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ONTARIO GEOLOGICAL SURVEY
Open File Report 5338

Geology of the Northeastern Portion of the Shawmere Anorthosite Complex, District of Sudbury.

by

Luca Riccio

1981

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E.G. Pye, Director
Ontario Geological Survey

PREFACE

SHAWMERE ANORTHOSITE

This project was developed and implemented by the Ontario Geological Survey, Ministry of Natural Resources on behalf of the Ministry of Northern Affairs. The Shawmere Anorthosite body was first discovered by the Ontario Geological Survey during a reconnaissance survey in 1970 (Operation Chapleau). The body is located near Chapleau and is close to road and rail transportation. Similarities between the Shawmere Anorthosite and chrome bearing anorthosites in Greenland were noted as a result of the 1970 reconnaissance work and since that time the extraction of aluminum from high purity anorthosite has been proven technologically feasible. This detailed survey of part of the Shawmere anorthosite was undertaken to assess the potential of this body for chromite mineralization and to generally delineate high purity anorthosite zones of potential interest for aluminum.

E. G. Pye
Director
Ontario Geological Survey

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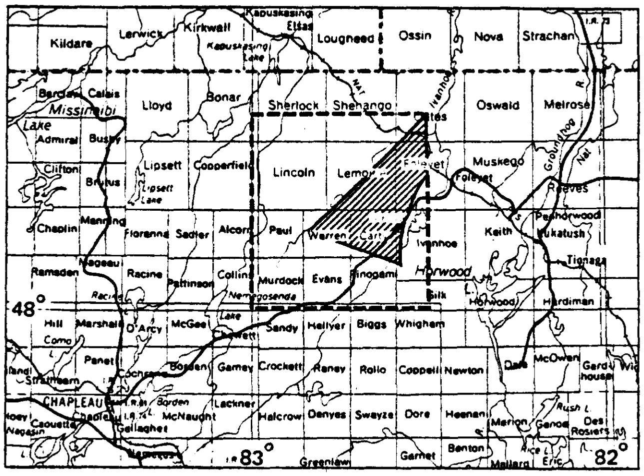
ABSTRACT



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1 inch to 25 miles

Key Map of Shawmere Anorthosite Complex

The Shawmere Anorthosite Complex is a highly deformed and metamorphosed Archean basement type anorthosite located in the Kapuskasing Structural Zone of the Central Superior Province. It strongly resembles other basement anorthosites such as the Fiskenaesset Complex of Greenland. The Anorthosite is surrounded by semipelitic paragneisses, amphibolites, and tonalitic orthogneisses of the Kapuskasing Structural Zone. The latter are, in part at least, intrusive into the Anorthosite, the paragneisses,

and the amphibolites. Metamorphic mineral assemblages in the area are typical of the upper amphibolite subfacies and the intermediate to high-pressure subfacies of the Hornblende Granulite Facies.

The Anorthosite Complex consists of a Main Zone of leucogabbro,anorthosite, subordinate gabbro and melagabbro, minor troctolite and ultramafic rocks, a Marginal Zone of foliated garnetiferous amphibolite, and younger metamorphosed anorthositic and gabbroic dikes. Leuco to melagabbroic rocks of the Main Zone are interpreted as metamorphosed gabbros, norites, gabbronorites, and olivine gabbros, whereas ultramafic rocks (hornblende-olivine-hypersthene-aluminum spinel $\pm$ plagioclase $\pm$ garnet rocks) are metamorphic products of troctolites. Typical high-grade metamorphic minerals from the Anorthosite are hornblende, garnet, cummingtonite, hypersthene, anthophyllite, Al-spinel, and sapphirine. Relict igneous minerals are plagioclase, orthopyroxene and clinopyroxene, and olivine. Anorthite content in plagioclase is generally in the 70 to 80% range but may be as high as 96%. Plagioclase megacrysts, clotty and coronitic textures are common within the central portion of the Complex whereas streaky and gneissic textures predominate along its margins.

Tonalitic gneisses are K-spar-free quartzofeldspathic rocks containing variable amounts of hornblende and biotite or biotite alone. They may be garnetiferous, especially the hornblende-rich types. The semipelitic paragneisses are plagioclase-quartz-

biotite-garnet rocks which may or may not contain hypersthene and K-spar. The amphibolites are generally quartz-bearing and garnetiferous, may contain biotite, commonly contain clinopyroxene, and very rarely orthopyroxene. Orthogneisses and paragneisses, amphibolites, and some peripheral zones of the Anorthosite, are characterized by the presence of variable amounts of concordant, semiconcordant, or discordant, medium to coarse grained trondhjemitic and quartz-rich segregations and veins. All lithologies in the area are intruded by undeformed "granitoid" pegmatites and Mid to Late Precambrian quartz or olivine-bearing diabase dikes.

Mesoscopic folds in the area are isoclinal, inclined to recumbent, and with shallow plunges to the WSW or, rarely, to the ENE. Metamorphic S-surfaces are parallel to axial planes of mesoscopic isoclinal folds and mineral lineations coincide with fold axes. Late North-northeast trending cataclastic zones are widespread in the eastern part of the map-area.

Although no chrome mineralization was found in the Shawmere Anorthosite Complex, the possibility of finding Fiskenaesset-type chromite occurrences cannot be excluded. The Shawmere Anorthosite as a whole contains about 24 to 26% Al_2O_3 (in plagioclase alone) and 30% or more in anorthosite-rich zones. It thus represents a possible source of low-grade aluminum ore.

GEOLOGY OF THE NORTHEASTERN PORTION OF THE SHAWMERE ANORTHOSITE COMPLEX DISTRICT OF SUDBURY

By

Luca Riccio[1]

1980

INTRODUCTION

This report summarizes the results of mapping in the 1979 field season and subsequent laboratory investigations on the northeastern portion of the Shawmere Anorthosite Complex (Thurston et al. 1977) and surrounding country rocks. The complex is a deformed and metamorphosed basement-type anorthosite (Windley, 1973) of Archean age (K/Ar age of 2.51 b.y.; Watkinson et al., 1972). The map-area is entirely within the Kapuskasing Structural Zone, a northeast trending zone of structural, metamorphic, and lithologic discontinuity separating the low grade east-trending Abitibi greenstone belt from high-grade northeast to east-northeast trending gneissic terranes of the Kapuskasing Structural Zone. The area is covered by ODM-GSC aeromagnetic maps 2247G and 2248G. It was previously mapped at a scale of 1:126720 as part of Operation Chapleau (Thurston et al.,

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[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto. Approved for publication by the Chief Geologist, 1980.

1977). The G.S.C. is currently investigating (Card et al., 1980) the nature and evolution of the Kapuskasing Structural Zone in the Chapleau Foleyet area.

Mapping in the summer of 1979 was carried out at a scale of 1:15840 using air photographs at the same scale supplied by the Air Photo Library, Ontario Ministry of Natural Resources. The geology was first plotted on acetate overlays and later transferred to base maps prepared by the Cartography Section, Surveys and Mapping Branch, Ministry of Natural Resources. Laboratory investigations consisted of examination of 178 thin sections, and interpretation of chemical data on rocks and minerals. Electron microprobe analysis of minerals is currently being done at the Univeristy of Western Ontario and will be incorporated in a later report. The primary objective of this project was to evaluate the Cr and Al potential of the Shawmere Anorthosite.

LOCATION AND ACCESS

The area investigated is centered at Latitude 48°15' North, Longitude 82°35' West, and covers about 300 km^2. It is located about 100 km west of Timmins and 90 km northeast of Chapleau. It includes Carty Township, the southeastern part of Lemoine Township, and small parts of Oates, Foleyet, and Ivanhoe Townships.

Access to the southern part of the area is provided by a series of forest access roads branching off Highway 101 and extending 5 to 8 km to the northwest. The Canadian National

Railway line crosses the northeastern corner of the area in Oates Township. The remainder of the area can be reached by float-equipped aircraft from nearby Ivanhoe Lake. The Shawmere River north of Shawmere Lake and the narrow, shallow stream connecting Wakagami and Carty Lakes are navigable by canoe.

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The author was capably assisted in the field by G. Bilcox, T. Hart, T. Noell, and S. Abercrombie. G. Bilcox conducted independent mapping.

Thanks are extended to J. Percival, K. Card, and K. Coe, for stimulating discussions in the field.

The author wishes to acknowledge the assistence provided by the District Office, Ministry of Natural Resources, Chapleau.

TERMINOLOGY

Rocks of the Shawmere Anorthosite Complex have been named according to the nomenclature for plutonic rocks proposed by the IUGS subcommission on the Systematic, of Igneous Rocks (Streckeisen, 1976). The term amphibolite is applied to mesocratic (C.I.#30-60) to melanocratic (C.I. 60-90) rocks in which hornblende and plagioclase are the main constituents, irrispective of whether the mineral assemblages of these rocks belong to the amphibolite or to the hornblende granulite facies.

The term foliation has been used to cover all types of mesoscopically recognizable S-surfaces of metamorphic origin

(Turner and Weiss, 1963). Banding applies to parallel intercalations of meta-igneous rock types of contrasting composition though to represent magmatic layering.

GENERAL GEOLOGY

SUMMARY

All bedrock in the map-area is Precambrian in age (Table 1) and lies near the southeastern margin of the Kapuskasing Structural Zone. The latter is a NE-trending zone of structural discontinuity extending from south of James Bay to Lake Superior (Card et al., 1980) and separating the Abitibi subprovince to the east, from the Wawa Subprovince to the west (Thurston et al., 1977).

The portion of the Abitibi Subprovin e to the east of the map area is referred to as the Swayze-Deloro Metavolcanic-metasedimentry Belt (Thurston et al.,1977), an east-west trending weakly metamorphosed series of supracrustal sequences of massive and pillowed basalts, subordinate intermediate to felsic flows and pyroclastic rocks, mainly volcanogenic clastic sediments, and intrusive to extrusive ultramafics. The supracrustal sequences of the Swayze-Deloro Belt are surrounded and locally pierced by intrusive plutons and stocks of trondhjemitic to granitic composition. Near the contact with the Kapuskasing Zone, supracrustal sequences and granitic intrusions are in turn cut by quartz monzonite stocks (personal observation; Card, 1980).

The Kapuskasing Structural Zone in the Foleyet-Chapleau Area

(Thurston et al., 1977) is underlain by meta-igneous rocks, melanocratic granulites, paragneisses of pelitic and psammitic composition, minor arkosic metasediments, and rocks of the Shawmere Anorthosite Complex (including tonalites). The Kapuskasing Structural Zone in the present map-area is mainly underlain by the Shawmere Anorthosite Complex tonalitic orthogneisses, semipelitic paragneisses and amphibolites (Table 1) (corresponding to the melanocratic granulites and metaolcanic gneisses of Thurston et al., 1977). All rocks in the map-area and elsewhere in the Chapleau-Foleyet portion of the Kapuskasing Structural Zone contain mineral assemblages of the upper amphibolite subfacies and hornblende granulite facies (Bennett, 1969; Thurston et al., 1977).

The metamorphosed Anorthosite Complex is a deformed, wedge-shaped, layered intrusion of greatest width north of Nemegosenda Lake in Paul and Collins Townships (Thurston et al., 1977) and tapering out in a northeasterly direction terminating just north of the CNR railway in Oates Township, a distance of approximately 60 km. Its maximum width in the map-area is less than 7 km. The Anorthosite Complex is composed of metamorphic derivatives (Table 1) of anorthositic, leuco- to melagabbroic and troctolitic rocks, and surrounded by garnetiferous amphibolites.

The Shawmere Anorthosite Complex is surrounded by a poorly exposed heterogeneous suite of quartzo-feldspathic rocks almost totally devoid of K-feldspar, and amphibolites. The quartzo-feldspathic rocks include orthogneisses of tonalitic composition (hornblende-biotite, biotite-hornblende, and biotite tonalites), trondhjemites, and garnetiferous biotite-rich paragneisses. The amphibolites comprise garnetiferous and garnet-free types, biotite-bearing types, all of which may or may not contain clinopyroxene. Orthopyroxene in amphibolites is rare. Concordant to slightly discordant medium- to coarse-grained, thin hololeucocratic segregations composed of variable proportions of quartz and plagioclase permeate both quartzo-feldspathic and amphibolitic country rocks.

In the area as a whole, quartzo-feldspathic orthogneisses greatly exceed in volume amphibolites and garnet-biotite paragneisses and are thought to have been intruded into them and into the anorthosite as semiconcordant sheets and masses.

Intrusive relations between hornblende-rich orthogneisses and anorthositic rocks can be seen northeast of Wakagami Lake where the regional foliation cuts across lithologic contacts separating the two units. Elsewhere, amphibolites and paragneisses occur as inclusions or as discontinuous outcrops completely surrounded by tonalitic gneisses. Based on the relative age relations and the relative abundance of orthogneisses and paragneisses the country rocks have tentatively been subdivided into a predominantly older unit (Unit 1) containing semipelitic metasediments, subordinate amphibolite and minor orthogneisses, and a predominantly younger one (Unit 5) made up of tonalitic rocks, subordinate amphibolite and minor paragneisses. It should be stressed that these subdivisions are preliminary. The paragneisses are plagioclase-quartz-biotite-garnet rocks which may or may not contain K-spar and orthopyroxene, and are chemically classifiable as greywackes. Best exposures of metasediments are to the north of the Anorthosite, in the Shawmere Lake Area, where they occur intercalated with amphibolites, hornblende-rich orthotonalites, and trondhjemites, or surrounded by tonalitic gneisses. The latter are K-spar free or almost free quartzo-feldspathic rocks containing variable amounts of hornblende and biotite or biotite alone and which may or may not be garnetiferous. They are the most common country rocks in the map-area. They surround the Anorthosite Complex, contain inclusions of amphibolites and paragneisses, and are intrusive, in part at least, into the Anorthosite. Thus the tonalitic gneisses are younger than the Anorthosite, paragneisses, and amphibolites, and consequently the Anorthosite must have intruded the metasediments and associated amphibolites. However, no direct intrusive contact has been observed between the Anorthosite and the metasediments.

The Shawmere Anorthosite Complex and surrounding country rocks are cut by semiconcordant and deformed medium-grained trondhjemitic segregatios, weakly deformed plagioclase-quartz-hornblende pegmatites, and undeformed "granitoid" pegmatites. The Shawmere Anorthosite Complex is also cut by more or less deformed but highly metamorphosed gabbroic and anorthositic dikes. Fresh to altered quartz- or olivine-bearing diabase dikes cut the above lithologies.

Deformation within the Kapuskasing Structural Zone gave rise to inclined to recumbent isoclinal folds with shallow plunges to the west-southwest and rarely to the east-northeast, shallow plunging mineral lineations, and metamorphic S-surfaces with shallow to moderate dips to the northwest. Northeast-southwest trending structural elements, shallow plunging lineations and shallow dipping S-surfaces characterize rocks of the Kapuskasing Structural Zone and contrast with the east-west structural elements, steeply dipping foliations and steeply plunging lineations within metavolcanic rocks from the nearby Abitibi Subprovince exposed along Highway 101 near the boundary between Carty and Pinogami Townships. Late north-northeast trending cataclastic zones locally affecting diabase dikes and accompanied by local development of ultramylonite and possibly pseudotachylite are common along the eastern margin of the map-area. They are likely to have developed along a preexisting zone of weakness corresponding to the eastern margin of a "graben-like" structure into which the Kapuskasing Structural zone rocks evolved.

The geological history of the map-area can be summarized as follows:

1. Deposition of clastic sediments with penecontemporaneous extrusion or intrusion of rocks of basaltic composition.
2. Intrusion of the Shawmere Anorthosite Complex near the base of the pile. Some coronitic textures formed during cooling from the solidus to the local geotherm (see section on metamorphism).
3. Intrusion of tonalitic rocks.

4. Beginning of deformation and prograde regional metamorphism.
5. Development of trondhjemitic segregations.
6. Formation of gabbroic and anorthositic dikes during the waning stages of the main deformation event.
7. Peak of regional metamorphism and beginning of retrometamorphism.
8. Intrusion of plagioclase-hornblende-quartz pegmatites.
9. Intrusion of "granitoid" pegmatites
10. Injection of diabase dikes.
11. Cataclasis.

EARLY PRECAMBRIAN (ARCHEAN)

METASEDIMENTS

Biotite-rich garnetiferous metasediments are fine-grained, schistose and light to rusty brown on weathered surfaces. They are best exposed along the shores of Shawmere Lake where they occur intercalated with greyish hornblende-biotite quartzo-feldspathic rocks of tonalitic composition, amphibolites, and minor hololeucocratic trondhjemites. The metasediments are compositionally banded and contain concordant augen-shaped and boudinaged quartzo-feldspathic segregations made up of large (up to several cm) plagioclase porphyroblasts and minor fine grained quartz and plagioclase (Photo 12). Individual bands are only a few centimetres thick and consist of alternating biotite-garnet rich and biotite-garnet poor layers. Melanocratic pelitic layers are very rare. The semipelitic metasediments are composed of plagioclase (An_{40} to An_{45}, 35-40%), quartz (25-30%), biotite (20-25%), garnet (3-15%), hypersthene (3-7%), accessories apatite, zircon, and opaques, and may contain minor hornblende. Semipelitic metasediments south of Shawmere Lake and east of the Shawmere Anorthosite Complex are mineralogically similar but do not contain hypersthene. Minor K-feldspar (probably orthoclase) previously undetected in thin section, has been observed in a few stained slabs of semipelitic metasediments. Quartz and plagioclase occur as granoblastic elongate aggregates with straight to slightly curved boundaries and with longest dimensions subparallel to small biotite (Z=brownish red to reddish brown) flakes defining a lepidoblastic foliation. Quartz also ocurs as discrete highly strained and flattened ribbon-like segregations. Garnet may be present as porphyroblasts with poikiloblastic cores and subidioblastic rims crosscutting the foliation or as xenoblastic grains with the foliation wrapping around them. Orthopyroxene occurs as colourless non-pleochroic xenoblastic grains invariably associated with biotite. It can be fresh or totally pseudomorphosed by a greenish-yellow fibrous alteration product which retains the crystallographic habit of the pyroxene. Alteration invariably begins along fractures and cleavage planes. Hornblende (Z=bluish green) is found as xenoblastic grains within horizons rich in garnet and biotite.

Quartzo-feldspathic rocks of tonalitic composition are invariably schistose and fine grained and display a gneissosity defined by variable concentration of mafic minerals in adjacent layers. Some quartzo-feldspathic rocks contain hornblende (up to 20%) and very minor biotite (1-3%) while others contain subequal amounts of both minerals. Both types are garnetiferous, the garnet rarely exceeding 2-3% of the mode. Texturally they are similar to semipelitic metasediments.

Hololeucocratic trondhjemitic layers alternating with semipelitic metasediments have been observed along Shawmere Lake and the Shawmere River. They are fine to medium grained granoblastic and heteroblastic rocks composed of plagioclase (An_{25}, 50-70%), quartz (25-45%), biotite (trace to 3%), and K-feldspar (trace to 3%). They may contain up to 2% garnet as well as accessory zircon and apatite. Interlocking quartz and plagioclase grains have highly irregular grain boundaries, whereas boundaries between plagioclase grains are straight and meet as 120° triple points.

Amphibolites of Unit 1 are mainly fine to medium grained mesocratic rocks composed of subequal (40%) amounts of hornblende and plagioclase (An_{50-55}), garnet (10%), greenish clinopyroxene (5-10%), quartz (trace to 5%), opaques (trace), and occasionally a little biotite. Hornblendes (Z=brown to brownish green) occur as strongly oriented idioblastic to subidioblastic prisms with straight mutual boundaries meeting at 120° triple points and curved boundaries against twinned plagioclase grains. Garnet grains are generally small (1 mm), rounded, subidioblastic or xenoblastic, and may or may not be poikiloblastic. Quartz is present as small (0.2 mm) xenoblastic grains or as flattened and deformed lensoidal segregatios up to 2 mm in length. Rare mafic lithologics include melanocratic amphibolites composed of hornblende (Z=brownish green) and subordinate amounts of plagioclase (15%), pink orthopyroxene (8%), pale green clinopyroxene (5%), and minor garnet, biotite, and opaques; and a melanocratic rock, exposed along the Shawmere River south of the northern end of Shawmere Lake, consisting of a grenoblastic aggregate of green clinopyroxene, subordinate garnet, secondary amphibole, and interstitial calcite and scapolite. In orthopyroxene-bearing amphibolites, orthopyroxene-clinopyroxene and plagioclase form irregular concentrations which replace previously crystallized amphibole thus indicating that they represent dehydration products of amphibole breakdown. The common presence of amphibolite units in the metasediments suggests that they may be penecontemporaneous flows or sills.

THE SHAWMERE ANORTHOSITE COMPLEX

The Shawmere Anorthosite Complex has been subdivided into a Main Zone of highly and variably deformed leucogabbro, anorthosite, subordinate gabbro, and ultramafic rocks and a Marginal Zone of foliated garnetiferous amphibolite. During mapping on a scale of 1:15840 an attempt to subdivide the Main Zone into separate lithologic units of contrasting compositional or textural characteristics was unsuccessful for the following reasons:

1. The distribution of each rock type is irregular and it is common to find exposures where several rock types are present.
2. Inclined to recumbent isoclinal folding has caused repetition of units.
3. Exposures other than those along lake shores and road cuts do not always provide enough information on composition and textures because of shallow plunge.
4. Mineral textures vary both on a regional and on a local scale.

Only on a more regional scale (Figure 1) is it possible to show the distribution of certain litholoic units and the relative intensity of deformation within the Complex. Figure 1 shows that a main anorthosite zone is located near the northwestern margin of the Anorthosite Complex and is traceable from the CNR railway in Oates Township in the north to north of the southern end of Lemoine Lake, a distance of approximately 12 km. The main anorthositic zone (0.5 to 1.0 km wide) which is entirely within a perhipheral deformed portion of the Complex (Figure 1), contains less than 10% mafic minerals on average, and locally consists of almost pure (2-3% mafics) anorthosite. It is either in direct contact with garnetiferous amphibolites of the Marginal Zone or is separatd from them by a thin zone of deformed gabbros. Towards the south, the anorthosite zone grades into less deformed predominantly leucogabbroic rocks.

Other anorthositic units (Figure 1) have been outlined along the southern margin of the Complex. However outcrops at those localities are not as continuous as those in the Main Anorthosite Zone and therefore contact relations between the southern anorthosite zones and surrounding rocks cannot be evaluated. The remainder of the anorthosite complex consists predominantly of leucogabbro containing intercalations of anorthosite or more mafic rock types and discountinous elongate patches of predominantly gabbroic rocks (Figure 1). Most of the central part of the Anorthosite Complex is moderately to highly deformed and contains relict magmatic features (Figure 1 and following descriptions) whereas the peripheral zone of the Complex is highly deformed and relict magmatic textures are seldom preserved.

MAIN ZONE

In areas of moderate deformation, leucogabbroic, gabbroic, and troctolitic rocks consist of large (1-50 cm) ellipsoidal (rarely subspherical) plagioclase megacrysts embedded in a fine to medium grained granular matrix (Photo 1). Anorthositic rocks from the same areas are made up of a granulated mosaic of small (2-4 mm) plagioclase grains and rarely contain plagioclase crystals of megacrystic size (Photo 2). Ultramafic rocks are invariably fine grained.

Individual plagioclase megacrysts are internally composed of irregular fragments of macroscopically twinned dark-grey primary igneous plagioclase and aggregates of small greyish-white granulated secondary plagioclase (Photo 1). Megacrysts composed of totally fresh igneous plagioclase or totally granulated secondary plagioclase are rare. The packing density and size of megacrysts vary both locally and regionally. In general, packing density in leucogabbros is between 60 and 70% but can be as low as 20%. The size of megacrysts tends to decrease from the center to the margins of the intrusion and is variable both between and within outcrops (Figure 2).

