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MAJOR ROCK UNITS OF THE MORIN COMPLEX, SOUTHWESTERN QUEBEC

R.F. Emslie
(with petrographic contributions by I.F. Ermanovics)

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ABSTRACT

The Morin Complex contains the largest mass of anorthositic rocks in southwestern Quebec. The major meta-igneous units of the complex from older to younger comprise anorthosite-leucogabbro, pyroxene monzodiorite and pyroxene quartz monzonite compositions. Anorthosite-leucogabbro and pyroxene quartz monzonite underlie by far the largest areas.

Relict igneous textures and structures are preserved in much of the anorthosite-leucogabbro except in the southern part of the east lobe where recrystallization to polygonal textures is far advanced or complete. Most measured plagioclase compositions in anorthosite-leucogabbro lie in the range An_{42} to An_{54}. The Or content of plagioclase averages about 5 mol per cent but drops to about 1. 5 mol per cent in recrystallized plagioclases. Orthopyroxenes typically contain 60 to 70 mol per cent $MgSiO_3$ in anorthosite-leucogabbro and range down to less than 40 mol per cent $MgSiO_3$ in pyroxene quartz monzonite.

Anorthosite-leucogabbro is interpreted as essentially a plagioclase cumulate with interstital pyroxenes. Rocks corresponding to the liquid from which this cumulate crystallized have not been identified and may not be present at the existing level of exposure. The pyroxene and oxide-rich pyroxene monzodiorite probably also formed in part by crystal accumulation processes. The pyroxene quartz monzonites, on the other hand, show little or no evidence of having formed by crystal accumulation. Fe-Ti oxide concentrations are common in parts of the complex. Many of these are associated with contacts between anorthosite-leucogabbro and pyroxene monzodiorite.

Direct dating of rocks of the complex has not been carried out but recent Rb-Sr whole rock ages indicate that the age of last regional metamorphism (Grenvillian Orogeny) was 1100-1125 m. y. ago. It has also been suggested that this is also a close approximation to the age of emplacement of the smaller Lac Croche meta-anorthositic complex nearby.

RESUME

Le complexe Morin renferme la plus grande masse de roches anorthositiques du sud-ouest du Québec. Les principales unités métamorphiques ignées de ce complexe sont constituées, par ordre d'ancienneté, d'anorthosite-leucogabbro, de monzodiorite à pyroxène et de monzonite quartzeuse à pyroxène. Les couches sous-jacentes d'anorthosite-leucogabbro et de monzonite quartzeuse à pyroxène sont les plus étendues.

Les textures et structures ignées résiduelles ont été préservées dans la majeure partie de la zone d'anorthosite-leucogabbro sauf dans la partie sud du lobe est où la recristallisation des textures polygonales est très avancée ou terminée. La plupart des compositions de plagioclases que l'on peut déceler dans l'anorthosite-leucogabbro se situent entre An_{42} et An_{54}. La teneur en or des plagioclases totalise environ 5 pour cent de molécules-grammes mais tombe à 1. 5 pour cent dans les plagioclases recristallisés. Les orthopyroxènes de composition anorthosite-leucogabbro contiennent normalement de 60 à 70 pour cent de molécules-grammes de $MgSiO_3$, et cette proportion se réduit à 40 pour cent de molécules-grammes de $MgSiO_3$ en ce qui concerne la monzonite quartzeuse à pyroxène.

L'auteur définit l'anorthosite-leucogabbro comme étant essentiellement une accumulation de plagioclases avec des pyroxènes interstitiels. Les roches qui se sont formées à la suite de la cristallisation de ces liquides accumulés n'ont pas été identifiées et ne sont peut-être pas visibles actuellement. Le pyroxène ainsi que la monzodiorite à pyroxène fortement oxydée se sont probablement formés aussi de la même façon. D'autre part, les monzonites quartzeuses à pyroxène ne semblent pas avoir été formées par cristallisation. On retrouve de fréquentes concentrations d'oxyde Fe-Ti dans certaines parties du complexe. L'auteur explique ces concentrations par le contact de l'anorthosite-leucogabbro avec la monzodiorite à pyroxène.

L'âge exact des roches de ce complexe n'a pas encore été déterminé quoique de récentes méthodes de datation au strontium et au rubidium indiquent que l'âge du dernier métamorphisme régional (phase tectonique de Grenville) remonte à 1100-1125 millions d'années. Il semble que la mise en place du complexe méta-anorthositique du lac Croche date d'environ de la même époque.

MAJOR ROCK UNITS OF THE MORIN COMPLEX, SOUTHWESTERN QUEBEC

INTRODUCTION

The central purpose of this study was to map and describe the rocks that comprise the Morin Complex and to describe relationships among the various units. For this reason description of rock-units having no genetic relation to the anorthosite suite is kept to a minimum and drawn mainly from reports of the Quebec Department of Natural Resources.

Preparation of a suitable geological map of the complex and particularly of its surroundings has been based heavily on existing maps. Because previous mapping covers a long time interval it is inevitable that changes in emphasis and interpretation should have occurred and that the quality of treatment of different aspects of the geology was variable. Comparison of existing maps revealed discrepancies and disagreements for which, so far as possible, satisfactory solutions were sought (although not always successfully). Nevertheless an overall compilation was clearly necessary even if it required some generalizations and simplifications. Problems such as the age and relationships of the Grenville Supergroup to other units and the origins of certain gneisses and granulites have undergone interpretation and reinterpretation but decisive information is still lacking.

This contribution to the geology and petrology of the Morin Complex is based on two seasons in the field combined with information compiled from the literature. The work is intended to serve as a basis for more detailed studies by providing a map of the units of the complex together with results of preliminary studies of their mineralogical and chemical characteristics.

Previous Work

The Morin anorthosite has been subject to study and controversy at least as far back as publication of Logan's Geology of Canada (1863). Logan's views on the anorthositic rocks were apparently influenced by the somewhat Wernerian tendencies of T. S. Hunt who is generally credited with the rock name anorthosite (Hunt, 1862, 1870). Hunt and Logan undertook to fit the anorthositic rocks into a stratigraphic succession in which they were supposed to overlie, possibly unconformably, the Grenville Group.

Significant advances in understanding the rocks were not made until the classic studies of F. D. Adams appeared in 1896. After careful field and petrographic investigations Adams had no hesitation in pronouncing the anorthositic rocks to be of igneous origin. Adams did not associate any of the pyroxene monzodiorites or pyroxene quartz monzonites with the genesis of the Morin anorthosite apparently believing all or most of them to be older. Since Adams' time no workers have seriously questioned an essentially igneous origin for the anorthositic rocks. Subsequent study on parts of the complex have been pursued principally under the auspices of the Quebec Department of Natural Resources. Such authors as Osborne (1935, 1938, 1949) Côté (1960), Klugman (1960), Déland (1960) and others have provided a fund of information and have offered their own interpretations in agreement or disagreement with previous hypotheses. Recent publications on the Morin Complex by Martignole and Schrijver (1970a, 1971) have brought forth some interesting new structural interpretations of the eastern lobe of anorthosite-leucogabbro and its adjoining rocks.

Present Work

The present investigation was undertaken as part of a larger program aimed at clarifying some of the perplexing mysteries associated with the so-called "anorthosite problem". Earlier work on the Michikamau intrusion in central Labrador (Emslie, 1965, 1969, 1970) prompted a desire to examine an intrusion of similar size in the Grenville Province for purposes of comparison. The Morin area was chosen because it has an existing fund of data to draw upon and was relatively easy of access.

No attempt was made systematically to map the Morin Complex as a whole. Instead, attention was focused chiefly upon relations among the various rock-units of the complex to each other and to the country rocks. Extensive sample collections were made from all of the major rock-units of the complex. The field seasons of 1964, in company with G. B. Skippen and A. N. LeCheminant, and 1965 with D. Bilodeau were devoted to these pursuits. The able assistance and good companionship of these men is gratefully acknowledged.

In the summer of 1968, in collaboration with L. W. Sobczak of the Gravity Division, Earth Physics Branch, a series of gravity profiles were measured over parts of the Morin Complex. A report dealing with this aspect of the study will appear elsewhere.

Most of the modal analyses and some of the optical mineral determinations were carefully carried out by I. F. Ermanovics.

GEOLOGICAL AND TECTONIC SETTING

General Statement

The St. Lawrence Lowlands underlain by relatively undisturbed Paleozoic rocks, comprises a small segment in the southeast corner of the area. At the edge of this plain the Precambrian Shield rises abruptly as low rolling hills which become progressively higher and more rugged toward the north and west. A few remnants of Paleozoic rocks are preserved around

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Lac Echo (Fig. 1). Local relief over much of the region averages 500 feet but isolated hills and groups of hills stand as much as 1,000 feet above their surroundings and at Mont Tremblant, the highest point in the area, the relief is over 2,000 feet.

Rock exposure is erratic in quantity and in quality. Thick deposits of glacial stream gravels and drift fill valleys and lowlands and most hills are at least partly mantled by drift. In addition, the hills are heavily forested and outcrops occurring on them are commonly obscured by moss and forest litter so that details of their structures are rarely seen on large surfaces, except in a few cliff faces which are difficult of access. By far the best exposures occur in rock-cuts where blasting and earth moving have revealed fresh clean rock. Unfortunately, along some of the well-travelled thoroughfares the lavish use of paint to proclaim various political and religious tenets, expressions of affection and other trivia has defaced otherwise excellent exposures. Much of the Morin Complex, except for the extreme northeastern part is accessible by roads of varying quality.

The relative ages of some of the rocks in the area has been a matter of some controversy. For many years geological reports of the Quebec Department of Natural Resources have indicated that rocks of the Grenville Supergroup are the oldest recognizable. More recently, the hypothesis that certain gneissic and granulitic rocks may predate the Grenville Supergroup has been resurrected and refined by Wynne-Edwards et al. (1966). This latter interpretation has been adopted for this presentation although it is clearly recognized that the

Figure 1. Paleozoic conglomerate comprised chiefly of angular pyroxene quartz monzonite clasts in a dark silty matrix. West of Lac Echo.

evidence to support it, except in a few widely dispersed localities, is less substantial than one might wish. In other words, the question of which specific units form a basement to the Grenville Supergroup in the Morin area remains debatable for lack of decisive data. Adoption of the premise that rocks predating the Grenville Supergroup can be recognized merely reflects this author's prejudices and does not, in any case play a central role in the geological interpretation presented here.

Nearly all of the Precambrian rocks in the region carry mineral assemblages consistent with upper amphibolite to granulite facies of regional metamorphism. Thus most rocks of igneous origin including the anorthosite suite should be designated, if rigorous nomenclature were observed, as meta-igneous rocks. In the interests of simplicity the prefix meta- is omitted although it should be borne in mind that its applicability is understood.

The bulk of the plagioclase-rich rocks of the Morin Complex fall within the range of anorthosite to leucogabbro, that is they contain approximately 5 to 20 per cent mafic minerals. Although rather large areas of relatively uniform rock probably exist, the sparse outcrop together with erratic local variations in mafic mineral content made attempts to further subdivide rock-units on the basis of colour index unworkable. Similarly, grain size variations do not seem to be systematic. The essential minerals of the rocks are plagioclase, orthopyroxene and clinopyroxene usually accompanied by small amounts of opaque oxide minerals. Alteration products include zeolites, chlorite, scapolite, sericite and amphibole. Garnet and hornblende are locally present as metamorphic reaction products, chiefly in the more mafic leucogabbros and the gabbros. Attitudes of primary layered structures measured in the field are variable. Relatively low dips (below 30 degrees) were found at a number of localities especially in the western part of the intrusion. Dips of 60 degrees or greater have also been measured and it is possible that these may be due to deformation or faulting.

Although the most distinctive unit of the Morin Complex is anorthosite-leucogabbro, large areas are underlain by pyroxene quartz monzonite and lesser areas by pyroxene monzodiorite. Both of these units show crosscutting relations toward anorthosite-leucogabbro. Pyroxene quartz monzonite also cuts pyroxene monzodiorite so there is little doubt of the age sequence. Pyroxene monzodiorite is typically found at contacts between anorthosite-leucogabbro and pyroxene quartz monzonite but also occurs as masses and dykes within anorthosite-leucogabbro. Primary igneous structures in pyroxene quartz monzonite and pyroxene monzodiorite, although present, are not sufficiently abundant to assist in determination of the forms of these intrusions.

Few fault zones have been identified within the complex although it would be surprising if more were not present. Lineaments are recognizable on air photographs but rock exposure is rare or nonexistent along most valleys so that chances of verifying the presence of faults on the ground are small.

Tectonic Summary

The principal problems involved in a tectonic interpretation of the region centre about: (1) definition and significance of the Grenville Supergroup; (2) basement-cover relationships; (3) character, timing and extent of the Grenvillian orogeny; (4) origin and significance of the anorthosite suite. These questions all have a venerable history of discussion, interpretation and reinterpretation dating back to Sir William Logan. Some brief comment on the principal aspects of these problems is presented here to serve as a background for discussion of the Morin Complex.

Grenville Group

Logan first used the term Grenville series in Geology of Canada (1863) in reference to the sequence of marble, quartzite and paragneiss outcropping near the village of Grenville, Argenteuil County, Quebec and in the adjoining region to the northeast. Most workers have accepted correlation of similar but variable lithological sequences in eastern Ontario, western Quebec and northern New York with the Grenville Supergroup.

The thickness of the Grenville Supergroup in the type area has been estimated as between 5,000 and 10,000 feet (Osborne, 1936). Engel and Engel (1953) estimated the relative abundance of rock types there as 35 per cent marble, 12 per cent quartzite, 45 per cent feldspathic gneisses and 8 per cent amphibolite. A thickness of somewhat less than 20,000 feet has been estimated for correlative rocks of the Haliburton-Bancroft district to the west, and about 5,000 to 7,000 feet in the Shawinigan region to the east. Folding and flowage render all of these estimates uncertain. In addition, neither the top nor the base of the Grenville has ever been defined.

The depositional age of the Grenville Supergroup has been variously estimated to be late Precambrian (Hewitt, 1957), Middle Proterozoic (Wynne-Edwards, 1964), Aphebian (Stockwell, 1964) and Paleohelikian (Emslie, 1970). A recent estimate by Wynne-Edwards (1972) suggested that deposition took place over the interval from about 1,700 to 1,200 m.y. ago.

Rocks of the Grenville Supergroup are commonly metamorphosed to at least amphibolite facies except in a few districts such as the Hastings Lowlands where greenschist facies occur. Generally northeasterly structural trends can be recognized in the Grenville Supergroup in southeastern Ontario and southwestern Quebec. In the vicinity of the Morin Complex, however, recognizable supracrustal rocks presumably correlative with the Grenville Supergroup tend to wrap around the area of the complex as though it had formed a relatively unyielding plexus during deformation.

Basement Rocks

Interpretations of basement - cover relationships in the Grenville Province may be traced back to Logan's early opinion that the "Fundamental Gneiss" formed a basement upon which the Grenville Supergroup was deposited. In recent years controversy has been revived and evidence bearing on the recognition of basement and cover rocks in the Grenville Province has been widely discussed.

Hewitt (1962) interpreted granite gneiss domes in the Hastings-Haliburton Highlands as autochthonous. He suggested that the granitic rocks became mobile under catazonal conditions and rose into overlying paragneisses thus implying the presence of granitic basement.

North of Ottawa, Pollock (1962) using structural and lithologic arguments, concluded that rocks forming a basement to the Grenville Supergroup were recognizable and had been remobilized and intruded into the Grenville Supergroup.

Walton and DeWaard (1963) offered an interpretation of the geological history of the Adirondack Highlands that recognized a basement complex to which most rocks of igneous origin belong, including those of the anorthosite suite, overlain by Grenville sediments. Their preferred hypothesis of evolution of the region involved at least two orogenic cycles.

Wynne-Edwards et al. (1966) interpreted structural elements in the Mont Laurier-Kempt Lake area as reflecting relict Kenoran and Hudsonian deformational episodes overprinted by Grenvillian deformation. Wynne-Edwards (1972) concluded that 60 per cent of the Grenville Province consists of reworked crystalline basement that underlies the Grenville Supergroup.

In the vicinity of the Morin Complex the chief candidates for possible basement rocks are the substantial areas of granulitic gneisses located north and southwest of the complex and interspersed with folded Grenville Supergroup rocks to the east. Katz (1969) however, has suggested that quartzofeldspathic granulites to the north are stratigraphically equivalent to the Grenville Supergroup.

Grenvillian Orogeny

Although the nature of the Grenvillian Orogeny is poorly understood, most students of the Grenville would probably agree that a major orogenic event affected most of the rocks now comprising the Grenville Province and is not recorded in rocks of adjacent structural provinces. The metamorphic culmination of this event based on Rb-Sr whole rock isochrons appears to be about 1100 m.y. ago in the Morin area. The 950± m.y. old K-Ar mineral ages characteristic of the Grenville Province are now widely recognized as reflecting the end of post-orogenic uplift.

With respect to the Morin Complex the principal problem concerns the timing of the igneous intrusive event relative to the Grenvillian Orogeny. Emplacement may either have predated the main metamorphic and deformational phases of the orogeny or else have been synorogenic. Because inclusions of presumably Grenville Supergroup rocks are contained within the Morin Complex there can be no doubt that emplacement occurred after the depositional phase of the Grenvillian Orogenic cycle had begun.

Barton and Doig (1972, 1973) have reported a number of Rb-Sr isochrons from rocks east and northeast of the Morin Complex. These include meta-igneous rocks of the Lac Croche Complex and paragneisses assumed to belong to the Grenville Supergroup. The Lac Croche Complex comprises rocks of the anorthosite suite and isochrons have been interpreted by Barton and Doig as meaning that it was emplaced and immediately deformed and recrystallized about 1124 m. y. ago. An isochron on paragneisses of the Grenville Supergroup yielded a metamorphic age of about 1094 m. y. Another isochron on alaskite suggests that a basement complex at least 1460 m. y. old is present. These data support the interpretation that the Grenvillian Orogeny in the area culminated about 1100 m. y. ago and that relict ages of older events can be recognized.

Country Rocks

Quartzofeldspathic gneisses and granulites (units 1 and 2)

This category contains all of the rocks that would be called granulites in the classic sense - that is they are fine to medium grained, foliation is virtually absent to moderately well developed and a resinous, slight to marked, greenish cast is characteristic of fresh surfaces. Small amounts of orthopyroxene, clinopyroxene and garnet are commonly present and these may be accompanied by a little red-brown biotite and/or brown hornblende. The remainder of the rock is made up of plagioclase (commonly antiperthite) potash feldspar and quartz. The colour index of these rocks is rarely greater than 10 and commonly less than 5, although the dark grey-green colour of fresh specimens gives a false impression of higher colour index.

Also included within this unit are pinkish to light grey rocks that have a granitic appearance yet texturally and mineralogically are similar to the granulites (see also Katz, 1969). They occur in close association with the granulites but also underlie rather large areas where typical granulites are rare or absent. Because they do occur in close association with granulites it seems possible that the differences in colour are mainly a secondary effect due to iron oxidation that may have penetrated to considerable depths in some areas. Katz (1969) suggested that there are significant chemical differences and that the two types may be unrelated.

Both the granulites and the pink to grey gneisses carry local lenses, discontinuous layers and groups of layers of more mafic rock. Individual layers are commonly a few inches to a foot or more thick and a few feet to several tens of feet long. They may be regular in attitude or strongly deformed. In some cases the layers are simply caused by a slight increase in concentration of mafic minerals in the rocks but many are distinct entities of amphibolite, pyroxene amphibolite or mafic granulite. The origin of these layers is unknown; they may represent original sedimentary features or be relics of dykes and sills or a combination of both. In any case they constitute at most 5 per cent of the total granulite and gneiss unit.

It is the age relationship of these rocks (units 1 and 2) to the Grenville Supergroup that is one of the more enigmatic problems of the region. Logan included most of these rocks in a unit he referred to as "Fundamental Gneiss" - that is the oldest recognizable rocks. This interpretation was in time rejected in favour of one that viewed the rocks as batholithic intrusions into the Grenville Supergroup (Adams, 1897; Osborne, 1935) but more recently Logan's interpretation has been revived and refurbished (Wynne-Edwards, 1964; Wynne-Edwards et al., 1966).

Metasedimentary rocks (units 3, 4, 5 and 6)

Early studies on rocks of the Grenville Supergroup ("Grenville Series") were carried out by Logan partly in the southern and western portions of the present map-area. His principal concern was with the crystalline limestones (marbles) which were of economic interest as a source of agricultural lime.

Lacking evidence to the contrary, it is assumed that all of the rocks described in this section should be assigned to the Grenville Supergroup. For present descriptive purposes the rocks can be conveniently subdivided into marble, quartzite, paragneiss and amphibolite.

Marble (unit 3) the marbles are typically coarsely crystalline, nearly white or pale shades of blue, green, pink or brown. Typically they weather rather deeply to a rust-stained friable aggregate. Because of this deep weathering they were readily susceptible to glacial scour and therefore tend to underlie valleys and other areas of negative relief.

Only rarely do the marbles approach high purity although many contain 90 per cent or more carbonate minerals. Varying amounts of other minerals are present including graphite, phlogopite, forsterite, diopside, serpentine, chondrodite, vesuvianite, scapolite, brucite, quartz and feldspar. Thick bodies of marble show little if any coherent internal structure. Where interbeds of paragneiss and amphibolite or other layers of impurities occur they are commonly extremely contorted.

Quartzite (unit 4) quartzites range from relatively pure coarse vitreous varieties to impure quartzites bearing garnet, feldspars, sillimanite, biotite, pyroxenes, hornblende, chlorite, graphite, sphene, zircon and pyrite.

Structurally and texturally the quartzites range from nearly massive to weakly foliated to well layered. The purer varieties of quartzite occur in relatively thick sections whereas quartzite interlayered with paragneiss and amphibolite tends to be less pure.

Paragneiss (unit 5) paragneisses cover a range of compositions from moderately aluminous to fairly mafic. Some of the common mineral assemblages are:

Sillimanite - garnet - quartz - potash feldspar - plagioclase (biotite)

Biotite - hornblende - quartz - plagioclase

Garnet - quartz - potash feldspar - plagioclase (biotite, graphite, pyrite)

Biotite - hornblende - pyroxene - plagioclase (potash feldspar, quartz, garnet)

Biotite - quartz - plagioclase (garnet, sillimanite)

Most of these rocks are moderately to well foliated parallel to layering and commonly are layered on a scale of a few millimetres to a few metres. Intercalated quartzite and amphibolite layers are common; marble layers occur but are rarer.

Martignole and Schrijver (1970a) have defined the Lac Quinn Formation which is approximately 50 metres thick and grades upward from quartzite into garnet-sillimanite gneisses. They believe that this formation is present discontinuously around much of the east lobe of anorthosite-leucogabbro and may perhaps be more widespread. If this interpretation is correct the formation may have been an important structural control on emplacement of the anorthosite-leucogabbro as Martignole and Schrijver have pointed out.

Amphibolite these are essentially hornblende-plagioclase rocks that may contain one or more of: biotite, quartz, orthopyroxene, clinopyroxene, or garnet together with minor accessory minerals. For the most part these rocks occur as layers and lenses intercalated with other metasedimentary units. Amphibolite is most abundant east and northeast of the Morin Complex. What proportion, if any, of the amphibolites are of volcanic origin is unknown.

Other country rocks

Dykes and irregular small intrusive masses of alaskitic granite are ubiquitous and can be found cutting all major rock-units in the area. The ultimate origin of these small masses is unknown but it seems reasonable to ascribe their development to anatectic processes attending a regional metamorphic event (The Grenvillian Orogeny ?).

Several small intrusive bodies of metagabbroic rock occur within the map-area. The most extensive is a narrow discontinuous body of metagabbro and metatroctolite along and near the southwest contact of the east lobe of the anorthosite-leucogabbro. The relationship of these rocks to the anorthosite suite is uncertain but a genetic association seems unlikely (Osborne, 1949). Martignole and Schrijver (1972) however, regard the metatroctolite as a member of the Morin intrusive suite. Osborne (1949) first reported that small anorthosite dykes cut the metatroctolite at one locality south of St-Calixte-de-Kilkenny.

Large and small diabase dykes are present throughout the region. They are most abundant in the southern part of the map-area where a persistent east-west trend is evident subparallel to the Ottawa River. They are probably the youngest Precambrian igneous rocks present in the area.

THE MORIN COMPLEX

General Statement

Adams (1897) clearly recognized the igneous character of the Morin anorthositic rocks and their intrusive relationships toward metasedimentary rocks of the Grenville Group. Adams did not associate any of the pyroxene-bearing monzodiorites or quartz monzonites with the Morin anorthosite, believing all or most of them to be older.

Osborne (1935, 1938) postulated the existence of an igneous rock series (for which he coined the term "Morin Series") whose earliest members were anorthositic followed by a progression of intermediate to silicic rocks ("the quartzose rocks of the Morin Series"). Osborne adopted quartz monzonite as the probable parental magma of the entire series. Philpotts (1966) although not directly concerned with the Morin Complex, offered several lines of evidence in arguing for a fractional crystallization sequence from anorthosite through quartz mangerite with quartz diorite as the parental magma of the Morin Series.

Apart from anorthosite, criteria suitably defining other members of the "series" have never been clearly stated. In addition, subsequent deformation and metamorphism have contributed to the difficulties of providing precise definitions. Despite these inadequacies, the term "Morin Series" has been widely used by geologists of the Quebec Department of Natural Resources, and by others in their reports, sometimes in localities remote from the type area.

Although Osborne clearly considered the "Morin Series" to be of igneous origin, it is now apparent that his mapping and that of later workers have included, either mistakenly or purposely, areas of granulites now generally believed to be of older, unrelated origin. Some authors, i.e. Béland (1960), Côté (1960) have clearly stated that they used the term granulite to describe some rocks included with the "Morin Series". It is not difficult to understand how this usage has arisen, for example Osborne and Morin (1962) have used the term "green rocks" to include both quartz-bearing meta-igneous rocks of the "Morin Series" and granulites. Although "green-ness" may be a picturesque characteristic it is clearly not sufficient to suitably define units where rocks equally green and of quite different origin are also present.

Because of past ambiguities and to avoid genetic implications insofar as possible, the term "Morin Series" is not used further in this report. In its place "Morin anorthosite suite" or "Morin Complex" will be substituted to denote collectively the rocks of the complex and to emphasize their close spatial association rather than their poorly understood genetic relationships. At present it is possible to argue with some assurance that a genetic relationship exists among the various members of the suite. It is not possible, however, to state with any confidence what that genetic relationship is, whether differentiation from a common parent magma, progressive contamination of a mantle-derived magma by crustal rocks, partial melting of crustal rocks or some other process.

All of the rocks of the Morin Complex are meta-igneous although they range in texture from incipiently recrystallized to completely recrystallized. For the sake of simplicity, however, an igneous terminology is used in this report. Furthermore, although rock names such as charnockite, mangerite, farsundite and jotunite have been applied to various rocks by some authors they are not used here except for explanatory purposes. These names are normally used to denote the presence of orthopyroxene in rocks which in other respects are not essentially different from other igneous rocks. Most rocks of the Morin Complex carry two pyroxenes and this is indicated by using the prefix "pyroxene" with the common rock name for the appropriate bulk composition.

Effects of contact metamorphism caused by rocks of the Morin Complex have not been closely studied. There are reasons, however, for believing that some contact effects are recognizable. Wynne-Edwards suggested that an isograd can be drawn which delimits extensive contact metamorphism by the complex at a time prior to the main regional metamorphism. The anorthosite suite, however, crystallized with dominantly anhydrous mineralogies which have subsequently had hydrous retrograde mineralogies impressed upon them. It seems possible that much of the anorthosite suite was capable of acting as a sink for water and as such might tend to desiccate ("upgrade") surrounding envelope rocks during a subsequent regional metamorphism forming an aureole but not of contact origin.

Wollastonite-bearing quartzites occur close to the Morin Complex but wollastonite appears to be absent from calcareous rocks far removed from the complex. This suggests that it is a product of contact metamorphism. Adams (1897, p. 85J) reported an analysis of what seems to be a fassaite pyroxene (CaO - 25.38%, Al_2O_3 - 8.39%) from a calcareous assemblage close to the eastern contact of the anorthosite-leucogabbro.

Martignole (1969) reported cordierite-bearing rocks from what he believed to be the contact aureole around a small norite-anorthosite body near Shawinigan. Martignole and Schrijver (1970a) reported cordierite and corundum in rocks associated with the Lac Croche Complex which is comprised of rocks of the anorthosite suite. It therefore seems that some contact metamorphic effects near anorthositic bodies in the Grenville Province can be recognized. Closer study of some of these might yield valuable information on the intensity and extent of contact metamorphism accompanying these intrusive rocks and thus provide a clearer understanding of their environment of emplacement.

Katz (1968) suggested that contact metamorphism has had a retrograde effect on granulites intruded by pyroxene quartz monzonites of the "Morin Series" north of the Morin Complex.

A clearly defined contact aureole has not been recognized about the Morin Complex. Assuming that such an aureole did form at the time of intrusion it is not surprising that subsequent intense regional metamorphism succeeded in erasing nearly all of its effects.

External Form

Very little can be said with confidence about the overall three-dimensional form of the Morin Complex. The surface configuration of the anorthosite-leucogabbro however, is better known. In plan view the anorthosite-leucogabbro has a distinctive outline with a larger, subcircular west lobe connected to a north-south elongated east lobe. It is apparent from his structural sections that Adams (1897) recognized that the eastern contact of the east lobe dipped to the west. Osborne (1956) has referred to the west lobe as having a domical shape. Martignole and Schrijver (1970a) after detailed structural studies in the eastern part of the complex interpreted the southern part of the east lobe as the root of a nappe extruded and overturned by flowage toward the east. The northern part of the east lobe was tentatively interpreted by these authors as a diapiric structure and they agree with a generally dome-shaped west lobe. These interpretations are considered in more detail in a later section on deformation.

Observations made during the present work indicate that the southern contacts of the main lobe are steeply dipping to vertical. The western and northwestern margins, on the other hand, appear to have low to moderate outward dips. The distribution of pyroxene monzodiorite marginal to the main lobe and occurring as large re-entrants and isolated patches within it support an interpretation of a domed, unroofed structure. Several gravity profiles (unpublished data) across these high density rocks (see Table 9) indicate that they must have no substantial vertical extent (L. Sobczak, pers. comm.) and thus may be remnants of a once more widespread, though perhaps discontinuous, sheet. If this is so the anorthosite-leucogabbro of the west lobe of the complex may be just unroofed but not deeply eroded.

Thompson and Garland (1957) on the basis of regional gravity measurements together with density determinations of a limited number of rock specimens, suggested that the form of the anorthosite-leucogabbro was consistent with a cylinder extending to a depth of 8 miles based on a density contrast of .03 gm/cc. Simmons (1964) made an interpretation of a gravity survey over the Adirondack anorthosite which yielded a slab-like model 3 to 4½ km thick. The Adirondack mass is generally similar in size and geological setting to the Morin body and has a similar Bouguer gravity anomaly. It is conceivable that they may be similar in form. The mean density of anorthosite-leucogabbro specimens from the Morin Complex was found to be 2.75 (see p. 51). This seems rather high for rocks associated with a large negative gravity anomaly. It may be that if the anorthosite-leucogabbro has just been unroofed the sampling is biased toward higher densities by a more mafic marginal facies such as occurs in the Adirondack anorthosite (Buddington, 1939).

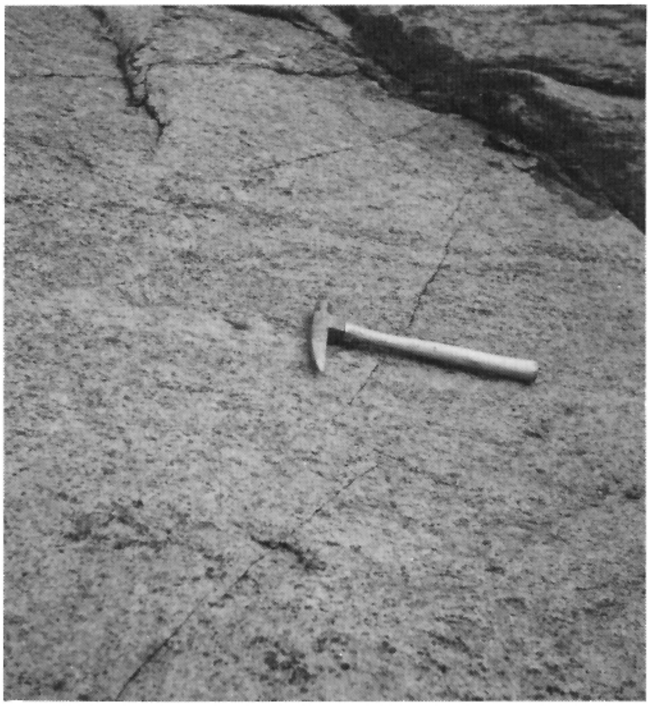

Figure 2. Weakly developed layers in leucogabbro. Station S64-102.

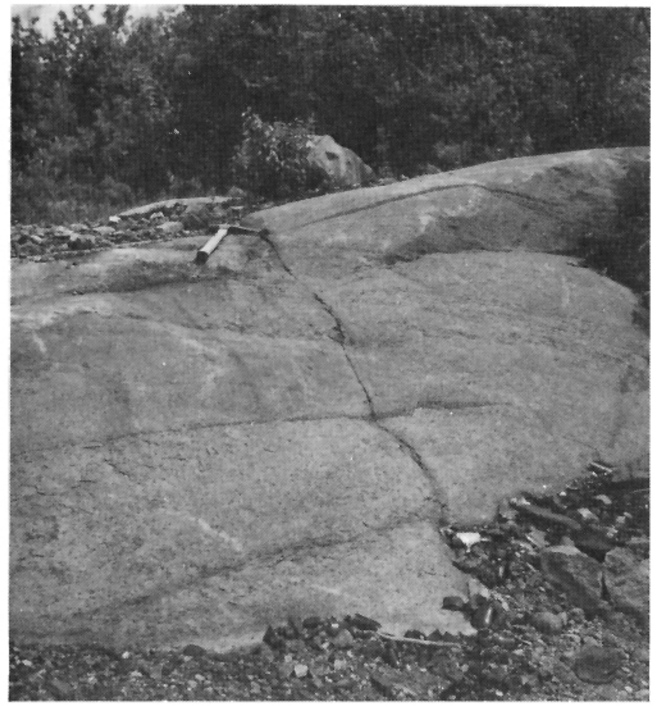

Figure 3. Discordant layering in anorthosite-leucogabbro diverges toward left. Thin seam of dark pyroxenite at back of outcrop probably represents a later fracture filling. Station E65-179.

Internal Structures

Good examples of mineral layered structures and planar plagioclase orientation are present but not abundantly exposed within the anorthosite-leucogabbro. In addition, those mapped are sufficiently dispersed that they are of limited value in defining an internal structural pattern. The best examples occur in the west lobe (Figs. 2, 3, 4). Where observed together, mineral layering and planar plagioclase orientation are subparallel. A number of these structures have relatively low to moderate dips but fairly steep dips also occur in places and may be the result of post-consolidation deformation for which there is abundant evidence. So-called "block structure" commonly described in anorthositic rocks is present in many outcrops (Figs. 5, 6, 7, 8). Angular and subangular blocks of anorthosite and leucogabbro are found in host rocks which may differ only slightly from them in composition. Most commonly, but not invariably, the inclusions have a lower colour index than the host. This suggests that local disturbances during crystallization may have broken up more rigid, purer anorthosite accumulates while leucogabbro with substantial amounts of interstitial liquid may have been capable of flowage. Mafic-rich rinds up to ½ inch thick are sometimes present and serve to emphasize the shapes of the inclusions (Fig. 6).

Much of the south half of the east lobe is strongly recrystallized and foliated with abundant low to moderate westerly dips. In these rocks mafic lenses and layers are relatively common and these are subparallel to the impressed foliation but they too are greatly drawn out and flattened so it is not clear to what extent they may have been rotated out of their original attitudes (Figs. 9, 10, 11). Indeed it is possible that some such layers and lenses did not exist prior to intense deformation which may have flattened and drawn out irregular masses into planar forms. Strong subhorizontal to gently south-plunging lineations are present in the southern part of the east lobe and in the pyroxene quartz monzonite of the St-Calixte synform immediately to the west (see Fig. 38). Further discussion of secondary structures is given in the section on deformation.

Subtle mineral layering and weak planar plagioclase orientation may be more abundant than has been recognized in the anorthosite-leucogabbro. The monotonously low and little variable colour index makes such structures difficult to detect in many exposures of these rocks. Although outcrops are fairly abundant, in many places they are typically heavily coated with lichens or obscured with forest litter. The best exposures are found in rock-cuts along the better quality roads.

Examples of mineral layering and plagioclase orientation are also present in pyroxene monzodiorite but are extremely rare in pyroxene quartz monzonite. A metamorphic foliation with varying degrees of intensity is more characteristic of these rocks.

Major Rock-Units

The rocks of the Morin Complex have been grouped into three major units for purposes of the present study. This procedure has been adopted for simplicity although there is a substantial range of variability within each unit and further subdivision would be possible with more detailed work. The major units comprise: 1) anorthosite, leucogabbro and minor gabbro; 2) pyroxene monzodiorite (jotunite of some authors); 3) pyroxene quartz monzonite (quartz mangerite or farsundite of some authors).

Anorthosite and leucogabbro areally form the largest discrete unit forming the mass that has for many years been designated as the Morin anorthosite. Pyroxene quartz monzonite is the next most widespread unit and extends beyond the limits of the map-area. Pyroxene monzodiorite is least abundant and is closely associated with the margins of the anorthosite-leucogabbro.

Shown in Figure 12 are the variations in concentration of the major minerals in the three rock groups. The diagram may be viewed as two faces of a tetrahedron APQM (alkali feldspar - plagioclase - quartz - mafic minerals) with rock compositions projected onto the faces APQ and APM. The compositions of the anorthosite-leucogabbro members of the suite are shown only on the APM face because all are poor in alkali feldspar and quartz and all project very near the P apex (>94% P) of the APQ face.

Compositions of the anorthosite-leucogabbro group lie close to the PM sideline and essentially represent varying proportions of plagioclase and pyroxenes. Such compositional variations are consistent with the interpretation that the rocks are plagioclase cumulates containing varying amounts of interstitial pyroxenes.

The pyroxene quartz monzonite group forms a fairly well defined cluster on both the APQ and APM projections. It is by no means clear from the diagram that these rocks are transitional into pyroxene monzodiorites although it is possible that further sampling might bridge the apparent gap.

The pyroxene monzodiorite group shows more scatter than the other groups and comprises rocks lying in a field intermediate between the previous two groups. As mentioned above, however, there appears to be a gap between the pyroxene quartz monzonites and pyroxene monzodiorites. Much of the variability in the pyroxene monzodiorites is due to differing concentrations of pyroxenes plus opaque oxides. These are heavy minerals and if they had been able to settle to the base of the pyroxene quartz monzonite a compositional gap would tend to be indicated by all but the most detailed sampling. Such basal enrichment in mafic minerals has been demonstrated by Buddington (1969) in several sheets of the Adirondack quartz syenite series.

Anorthosite, leucogabbro, minor gabbro (unit 8)

Field occurrence the rocks contained within this unit comprise the core area of the Morin Complex. An attempt to effect further subdivision based on colour

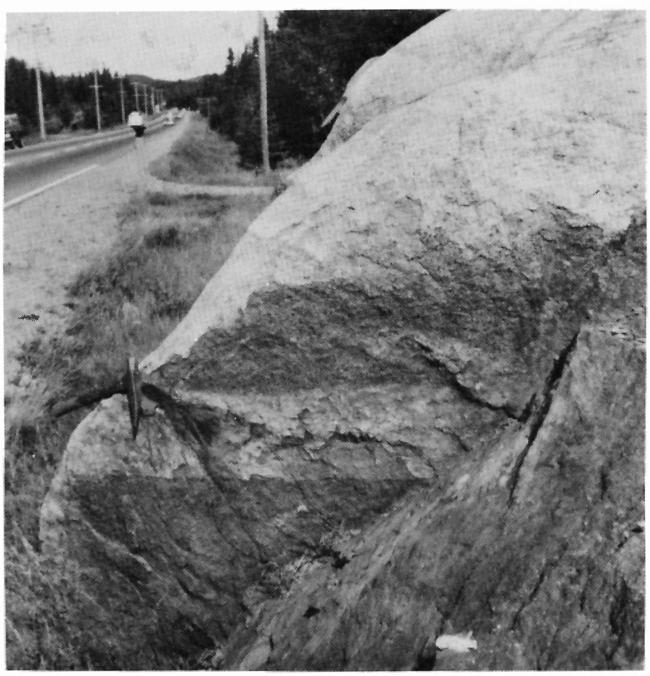

Figure 4. Tabular block (or layer ?) of anorthosite beneath hammer lies at an angle to the layering above it in leucogabbro. Highway 11 about 2/3 mile west of Desgrosbois.

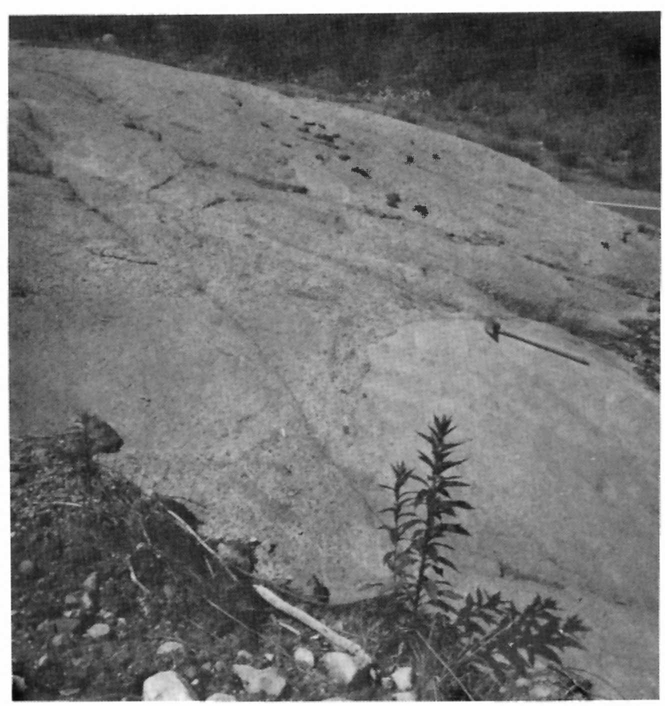

Figure 5. Large and small inclusions of anorthosite in leucogabbro. Station E65-178.

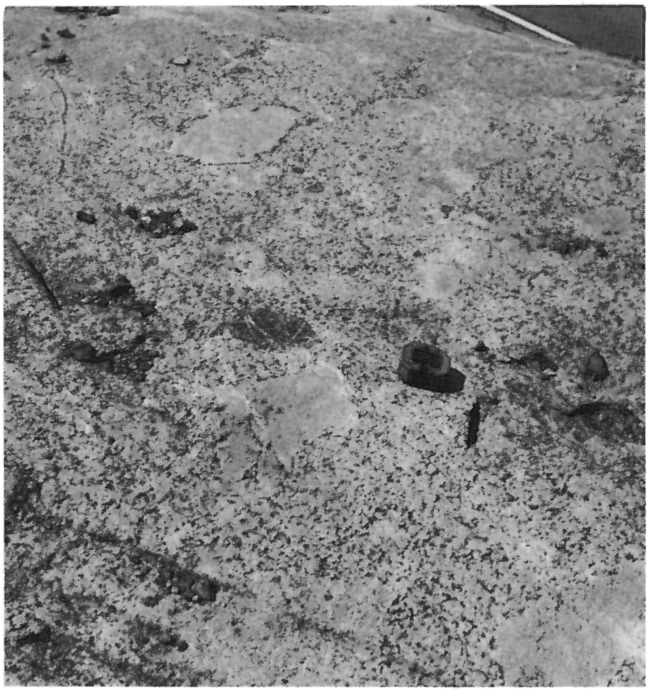

Figure 6. Angular and subangular anorthosite inclusions in coarse leucogabbro. Note mafic rinds on inclusions at upper centre and lower left. One small mafic inclusion at centre. Station E65-178.

Figure 7. Inclusion of coarse, equigranular, uniform leucogabbro enclosed in leucogabbro host with pocky weathering due to abundant poikilitic "spots". Near Highway 18 about 1 mile south of Notre-Dame-de-la-Merci.

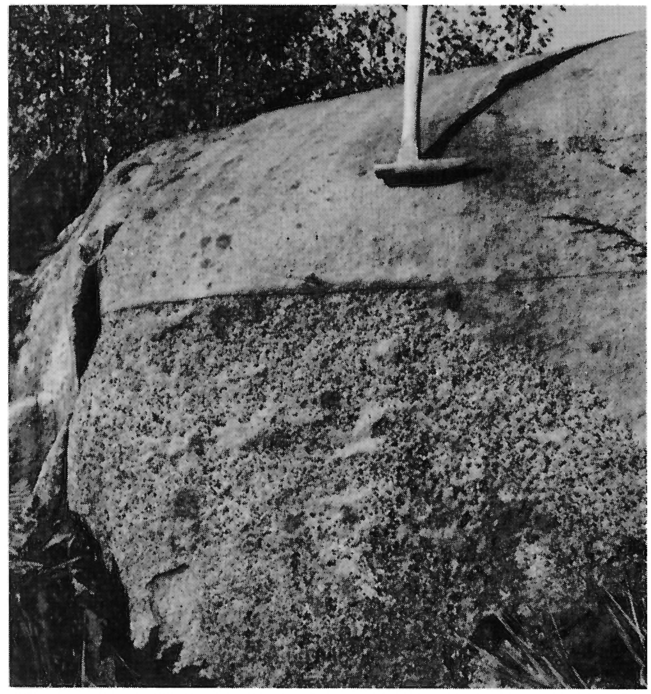

Figure 8. Contact between anorthosite "block" and leucogabbro with irregular small patches of anorthosite. Thin fracture occurs partly along contact. Same locality as Figure 7.

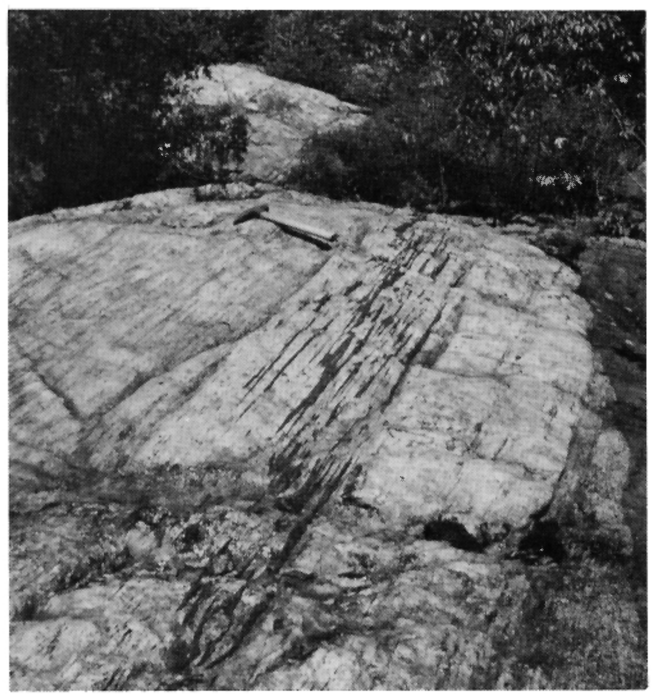

Figure 9. Layering and subparallel strong foliation in anorthosite-leucogabbro. Garnetiferous metagabbro dyke cuts across layering at low angle on right.

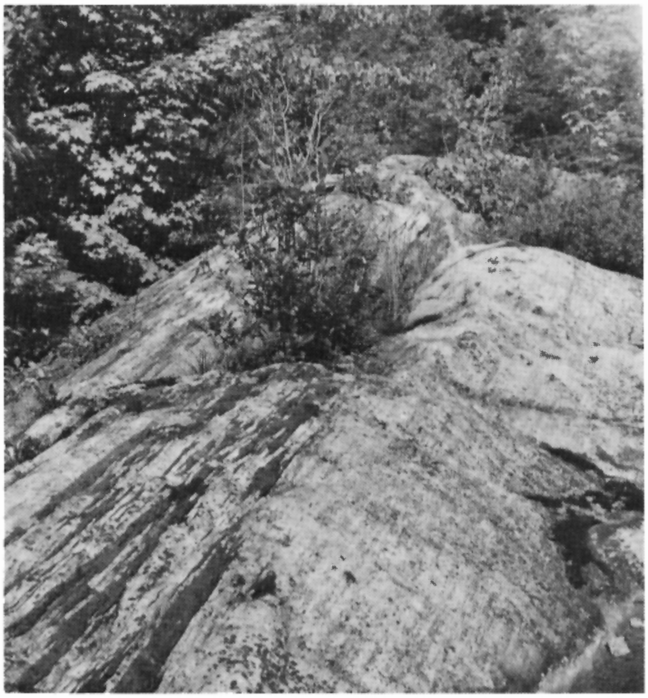

Figure 10. Highly deformed mafic-rich lenses in leucogabbro. Station E65-92.

Figure 11. Strongly recrystallized garnetiferous leucogabbro with layering of probable secondary origin. Southern part of east lobe. Station E65-277.

index was made in the field but the typically erratic variations in colour index encountered over short distances caused the effort to be abandoned. Much of the variation lies in the range of colour index from 10 to 20 and visual estimation is not satisfactory for subdivision within these limits. Locally the colour index rises sufficiently (>30) for the rock properly to be termed gabbro although, as a proportion of the whole body, such rocks are minor.

Most exposures of this unit in the western lobe of the mass retain clearly recognizable igneous textures (ophitic, subophitic, poikilitic) although they may be modified to varying degrees by deformation, recrystallization or alteration of the primary minerals. Kink-banded pyroxenes, chloritization of pyroxenes, cataclasis and recrystallization of plagioclase, and zeolithic and sericitic alteration of plagioclase have been noted.

Grain sizes in many exposures are highly variable. Commonly plagioclase megacrysts 0. 5 to 2 cm or larger make up from a few per cent to more than one half of the rock. These are contained in a matrix with a mean grain sixe of 2 to 5 mm. In many outcrops a clear distinction cannot be drawn between megacrysts and groundmass because a serial relationship exists. Plagioclase megacrysts up to 0. 5 m across have been observed but such large individuals are invariably shattered (Fig. 13). The matrix grain size of highly recrystallized rock is relatively homogeneous and usually averages about 1-2 mm. Relict augen of plagioclase from 1 to 3 cm across are sparse but commonly present in these rocks.

Variation in the colour of plagioclase has been commented upon by most authors who have worked on the complex. Apart from the common medium to dark grey colour, certain areas contain plagioclase with a distinct bluish cast and in large areas plagioclase has a pronounced reddish-brown or maroon colour. Polished sections of these maroon plagioclases show them to contain large quantities of finely divided hematite. