapes
- Pit limit
- Building

LEGEND

CENOZOIC

RECENT and PLEISTOCENE - Gravel, sand, clay **

UNCONFORMITY

PRECAMBRIAN

KEWEENAWAN (?)

Diabase, quartz diabase, olivine diabase

INTRUSIVE CONTACT

MATACHEWAN (?)

Diabase, quartz diabase

INTRUSIVE CONTACT

ALGOMAN (?)

Granite, syenite, feldspar porphyry, quartz porphyry

INTRUSIVE CONTACT

HAILEYBURIAN (?)

4a 4b Gabbro, diabase (4a); pyroxenite, peridotite, dunite, serpentinite (4b)

INTRUSIVE CONTACT

VOLCANICS

Rhyolite, rhyolite fragmental

Basalt, andesite, basalt fragmental

SEDIMENTS

Greywacke, arkose, quartzite, slate, conglomerate

* Some of the contacts are, in places, generalized. For greater detail refer to the township maps of the Ontario Department of Mines.

** These deposits are not shown.

Sources of Information

Compiled from township maps of the Ontario Department of Mines.

Note

Magnetic declination was approximately 12° W., 1951.

Drawn by F.C. Taylor, 1952.