The matrix between megacrysts can consist of secondary granulated plagioclase (in anorthositic rocks), a mixture of granulated plagioclase and mafic mineral (Photo 1), or clots and pods of mafic minerals. In some outcrops, matrix plagioclase appears to have been derived from marginal granulation of megacrysts while in others it seems to represent recrystallized small igneous plagioclases. Clots and pods surrounding the plagioclase megacrysts vary in size from less than 1 cm to several cm and can be partially or totally amphibolitized. Partially amphibolitized clots are invariably coronitic, consisting of an inner core occupied by anhydrous minerals, surrounded by amphibole and occasionally by a discontinuous outer rim of granulated garnet (Photo 3). There are various types of corona assemblages and these will be described in more detail in the petrography section. In general clotty textures are useful in documenting the existence of plagioclase megacrysts in outcrops where the outline of individual megacrysts is no longer recognizable.

In zones of intense deformation, megacrystic and clotty textures tend to be replaced by streaky (Photo 4) and gneissic textures. The mafic clots are elongated into discontinuous subparallel stringers of mafic minerals and concomitantly the plagioclase megacrysts are streaked out into discontinuous leucocratic layers. Eventually the segregation of leucocratic and melanocratic layers can give rise to small scale gneissic layering. Although streaky and gneissic textures are characteristically developed within the periphery of the intrusion (Figure 1), they also occur in less deformed areas either along localized shear zones or along limbs of megascopic folds.

Primary igneous banding in rocks of the Shawmere Anorthosite Complex is manifested by changes in the proportion of plagioclase megacrysts and mafic mineral matrix (Photo 5), changes in size of plagioclase megacrysts, alternation of granulated anorthositic layers, and megacrystic leucogabbroic and gabbroic layers (Photo 6), alternation of granulated malagabbroic or ultramafic layers and megacrystic leucogabbroic layers, and alternation of granulated anorthositic, mafic, and ultramafic layers. Thickness of individual layers ranges from a few centimetres to several metres. In highly deformed peripheral zone of the Complex such as those exposed along Carty and Wakagami Lakes, compositional banding, foliation, and gneissosity are parallel to each other and care must be taken in differentiating between primary and metamorphic features. In less deformed internal zones of the intrusion, foliation may crosscut lithologic contacts between megacrystic layers at angles varying between 5° and 20° (Photo 5). Magmatic sedimentary structures have been obliterated by the deformation. At one locality on the northeastern shore of Carty Lake, layers rich in mafic minerals at the base and plagioclase at the top appear to be size-graded as well (Photo 7) and have been tentatively used as top indicators. Structures strongly resembling cross-bedding (Photo 8) can be observed at Carty Lake. However, since the rocks in the area are tightly folded and the folds are isoclinal and recumbent, the cross beds have been intrepreted as shear folds.

PETROGRAPHY

The post-igneous history of the Shawmere Anorthosite Complex involved polyphase metamorphism, hydration, dehydration, subsolidus reaction between mineral pairs, deformation, recrystallization, and minor retrometamorphism. These processes caused extensive modification of the original igneous mineralogy and textures. One of the main objectives of this petrographic study was to detect remnants of igneous minerals and to reconstruct the pre-metamorphic mineralogical composition of different rock types. These results are summarized in Table 2.

ANORTHOSITES (Map Code 3a)

Anorthosites consist of a mosaic of polysynthetically twinned recrystallized plagioclase grains (2-4 mm) with predominantly straight boundaries and 120° triple points, minor mafic minerals (less than 5%) interstitial to the plagioclase grains, and rare opaque minerals. Xenoblastic remnants of larger igneous plagioclas megacrysts can be observed in anorthositic rocks from the central part of the intrusion. Maficminerals are primarily hornblende (Table 2) (Z=bluish green to green) but may also include a variety of other metamorphic minerals formed during both prograde and retrograde metamorphism of the Anorthosite: garnet, sphene, rutile, epidote, zoisite, chlorite, calcite, biotite, and scapolite. Epidote, amphibole, and chlorite commonly form symplectitic intergrowths with quartz especially where amphibole cores are surrounded by zoisite shells and where chlorite replaces epidote. Some anorthosites contain up to 2% quartz as small (less than 1 mm) xenoblastic grains interstitial to plagioclase. Primary orthopyroxene and clinopyroxene are rare and, where present, are invariably mantled by hydrous minerals. Tiny (less than 0.05 mm) idioblastic grains (probably amphibole) often grow at the contact between recrystallized plagioclase crystals.

GABBROS (Map Codes 3d, e, f)

Rocks interpreted as originally of gabbroic mineralogy include garnet amphibolites and garnetites (3d),hornblende gabbros(3e), and gabbroic rocks composed of plagioclase and variable relative proportions of amphibole and clinopyroxene (3f). Garnet amphibolites and garnetites occur exclusively within the periphery of the Anorthosite Complex, especially within granoblastic-banded sequences exposed at Carty and Wakagami Lakes. Hornblende and hornblende-clinopyroxene gabbros are common along the margin f the intrusion and rare are in the center.

Garnet amphibolites and garnetites are fine to coarse grained melanocratic rocks characterized by dark green amphibole and dark red garnet. Garnet amphibolites are composed of amphibole (40-65%; Z = brownish green, greenish brown or emerald green), garnet (15-35%), quartz (3-18%) and opaques (trace to 4%) with or without plagioclase (0 to 3%) and apatite (0 to trace). Garnetites contain garnet (50-65%), amphibole (20%), plagioclase (5-25%), quartz (trace to 15%), opaques (trace to 2%), and apatite (trace to 2.5%). Sphene is absent in garnetites rich in opaques but abundant (up to 3%) where opaques are scarce. It occurs as inclusions in hornblende and garnet and as granular aggregates rimming opaques minerals (probably ilmenite). Textures of garnet amphibolites and garnetites are dominated by nematoblastic preferred orientation of hornblende prisms and porphyroblastic growth of garnets. In both garnet amphibolites and garnetites, garnet porphyroblasts are highly variable in size (0.2 to 5 mm). Small garnet porphyroblasts tend to be subidioblastic and inclusion-free whereas larger ones are generally xenoblastic and heavily poikiloblastic.

Poikiloblastic garnets commonly display a zonal texture defined by a core riddled with inclusions surrounded by a massive homogeneous rim. Clinopyroxene is rarely found in both garnet amphibolites and garnetites and does not amount to more than 3% of the mode.

Hornblende gabbros (Map Code 3e) are fine to medium grained, foliated, and frequently lineated metamorphic rocks containing hornblende (Z = bluish green) and plagioclase in subequal proportions. Minor garnet and trace amounts of quartz and opaques may be present in some hornblende gabbros. Hornblende gabbros differ from garnet amphibolites in that the latter are distinctly richer in garnet and opaques. At one locality on the northern shore of Carty Lake, a strongly lineated fine grained garnet-bearing hornblende gabbro contains numerous patches, 3 to 4 mm wide, consisting of optically continous hypersthene grain interdigitating with and poikiloblastically enclosing plagioclase grains with variable crystallographic orientation. The orthopyroxene-plagioclase intergrowths cut across the amphibole lineation and are in turn deformed and lineated.

Gabbroic rocks containing hornblende and clinopyroxene (Map Code 3f) are fine to medium grained, mesocratic to melanocratic rocks, often strongly lineated and invariably garnet-free. They include partially and totally recrystallized types.

In hand specimen, clinopyroxene of the totally recrystallized type is bright green whereas that of the partially recrystallized type is greyish-green. Partially recrystallized hornblende-clinopyroxene gabbros consist of highly strained interlocking anhedral primary clinopyroxene grains (1-6 mm), secondary granulated clinopyroxene, and patches of recrystallyzed granoblastic polygonal plagioclase with or without remnants of igneous plagioclase. Remnants of primary clinopyroxene contain orthopyroxene exolution lamellae and are clouded with dust and inclusions. Rims of granoblastic brownish hornblende surround the clinopyroxene and brown hornblende locally replaces the clinopyroxene along cleavage planes. Granular, symplectite-like intergrowths of orthopyroxene and plagioclase are rarely found outside the amphibole rims around clinopyroxene.

Totally recrystallized clinopyroxene-hornblende gabbro is composed of often zoned granoblastic plagioclase (An 60-65), subidioblastic hornblende (Z = bluish green), and subordinate (10-15%) small (0.5 mm) xenoblastic and fractured clinopyroxene grains free of inclusions and exsolutions.

NORITES (Map Code 3g)

Noritic rocks are common throughout the Anorthosite Complex. They consist of plagioclase megacrysts totally or partially recrystallized into a granoblastic polygonal mosaic of secondary plagioclase and a coronitic assemblage of brown orthopyroxene rimmed by dark-green amphibole, in turn rimmed by a discontinuous rim of pink garnet. The orthopyroxene can be totally recrystallized into a granoblastic aggregate of small grains (0.2-0.6 mm) or consist of a mixture of anhedral igneous orthopyroxene and secondary granoblastic orthopyroxene. Both primary and secondary orthopyroxenes are weakly pleochroic. The amphibole rim consists of a granoblastic polygonal mosaic of idioblastic pargasitic hornblende grains (Z = light bluish green) with dimensions ranging between 0.5 and 1 mm. The garnet rim forms a very fine grained aggregate of granoblastic and poikiloblastic grains which nucleated at the contact between amphibole and plagioclase and grew outward and inward replacing both plagioclase and amphibole. Occasionally the garnet penetrates deeply into the amphibole corona and can be seen in contact with orthopyroxene. Recrystallized simplectic intergrowths of orthopyroxene and plagioclase are rarely developed where garnet and orthopyroxene are in close contact. Plagioclase enclosed in garnet may contain inclusions of pale green spinel. At one locality on the northern shore of Lemoine Lake the coronitic orthopyroxene has been completely replaced by colourless (beige in hand specimen) anthophyllite prisms which are in turn surrounded by clino-amphibole partially replaced by anthophyllite and by an outer shell of granoblastic garnet.

GABBRONORITES (Map Codes 3j, 3L)

Gabbronorites are, along with norites, the most common gabbroic types of the Shawmere Anorthosite Complex. They are composed of plagioclase megacrysts, partially or totally recrystallized into a granoblastic polygonal mosaic of secondary plagioclase, surrounded by finer grained aggregates of plagioclase, two pyroxenes, minor brown amphibole, and occasionally garnet. Clinopyroxenes and orthopyroxenes of gabbronorites from the central part of the intrusion occur as relatively large (up to 1 cm) grains surrounded by fine grained granoblastic polygonal aggregates of granulated secondary pyroxenes and minor amphibole. In the more deformed gabbronorites only the secondary granoblastic polygonal mosaic can be seen. Discontinuous garnet rims similar to those in the norites may grow at the contact between mafic mineral aggregates and plagioclase, especially where amphibole is a major constituent of the aggregates. Apparently garnet does not grow in gabbronorites containing little amphibole.

Medium grained rocks composed of approximately 30% igneous plagioclase, 30% igneous clinopyroxene, and 40% coronitic assemblages, crop out 0.5 km east of the southeastern shore of Wakagami Lake in Lemoine Township. The plagioclase in those rocks occur as laths (2-3 mm) heavily clouded with dust and inclusions except for the outermost rim which is clear and inclusion-free. Primary clinopyroxenes are augite, commonly twinned, containing fine exsolution lamellae, dust and inclusions and displaying a clear rim surrounded by granoblastic brown amphibole. Coronitic assemblages consisting of cores of fine grained granoblastic polygonal orthopyroxene, surrounded by an inner shell of fine grained radially arranged clinopyroxene grains partially or totally replaced by colourless amphibole and an outer rim of poikiloblastic garnet replacing amphibole and plagioclase. Remnants of amphibole-spinel symplectites are preserved as inclusions within the poikiloblastic garnet rim. The coronitic assemblages are interpreted as products of subsolidous reactions involving olivine (now totally obliterated) and plagioclase, which led to the formation of orthopyroxene, clinopyroxene, and spinel, followed by partial hydration of clinopyroxene and subsequent garnet development. Thus the "metamorphic" garnet-amphibole gabbronorites were derived from igneous olivine-gabbronorites.

TROCTOLITES (Map Code 3m), ULTRAMAFIC ROCKS (Map Codes 3p, 3q, 3r) AND GARNET-CLINOAMPHIBOLE METAGABBRO (Map Code 3h)

Troctolitic rocks contain olivine, plagioclase (An_{74}-An_{94}) and a metamorphic coronitic assemblage derived from the subsolidous reaction between olivine and plagioclase. Ultramafic rocks can be subdivided into three main types: (1) an olivine-rich type derived from melatroctolite (Map Codes 3p, 3d); (2) a clinopyroxene-hornblende type corresponding to original plagioclase clino-pyroxenites (Map Code 3s); and (3) an ultramafic type composed essentially of clinoamphibole, subordinate garnet and with or without minor orthopyroxene, plagioclase, and green spinel (Map Code 3r). These garnet-hornblendites are the more ultramafic equivalent of garnet-clinoamphibole melagabbros (Map Code 3h).

The coronitic assemblage in coronitic troctolite consists of an inner rim of granoblastic pink and strongly pleochroic hypoersthene in contact with olivine surrounded by a wider rim of granoblastic polygonal pargasitic hornblende (Z = greenish blue) and green spinel. Green spinel occurs as very small (0.1 mm) xenoblastic grains interstitial to pargasite or as symplectitic intergrowths with amphibole. The amphibole-spinel rim is separated from the plagioclase by a fine grained garnet rim composed of both subidioblastic and inclusion-free grains and xenoblastic poikiloblasts. Although the garnet is preferentially developed at the contact between amphibole-spinel rim and plagioclase, it can also be seen penetrating the amphibole-spinel shell and preferentially replacing the amphibole. The plagioclase in immediate contact with the garnet rim is a mixture of fine grained granoblastic polygonal aggregates of inclusion-free grains and xenoblastic grains riddled with inclusions (amphiboles?). Less than 15 mm away from the contact it becomes coarser grained, granoblastic polygonal, and inclusion-free. The coronitic assemblages in troctolitic rocks are the result of reactions of the type: olivine + plagioclase + H_2O = orthopyroxene + amphibole + spinel followed by garnet formation at the expense of the amphibole-spinel symplectite. The coronas between olivine and plagioclase are similar to those described by Grieve and Gittins (1975) from the Hadlington Gabbro and to those occurring in olivine gabbros and troctolites from Norway (Mason, 1967; Stormer, 1969; Frodesen, 1968).

Olivine-bearing ultramafic rocks (Map Codes 3p, 3d) are fine grained, dark-greyish green rocks containing the metamorphic mineral assemblage orthopyroxene-amphibole-green spinel plus variable amounts of recrystallized and partially serpentinized primary olivine. They crystallized as melatroctolites and the original plagioclase was subsequently consumed during the formation of the orthopyroxene-amphibole-green spinel coronitic assemblages. Some olivine-bearing ultramafics have preserved corona textures similar to those previously described while other have been deformed into a granoblastic polygonal elongate mosaic of idioblastic olivine, hypherstene, amphibole, and interstitial green spinel. The granoblastic elongate mosaic is characterized by straight interphase boundaries meeting at 120^{o} triple points.

Clinopyroxene hornblendites (Map Code 3s) are medium grained dark green rocks composed of subidioblastic and randomly oriented hornblende (Z = bluish green) grains (1-2 mm), smaller light green clinopyroxene grains and 3-4% highly strained xenoblastic quartz occurring interstitially to the mafic minerals. These ultramafic rocks which are related to the clinopyroxene-hornblende gabbros are thought to represent original clinopyroxene-plagioclase cumulates. Garnet clinoamphibolites (Map Codes 3r, s) and garnet-hornblende melagabbros (Map Code 3h) are medium to coarse grained rocks composed essentially of bright emerald green amphibole and subordinate light pink garnet. Up to 15% plagioclase is present in melagabbroic types and minor amounts of hypersthene, plagioclase, anthophyllite, and green spinel may be present in ultramafic types. Sapphirine may occur in both types. The clinoamphibole in these rocks is characteristically weakly coloured and pleochroba (Z = almost colorless) has high interference colours and Z > c of about 20°. Microprobe studies are under way to determine its exact composition. The clinoamphibole occurs as interlocking subidioblastic and heteroblastic grains (1 to 5 mm) with straight mutual boundaries. Colourless anthophyllite prisms may replace the clinoamphibole, especially near amphibolegarnet contacts. Garnets form granoblastic aggregates of xenoblastic and heavily poikiloblastic crystals replacing plagioclase and amphibole. Orthopyroxene, where present, occurs as strongly pleochroic grains (Z = pink) interstitial to the clinoamphibole. It may contain irregularly-shaped inclusions of olive green spinel. Sapphirine occurs at two localities along the shores of Carty Lake, in a melagabbroic rock composed of clinoamphibole (50%), garnet (30%), plagioclase (18%), sapphirine (1%), and minor anthophyllite and in an ultramafic lithology in which it coexists with amphibole, garnet, orthopyroxene and trace amounts of anthophyllite and spinel. The sapphirine occurs as discrete small (0.1-0.3 mm) subidioblastic grains interstitial to the other silicates or as inclusions in the garnet. Sapphirine can be colourless or blue and displays the following distinct pleochroism; X = colourless, Y = sky blue, Z = blue.

MARGINAL ZONE

The marginal zone is a distinct lithologic unit, less than 100 m wide which separates the Main Zone of the Shawmere Anorthosite Complex from the predominantly quartzofeldspathic country rocks. It crops out discontinuously along the northeastern margin of the intrusion, the southeastern shore of Carty Lake, and the Shawmere River in the northwestern corner of the map-area. Exposures along the eastern margin of the anorthosite are very scarce and although amphibolite outcrops have been found, it was not possible to define a mappable amphibolitic marginal zone at those localities.

The Marginal Zone is made up of a melanocratic, quartz-bearing garnetiferous amphibolite containing 5 to 20% concordant to slightly discordant medium to coarse grained hololeucocratic trondhjemitic and quartz-rich layers, 2 to 20 cm thick, and occasionally anorthositic layers up to 50 cm thick. In the Carty Lake region the contact between Main Zone anorthositic rocks and Marginal Zone rocks appears to be concordant and transitional: Main Zone sequences composed of interbanded granoblastic-textured anorthosite, gabbro, garnet amphibolite, garnetite, and minor quartzofeldspathic segregations grade into melanocratic garnetiferous amphibolites interbanded with subordinate anorthositic layers and minor quartzofeldspathic segregations. A few metres away from the contact the quartzofeldspathic segregations become more prominent and anorthositic layers disappear (Photo). Still further away from the contact, the garnetiferous amphibolites become increasingly migmatized and locally injected by gneissic tonalite. Contact relationships in the north are less clear. At two localities along the Shawmere River anorthositic layers occur interbanded with garnet amphibolites. Elsewhere, garnet amphibolites containing quartzofeldspathic segregations form prominent ridges separated from anorthositic rocks by a possible fault.

The garnet amphibolites of the Marginal Zone are medium grained rocks composed of hornblende (Z = brownish green, 40-70%) and subordinate amounts of plagioclase (An_{45-55}, 10-30%), garnet (4-20%), quartz (2-10%), and opaques (trace to 2%). They may contain clinopyroxene, sphene, and apatite. Hornblende occurs as subidioblastic grains with straight mutual boundaries and longest dimension oriented parallel to the foliation. Garnet forms porphyroblasts often with poikiloblastic cores and massive homogeneous rims. Small (0.2-0.4 mm) xenoblastic quartz grains and larger twinned and zoned plagioclase grains are found interstitial to hornblende grains or as inclusions (quartz especially) in garnet. Sphene and opaques are preferentially concentrated at the edge of hornblende crystals or are poikilitically enclosed in hornblende and garnet. Clinopyroxene is present as xenoblastic grains in sharp contact with the other phases. In one sample from Carty Lake, a few clinopyroxene grains are totally surrounded by garnet, and garnet apophyses penetrate deeply into the clinopyroxene grains.

The garnet amphibolite unit which rims the Main Zone of the Shawmere Anorthosite Complex is considered to be part of the intrusion on the basis of the contact relationships between Main Zone rocks and garnet amphibolites at Carty Lake. However, other interpretations should not be ruled out: (1) The garnet amphibolites unit represents a metamorphosed chill margin, (2) The garnet amphibolites are metamorphosed mafic country rocks, (3) The garnet amphibolites represent metamorphosed lit par lit injections of basaltic composition in the Shawmere Complex. While the above interpretations will be further discussed in the section dealing with the chemistry of the garnet amphibolites, it should be pointed out that whatever the genetic significance of the Marginal Zone, it still remains the best mappable lithologic unit in the area.

METAMORPHOSED DYKES

Main Zone rocks of the Shawmere Anorthosite Complex are cut by a variety of metamorphosed anorthositic and gabbroic dikes and dikelets a few centimetres to tens of centimetres thick. Anorthositic dikes are coarse grained to pegmatitic and white on weathered surfaces whereas gabbroic dikes are invariably fine grained and can be greyish, dark green, or reddish coloured. The main mineralogical and textural features of the different dike types are summarized in Table 3. Most of the dikes are almost undeformed or slightly deformed. Thus they were likely injected during or soon after the waning stages of the deformational event which was responsible for the development of the main foliation-lineation in anorthositic rocks. Relative age relations between anorthositic and gabbroic dikes have been determined at only two localities. At the northwest end of Lemoine Lake anorthositic dikes (Type 3) are cut by fine grained garnetiferous dikes (Type 6?) and at the southeastern end of the same lake anorthositic dikes (Type 1) cut gabbroic dikes (Type 4). Hornblenderich reaction selvages have been observed at the contact between Type 1 anorthositic dikes and megacrystic country rocks. Thin (5-10 cm thick), fine grained, garnetiferous dikes from the northwestern end of Lemoine Lake are internally zoned. The central portion of the dikes contains garnet, subordinate amphibole, quartz, opaques, and clinopyroxene; whereas the margins are composed of plagioclase, garnet, and amphibole, and contain only trace amounts of quartz and opaques as well as sphene and rutile.

All early metamorphosed dikes are of great petrologic significance in that a comprehensive study of their chemistry may help to unravel the differentiation trend(s) of the liquid(s) which gave rise to the layered sequence of the Shawmere Anorthosite Complex.

CHEMISTRY

Major and trace element analysis data of 16 samples from the Shawmere Anorthosite Complex are listed in Table 4.

Anorthositic rocks (Samples 1 and 2) are extremely depleted in trace elements and have an average CaO/Na_2O ratio of 6.06 whereas rocks of leucogabbroic composition (Samples 3 and 4) have a slightly higher CaO/Na_2O ratio of 7.22 and Cr contents (273 ppm) areapproximately 300 times higher than those in anorthosite. The CaO/Na_2O ratio and Cr content of leugogabbros reflects the presence of clinopyroxene in these rocks. The affinity of Cr for clinopyroxene is even more evident in hornblende-clinopyroxene gabbros (Sample 5) and clinopyroxene-hornblendites (Sample 6), both of which have Cr contents in excess of 1,400 ppm. The CaO/Na_2O ratios of anorthositic and leucogabbroic rocks from the Shawmere Anorthosite Complex are comparable to those of similar rocks from the Fiskenaesset Complex (CaO/Na_2O = 8.01; Windley, 1973, Table 1) and the Limpopo Belt (CaO/Na_2O = 5.83; Hor et al., 1975, Table 1, (Columns 2 to 6), distinctly higher than Adirondack type anorthosites (CaO/Na_2O = 2.32; Windley, 1973, Table 1), but lower than CaO/Na_2O ratios than other basement type anorthosites such as the Sittampundi Complex (CaO/Na_2O = average = 14.9, maximum 65.5; Subramanian, 1956, Table 31).

Garnet-hornblende melagabbros (Sample 7) and spinel-olivine-hypersthene hornblendites (Sample 8) are ultramafic rocks with Ni content (550 and 590 ppm respectively) typical of olivine-rich rocks. Simple calculations show that mineral assemblages of both ultramafic rocks are the product of isochemical hydrous metamorphism of original troctolites containing different initial proportions of forsteritic olivine and Ca-rich plagioclase (Table 5). More specifically the sapphirine-bearing garnet hornblende melagabbro corresponds to an initial mixture of 59.5% plagioclase (An_{81}) and 40.5% olivine (Fo_{69}) and the spinel-olivine-hypersthene hornblendite to a troctolite containing 58% olivine (Fo_{69}) and 42% plagioclase (An_{80}). Thus these petrochemical calculations coupled with previous petrographic observations indicate that there are two types of ultramafic or melagabbroic rocks which were derived from troctolites or melatroctolites: one type contains the mineral assemblage amphibole-orthopyroxene-olivinespinel $\pm$ garnet (Map Codes 3p, 3q) and the other is composed of amphibole, subordinate garnet, and may or may not contain plagioclase, orthopyroxene, minor Al-spinel (Map Codes 3h, 3r, 3t).

Quartz-bearing garnet amphibolites and quartz-bearing hornblende garnetites (Samples 9-10) from the Main Zone of the Shawmere Anorthosite have variable SiO_2 contents (42.7-50.7%), very low Cr and Ni concentrations, very high FeO^*/MgO ratio (3.13-4.0), high TiO_2 (2.22-2.44) and low to very low Na_2O. Such chemical compositions suggest a magmatic origin as titanomagnetite-rich cumulates. Quartz-bearing and quartz-free garnetites similar to those from the Shawmere Anorthosite Complex also occur intercalated with anorthosites and sapphirine-bearing gabbros and amphibolites in granulite-facies terranes of the Massif Central of France (Lasnier, 1977).

Garnet-amphibole-quartz layers also occur in the Fiskensesset Complex (Windley and Ghisler, 1967).

Marginal Zone rocks (Samples 11-14) are typical tholeiitic basalts with relatively low FeO*/MgO ratios (1.4 - 1.58) Al_2O_3 (14.3-14.9%) and TiO_2 contents. They are chemically comparable to the low Fe-Ti tholeiites from greenstone belts of South Africa, Canada, Australia, Brazil, and Rhodesia (Kishida and Riccio, 1980). The only metamorphosed gabbroic dyke analyzed (Sample 16) is a high-Al basalt (Al_2O_3 18.5%) with low FeO^1/MgO ratio (1.18) and TiO_2 content (0.62%). The inferred crystallization path of such liquids can be determined by projecting their normative composition from the olivine and clinopyroxene apexes, respectively, of the basalt tetrahedron (Irvine, 1970; Figure 3). The dike composition plots in the plagioclase volume (Cpx-projection, Figure 3A) and projects well into the plagioclase boundary surface of the olivine volume (ol-projection, Figure 3B) at 1 atmosphere. At higher pressures (4.5 Kb) the same liquid plots in the olivine volume (Figure 3A) and projects in the plagioclase boundary surface of the olivine volume (Figure 3B). Marginal Zone compositions cluster around the olivine-plagioclase boundary line (Figure 3A) and plot in the plagioclase boundary surface of the olivine volume (Figure 3B). At higher pressures (4.5 Kb) Marginal Zone rocks fall in the olivine field of the clinopyroxene projection and in either the orthopyroxene or clinopyroxene fields of the olivine projection. Thus liquid compositions such as the early metamorphosed dike would produce abundant plagioclase and plagioclase-olivine cumulates irrespective of load pressure during crytallization whereas Marginal Zone compositions would give rise to early olivine-plagioclase cumulates at very low pressures but mainly olivine and pyroxene cumulates at higher pressures. Hence the Shawmere Anorthosite Complex is more likely to have been derived from a liquid composition such as the early metamorphosed dike rather than the Marginal Zone rocks. Possibly Marginal Zone rocks represent metamorphosed basaltic flows rather than the chilled margin of the anorthosite. Clinopyroxene (Figure 3A) and Olivine (Figure 3B) projections of analyses of one early metamorphosed dike (open circle) and four Marginal Zone rocks (solid dots) from the Shawmere Anorthosite Complex. Projections and liquidus boundaries are from Irvine (1970). The cation norm for each sample has been calculated assuming an Fe_2O_3 content equal to TiO_2 (wt%) + 1.5.

Ol = olivine; Pl = plagioclase; Opx = orthopyroxene; Cpx = clinopyroxene; Q = quartz.

FELSIC PLUTONIC ROCKS

Tonalitic gneisses, subordinate amphibolite, and scattered remnants of metasediments are the main lithologies of Unit 5. Hornblende-rich, biotite-poor relatively "mafic" tonalitic gneisses are preferentially concentrated around the periphery of the anorthosite and make up the bulk of tonalitic rocks intrusive into the anorthosite. More leucocratic biotite-rich, hornblende poor tonalitic gneisses crop out along the Fire Tower Road in Foleyet Township and extend several kilometres northeastward where they grade laterally into garnetiferous metasediments. Biotite tonalites are less common and occur associated with both hornblende-biotite and biotite-hornblende tonalites. Amphibolite occurrences are common in the vicinity of the anorthosite and along the southeastern margin of the map area. Preliminary geological traverses further to the east-southeast, in the area bounded by the Foleyet Fire Tower Road in the south, and the Ivanhoe River in the east, have indicated the presence of foliated amphibolites, banded tuffs of intermediate to mafic composition, fine grained schists of leucodiorite composition, minor ultramafic rocks (clinopyroxene, hornblende, minor sphene, and apatite), and both clinopyroxene-bearing and clinopyroxene-free quartz monzonite stocks. The latter are similar to the quartz monzonites occurring near the margin of the Kapuskasing Structure and crosscutting the Granulite Gneiss Complex in Belford Township (Bennett, 1969).

BIOTITE-HORNBLENDE TONALITIC GNEISSES

Biotite-hornblende tonalitic gneisses are grey, fine to medium grained, schistose rocks composed of plagioclase (An_{30-40}, 30-60%), quartz (20-30%), hornblende (15-35%), biotite (trace to 15%) and accessories, apatite (up to 1%) zircon and opaques. They are almost invariably garnetiferous. Outcrops of gneissic tonalites display large scale gneissic banding caused by alternating bands (2-50 cm thick) containing variable proportions of ferromagnesian minerals and fine scale gneissic lamination due to alternating thin (1-5 mm) hololeucocratic quatzo-feldspathic segregations. The quartzo-feldspathic segregations may consist of interlocking quartz and plagioclase grains with highly irregular mutual boundaries, or a combination of interlocking plagioclase grains with straight self boundaries and lensoidal, flattened and discontinuous ribbon-like quartz segregations. Hornblende (Z = bluish green to green) and biotite (Z = dark brown) are invariably oriented with their longest dimensions subparallel to the schistosity plane. Garnet grains are generally small (0.5-2 mm) moderately poikiloblastic and predominantly subidioblastic.

HORNBLENDE-BIOTITE TONALITIC GNEISSES

Hornblende-biotite tonalites are texturally similar to hornblende biotite gneissic tonalites except that the former rarely display a well developed gneissic banding but only gneissic lamination. They are light grey rocks composed of plagioclase (40-65%), quartz (15-30%), biotite (8-20%), hornblende (2-15%, average 5%), and accessories apatite, zircon, and opaques. They are generally nongarnetiferous and 70% of thin sections examined contain epidote. Trace to 2-3% microcline and, rarely, accessory sphene, can be present in biotite-hornblende tonalitic gneisses. Microcline occurs as small grains (less than 1 mm) interstitial to quartz and plagioclase and is generally restricted to hololeucocratic quartzo-feldspathic segregations. Biotite in these rocks have dark brown to black absorption colours along Z. Epidote is alway in contact with biotite flakes and is especially common in samples containing the most iron-rich (Z = black) biotites. Both biotite and epidote may form fine symplectitic intergrowths with quartz. Hornblende (Z = bluish-green to deep bluish-green) occurs as xenoblastic grains often with poikiloblastic quartz inclusions.

BIOTITE TONALITE GNEISSES

Biotite tonalites include fine to medium grained schistose types texturally similar to tonalitic gneisses containing both hornblende and biotite and medium to coarse grained foliated and augen-textured types possibly representing intrusive phases younger than the other tonalitic gneisses. Many biotite tonalites have colour indexes of less than 10 and should therefore more properly be classified as trondhjemites. The main constituents of biotite tonalites are plagioclase (An 30-40), biotite (Z = dark brown to black' 4-20%), quartz (25-40%) plus accessories apatite, zircon and opaques. They may contain epidote, microcline, sphene, and tourmaline. Muscovite (up to 2%) is present in some biotite tonalites from the Foleyet Fire Tower Road and adjoining areas, while minor garnet occurs within biotite tonalites cutting the Shawmere Anorthosite Complex. In coarse grained types, large (up to several mm) antiperthitic plagioclase porphyroblasts and porphyroclasts are surrounded by small interlocking quartz and plagioclase grains and bundles of biotite flakes. Small microcline grains tend to ocur at the margins of plagioclase porphyroblasts.

AMPHIBOLITES

Amphibolites occur as boudins, rafts, discontinuous layers, and irregular patches enclosed in gneissic tonalites and as discrete outcrops injected by variable amounts of hololeucocratic microcline-free quartzo-feldspathic material (Photo 13). The plagioclase portion of the quartzo-feldspathic material appears pink when saussuritized and may be mistaken for K-feldspar. Although amphibolites of Unit 5 are commonly garnet-free, garnetiferous amphibolites do occur in the vicinity of the Shawmere Anorthosite and also in the southeastern corner of the map-area. At one locality on the western shore of a small lake 1 km to the west of East Carty Lake, melanocratic clinopyroxene-bearing amphibolites consist of alternating, 2-5 cm thick, garnet rich (up to 40% garnet) and garnet poor layers. Possibly the banding reflects original compositional variations within mafic pyroclastic rocks. Most amphibolites of Unit 5 are texturally and compositionally similar to amphibolitic rocks previously described. Biotite amphibolite are often very fine grained (average grain size 0.5 mm) schistose and consist of a granoblastic elongate mosaic of plagioclase grains, xenoblastic hornblende grains (Z = greenish brown) and small biotite (Z = brown to reddish brown). Quartz is rare and is mainly present as poikiloblastic inclusions in hornblende.

CHEMISTRY

Chemical analyses of orthogneisses and paragneisses from the Shawmere Area, of similar Archean quartzo-feldspathic rocks from Ireland, Scotland, Minnesota, and Greenland, and of volcanic rocks from the Superior Province are shown in Table 6. The relative proportions of CaO, Na_2O, and K_2O are plotted in Figure 3.

Tonalitic and trondhjemitic rocks from the Shawmere area and Archean basement complexes elsewhere are characterized by high Na_2O/K_2O ratios (greater than 2 and commonly greater than 4) and low to moderately low Cr and Ni contents. In contrast, pelitic and semipelitic metasediments have lower Na_2O/K_2O ratios (less than 2 and less than 1 in truly pelitic varieties) and much higher Ni and Cr concentrations. The high Ni and Cr contents of Samples 8 and 9 from the Shawmere area is suggestive that these metamorphic rocks were originally clastic metasediments. Furthermore, the high concentrations of both Cr and Ni indicate that the source area for the detritus must have contained significant amounts of basaltic and possibly ultramafic rocks. Tonalitic gneisses from the map-area are chemically comparable to similar lithologies from Scotland and Greenland except that the latter are consistently richer in Ba. Tonalitic gneisses from the Shawmere area are also not dissimilar to calc-alkaline andesitic and dacitic lavas from the Superior Province. More specifically the hornblende-biotite tonalitic gneisses are chemically comparable to andesites and biotite tonalites to dacites.

This preliminary geochemical data would suggest two genetic interpretations for the orthogneisses: (1) if all quartzo-feldspathic orthogneisses in the area were intruded into supracrustal sequences then it follows that they represent intrusions of partial melts similar to those which produced the extrusive andesite-dacite sequences of the Superior Province; (2) if, on the other hand, the quartzo-feldspathic orthogneisses are, in part at least, reworked supracrustal sequences, then they might represent metamorphosed volcanics of intermediate composition.

EARLY TO MIDDLE PRECAMBRIAN

MAFIC INTRUSIVE ROCKS

DIABASE DIKES

Diabase dikes, a few centimetres to a few tens of meters thick, cut all other rock types in the area. They are commonly found in the southeastern and eastern part of the map-area and less frequently in regions further to the north and northeast. All dikes are brownish to brownish-red on weathered surfaces and dark grey to black on fresh surfaces. Small dikes are aphanitic throughout while larger ones are medium grained with macroscopically visible ophitic textures in the center and fine grained to aphanitic near the margins of the dikes. Many dikes display well developed chilled margins. Most of the dikes in the area trend east-northeast but west-northwest, north-northwest, and northeast trending dikes are also present (Figure 4). Dips vary from vertical to steep to the south and east. The attitudes of the diabase dikes from the area are comparable with those of the Early to Middle Precambrian SET 1, 2, 3 and 4 diabase dikes from the Chapleau area (Thurston et al. 1977). North-trending diabase dikes were not found, an observation which corroborates Thurston's et al., (1977) statement that northerly trending Early Precambrian diabase dikes from the Chapleau region do not cut the Kapuskasing Structural Zone or the Shawmere Anorthosite Complex.

Petrographically the diabase dikes can be subdivided into: (1) quartz diabase types (by far the most common types) composed of plagioclase (45-60%), augite (30-50%), up to 10% micropegmatite (quartz and plagioclase), and 3-5% opaques, and (2) olivine diabase types consisting of subequal amounts of plagioclase and augite, 15-20% olivine, and 1-3% opaques. In quartz diabases plagioclase occurs as fresh to moderately saussuritized, twinned and strongly zoned euhedral laths (1-3 mm average length) ophitically or subophitically enclosed in granular augite. The latter is anhedral, often twinned, and invariably surrounded by an alteration rim of green to blue-green hornblende. Micropegmatitic intergrowths of quartz and plagioclase occupy the interstices between plagioclase and clinopyroxene grains. Opaques occur as anhedral grains (0.2-1 mm) rimmed by red biotite and minor hornblende. In olivine diabase dikes, augite and plagioclase bear the same ophitic to subophitic relationship as in quartz diabases, whereas olivine occurs as separate anhedral to subrounded grains. The olivines are invariably fractured and contain opaques within fractures and around the margins of the grains. Discrete opaque grains are generally irregularly-shaped and have straight boundaries against the silicates. Small (0.2 mm) amygdules filled with calcite and zeolite have been seen in a sample of olivine diabase from Shawmere Lake.

METAMORPHISM

In high grade terranes containing both upper amphibolite and granulite facies parageneses, the transition from almandine amphibolite to hornblende granulite facies (de Waard, 1967) is characterized by PH_2O-T controlled dehydration reactions leading to the formation of orthopyroxene. In rocks with excess Si, depending on bulk composition, orthopyroxene can form through reactions between biotite and quartz; hornblende and quartz, biotite, sillimanite and quartz; or hornblende, garnet and quartz (de Waard, 1965). Once in the granulite stability field, metamorphic reactions and resulting mineral parageneses are then controlled by variations in P_{load}, PH_2O, and T. While further PH_2O-T controlled dehydration reactions eventually lead to the disappearance of hydrous minerals and the formation of anhydrous mineral assemblages of the pyroxene-granulite facies, P_{load}-T controlled reactions give rise to low, intermediate, or high pressure mineral assemblages. Thus mineral assemblages of granulite terranes can be ascribed to the low, intermediate, and high pressure subfacies of the hornblende granulite facies; or to the low, intermediate, and high pressure subfacies of the pyroxene granulite facies (de Waard, 1965b). Low pressure granulites are characterized by the presence of cordierite (cordierite-almandine subfacies) and the stable association olivine-plagioclase in basaltic rocks (Green and Ringwood, 1967). Intermediate pressure granulites contain orthopyroxene and plagioclase (orthopyroxene-plagioclase subfacies) whereas the pair olivine-plagioclase is unstable. High-pressure granulites contain the assemblage garnet-clinopyroxene-quartz (clinopyroxene-almandine subfacies) which forms at the expense of plagioclase and hypersthene. In brief, important isograds in high grade terranes are the orthopyroxene isograd, separating amphibolite and granulite facies, the biotite-hornblende isograd separating hornblende and pyroxene granulite facies, and the cordierite and garnet isograds which mark the lower and upper limit, respectively, of the intermediate pressure granulite subfacies.

Mineral assemblages from the map-area (Table 7) indicate that the rocks crystallized under P-T conditions of the upper almandine-amphibolite, and of the intermediate and possibly high pressure subfacies of the hornblende granulite facies. Cordierite is absent, the pair olivine-plagioclase is unstable, and totally anhydrous parageneses are absent. Interestingly, mineral assemblages of the amphibolite and hornblende granulite facies can occur in adjacent layers, an intermingling which characterizes many deep-seated regions (Turner, 1968).

The transition between the amphibolite facies and the orthopyroxene-plagioclase subfacies of the hornblende granulite facies can be observed in semipelitic rocks at Shawmere Lake and in mafic rocks from Shawmere and Carty Lakes. Quartzo-feldspathic semipelitic metasediments immediately to the south of Shawmere Lake contain biotite + garnet whereas compositionally similar rocks exposed along the shores of the same lake are characterized by the stable assemblage biotite + garnet + K-spar ± hornblende. Thus field evidence points to prograde dehydration reactions of the type BIOTITE + QUARTZ -- ORTHOPYROXENE + ALMANDINE + KSPAR + H_2O (de Waard, 1965a) and/or HORNBLENDE + BIOTITE + QUARTZ -- ORTHOPYROXENE + ORTHOCLASE + PLAGIOCLASE + H_2O (de Waard, 1965b). Melanocratic mafic layers consisting essentially of hornblende and very minor garnet, contain irregular patches of orthopyroxene, clinopyroxene, and plagioclase, developed at the expense of hornblende. The hornblende breakdown can qualitatively be interpreted as the result of the reaction: HORNBLENDE -- ORTHOPYROXENE +

CLINOPYROXENE + PLAGIOCLASE + H_2O. At Carty Lake hornblende-garnet metagabbros are seen to locally contain orthopyroxene-plagioclase intergrowths which replace hornblende. The likely reaction to produce the orthopyroxene-plagioclase assemblage was: HORNBLENDE + ALMANDINE + QUARTZ -- ORTHOPYROXENE + PLAGIOCLASE + H_2O (de Waard, 1965b). Quartz was consumed during the production of orthopyroxene and excess almandine remained as a stable phase. Other assemblages typical of the hornblende-orthopyroxene-plagioclase subfacies are present in metamorphosed mafic dikes and in non-coronitic totally recrystallized ultramafic rocks (olivine-hornblende-orthopyroxene-spinel). O'Hara (1961) describes similar metamorphosed plagioclase-normative ultramafic rocks from the Lewisian Complex of Scotland and their mineral assemblage (olivine + hypersthene + hornblende + spinel ± augite) has been interpreted by Green and Ringwood (1967) as typical of intermediate pressure granulites.

Mineral assemblages considered to characterize the high-pressure subfacies of the hornblende-granulite facies occur in mafic rocks containing clinopyroxene,garnet and quartz. The high-pressure assemblage is thought to be derived by the reaction ORTHOPYROXENE + PLAGIOCLASE -- CLINOPYROXENE + GARNET + QUARTZ (Green and Ringwood, 1967). In the map area however, it cannot be proved that the clinopyroxene-plagioclase-quartz assemblage was derived from subsolidus reaction between orthopyroxene and plagioclase, since clinopyroxene never coexists with orthopyroxene in these rocks. This can either mean that the orthopyroxene-consuming reactions had invariably gone to completion, or that the clinopyroxene-garnet-quartz assemblage did not form through reactions involving orthopyroxene. It should also be pointed out that at Shawmere Lake the supposedly high- pressure clinopyroxene-garnet-quartz "amphibolites" coexist with intermediate pressure mafic and semipelitic rocks containing orthopyroxene.

Coronitic rocks are particularly instructive in that they often show both reactants and products of the corona-forming reactions. In coronitic rocks of initial troctolitic composition the original igneous assemblage (olivine-plagioclase) is first overprinted by orthopyroxene + amphibole + spinel and subsequently by garnet which grows at the expense of both amphibole and plagioclase. In olivine-normative coronitic gabbros containing plagioclase, clinopyroxene, orthopyroxene, garnet, minor amphibole, and very minor spinel, textural evidence indicates that primary olivine was totally replaced by orthopyroxene + clinopyroxene + amphibole + spinel while garnet grew at a later stage. Thus olivine-plagioclase rocks from the Shawmere Anorthosite Complex first crossed the field of intermediate pressure granulites (formation of orthopyroxene) and subsequently that of high pressure granulites (formation of garnet). Coronitic rocks of noritic and gabbronoritic composition first developed amphibole rims around the pyroxenes and then garnet which partially resorbed the amphibole corona around orthopyroxene. These textures suggest an initial hydration (formation of amphibole) followed by a dehydration reaction (garnet formation) which may have been caused by changes in PH_2O, P_{load}, T or a combination of changes in all three parameters.

Based on the mineral assemblages of anorthositic and country rocks the following metamorphic history is proposed for the Shawmere Anorthosite Complex (Figure 5). The Shawmere Anorthosite was intruded at moderate pressure and cooled at constant or slightly rising pressure. During cooling from the solidus to the geothermal gradient the Anorthosite crossed the low-pressure boundary separating low and intermediate-pressure granulites and was slightly hydrated. Olivine and plagioclase became unstable and were replaced by the orthopyroxene + amphibole + spinel $\pm$ clinopyroxene assemblage. Pyroxenes on the other hand, only developed amphibole at the contact with plagioclase. After reaching the regional geotherm, both Anorthosite and country rocks underwent prograde dynamo-metamorphism which was responsible for the development of regional upper amphibolite and hornblende granulite parageneses. Fluctuations in PH_2O were probably responsible for the development of either amphibolite or granulite parageneses. In spite of the intense deformation which accompanied the prograde metamorphism, corona textures in the interior of the Anorthosite were deformed, recrystallized, but not obliterated. Some of the gabbroic dikes emplaced during the waning stages of the main deformation event were totally recrystallized into metamorphic mineral assemblages of the hornblende granulite facies. During subsequent cooling all previously metamorphosed rocks were partially retrometamorphosed.

STRUCTURAL GEOLOGY

FOLDS, FOLIATIONS, AND LINEATIONS

The main structural elements in the area are northeast to east-northeast striking planar structures with shallow to moderate dips to the northwest to west-northwest; lineations trending 245^{o} ($\pm15^{o}$) with shallow ($\pm10^{o}$) plunges to the west-southwest and rarely to the east-northeast (Figure 6); and inclined to recumbent mesoscopic, mainly isoclinal folds with northwest dipping axial planes. Planar structural elements include compositional banding in rocks of the Shawmere Anorthosite Complex, and S-surfaces of metamorphic origin (foliation sensu lato) due to segregation of leucocratic and melanocratic layers (gneissosity), planar alignment of micas and hornblendes (schistosity), and planar preferred orientation of elongate plagioclase megacrysts. Lineations include fold axes, rodding of plagioclase and quartz in anorthositic and quartzo-feldspathic rocks, respectively, linear segregations of hornblende or hornblende and clinopyroxene aggregates in gabbroic rocks, and linear alignment of hornblende and/or biotite in quartzo-feldspathic rocks. The isoclinal folds are generally steeply inclined to recumbent in the southeastern part of the area and inclined farther to the north. Folds with diverging limbs have only been observed near the northern extremity of Carty Lake and along the southern shore of Lemoine Lake. In the Shawmere Anorthosite Complex the style of isoclinal folds vary from similar, in more deformed zones (e.g. Carty Lake), to concentric, in the central part of the intrusion (e.g. Little Lemoine Lake).

The relations between fold axes of isoclinal folds, compositional banding, schistosity, and mineral lineations can be observed in several exposures of mesoscopic folds from the Shawmere Anorthosite Complex.

In general, isoclinally folded layers of contrasting composition develop prominent mineral lineations along the hinge zones (Photos 6 and 14) and both foliaton and lineation along the limbs. Mineral lineations associated with the isoclinal folds are invariably coaxial with the fold axes and foliations along the limbs are subparallel to the axial plane. Shallow isoclinal folds have been observed only in peripheral zones of the Shawmere Anorthosite Complex where the foliation wraps around fold noses. Outcrops of the Shawmere Anorthosite Complex, showing only linear structures, can thus be used to locate hinge zones of isoclinal folds where fold closures are not visible.

The deformation event responsible for the development of isoclinal folds and associated lineations in rocks of the Shawmere Anorthosite Complex also produced similar structures in the country rocks (see Figure 6) and partly affected early dikes and quartzo-feldspathic segregations. Only late pegmatitic dikes and diabase dikes of Unit 6 remained undeformed. Deformation events postdating the isoclinal folding gave rise to gentle regional warps about northwest trending subhorizontal axes, and localized warps about steeply dipping north to north-northwest plunging axes. Warps about subhorizontal axes were probably responsible for reversals in the direction of plunge of mineral lineations and fold axes of isoclinal folds.

A regional structural interpretation of the Shawmere Anorthosite Complex cannot be made at this stage, due to lack of good stratigraphic tops and uncertainties about the nature of the Marginal Zone.

LATE SHEAR ZONES

North to northeast trending shear zones characterized by intense cataclasis, mylonitization, and local development of ultramylonite and pseudotachylite bands and veinlets are common along the eastern margin of the map-area. They are indeed common features along the eastern boundary of the Kapuskasing Structural Zone (Bennet, 1969; Thurston et. al., 1977). The most prominent cataclastic zone, up to 250 m wide, straddles the boundary between Anorthosite and country rocks from the CNR railway in Oates Township, to the Fire Tower Road in Foleyet Township. Other major cataclastic zones are exposed at Wakagami Lake and to the west of East Carty Lake. Typical ultramylonites are extremely competent, black, aphanitic, and cherty-looking rocks composed of tiny quartz and feldspar porphyroclasts embedded in a structurless cryptocrystalline matrix. Shearing in anorthositic rocks has produced numerous yellowish fine grained alteration bands (5-10 cm thick) composed of paragonite, minor plagioclase, and saussuritazion products. The bands strike north-northeast to northeast and dip moderately to steeply to the southwest.

The cataclastic zones are late structural features which cut across lithologic units and locally affect diabase dikes. Nevertheless, they locally separate domains of contrasting lithologic and structural characteristics. For example, the mylonite zone to the west of East Carty Lake separates tonalites, mafic rocks, and paragneisses with shallow planar and linear structures, from locally unfoliated "greenstone type" granodiorites. This would suggest that the cataclastic zones did develop, in part at least, along preexisting faults marking the structural boundary between greenstone terranes and the Kapuskasing Structural Zone.

ECONOMIC GEOLOGY

CHROMITE

Economically significant chromite occurrences are found in large layered intrusions of Late Archean (Stillwater) or Lower Proterozoic (Bushveldt) age, in Early Archean, small intrusions within greenstone terranes (Seluwke, Rhodesia; Bahia State,

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Brazil) and in Phanerozoic ophiolite complexes (Turkey, Philippines, etc.). Significant but presently uneconomic chromite mineralization also occurs in basement anorthosites from Greenland (Windley, 1973), India (Subramanian, 1956), the Limpopo Belt (Hor et. al., 1975), and Sierra Leone (Andrews-Jones, 1966).

The first three types of chromite occurrences are generally found within the stratigraphically lower portions of tholeiitic intrusions, are associated with ferromagnesian minerals (especially olivine) with high Mg/Fe ratios, and tend to occur at the base of cyclic units. Furthermore, individual chromite grains have low Fe_2O_3 contents and are rarely found associated with cumulus clinopyroxenes. The stratigraphic position of the chromites and the chemical composition of both spinel and silicates are in agreement with experimental (Hill and Roeder, 1974) and field-based (Irvine, 1977) genetic models on crystallization and concentration of chrome-spinels. Work by Hill and Roeder, and Irvine has indicated that: (1) chrome rich spinels can only crystallize from primitive liquids due to the very large enrichment of chromium in spinels and ferromagnesian silicates relative to the liquid with which they are in equilibrium, (2) the crystallization of large amounts of clinopyroxene (which can easily contain up to 1% Cr_2O_3) in effect reduces the Cr content of the liquid to the point that chromite is no longer stable, (3) crystallization under high fO_2 conditions would produce chrome-spinel with high Fe_2O_3)

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contents, and (4) if chrome-spinel begins crystallizing as a disseminated phase along with another silicate, it cannot give rise to massive chromitite layers unless the liquid composition is changed through mixing with new magma injections. The last point would explain the occurrence of massive chromitite layers at the base of cyclic sequences (Irvine, 1977). Another feature of many layered intrusions containing chromite in the lower part of the stratigraphy (Bushveldt, Stillwater) is the presence of cumulus titanomagnetite and ilmenite toward the top of the intrusion. The incoming of Fe-Ti oxides is usually abrupt and follows a period of magmatic differentiation during which no spinel phase was crystallizing. This "SPINEL GAP" is well represented in the Bushveldt intrusion whose spinel-free Main Zone (+ 3 km thick) separates the chromite-bearing Critical Zone from the overlying titanomagnetite-ilmenite bearing Upper Zone.

Chromite occurrences of basement anorthosites such as the Fiskenaesset Complex (Ghisler and Windley, 1967; Windley, 1973) are anomalous when compared with those of other layered intrusions in that chromite layers from basement anorthosites occur stratigraphically above magnetite-rich layers and contain chromites very rich in both FeO and Fe_2O_3. Analyzed chromites from the Fiskenaesset Complex (Ghisler and Windley) have less than 40% Cr_2O_3, about 35% combined FeO and Fe_2O_3, more than 20% Al_2O_3, less than 60% combined Al_2O_3 + Cr_2O_3, a Cr/Fe weight ratio of less than 1, and may contain up to 0.5% V_2O_5. Such a composition does not meet the requirements of metallurgical,

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chemical, or refractory grade chromite Morning, 1977). Although these chromite occurrences are, like those of he Bushveldt Complex, associated with anorthositic rocks, the similarity between the Bushveldt Complex and basement anorthosite stops there. Chromites from the Bushveldt Complex lie at a specific stratigraphic horizon within a layered intrusion differentiating along a classical Fe-enrichment trend. Chromites from Fiskenaeesset are also found within a restricted stratigraphic horizon (Windley, 1973, Figure 5) but their positioning and other features of the intrusion cannot easily be explained in terms of fractional crystallization of basaltic magmas. In order to explain the high-Ca nature of the Fiskenaesset plagioclases, the presence of supposedly magmatic amphiboles, and the early precipitation of magnetite, Windley (1973) has suggested that the Fiskenaesset magma was hydrous. While this interpretation may be valid, it still does not account for the presence of chrome-rich spinels stratigraphically above Fe-Ti oxides (unless of course the chromite bearing cumulates crystallized from an independent magma batch).

The Shawmere Anorthosite Complex is comparable to the Fiskenaesset Complex insofar as regional lithologic and structural similarities, preponderance of anorthositic and leucogabbroic rocks over gabbroic and ultramafic rocks, presence of hornblende-rich ultramafics, occurrences of quartz-hornblende-garnet rocks, and presence of Fe-rich marginal amphibolites (Thurston, 1974). However, while the Fiskenaesset

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Complex contains chromite mineralization and is thought to have crystallized from a hydrous magma, the Shawmere Anorthosite Complex is apparently chromite-free and was derived from an anhydrous magma.

With regard to the chrome potential of the Shawmere Anorthosite, the following possibilities are offered for consideration:

1. The Shawmere Anorthosite does not contain chromite disseminations or concentrations because it represents a cumulate sequence crystallized during a "SPINEL GAP" similar to that which characterizes the Bushveldt and other layered intrusions.
2. The Shawmere Anorthosite, although similar to the Fiskenaesset Complex in many respects, does not contain chromite because it crystallized under physicochemical conditions different from those existing during crystallization of Fiskenaesset.
3. The Shawmere Anorthosite does contain chromite mineralization. If so, then in view of the limited knowledge about the genesis and the stratigraphic positioning of chromites in basement anorthosites a search for chromite could be carried out in two ways. One alternative is to assume that the Shawmere Anorthosite Complex is stratigraphically and structurally comparable to the Fiskenaesset Complex. If this is the case, then the chromitiferous horizons should be searched for within the central portion of the intrusion, especially

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within alternating leucogabbroic and anorthositic layers. The second would be to do further mapping with the aim of better defining the stratigraphy of the intrusion and to prospect for chromite.

4. As a final consideration it should be pointed out that any chromite find in the Shawmere area would probably be subeconomic at the present time. However such a find could become economic in the future due to the strategic importance of chrome, the lack of significant chromite deposits in North America, and the high vanadium content of chromites from basement anorthosites.

ALUMINUM

World aluminum production (Figures are for 1979 aluminum and bauxite production of the western world. Source of information: 1979 Mining Annual Review) (11.55×10^6 tons) comes exclusively from bauxite (72×10^6 tons). Major aluminum producers are the U.S. (4.3×10^6 tons), Japan (1.05×10^6 tons), Canada (1.05×10^6 tons), West Germany (0.74×10^6 tons), and Norway (0.65×10^6 tons). The largest bauxite producers are Australia (24.3×10^6 tons), Guinea (12×10^6 tons), Jamaica (11.73×10^6 tons), Surinam (4.8×10^6 tons), Guyana (3.3×10^6 tons), and a number of other countries with bauxite outputs in the 1 to 2 million tons range. Estimated bauxite reserves run in the several tens of billion tons. Brazil alone, which is presently producing 1.2 $\times 10^6$ tons of bauxite a year, has estimated reserves of 4×10^9 tons, 3×10^9 of which come from the newly opened Trombetas

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deposit on the Amazon River (Globe and Mail, February 25,1980; p.B6).

In spite of the optimistic outlook regarding world bauxite reserves, there are two factors of concern to the aluminum industry: 1) Rising transportation costs, and (2) uncertainty about supplies (Mining Journal, February 29, 1980). Uncertainty about supply stems from the political instability of many bauxite producing countries as well as from the tendency of bauxite exporters to turn into aluminum producers. For these reasons, in order for the aluminum industry in the western world "to maintain its competitive position, the industry will have to adapt to .... changing circumstances in the coming decade by a combination of geographical change in the location of smelting and refining centres, by utilising low-grade and non bauxite raw materials" (alunite, anorthosite (Up to 98% Al_2O_3 can be recovered from anorthosite by using the Lime-Soda Sinter Process; Quon, 1977), and micaceous residues)" and by technological developments aimed at reducing processing costs" (Mining Journal, February 20,1980, p. 155).

The aluminum content of anorthosites is a function of the anorthite content of the plagioclase and of the modal ratio plagioclase/mafic minerals. Preliminary bulk chemical and electron micro probe determinations on plagioclase composition from anorthositic and leucogabbroic rocks from the Shawmere Anorthosite Complex suggest an anorthite content in the range An_{70}-An_{80} corresponding to 31.5 and 33.2% Al_2O_3, respectively.

This author's estimate of the average mafic mineral content of the Shawmere Anorthosite Complex (northeastern half) as a whole is about 20-25% corresponding to an overall Al_2O_3 content from plagioclase alone ranging from 23.5% to 26.5%. The predominantly anorthositic zones outlined in Figure 1 should contain about 30% Al_2O_3. The average Al_2O_3 content of pure Adirondac-type anorthosite is about 26% Al_2O_3 which is comparable to the average Al_2O_3 content of the Shawmere Anorthosite Complex as a whole, but distinctly lower than the Al_2O_3 content of the Shawmere Anorthosite anorthositic zones.

Thus the Shawmere Anorthosite Complex as a whole, its anorthositic zones, and more specifically, the anorthositic zone along the northwestern margin of the intrusion (Figure 1) represent viable supplies of low-grade Al_2O_3. Easy accessibility by existing road and rail would make the Shawmere Anorthosite Complex particularly interesting should anorthosites become economically exploitable.

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Table 1: TABLE OF LITHOLOGIC UNITS

PHANEROZOIC
CENOZOIC
QUATERNARY
PLEISTOCENE AND RECENT
Till, sand, clay, and gravel

Unconformity

PRECAMBRIAN
EARLY TO MIDDLE PRECAMBRIAN
MAFIC INTRUSIVE ROCKS
Diabase

Intrusive Contact

EARLY PRECAMBRIAN (ARCHEAN)
FELSIC PLUTONIC ROCKS
Biotite-hornblende, hornblende-biotite, and biotite tonalite gneiss, garnetiferous tonalite gneisses; inclusions of amphibolite, garnetiferous amphibolite, clinopyroxene garnet amphibolite, and paragneisses (biotite-rich garnetiferous quartz plagioclase rocks).

Intrusive or Fault Contact

SHAWMERE ANORTHOSITE COMPLEX
Metamorphosed Dikes
Anorthosite and gabbro (mainly garnetiferous) dikes[1]

Intrusive Contact

Main Zone
Anorthosite and garnetiferous anorthosite, coronitic and non-coronitic leuco to melagabbros including hornblende gabbro, clinopyroxene-hornblende gabbro, garnet hornblende norite, horn blende and garnet-hornblende gabbronorite; metamorphosed troctolites and melatroctolites including hornblende-olivine-hypersthene-spinel $\pm$

plagioclase + garnet rocks and clinoamphibole-garnet ± plagioclase ± hypersthene ± spinel ± sapphirine rocks; clinopyroxene hornblendite and quartz ± plagioclase ± clinopyroxene hornblende-garnet rock.

Marginal Zone

Quartz ± clinopyroxene-garnet amphibolite

Intrusive Contact

METASEDIMENTS

Garnet-biotite-quartz-plagioclase± hypersthene ± hornblende schist (metawacke), intercalation of quartz-clinopyroxene garnet amphibolite locally orthopyroxene bearing; interlayered with younger biotite-hornblende tonalitic gneisses and trondhjemites.

[1]One metamorphosed gabbroic dike was seen cutting tonalite gneiss rocks.

TABLE 2: MINERALOGICAL CHARACTERISTICS AND NOMENCLATURE OF ROCKS

Map Code(s) and Nomenclature	Inferred Igneous Nomenclature
3a Anorthosite	Anorthosite
3b Leucogabbro[3]	
3d[4] Quartz ± cpx garnet amphibolite, to quartz ± cpx amphibole garnetite	Fe-Ti gabbro
3e Hornblende gabbro ± garnet ± quartz	Gabbro
3f Hornblende-clinopyrox. gabbro	Gabbro
3g Garnet-hornblende norite	Norite
3j 3L Hornblende gabbro-norite, garnet-bearing hornblende gabbronotire	gabbronorite, minor olivine gabbronorite
3m Coronitic troctolite	Troctolite
3p,3q Spinel harzburgite; spinel-olivine-hypersthene hornblendite	Troctolite
3h[4],3fr[4] Garnet-clinoamphibole melagabbro; garnet clinoamphibolite	Troctolite
3s Plagioclase clinopyroxenite hornblendite	plagioclase clinopyroxenite

Table 2: FROM THE MAIN ZONE OF THE SHAWMERE ANORHOSITE COMPLEX

Inferred Igneous Mineralogy	Remnant Igneous Minerals	Secondary Recrystallized Igneous Minerals[1]
plag; minor cpx and/or opx	plag	plag, minor cpx, opx
	plag	plag
		plag
plag, cpx	plag, cpx	plag, cpx
plag, opx	plag, opx	plag, opx
plag, opx, cpx; oliv.	plag, opx, cpx	plag, opx, cpx
oliv, plag	oliv, plag	oliv, plag
oliv, plag	oliv, plag	oliv, plag
oliv, plag		plag
cpx, plag		cpx, plag

Metamorphic Minerals[2]

hornble., garnet

hornbl, garnet, quartz,
sphene, opaques(ilm.),
apat., clinopyroxene

hornbl., garnet
quartz

hornblende

hornblende, garn,
anthophylite

hornblende, garnet,
opx

opx, hornbl, spinel, garnet

opx, hornbl., spinel,
garnet

clinoamph., garnet,
opx, spinel, anthophyll.,
sapphirine

hornbl. quartz

Plag = plagioclase
hornbl. = hornblende
cpx = clinopyroxene
opx = orthopyroxene
qtz = quartz
ilm = ilmenite
apat = apatite
autophyl = autophyllite
oliv = olivine
clinoamph= clinoamphibole (possible magnesio-ccummingtonite)

1) Secondary recrystallized igneous minerals are those which formed through marginal granulation and recrystallization of larger igneous grains.

2) The list below includes all metamorphic minerals thought to have formed during prograde regional metamorphism of the Shawmere Anorthosite Complex. Excluded from this list are metamorphic minerals formed during retrometamorphism.

3) Leucogabbros have not been subdivided according to the nature of their mafic minerals. They include leucogabbroic, leuconoritic and leucogabbronitic types.

4) These rocks have totally metamorphic mineral assemblages. Their igneous nomenclature is defined on the basis of their chemistry.

TABLE 3: Textural and Compositional Characteristics of Metamorphosed Anorthosite and Gabbro Dikes Cutting Main Zone Rocks of the Shawmere Anorthosite Complex.

Dyke type	Texture[1]	Composition[2]	Occurrence
Anorthositic (1)	coarse grained to pegmatitic	plagioclase	common throughout the central portion of the intrusion.
Anorthositic (2)	"	plagioclase, minor hbl.	"
Anorthositic (3)	coarse grained to pegmatitic and coronitic	plag., minor amph., garn, opaques	"
Gabbroic (4)	fine grained	amph. plag.	"
Gabbroic (5)	fine grained granoblastic with garnet porphyroblastics (Photo 10)	plag ($An_{55; 60}$) amphib. (15%), garnet (24%), apatite (0.5%), rutile (0.5%)	"
Gabbroic (6)	fine grained, granoblastic	plag (An_{60}; 35-47%), amph. (27-40), garn (15-20), cpx (6%), quartz (2%), opaques (tr.), rutile (tr).	relatively rare
Gabbroic (7)	fine grained granoblastic (Photo 11)	hbl (55-60), plag (32-37%), garn (6%), quartz (2%), opaques (tr)	"
Gabbroic (8)	fine grained, granoblastic polygonal	plag ($An_{55,60}$), hbl. (30%), opx (5%)	rare

1-2: Capital letters: texture and composition inferred from field examination.
Small letters: texture and composition determined from thin section examination.

TABLE 3:

Gabbroic (5)	Hornblende (Z=yellowish green) garnet may form large idioblastic grains with pink cores and colourless rims.
Gabbroic (6)	Hornblende (Z=light brown) may occur as optically continuous poikiloblasts. Plagioclase strongly zoned. Similar to Scourne dikes of the outer Helnides described by Dearnley (1973).
Gabbroic (7)	Hornblende (Z=green, slightly bluish). Plagioclase strongly zoned.
Gabbroic (8)	Hornblende (Z=brownish green). Opx. weakly pleochroic. Plagioclase zoned.

Table 4:	1	2	3	4	5	6	7	8
SiO_2	47.7	47.6	47.7	49.0	49.3	53.1	43.1	40.9
Al_2O_3	31.1	32.1	28.5	26.5	19.6	7.77	19.2	13.4
Fe_2O_3	0.40	0.09	0.07	0.91	0.52	3.30	3.19	5.65
FeO	0.42	0.92	1.58	2.58	3.66	6.57	5.82	7.07
MgO	0.50	0.53	2.82	4.33	8.30	13.9	15.5	21.9
CaO	15.0	15.4	14.6	14.0	15.6	12.8	9.55	6.23
Na_2O	2.43	2.58	1.96	2.00	1.50	0.62	1.22	0.94
K_2O	0.00	0.01	0.00	0.04	0.03	0.29	0.18	0.11
H_2O^+	0.00	0.02	0.54	0.23	0.26	0.52	0.62	3.03
H_2O^-	0.32	0.46	0.29	0.24	0.29	0.12	0.29	0.15
CO_2	0.29	0.61	1.34	0.09	0.14	0.15	0.22	0.37
TiO_2	0.07	0.09	0.07	0.13	0.15	0.39	0.09	0.07
MnO	0.01	0.02	0.03	0.05	0.08	0.14	0.11	0.15
P_2O_5	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.02
S	0.01	0.02	0.03	0.02	0.02	0.06	0.01	0.03
Total	98.3	100.5	99.5	100.1	99.5	99.8	99.4	100.0
Ba	60	80	50	50	60	40	190	60
Co	7	9	16	20	29	50	72	80
Cr	8	10	273	274	1420	1400	65	66
Cu	12	12	88	18	100	375	20	32
Li	4	4	4	4	4	4	6	< 3
Ni	< 5	9	81	83	137	250	555	590
Pb	15	37	19	< 10	30	20	550	<10
Zn	13	14	15	28	33	78	46	28

9	10	11	12	13	14	15	16
42.7	50.7	47.6	47.7	48.7	49.3	48.7	47.1
12.5	14.1	14.3	14.8	14.4	14.9	13.8	18.5
6.70	3.40	3.0	4.20	2.90	3.40	3.70	3.12
16.1	13.6	9.57	9.82	9.32	9.15	12.7	6.91
7.07	4.16	8.75	8.10	7.91	7.70	5.41	8.24
8.21	9.30	11.5	10.6	10.3	10.5	9.52	11.1
1.10	0.33	2.23	1.76	2.34	2.45	0.84	2.48
0.08	0.10	0.23	0.12	0.28	0.06	0.17	0.18
0.38	0.39	0.22	0.80	0.50	0.39	0.54	0.75
0.16	0.50	0.69	0.32	0.36	0.18	0.25	0.25
0.13	0.15	0.08	0.12	0.15	0.11	0.37	0.31
2.44	2.22	0.82	10.19	1.02	0.97	1.97	0.62
0.29	0.36	0.15	0.20	0.16	0.17	0.25	0.14
0.15	0.27	0.07	0.10	0.05	0.06	0.21	0.03
0.03	0.08	0.06	0.06	0.03	0.07	0.04	0.06
98.0	99.7	99.3	99.9	98.5	99.4	98.5	100.0
50	50	60	60	80	60	60	120
78	49	48	52	47	49	53	42
19	10	355	263	340	244	124	287
86	275	74	58	103	40	250	109
4	4	4	4	7	4	4	< 3
28	42	160	123	118	140	54	202
22	15	12	10	14	< 10	10	12
220	58	118	115	103	60	132	100

TABLE 5: Comparison of the Chemical Compositions of Samples 7 and 8 of Table 4 with those of Hypothetical Troctolitic Compositions.

	SAMPLE 7[1]	TROCTOLITE WITH 59.5% Plag. (An_{81}) and 40.5% Oliv. (Fo_{69})	Sample 8[1]	TROCTOLITE WITH 58% Oliv (Fo_{69}) and 42% Plag (An_{80})
SiO_2	44.31	44.35	42.81	42.84
Al_2O_3	19.74	19.86	14.03	13.95
FeO	8.94	8.84	12.72	12.65
MgO	15.94	15.93	22.93	22.81
CaO	9.82	9.69	6.53	6.76
Na_2O	1.25	1.33	0.98	0.99
Total	100.00	100.00	100.00	100.00
FeO/MgO	0.56	0.55	0.55	0.55

1) Analysis recalculated to 100% water free and excluding K_2O, CO_2, TiO_2, MgO, P_2O_5.

2) Total Fe as FeO.

Table 6:

	(376) 1	(189A) 2	(6) 3	(486) 3	(176) 4	(62) 6	(477) 7	(63) 8
SiO_2	61.1	57.9	63.7	67.3	68.0	69.7	69.6	50.7
Al_2O_3	15.6	17.0	16.7	16.3	16.5	16.0	16.6	19.0
Fe_2O_3	1.33	2.59	1.48	1.38	1.32	1.26	0.93	2.69
FeO	5.41	5.33	4.16	2.41	1.66	1.66	1.00	5.74
MgO	3.62	3.06	2.65	2.13	0.94	1.04	0.85	8.30
CaO	5.64	6.66	5.85	4.03	3.37	3.34	2.93	2.81
Na_2O	3.64	3.68	3.26	3.90	4.69	4.41	5.89	3.36
K_2O	1.26	0.80	0.63	1.66	1.13	1.38	0.91	4.16
H_2O^+	0.40	0.27	0.39	0.62	0.30	0.26	0.22	1.04
H_2O^-	0.36	0.48	0.19	0.29	0.10	0.25	0.33	0.26
CO_2	0.12	0.10	0.14	0.22	0.08	0.48	0.22	0.53
TiO_2	0.85	1.07	0.64	0.47	0.43	0.39	0.31	0.74
MnO	0.11	0.09	0.09	0.08	0.05	0.04	0.03	0.09
P_2O_5	0.19	0.26	0.15	0.09	0.10	0.10	0.05	0.11
S	0.02	0.02	0.02		0.02		0.02	0.02
Total =	99.6	99.3	100.0	100.9	98.8	100.3	99.3	99.5
Ba	340	350	280	530	420	360	540	580
Co	22	21	17	16	11	12	9	30
Cr	47	61	55	49	7	6	13	206
Cu	29	30	8	10	6	26	10	5
Li	10	12	10	20	26	14	14	36
Ni	35	32	19	26	6	< 5	5	88
Pb	29	16	15	19	14	33	76	16
Zn	96	106	73	70	61	55	57	160

Table 6:

(465) 9	10	11	12	13	14	15	16
64.2	60.8	75.1	64.43	55.34	65.68	61.25	67.62
15.8	16.3	14.1	15.48	20.69	15.97	16.67	15.61
1.90	1.57	0.11	6.54*	1.98			1.89
4.33	5.35	1.33		7.33	3.45	6.48	1.05
2.93	4.02	0.60	3.12	2.83	1.36	2.29	1.46
3.06	4.30	1.96	2.22	1.63	5.56	5.89	3.42
3.68	3.43	4.98	3.74	1.90	3.86	4.96	4.97
2.18	1.90	0.60	2.44	3.42	0.98	0.85	1.13
0.73	0.46	0.04		2.99			1.19
0.26	0.05	0.29					
0.93	0.06	0.11		0.02			0.33
0.81	0.67	0.09	0.62	1.15	0.49	0.79	0.38
0.08	0.10	0.06		0.18			0.04
0.04	0.18	0.05		0.25			0.15
0.19	0.01	0.01					
101.1	99.20	99.4					
710		260	0	691	921	595	984
25		7	0	31	0	0	0
226		5	0	104	0	0	26
57		18	0	65	0	0	0
17		10	0	0	0	0	0
81		< 5	91	80	0	0	40
14		25	0	41	0	0	14
104		13	0	140	0	0	0

Table 6:

17	18	19	20	21	22
63.56	56.28	58.2	66.88	56.6	65.7
15.83	16.18	16.5	15.66	16.0	15.5
2.69	3.94	3.23	4.21	1.73	1.14
1.83	3.22	5.94		5.37	3.07
2.57	4.23	4.80	1.57	4.20	2.20
4.92	6.72	3.75	3.56	5.62	3.13
4.69	4.50	3.10	3.84	3.80	4.42
0.91	0.87	2.56	3.07	0.98	1.34
	1.70	1.40		2.55	
0.35	0.53	0.49		1.71	
	0.72	0.78	0.57	0.81	0.52
	0.09	0.11		0.14	0.09
0.17	0.32	0.07		0.20	0.20

728	668	786	0	298	334
0	0	0	0	27	12
52	106	355	0	405	15
0	0	0	0	57	34
0	0	0	0	0	0
44	67	159	0	112	16
12	15	39	0	6.2	8
0	0	0		74	65

LEGEND TO TABLE 6:

1) SA-79-376:- Hornblende-biotite tonalitic gneiss
   Plag(An_{30}, 50%) - Qtz (20%) - Hbl (20%) - Garnet (4) - Biotite (4) - apatite - Opaques - Zircon.

2) SA-79-189A: Hornblende-biotite tonalitic gneiss
   Plag (50%) - Qtz (25%) - Hbl (20%) - Biot (7%) - Garnet (3%) - Apatite - Opaques.

3) SA-79-6: Hornblende-biotite tonalitic gneiss
   Plag (An_{35}; 35%) - Qtz (30%) - Hbl (27%) - Biotite (5%) - Garnet (3%) - apatite - Zircon - opaques.

4) SA-79-486: Biotite-Hornblende tonalitic gneiss
   Plag (55%) - Quartz (25%) - Biotite (15%) - Hbl (4%) - Microcline (1-2%).
   Sphene - Opaques - Zircon - Apaite.

5) SA-79-176: Biotite Tonalite
   Plag (55%) - Qtz (30%) - Biotite (15-20%). Microcline - apatite - sphene - zircon - opaques - epidote.

6) SA-79-62: Biotite Tonalite
   Plag (An_{40}; 52%) - Qtz (30%) - Biotite (10%) - Muscov (2%). Epidote - Sphene - Apatite - Calcite Opaques - Zircon.

7) SA-79-477: Biotite Tonalite (Trondhjemite)
   Plag (An_{30}; 70%) - Qtz (25%) - Biotite (5%) - Epidote - Apatite - Zircon - Opaques.

8) SA-79-63: Pelitic Metasediments
   Biotite (50%) - Plagioclase, Qtz, Garnet (5-10%) - Apatite - Zircon. Opaques - calcite epidote.

9) SA-79-465: Semipelitic metasediments
   Plagioclase (55%) - Qtz (25%) - Biotite (15%) - Garnet (4%) - Hornblende (1%). Opaques - zircon - calcite.

10) Semipelitic metasediment from Shawmere Lake (Thurston et al. 1977, Table 8, Analysis 2).

11) SA-79-399A: Trondhjemitic layer in metasediments.
    Plagioclase (An_{20}; 58%) - Qtz (40%)- K-feldsp (3%) - Garnet (2%) - Biotite.

12) Average 23 Early Precambrian greywackes from Wyoming (Condie, 1967, Table 2).

13) Average 48 Dalradian garnetiferous pelites and semipelites (Senior and Leake, 1978, Table 7, Analysis 1).

14) Homogeneous trondhjemitic gneiss from SW Greenland (Compton, 1978, Table 2).

15) Tonalite from SW Greenland (Compton, 1978, Table 2).

16) Average of 39 acid biotite gneisses (>60% SiO_2) from the Assynt district, Scotland (Sheraton et al. 1973; Table 3, Analysis C).

17) Average of 46 Acid hornblende-biotite gneisses from the Assynt district, Scotland (Sheriton et al. 1973; Table 3, Analysis D).

18) Average of 40 basic hornblende-biotite gneisses (<60% SiO_2) from the Assynt district, Scotland (Sheraton et al. 1973; Table 3, Analysis F).

19) Average of 6 metasedimentary garnet - quartz gneisses from the Assynt district, Scotland (Sheraton et al. 1973, Table 3, Analysis J).

20) Average granodiorite (Condie 1967, Table 2).

21) Average of 386 Calc-alkalic andesites from the Superior Province (Goodwin 1977, Table 5, 1977).

22) Average of 133 calc-alkalic dacites from the Superior Province (Goodwin, 1977; Table 5).

TABLE 7:

Metamorphic Mineral Assemblages from the Shawmere Anorthositic Complex and adjoining areas.

In quartzofeldspathic rocks	Facies	Subfacies
Biotite	A	
Biotite+Muscovite	A	
Biotite+Hornblende	A	
Biotite+Hornblende+Garnet	A	
Biotite+Orthopyroxene+garnet+Kspar+ Hornblende	HblG	Hbl-op-pl

Quartz and plagioclase common to above assemblages.
Kspar rarely present with first two assemblages.

In mafic rocks	Facies	Subfacies
Hornblende+Plagioclase+Quartz	A	
Hornblende+Plagioclase+Biotite+Quartz	A	
Hornblende+Plagioclase+Garnet+Quartz	A	
Hornblende+Plagioclase+Garnet+ Clinopyroxene+quartz	HblG	Hbl-cp-al
Hornblende+Orthopyroxene+Clinopyroxene+ Plagioclase+Garnet	HblG	Hlb-op-pl
Hornblende+Garnet+Quartz	A	

In metamorphosed mafic dikes	Facies	Subfacies
Hornblende+Plagioclase±Quartz	A	
Hornblende+Plagioclase+Garnet+Quartz	A	
Hornblende+Orthopyroxene+Plagioclase	HblG	Hbl-op-pl
Hornblende+Plagioclase+Garnet+ Clinopyroxene+Quartz	HblG	Hbl-cp-al

In metamorphic-textured gabbroic and ultramafic rocks of the Shawmere Anorthosite	Facies	Subfacies
Hornblende+Plagioclase	A	
Hornblende+Plagioclase+Garnet	A	
Hornblende+Plagioclase+Garnet+Orthopyroxene	HblG	Hbl-op-al
Hornblende+Olivine+Orthopyroxene+Spinel	HblG	Hbl-op-al
Hornblende-Plagioclase-Anthophyllite-Garnet	A	
Hornblende+Garnet+Plagioclase+Sapphirine+ Anthophyllite	A	
Hornblende+Garnet+Orthopyroxene+ Anthophyllite+Spinel+Sapphirine	HblG	Hbl-op-al
Hornblende+Plagioclase+Clinopyroxene	A	

<u>In coronitic gabbroic and ultramafic rocks</u>

Hornblende+Plagioclase+Orthopyroxene±Garnet
Hornblende+Plagioclase+Orthopyroxene∓
Clinopyroxene ± Garnet
Hornblende+Plagioclase+Olivine+Orthopyroxene+
Spinel+Garnet
Hornblende+Olivine+Orthopyroxene+Spinel+Garnet

A = Amphibolite Facies
HblG = Hornblende Granulite Facies
Hbl-op-pl = Hornblende-Orthopyroxene-Almandine Subfacies of the Hornblende Granulite Facies.
Hbl-cp-al = Hornblende-Clinopyroxene-Almandine Subfacies of the Hornblende Granulite Facies.

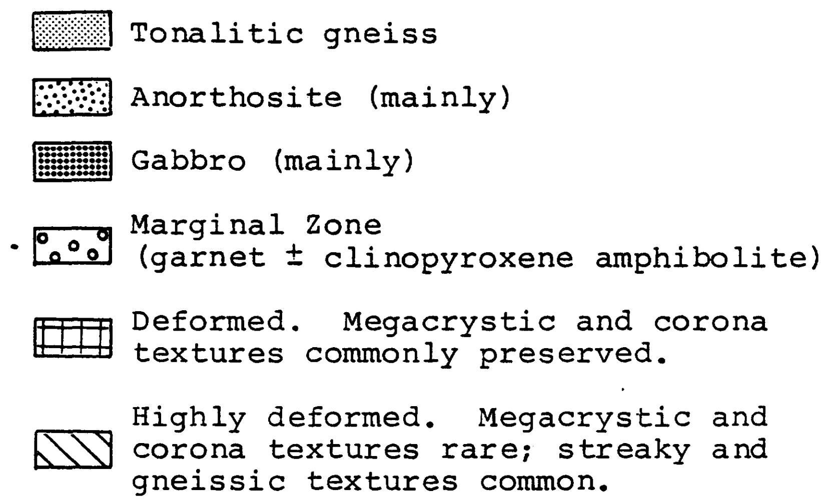
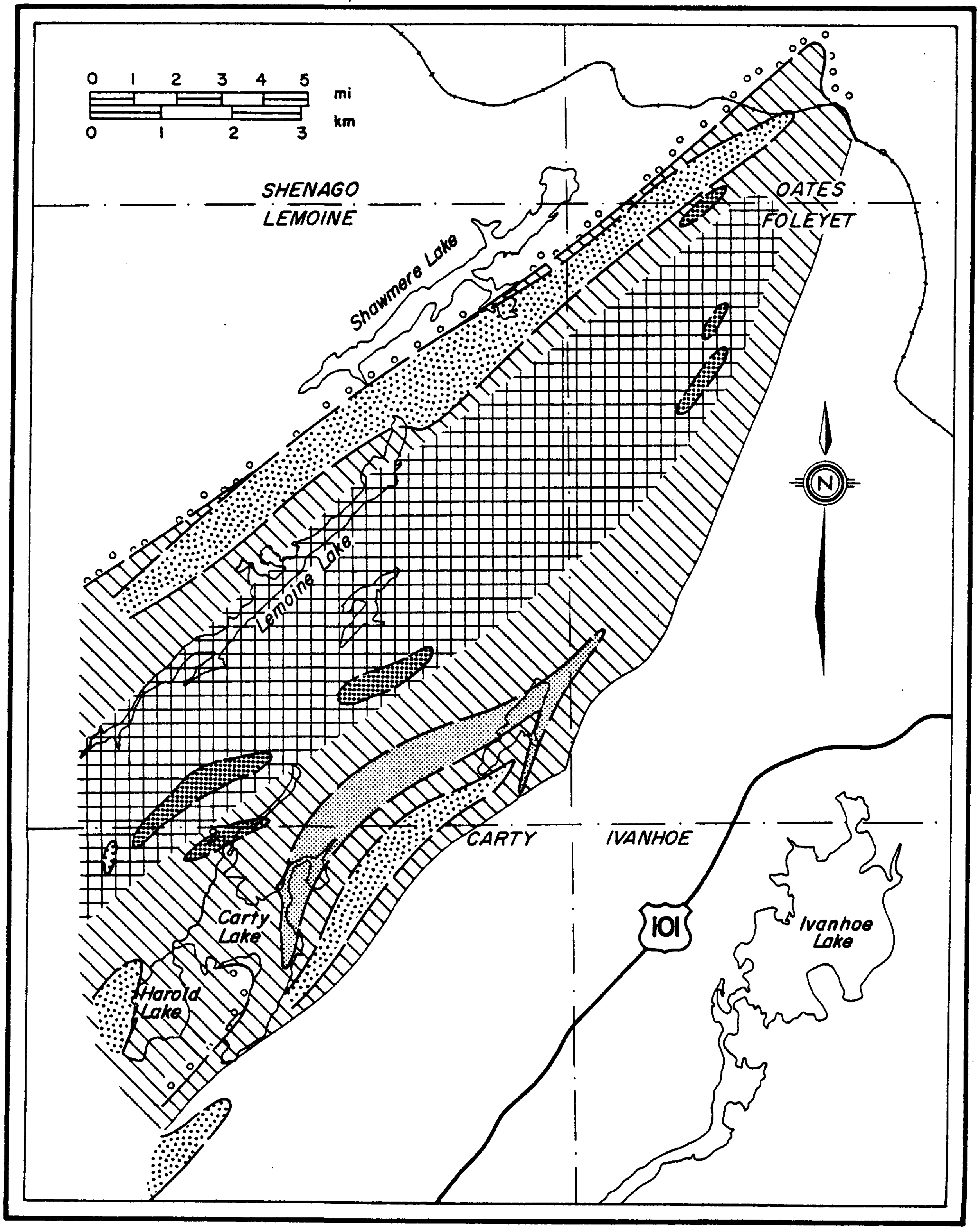


Figure 1: Distribution of lithologies and intensity of deformation within the Shawmere Anorthosite Complex. Areas not outlined as anorthosite or gabbro are underlain by leucogabbro, subordinate anorthosite, minor gabbro, and some ultramafic rocks.


0 1 2 3 4 5
mi
km
0 1 2 3
SHENAGO
LEMOINE
OATES
FOLEYET
Shawmere Lake
Lemoine Lake
CARTY
IVANHOE
101
Carty Lake
Harold Lake
Ivanhoe Lake
N

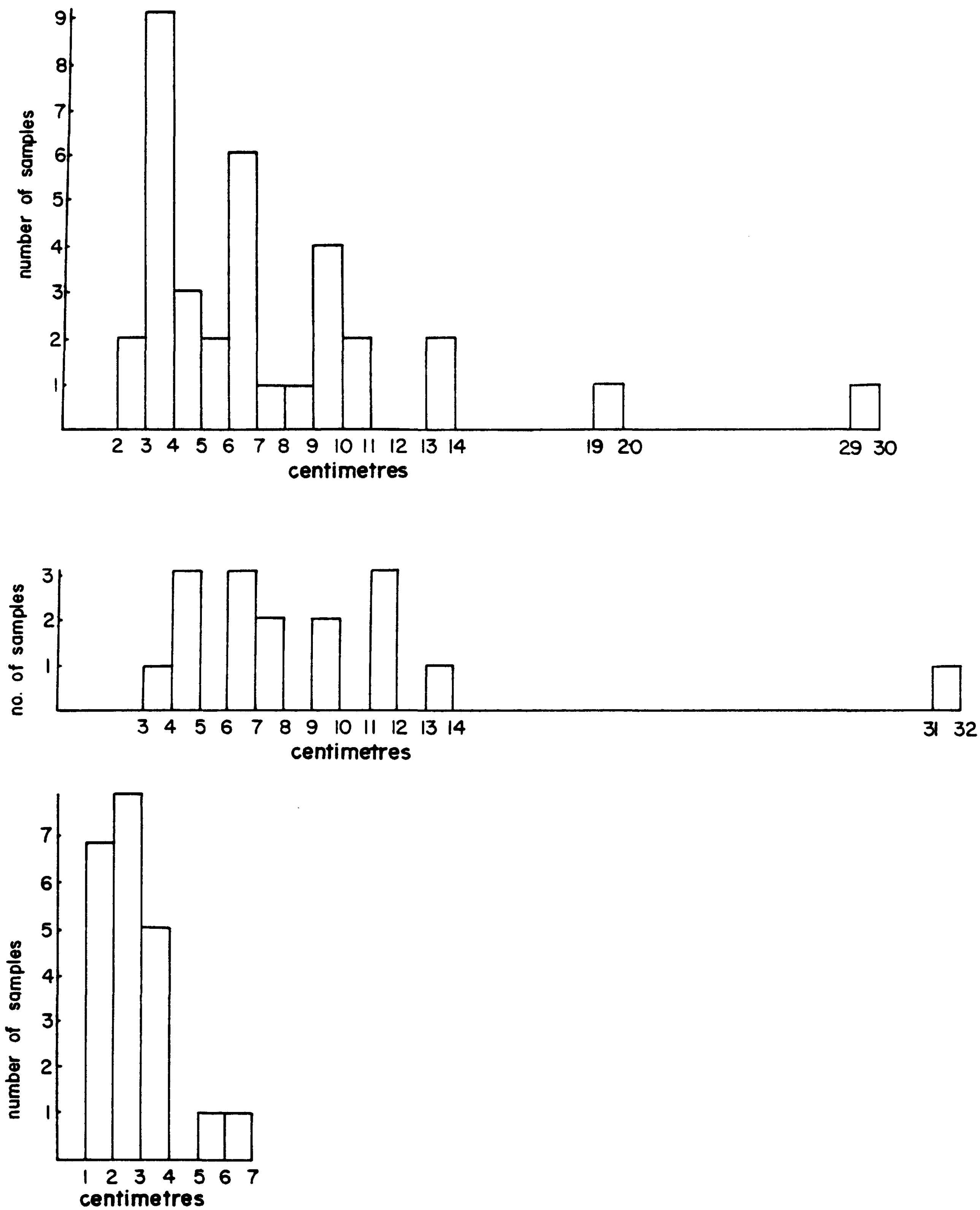


Fig 2. Size variability of plagioclase megacrysts from three separate outcrops of leucogabbros. The length/width ratio of megacrysts from these outcrops is approximately 1.5.

Fig 3
Riccio

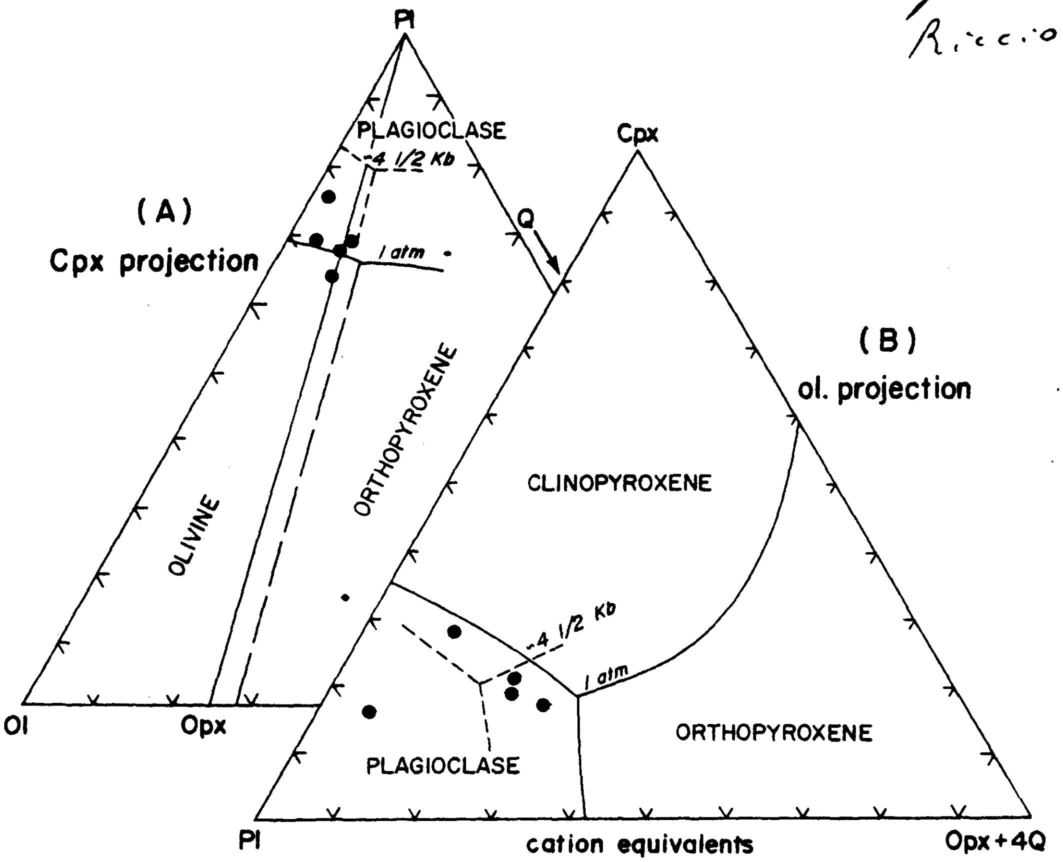


Fig 3. Inferred crystallization paths of Marginal Zone and Metamorphosed Dike compositions of the Shawmere Anorthosite Complex.

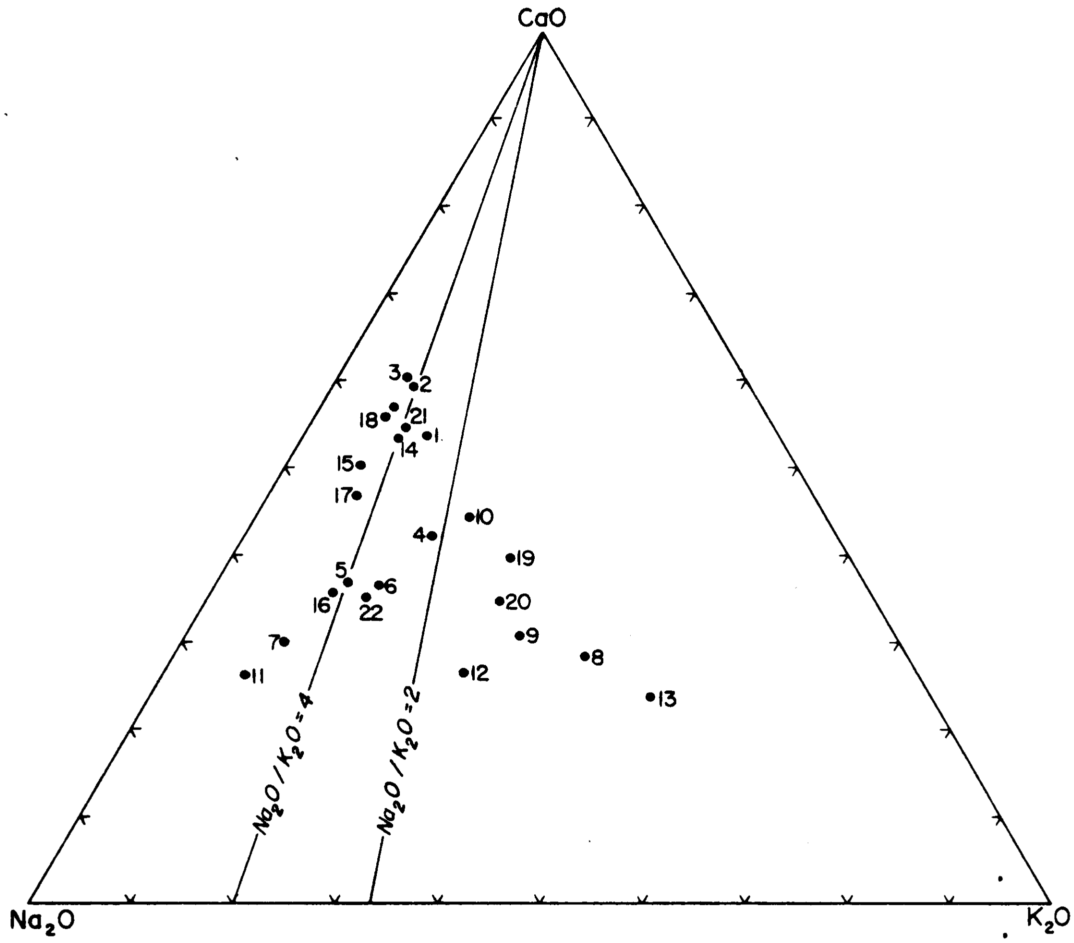


Fig. 4 $CaO-Na_2O-K_2O$ plot of quartzofeldspathic country rocks from the Shawmere area and of selected Precambrian rocks listed in Table 6.

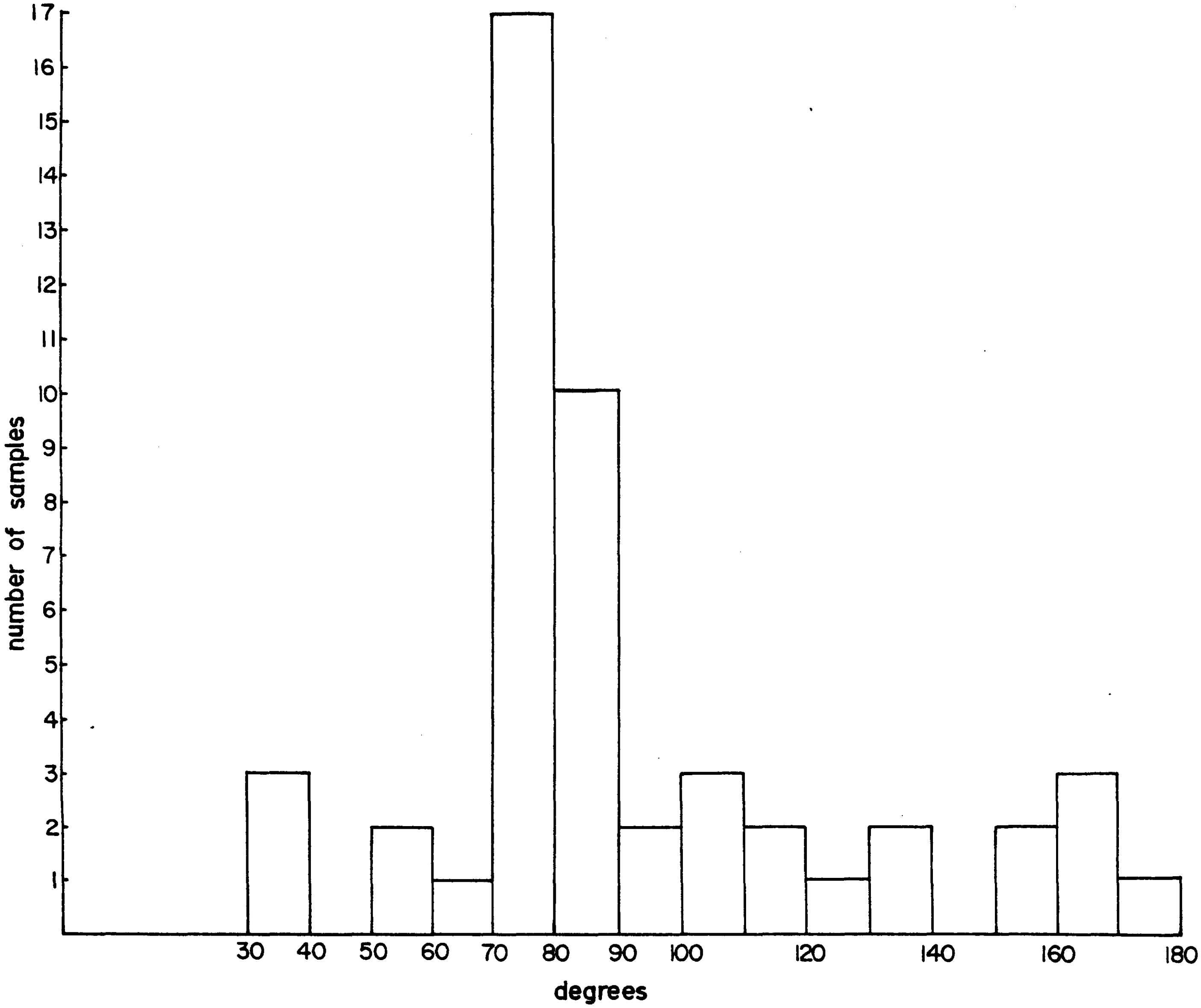


Fig 5. Measured attitudes of diabase dikes from the Shawmere area.

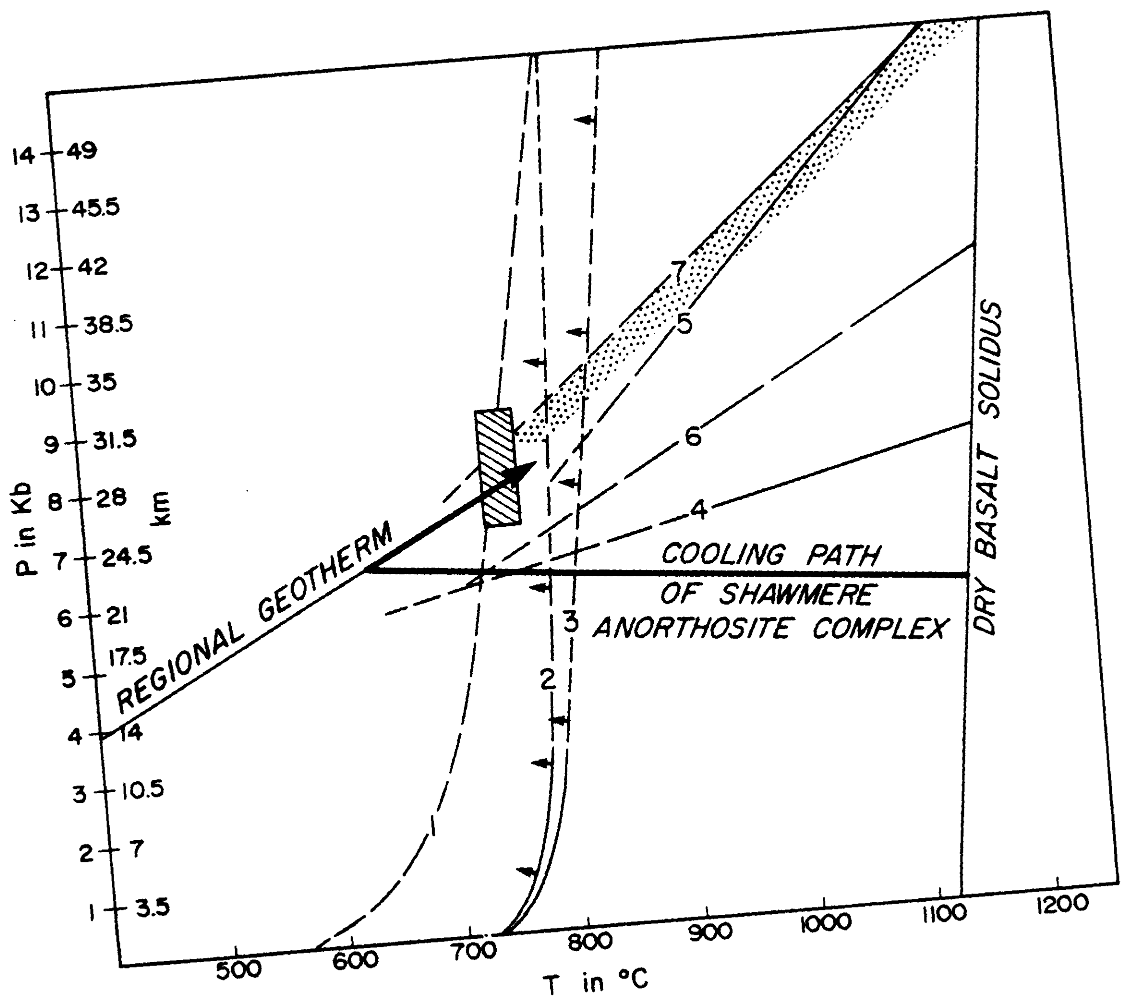


Fig 6. Inferred path of cooling and regional metamorphism of the Shawmere Anorthosite Complex.

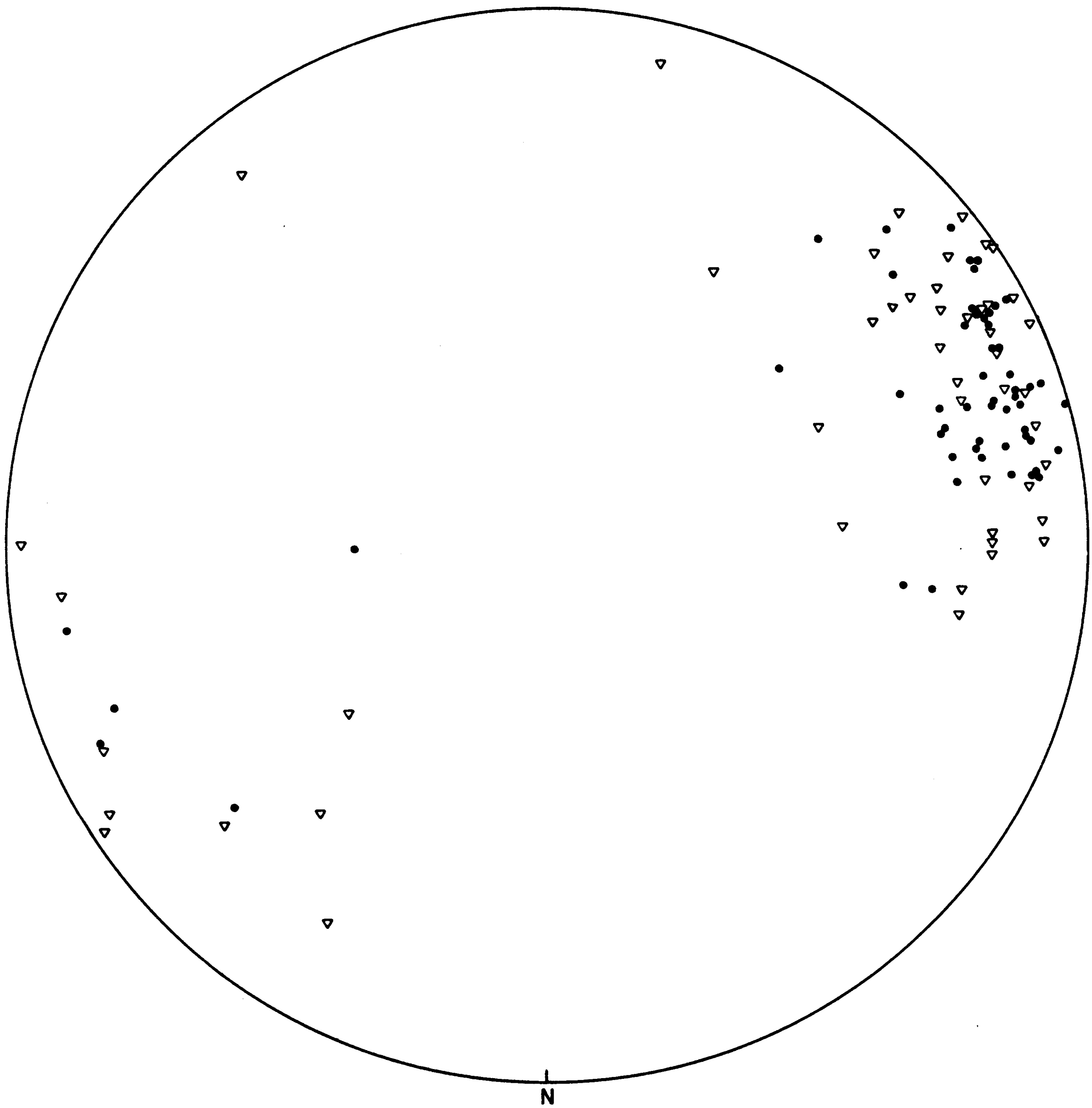


Fig 7. 138 Mineral lineations from the Shawmere Anorthosite Complex and country rocks.

Photo-Captions

(Long)

1) Plagioclase megacrysts surrounded by matrix of mafic minerals and minor plagioclase. Dark portion of megacryst is primary igneous plagioclase; light portion is secondary granulated and recrystallized plagioclase. Foleyet Township, 3 km north-northeast of fire tower.

2) Typical granulated anorthosite composed of a granoblastic polygonal mosaic of plagioclase grains and minor mafic minerals.

3) Corona texture in megacrystic troctolite. Olivine cores surrounded by orthopyroxene, in turn surrounded by amphibole, spinel, and minor garnet. Note the white colour of plagioclase immediately in contact with the outer corona rim. Southern end of Lemoine Lake.

4) Typical streaky texture due to alternating irregular and discontinuous segregaions of mafic minerals and plagioclase rich layers. Northeast end of Carty Lake.

5) Contact between megacrystic gabbro and leucogabbro. Note foliation (defined by planar preferred orientation of plagioclase megacrysts) cutting across lithologic contact.

Note also the size variability of plagioclase megacrysts in the gabbroic layer.

6) Fold hinge showing alternating granulated anorthosite and megacrystic gabbroic layers cut by late shear zone. Note the prominent mineral lineation (parallel to the laminae) and lack of foliation. Little Lemoine Lake.

7) Possible graded cumulate in alternating anorthositic and gabbroic layers. Upper dark layer is composed of garnet, amphibole, and minor quartz. Carty Lake.

8) Pseudo-crossbedding in granoblastic banded sequences, Carty Lake.

9) Marginal Zone garnetiferous amphibolites containing concordant to semi-concordant quartzo-feldspathic segregations. Small island along the southwest shore of Carty Lake.

10) Type 5, Table 3, metamorphosed gabbroic dike, with exceptionally large garnet porphyroblasts, cutting clotty leucogabbro. 3 km northeast of fire tower, Foleyet Township.

11) Type 7, (Table 3), metamorphosed gabbroic dike cutting

megacrystic leucogabbro. West shore of Lemoine Lake.

12) Orthopyroxene bearing potassic feldspar-garnet-biotite-quartz-plagioclase paragneiss containing abundant flattened quartzo-feldspathic segregations made up of plagioclase porphyroblasts and minor finer grained quartz and plagioclase. Shawmere Lake, south shore.

13) Amphibolite rafts in tonalitic gneiss cut by trondhjemitic segregations. Exposure along fire tower road, Foleyet Township.

14) Fold closure in megacrystic lencogabbro at Lemoine Lake. Note strong plagioclase lineation coinciding with fold axis (parallel to the hammer handle).,

Photo 1. Plagioclase megacrysts, Foleyet Township.

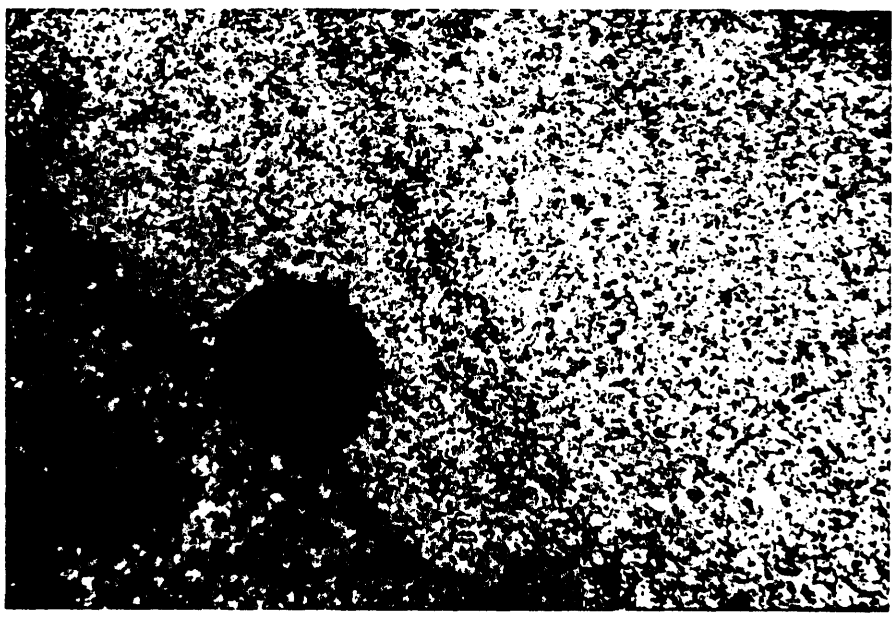


Photo 2. Typical granulated anorthosite.

Photo 3. Corona texture in megacrystic troctolite, Lemoine Lake.

Photo 4. Typical streaky texture, Carty Lake.

Photo 5. Contact between megacrystic gabbro and leucogabbro.

Photo 6. Alternating granulated anorthosite and megacrystic gabbro layers, Little Lemoine Lake.

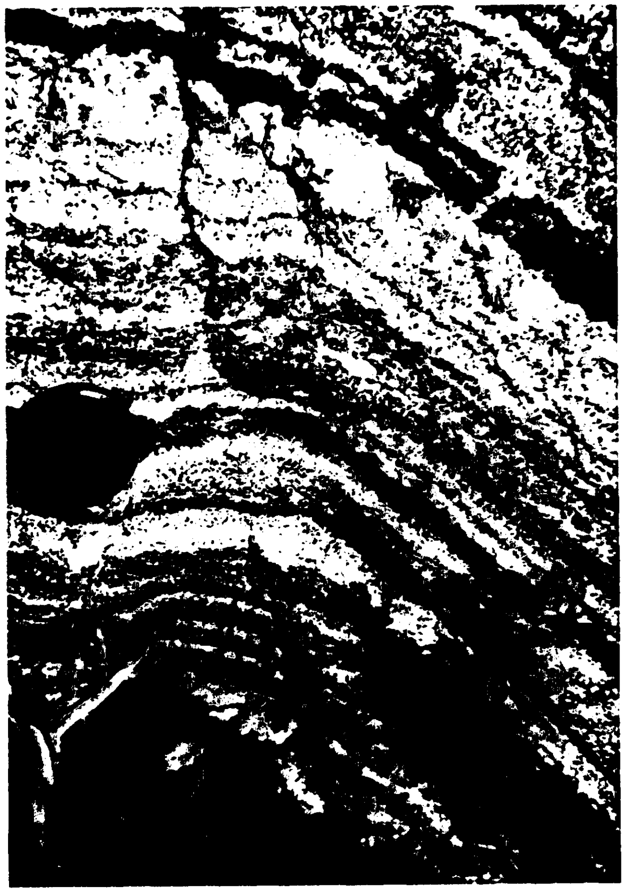


Photo 7. Possible graded cumulate in alternating anorthositic and gabbroic layers, Carty Lake.

Photo 8. Pseudo-crossbedding, Carty Lake.

Photo 9. Marginal Zone garnetiferous amphibolite, Carty Lake.

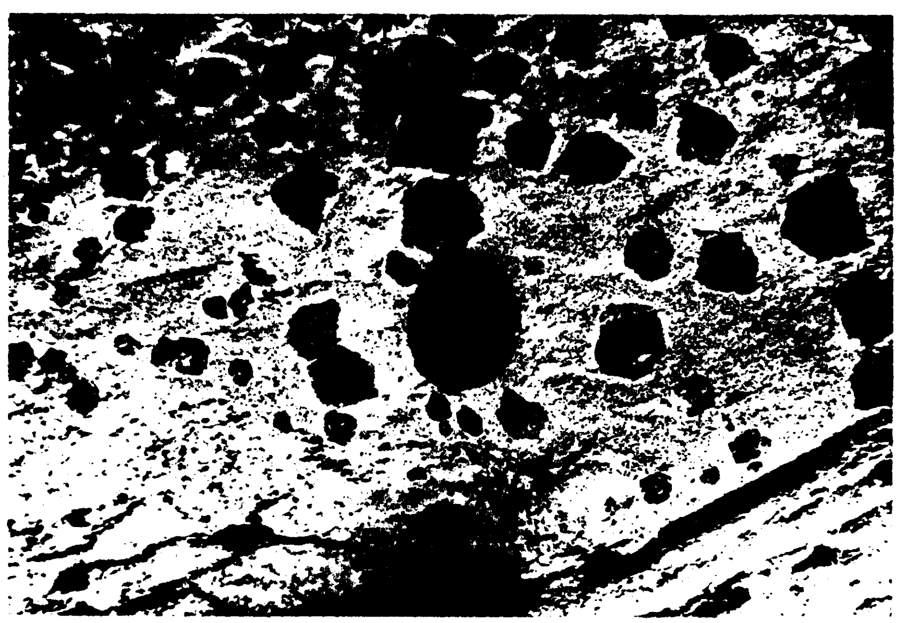


Photo 10. Metamorphosed gabbroic dike with exceptionally large garnet, Foleyet Township.

Photo 11. Metamorphosed gabbroic dike cutting megacrystic leucogabbro, Lemoine Lake.

Photo 12. Orthopyroxene bearing potassic feldspar garnet-biotite-quartz-plagioclase paragneiss, Shawmere Lake.

Photo 13. Amphibolite rafts in tonalitic gneiss, Foleyet Township.

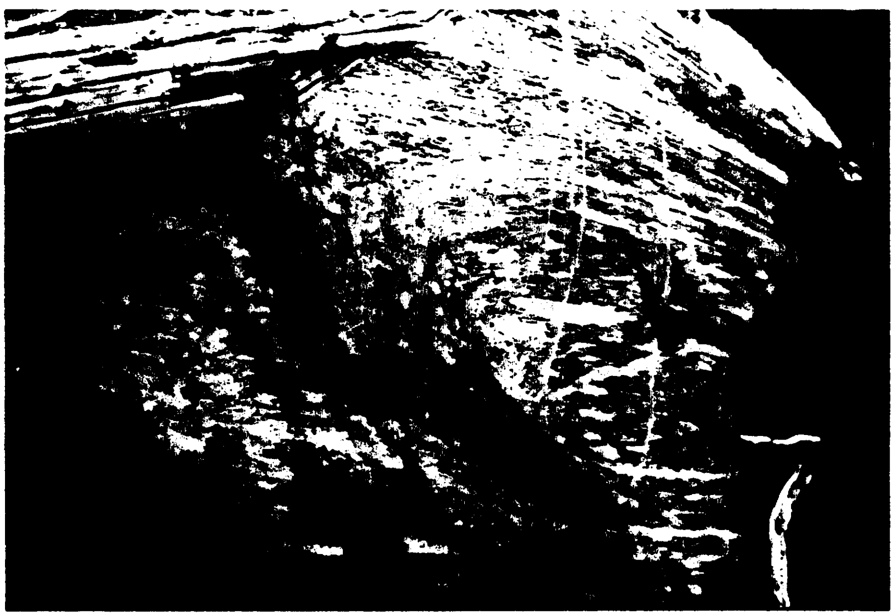
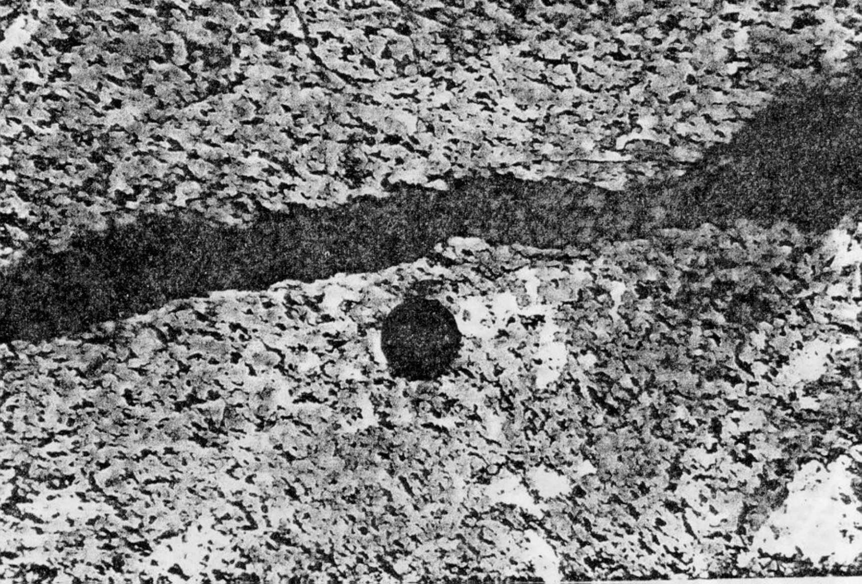
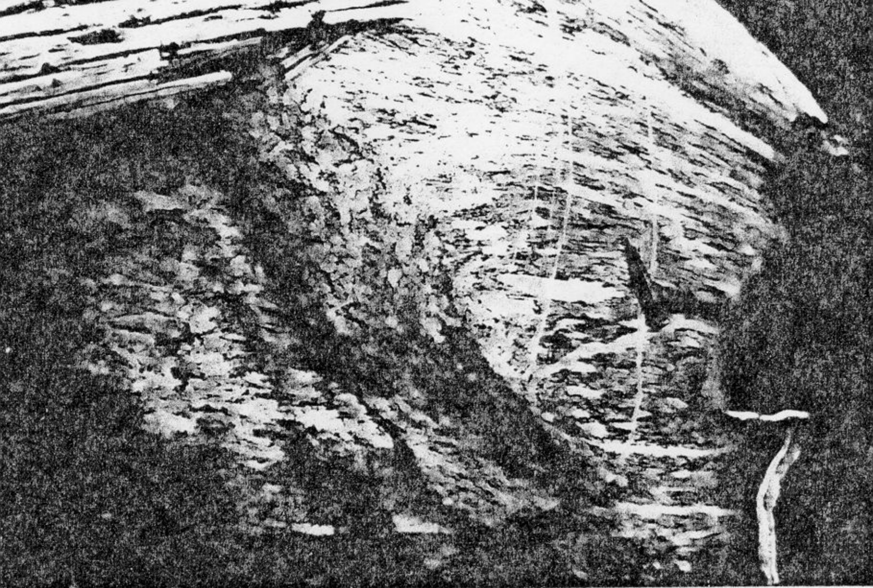
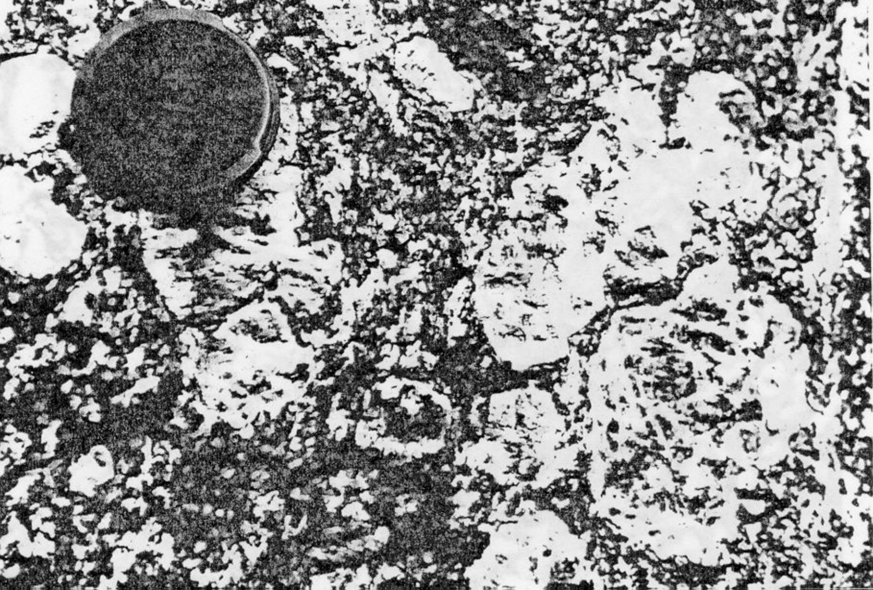
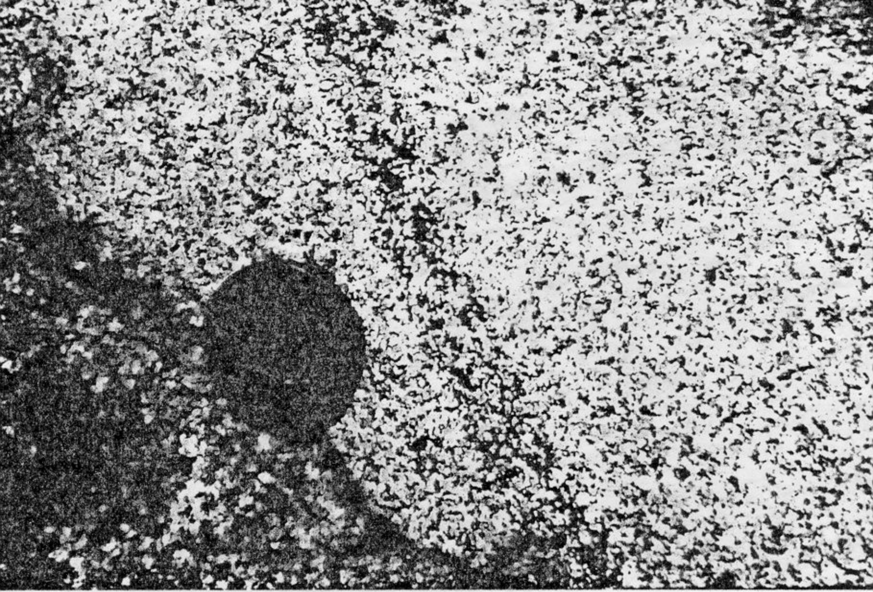


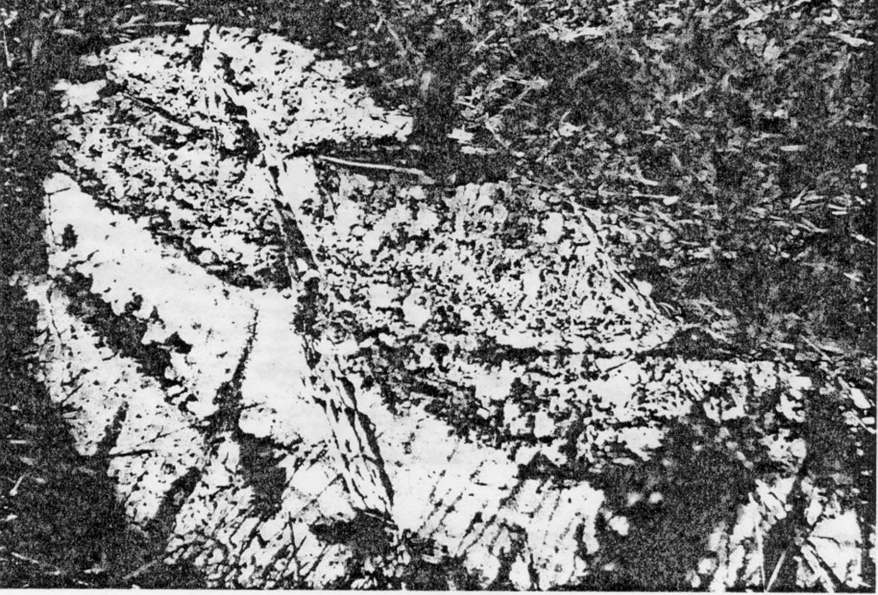
Photo 14. Fold closure in megacrystic leucogabbro, Lemoine Lake.

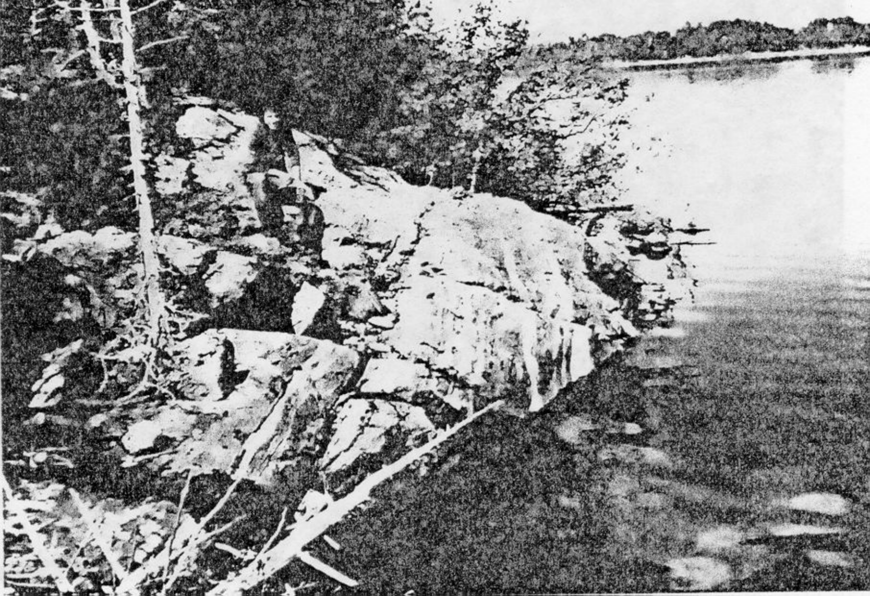












Ministry of Natural Resources — Ministry of Northern Affairs

Ontario

Hon. James A.C. Auld, Minister — Hon. Leo Bernier, Minister

W.T. Foster, Deputy Minister — Art Herridge, Deputy Minister

ONTARIO GEOLOGICAL SURVEY

PRELIMINARY MAP P. 2383

GEOLOGICAL SERIES

PRECAMBRIAN GEOLOGY OF THE SHAWMERE ANORTHOSITE COMPLEX (NORTH)

DISTRICT OF SUDBURY

Scale: 1:15 840

Mile ¼ 0 ¼ ½ Mile

Metres 100 0 0.2 0.4 0.6 0.8 1 Kilometre

NTS Reference: 42 B/7,8

ODM-GSC Aeromagnetic Maps: 2248G, 2264G

ODM Geological Compilation Map: 2221

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Parts of this publication may be quoted if credit is given and the material is properly referenced.

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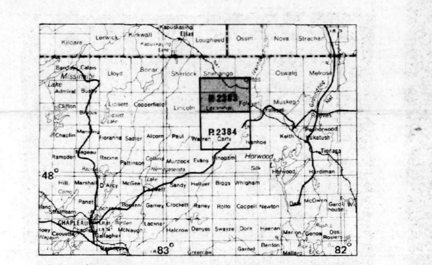

LOCATION MAP

Scale: 1: 1 584 000 or 1 inch to 25 miles

LEGEND[a]

PHANEROZOIC
CENOZOIC
QUATERNARY
PLEISTOCENE AND RECENT
Till, sand, clay and gravel

UNCONFORMITY

PRECAMBRIAN
EARLY TO MIDDLE PRECAMBRIAN
MAFIC INTRUSIVE ROCKS

6 — 6 Diabase dikes

INTRUSIVE CONTACT

EARLY PRECAMBRIAN
METAMORPHOSED IGNEOUS ROCKS
TONALITIC GNEISS UNIT[b]

5
- 5a Unsubdivided hornblende-biotite, biotite-hornblende and biotite tonalite gneiss
- 5b Biotite-hornblende tonalite gneiss
- 5c Biotite-hornblende tonalite
- 5d Biotite tonalite gneiss
- 5f Garnetiferous tonalite gneiss
- 5g Amphibolite, may contain biotite
- 5h Garnetiferous amphibolite
- 5L Garnet-clinopyroxene amphibolite
- 5m Garnetiferous biotite-rich paragneisses

INTRUSIVE OR FAULT CONTACT

SHAWMERE ANORTHOSITE COMPLEX[c]
METAMORPHOSED DIKES

4
- 4a Anorthositic dikes
- 4b Gabbroic, predominantly garnetiferous dikes

INTRUSIVE CONTACT

MAIN ZONE

3
- 3a Anorthosite, commonly garnetiferous
- 3b Leucogabbro, commonly garnetiferous, locally coronitic
- 3c Gabbro to melagabbro, commonly garnetiferous and coronitic:unsubdivided
- 3d Quartz ± clinopyroxene-garnet amphibolite, to quartz ± clinopyroxene-amphibole garnetite
- 3e Hornblende gabbro, melagabbro ± garnet ± quartz
- 3f Clinopyroxene, hornblende-clinopyroxene gabbro to melagabbro, commonly strongly lineated
- 3g Garnet-hornblende norite, melanorite (coronitic). (May contain green spinel).
- 3h Garnet-clinoamphibole melagabbro. (May contain green spinel, anthophyllite, sapphirine).
- 3j Hornblende gabbronorite, melagabbronorite
- 3L Garnet-bearing hornblende gabbro norite (coronitic)
- 3m Coronitic troctolite
- 3n Ultramafic rocks: unsubdivided
- 3p Spinel harzburgite
- 3q Spinel-olivine-hypersthene hornblendite. (May contain garnet).
- 3r Garnet clinoamphibolite (May contain plagioclase, orthopyroxene, spinel).
- 3s Clinopyroxene hornblendite
- 3u Sapphirine-bearing rocks
- 3A Megacrystic texture[d]
- 3B Clotty texture[e]
- 3C Streaky to gneissic texture[f]
- 3D Granoblastic texture[g]
- 3E Granoblastic-banded texture[h]

MARGINAL ZONE[j,k]

2 — 2 Quartz ± clinopyroxene-garnet amphibolite

INTRUSIVE CONTACT

METASEDIMENTS[l]

1
- 1a Garnet-biotite-quartz-plagioclase ± hornblende ± K-spar paragneisses (wackes)
- 1b Orthopyroxene bearing paragneisses
- 1c Quartz-clinopyroxene-garnet amphibolite
- 1d Orthopyroxene-bearing amphibolite
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- 1g Trondhjemite
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a This legend may be changed as a result of subsequent laboratory investigations.

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g Equigranular polygonal mosaic of recrystallized plagioclase and other mafic minerals, if present.

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- Orientation of dike (inclined)
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SOURCES OF INFORMATION

Horwood Lake Sheet, Ontario Department of Mines Preliminary Map P.673, Geological Series, Scale 1:126 720 or 1 inch to 2 miles.

Assessment Files Research Office, Ontario Geological Survey, Toronto.

Base maps derived from Forest Resources Inventory Sheets, Lands and Waters Group, Ministry of Natural Resources.

Magnetic declination approximately 7°11' at centre of map-area in 1979.

CREDITS

Geology by L. Riccio and assistants, 1979

Every possible effort has been made to ensure the accuracy of the information presented on this map, however, the Ontario Ministry of Natural Resources does not assume any liability for errors that may occur. Users may wish to verify critical information; sources include both the references listed here, and information on file at the Resident or Regional Geologist's office and the Mining Recorder's office nearest the map area.

Issued 1981

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

Riccio, L.
1981: Precambrian Geology of the Shawmere Anorthosite Complex (North), District of Sudbury; Ontario Geological Survey Preliminary Map P. 2383, Geological Series, Scale 1:15 840 or 1 inch to ¼ mile. Geology 1979.

MARGINAL NOTES

INTRODUCTION

This map presents the results of detailed mapping of the northeastern half of the Shawmere Anorthosite Complex (Thurston *et al.* 1977). The complex is a highly deformed and metamorphosed layered intrusion of Early Precambrian (Archean) age (K/Ar date of 2.51 b.y.; Watkinson *et al.* 1972) surrounded by biotite-rich garnetiferous paragneisses, quartzo-feldspathic schists and amphibolites. The map-area is entirely within the Kapuskasing Structural Zone, a structural-metamorphic zone separating east-trending, weakly metamorphosed "greenstone" terrane from northeast to east-northeast-trending highly metamorphosed schists and gneisses. The area is covered by ODM-GSC aeromagnetic maps 2247G and 2248G. It was previously mapped at a scale of 1:126 720 as part of Operation Chapleau (Thurston *et al.* 1977). The primary objective of this project was to evaluate the Cr and Al potential of the Shawmere Anorthosite.

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The area investigated covers about 300 km². It is located about 100 km west of Timmins and 90 km northeast of Chapleau. It includes Carty Township, the southeastern part of Lemoine Township, and small parts of Oates, Foleyet and Ivanhoe Townships.

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MINERAL EXPLORATION

In 1964-1965 Keevil Mining Group (now Teck Corporation Limited) carried out a magnetometer and electromagnetic survey on high-grade schists and gneisses within the Kapuskasing Structure in areas to the south of the map-area. A few EM anomalies were located and subsequently trenched and drilled. These anomalies proved to be caused by strong disseminations of pyrrhotite or pyrite and magnetite. The same company also staked 32 claims centered along the Fire Tower Road in Foleyet Township but no further work is on file.

GEOLOGY

The Shawmere Anorthosite Complex

The intrusion can be subdivided into zones of contrasting compositional and structural characteristics: a) Megacrystic Gabbroic Anorthosite[1] Zone, b) Anorthosite Zone, c) Banded Zone, d) Border Zone.

The Megacrystic Gabbroic Anorthosite Zone occupies the central portion of the anorthosite complex and extends to the northeastern margin of the intrusion. It is composed predominantly of gabbroic anorthosite with subordinate anorthosite, anorthositic gabbro and gabbro, and minor melagabbro. All rocks within this zone contain large (1 to 50 cm) cumulus plagioclase megacrysts embedded in a matrix of mafic minerals. Most megacrysts are internally granulated and totally recrystallized into aggregates of small (2-3 mm) plagioclase grains. Primary igneous plagioclase is best partially or totally preserved in rocks of gabbroic composition. In general the plagioclase megacrysts are deformed into prolate ellipsoids. In zones of more intense deformation, the megacrysts are streaked out into discontinuous leucocratic layers alternating with melanocratic layers. Mafic minerals within this zone consist of amphibole-clinopyroxene-orthopyroxene, irregular clots of dark green amphibole, and of orthopyroxene surrounded by an inner shell of amphibole, or mixed amphibole-clinopyroxene, and an outer shell of granular garnet. At one locality the core of the coronitic assemblage is occupied by olivine.

In the northwestern part of the map-area, the Megacrystic Gabbroic Anorthosite Zone grades into predominantly anorthositic rocks with average mafic mineral content not exceeding 5 percent. The Anorthosite Zone is separated from the Border Zone by a thin (50-100 m) discontinuous unit composed of lineated clinopyroxene-rich gabbro. Anorthositic rocks in this zone are made up of granular aggregates of grey to reddish-coloured plagioclase, minor interstitial amphibole, and, occasionally, scattered garnet grains. Outcrops of otherwise almost pure anorthosite may also contain thin (2-5 cm) layers composed of equal amounts of plagioclase and amphibole or garnet-amphibole and minor plagioclase. Remnants of igneous plagioclase are rare in this zone.

Rocks of the Banded Zone occupy the southeastern margin of the Shawmere Anorthosite between Carty and Wakagami Lakes. The Banded Zone is characterized by well developed small scale (1 to 30 cm) compositional banding, presence of deep-red garnet-rich layers, and lack of mafic clots and plagioclase megacrysts. Individual layers comprise pure anorthosite, lineated clinopyroxene-amphibole-plagioclase gabbro, sphene-plagioclase-quartz-amphibole-garnet (up to 60-70 percent) rocks, and minor ultramafic rocks composed of orthopyroxene, amphibole, serpentinized olivine and up to 5 percent green aluminum spinel. Thin quartzo-feldspathic segregations are locally present in this zone. Most of the layers are isomodal and mineral-graded layers are rare. At one locality on the northeastern shore of Carty Lake mineral-graded layers, rich in amphibole at the base and plagioclase at the top, are size graded as well and can be used as top indicators. Structures strongly resembling graded bedding can be observed at Carty Lake. However, since the rocks in the area are tightly folded and the folds are isoclinal and recumbent, it is possible that the "cross beds" are in fact sheared folds.

The Border Zone is a distinct lithologic unit, 50 to 100 m thick, which separates rocks of the Shawmere Anorthosite Complex from country rocks. It outcrops almost continuously along the northwestern margin of the intrusion and in the Carty Lake-Harold Lake area. Structurally, the Border Zone can be seen to underlie and overlie anorthositic rocks. The Border Zone is made up of a dense, dark-coloured, foliated garnetiferous amphibolite containing 5 to 20 percent concordant to slightly discordant quartzo-feldspathic layers, and at some localities, anorthositic layers. Border Zone rocks grade into predominantly anorthositic rocks containing subordinate layers of garnet amphibolite. The contact between Border Zone and country rocks can be sharp or transitional. Where transitional, the amphibolites become increasingly migmatized away from the anorthosite. The Border Zone is interpreted as the metamorphosed equivalent of a gabbroic marginal zone formed by cooling the magma against the country rocks.

The Shawmere Anorthosite Complex is metamorphosed to the hornblende granulite subfacies of the granulite facies. This is substantiated by the occurrence of sapphirine associated with garnet, pargasite, and plagioclase in melagabbro from Carty Lake, the presence of green aluminum spinel in ultramafic layers, and the coexistence of garnet, pyroxenes, amphibole, and plagioclase in gabbroic rocks.

Country Rocks

The Shawmere Anorthosite Complex is surrounded by fine- to medium-grained quartzo-feldspathic schists and gneisses, fine- to medium-grained semi-pelitic paragneisses, and medium-grained amphibolites and garnet amphibolites. All country rocks contain variable amounts of coarse-grained quartzo-feldspathic segregations probably formed during anatexis and then deformed with the country rocks.

Quartzo-feldspathic schists and gneisses are composed of quartz-feldspar-biotite-hornblende ± garnet, occuring as irregularly shaped masses within the southeastern part of the Shawmere Anorthosite, as discontinuous zones of variable width rimming the anorthosite, and as intercalations in semi-pelitic metasediments. The width of zones underlain by quartzo-feldspathic rocks surrounding the anorthosite increases in a southwesterly direction along both margins of the intrusion.

The semi-pelitic paragneisses are quartz-biotite plagioclase schists which may contain orthopyroxene and up to 30 percent garnet porphyroblasts. In the Shawmere Lake area, the metasediments display a well developed compositional banding. Individual layers, 2 to 5 cm thick and rich in biotite and garnet, alternate with equally thick layers poorer in both minerals.

Amphibolites are composed of amphibole and plagioclase, and may contain garnet, quartz, clinopyroxene, orthopyroxene and biotite. They occur as discrete outcrops, as rafts or boudinaged layers enclosed in quartzo-feldspathic rocks, and as discontinuous layers within semi-pelitic metasediments. Amphibolitic rocks in the southeastern corner of the map-area may represent metamorphosed equivalents of mafic tuffs and lavas of nearby "greenstone" terranes.

Dikes

Rocks of the Shawmere Anorthosite Complex are cut by metamorphosed dikes and dikelets of gabbroic and anorthositic composition. Most of these early dikes are deformed and garnet-bearing. Pegmatitic leucodioritic dikes intrude the anorthosite and banded zone of the anorthosite as well as the quartzo-feldspathic rocks surrounding the anorthosite. Undeformed pegmatitic dikes ranging in composition from granite to trondhjemite cut the country rocks and rare trondhjemitic dikes cut the anorthositic rocks. Late undeformed and unmetamorphosed fine- to medium-grained diabase dikes cut both the anorthosite and the country rocks. Diabase dikes trend predominantly east-northeast and less commonly northeast, west-northwest, northwest and north-northwest. They are wide-spread in the eastern and southeastern parts of the area and rarer further to the north and northwest.

STRUCTURAL GEOLOGY

At least three phases of deformation can be recognized in the map-area. The first and most intense phase of deformation (F_1) produced the prominent north-northwest- to northwest-dipping schistosity-gneissosity as well as a set of mesoscopic, close to tight, isoclinal folds with northwest-dipping axial planes and axes with shallow plunges to the west-southwest. The isoclinal folds are moderately inclined in the northern part of the map-area and strongly inclined or recumbent in the south. Folds with diverging limbs are very rare. Associated with the F_1 folds are widespread mineral lineations which include elongated plagioclase megacrysts and elongated aggregates of hornblende and clinopyroxene in "anorthositic" rocks, elongated biotite and hornblende in metasediments, and quartz rods in quartzo-feldspathic rocks. Mineral lineations are especially prominent in hinges of mesoscopic folds. Mineral lineations are invariably parallel to fold axes of F_1 folds. The second phase of deformation (F_2) gave rise to large open folds with subhorizontal northwest-trending areas. Occasional reversals in the direction of plunge of mineral lineations are considered to be related to F_2 folding. Open folds related to D_3 can be observed in the Shawmere Lake area. There the gneissosity in metasediments is locally warped about axes plunging steeply to the north-northwest. It is suggested that the Shawmere Anorthosite Complex is folded into a major southwest-plunging asymmetrical overturned syncline with a steeper inverted limb and a shallower normal limb. This interpretation is based on: a) the occurrence at Carty Lake of mineral and size-graded layers facing north, b) the presence of a Border Zone rimming the anorthosite on both sides forming the base of the sequence, c) the relatively undeformed nature of the central part of the intrusion, d) the style and attitude of F_1 folds and related lineations.

North- to north-northeast-trending shear zones characterized by intense mylonitization and development of pseudotachylite veinlets are common along the eastern margin of the Kapuskasing Structural Zone. The most prominent mylonite zone, up to 250 m wide, straddles the boundary between anorthosite and country rocks from the CNR railway to just north of the Fire Tower Road in Foleyet Township, a distance of approximately 11 km. Other major mylonite zones are exposed along the Fire Tower Road, at Wakagami Lake, west of East Carty Lake, and along Highway 101. Although the mylonite zones are late structures which cut across lithologic units and deflect the regional schistosity, they are in part developed along pre-existing faults. For example, the mylonite zone to the west of East Carty Lake separates high grade amphibolite and paragneisses of the Kapuskasing Structural Zone from "greenstone" terranes.

ECONOMIC CONSIDERATIONS

Cr and Fe, Ti

Anorthositic rocks are known to contain economically significant deposits of Cr-rich spinel, ilmenite, or magnetite-ilmenite.

Cr-rich spinels only crystallize from relatively undifferentiated basaltic liquids. Consequently chromites can only be expected to occur in anorthosite composed of highly calcic plagioclase. Ilmenite and magnetite, on the other hand, crystallize from more differentiated basaltic liquids and are usually found in anorthosite with plagioclase in the andesine-labradorite range. It is also known (e.g. Bushveldt Complex), and it has been experimentally shown (Hill and Roeder 1974), that basaltic magmas differentiating under normal oxygen fugacity conditions do not crystallize spinel phases during their middle stages of fractionation. Outcrops within the Shawmere Anorthosite Complex appear to be devoid of disseminations of either chromite, ilmenite, or magnetite. A few opaque minerals examined to date proved to be metamorphic aluminum spinels. On the basis of these field observations the potential for oxide mineralization in the Shawmere Complex is poor. However a petrogenetic study of the complex would help substantiate the field observations and might explain the apparent lack of oxide dissemination.

Aluminum

Technologically it is possible to extract aluminum from anorthositic rocks and recover up to 98 percent Al_2O_3 (Quon 1977). As the world's bauxite reserves are slowly being depleted, the demand for aluminum increases, and some of the foreign governments that control bauxite supply are politically unstable, the long-range economic potential of large anorthosite masses as sources of low-grade Al_2O_3 should be considered. In the Shawmere Complex, the best belt of anorthositic rocks with low mafic mineral content covers an area of between 4 and 7 km² extending from the CNR railway to just northeast of Lemoine Lake. This represents between 1.1 and 1.9 billion tons to a depth of 100 m.

Conversion factor 1 foot = 0.3048 m

[1]Terminology from Streckeisen (1976).

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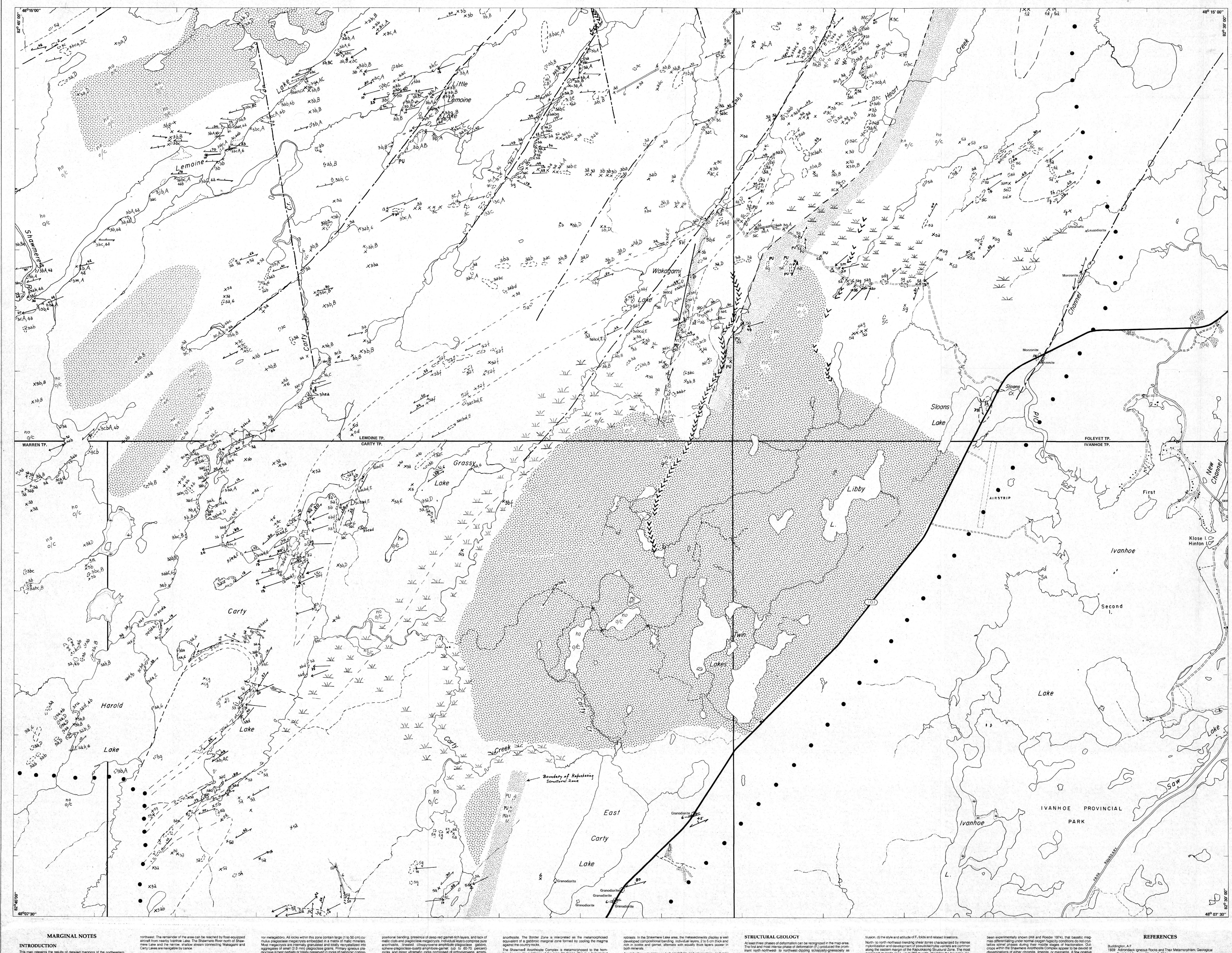

Ministry of Natural Resources
Ontario
Hon. James A.C. Auld, Minister
W.T. Foster, Deputy Minister

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ONTARIO GEOLOGICAL SURVEY
PRELIMINARY MAP P. 2384
GEOLOGICAL SERIES

PRECAMBRIAN GEOLOGY OF THE SHAWMERE ANORTHOSITE COMPLEX (SOUTH)

DISTRICT OF SUDBURY

Scale: 1:15 840

Mile ¼ 0 ¼ ½ Mile
Metres 100 0 0.2 0.4 0.6 0.8 1 Kilometre

NTS Reference: 42 B/1,2,7,8
ODM-GSC Aeromagnetic Map: 2248G, 2264G, 2263G, 2247G
ODM Geological Compilation Map: 2221

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Parts of this publication may be quoted if credit is given and the material is properly referenced.

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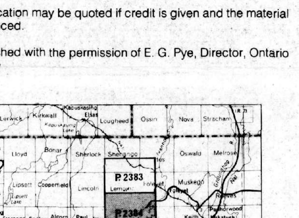

LOCATION MAP

Scale: 1: 1 584 000 or 1 inch to 25 miles

LEGEND[a]

PHANEROZOIC
CENOZOIC
QUATERNARY
PLEISTOCENE AND RECENT
Till, sand, clay and gravel

UNCONFORMITY

PRECAMBRIAN
EARLY TO MIDDLE PRECAMBRIAN
MAFIC INTRUSIVE ROCKS

6 — 6 Diabase dikes

INTRUSIVE CONTACT

EARLY PRECAMBRIAN
METAMORPHOSED IGNEOUS ROCKS
TONALITIC GNEISS UNIT[b]

5 —
- 5a Unsubdivided hornblende-biotite, biotite-hornblende and biotite tonalite gneiss
- 5b Biotite-hornblende tonalite gneiss
- 5c Biotite-hornblende tonalite
- 5d Biotite tonalite gneiss
- 5f Garnetiferous tonalite gneiss
- 5g Amphibolite, may contain biotite
- 5h Garnetiferous amphibolite
- 5L Garnet-clinopyroxene amphibolite
- 5m Garnetiferous biotite-rich paragneisses

INTRUSIVE OR FAULT CONTACT

SHAWMERE ANORTHOSITE COMPLEX[c]
METAMORPHOSED DIKES

4 —
- 4a Anorthositic dikes
- 4b Gabbroic, predominantly garnetiferous dikes

INTRUSIVE CONTACT

MAIN ZONE

3 —
- 3a Anorthosite, commonly garnetiferous
- 3b Leucogabbro, commonly garnetiferous, locally coronitic
- 3c Gabbro to melagabbro, commonly garnetiferous and coronitic:unsubdivided
- 3d Quartz ± clinopyroxene-garnet amphibolite, to quartz ± clinopyroxene-amphibole garnetite
- 3e Hornblende gabbro, melagabbro ± garnet ± quartz
- 3f Clinopyroxene, hornblende-clinopyroxene gabbro to melagabbro, commonly strongly lineated
- 3g Garnet-hornblende norite, melanorite (coronitic). (May contain green spinel).
- 3h Garnet-clinoamphibole melagabbro. (May contain green spinel, anthophyllite, sapphirine).
- 3j Hornblende gabbronorite, melagabbronorite
- 3L Garnet-bearing hornblende gabbro norite (coronitic)
- 3m Coronitic troctolite
- 3n Ultramafic rocks: unsubdivided
- 3p Spinel harzburgite
- 3q Spinel-olivine-hypersthene hornblendite. (May contain garnet).
- 3r Garnet clinoamphibolite (May contain plagioclase, orthopyroxene, spinel).
- 3s Clinopyroxene hornblendite
- 3u Sapphirine-bearing rocks
- 3A Megacrystic texture[d]
- 3B Clotty texture[e]
- 3C Streaky to gneissic texture[f]
- 3D Granoblastic texture[g]
- 3E Granoblastic-banded texture[h]

MARGINAL ZONE[j,k]

2 — 2 Quartz ± clinopyroxene-garnet amphibolite

INTRUSIVE CONTACT

METASEDIMENTS[l]

1 —
- 1a Garnet-biotite-quartz-plagioclase ± hornblende ± K-spar paragneisses (wackes)
- 1b Orthopyroxene bearing paragneisses
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The Shawmere Anorthosite Complex

The intrusion can be subdivided into zones of contrasting compositional and structural characteristics: a) Megacrystic Gabbroic Anorthosite[1] Zone, b) Anorthosite Zone, c) Banded Zone, d) Border Zone.

The Megacrystic Gabbroic Anorthosite Zone occupies the central portion of the anorthosite complex and extends to the northeastern margin of the intrusion. It is composed predominantly of gabbroic anorthosite with subordinate anorthosite, anorthositic gabbro and gabbro, and minor melagabbro. All rocks within this zone contain large (1 to 50 cm) cumulus plagioclase megacrysts embedded in a matrix of mafic minerals. Most megacrysts are internally granulated and totally recrystallized into aggregates of small (2-3 mm) plagioclase grains. Primary igneous plagioclase is best partially or totally preserved in rocks of gabbroic composition. In general the plagioclase megacrysts are deformed into prolate ellipsoids. In zones of more intense deformation, the megacrysts are streaked out into discontinuous leucocratic layers alternating with melanocratic layers. Mafic minerals within this zone consist of amphibole-clinopyroxene-orthopyroxene, irregular clots of dark green amphibole, and of orthopyroxene surrounded by an inner shell of amphibole, or mixed amphibole-clinopyroxene, and an outer shell of granular garnet. At one locality the core of the coronitic assemblage is occupied by olivine.

In the northwestern part of the map-area, the Megacrystic Gabbroic Anorthosite Zone grades into predominantly anorthositic rocks with average mafic mineral content not exceeding 5 percent. The Anorthosite Zone is separated from the Border Zone by a thin (50-100 m) discontinuous unit composed of lineated clinopyroxene-rich gabbro. Anorthositic rocks in this zone are made up of granular aggregates of grey to reddish-coloured plagioclase, minor interstitial amphibole, and, occasionally, scattered garnet grains. Outcrops of otherwise almost pure anorthosite may also contain thin (2-5 cm) layers composed of equal amounts of plagioclase and amphibole or garnet-amphibole and minor plagioclase. Remnants of igneous plagioclase are rare in this zone.

Rocks of the Banded Zone occupy the southeastern margin of the Shawmere Anorthosite between Carty and Wakagami Lakes. The Banded Zone is characterized by well developed small scale (1 to 30 cm) compositional banding, presence of deep-red garnet-rich layers, and lack of mafic clots and plagioclase megacrysts. Individual layers comprise pure anorthosite, lineated clinopyroxene-amphibole-plagioclase gabbro, sphene-plagioclase-quartz-amphibole-garnet (up to 60-70 percent) rocks, and minor ultramafic rocks composed of orthopyroxene, amphibole, serpentinized olivine and up to 5 percent green aluminum spinel. Thin quartzo-feldspathic segregations are locally present in this zone. Most of the layers are isomodal and mineral-graded layers are rare. At one locality on the northeastern shore of Carty Lake mineral-graded layers, rich in amphibole at the base and plagioclase at the top, are size graded as well and can be used as top indicators. Structures strongly resembling graded bedding can be observed at Carty Lake. However, since the rocks in the area are tightly folded and the folds are isoclinal and recumbent, it is possible that the "cross beds" are in fact sheared folds.

The Border Zone is a distinct lithologic unit, 50 to 100 m thick, which separates rocks of the Shawmere Anorthosite Complex from country rocks. It outcrops almost continuously along the northwestern margin of the intrusion and in the Carty Lake-Harold Lake area. Structurally, the Border Zone can be seen to underlie and overlie anorthositic rocks. The Border Zone is made up of a dense, dark-coloured, foliated garnetiferous amphibolite containing 5 to 20 percent concordant to slightly discordant quartzo-feldspathic layers, and at some localities, anorthositic layers. Border Zone rocks grade into predominantly anorthositic rocks containing subordinate layers of garnet amphibolite. The contact between Border Zone and country rocks can be sharp or transitional. Where transitional, the amphibolites become increasingly migmatized away from the anorthosite. The Border Zone is interpreted as the metamorphosed equivalent of a gabbroic marginal zone formed by cooling the magma against the country rocks.

The Shawmere Anorthosite Complex is metamorphosed to the hornblende granulite subfacies of the granulite facies. This is substantiated by the occurrence of sapphirine associated with garnet, pargasite, and plagioclase in melagabbro from Carty Lake, the presence of green aluminum spinel in ultramafic layers, and the coexistence of garnet, pyroxenes, amphibole, and plagioclase in gabbroic rocks.

Country Rocks

The Shawmere Anorthosite Complex is surrounded by fine- to medium-grained quartzo-feldspathic schists and gneisses, fine- to medium-grained semi-pelitic paragneisses, and medium-grained amphibolites and garnet amphibolites. All country rocks contain variable amounts of coarse-grained quartzo-feldspathic segregations probably formed during anatexis and then deformed with the country rocks.

Quartzo-feldspathic schists and gneisses are composed of quartz-feldspar-biotite-hornblende ± garnet, occuring as irregularly shaped masses within the southeastern part of the Shawmere Anorthosite, as discontinuous zones of variable width rimming the anorthosite, and as intercalations in semi-pelitic metasediments. The width of zones underlain by quartzo-feldspathic rocks surrounding the anorthosite increases in a southwesterly direction along both margins of the intrusion.

The semi-pelitic paragneisses are quartz-biotite plagioclase schists which may contain orthopyroxene and up to 30 percent garnet porphyroblasts. In the Shawmere Lake area, the metasediments display a well developed compositional banding. Individual layers, 2 to 5 cm thick and rich in biotite and garnet, alternate with equally thick layers poorer in both minerals.

Amphibolites are composed of amphibole and plagioclase, and may contain garnet, quartz, clinopyroxene, orthopyroxene and biotite. They occur as discrete outcrops, as rafts or boudinaged layers enclosed in quartzo-feldspathic rocks, and as discontinuous layers within semi-pelitic metasediments. Amphibolitic rocks in the southeastern corner of the map-area may represent metamorphosed equivalents of mafic tuffs and lavas of nearby "greenstone" terranes.

Dikes

Rocks of the Shawmere Anorthosite Complex are cut by metamorphosed dikes and dikelets of gabbroic and anorthositic composition. Most of these early dikes are deformed and garnet-bearing. Pegmatitic leucodioritic dikes intrude the anorthosite and banded zone of the anorthosite as well as the quartzo-feldspathic rocks surrounding the anorthosite. Undeformed pegmatitic dikes ranging in composition from granite to trondhjemite cut the country rocks and rare trondhjemitic dikes cut the anorthositic rocks. Late undeformed and unmetamorphosed fine- to medium-grained diabase dikes cut both the anorthosite and the country rocks. Diabase dikes trend predominantly east-northeast and less commonly northeast, west-northwest, northwest and north-northwest. They are wide-spread in the eastern and southeastern parts of the area and rarer further to the north and northwest.

STRUCTURAL GEOLOGY

At least three phases of deformation can be recognized in the map-area. The first and most intense phase of deformation (F_1) produced the prominent north-northwest- to northwest-dipping schistosity-gneissosity as well as a set of mesoscopic, close to tight, isoclinal folds with northwest-dipping axial planes and axes with shallow plunges to the west-southwest. The isoclinal folds are moderately inclined in the northern part of the map-area and strongly inclined or recumbent in the south. Folds with diverging limbs are very rare. Associated with the F_1 folds are wide-spread mineral lineations which include elongated plagioclase megacrysts and elongated aggregates of hornblende and clinopyroxene in "anorthositic" rocks, elongated biotite and hornblende in metasediments, and quartz rods in quartzo-feldspathic rocks. Mineral lineations are especially prominent in hinges of mesoscopic folds. Mineral lineations are invariably parallel to fold axes of F_1 folds. The second phase of deformation (F_2) gave rise to large open folds with subhorizontal northwest-trending areas. Occasional reversals in the direction of plunge of mineral lineations are considered to be related to F_2 folding. Open folds related to D_3 can be observed in the Shawmere Lake area. There the gneissosity in metasediments is locally warped about axes plunging steeply to the north-northwest. It is suggested that the Shawmere Anorthosite Complex is folded into a major southwest-plunging asymmetrical overturned syncline with a steeper inverted limb and a shallower normal limb. This interpretation is based on: a) the occurrence at Carty Lake of mineral and size-graded layers facing north, b) the presence of a Border Zone rimming the anorthosite on both sides forming the base of the sequence, c) the relatively undeformed nature of the central part of the intrusion, d) the style and attitude of F_1 folds and related lineations.

North- to north-northeast-trending shear zones characterized by intense mylonitization and development of pseudotachylite veinlets are common along the eastern margin of the Kapuskasing Structural Zone. The most prominent mylonite zone, up to 250 m wide, straddles the boundary between anorthosite and country rocks from the CNR railway to just north of the Fire Tower Road in Foleyet Township, a distance of approximately 11 km. Other major mylonite zones are exposed along the Fire Tower Road, at Wakagami Lake, west of East Carty Lake, and along Highway 101. Although the mylonite zones are late structures which cut across lithologic units and deflect the regional schistosity, they are in part developed along pre-existing faults. For example, the mylonite zone to the west of East Carty Lake separates high grade amphibolite and paragneisses of the Kapuskasing Structural Zone from "greenstone" terranes.

ECONOMIC CONSIDERATIONS

Cr and Fe, Ti

Anorthositic rocks are known to contain economically significant deposits of Cr-rich spinel, ilmenite, or magnetite-ilmenite.

Cr-rich spinels only crystallize from relatively undifferentiated basaltic liquids. Consequently chromites can only be expected to occur in anorthosite composed of highly calcic plagioclase. Ilmenite and magnetite, on the other hand, crystallize from more differentiated basaltic liquids and are usually found in anorthosite with plagioclase in the andesine-labradorite range. It is also known (e.g. Bushveldt Complex), and it has been experimentally shown (Hill and Roeder 1974), that basaltic magmas differentiating under normal oxygen fugacity conditions do not crystallize spinel phases during their middle stages of fractionation. Outcrops within the Shawmere Anorthosite Complex appear to be devoid of disseminations of either chromite, ilmenite, or magnetite. A few opaque minerals examined to date proved to be metamorphic aluminum spinels. On the basis of these field observations the potential for oxide mineralization in the Shawmere Complex is poor. However a petrogenetic study of the complex would help substantiate the field observations and might explain the apparent lack of oxide dissemination.

Aluminum

Technologically it is possible to extract aluminum from anorthositic rocks and recover up to 98 percent Al_2O_3 (Quon 1977). As the world's bauxite reserves are slowly being depleted, the demand for aluminum increases, and some of the foreign governments that control bauxite supply are politically unstable, the long-range economic potential of large anorthosite masses as sources of low-grade Al_2O_3 should be considered. In the Shawmere Complex, the best belt of anorthositic rocks with low mafic mineral content covers an area of between 4 and 7 km^2 extending from the CNR railway to just northeast of Lemoine Lake. This represents between 1.1 and 1.9 billion tons to a depth of 100 m.

Conversion factor 1 foot = 0.3048 m

[1]Terminology from Streckeisen (1976).

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SOURCES OF INFORMATION

Horwood Lake Sheet, Ontario Department of Mines Preliminary Map P.673, Geological Series, Scale 1:126 720 or 1 inch to 2 miles.

Assessment Files Research Office, Ontario Geological Survey, Toronto.

Base maps derived from Forest Resources Inventory Sheets, Lands and Waters Group, Ministry of Natural Resources.

Magnetic declination approximately 7°11' at centre of map-area in 1979.

CREDITS

Geology by L. Riccio and assistants, 1979

Every possible effort has been made to ensure the accuracy of the information presented on this map; however, the Ontario Ministry of Natural Resources does not assume any liability for errors that may occur. Users may wish to verify critical information; sources include both the references listed here, and information on file at the Resident or Regional Geologist's office and the Mining Recorder's office nearest the map area.

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Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

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1981: Precambrian Geology of the Shawmere Anorthosite Complex (South), District of Sudbury; Ontario Geological Survey Preliminary Map P. 2384, Geological Series, Scale 1:15 840 or 1 inch to 1/4 mile. Geology 1979.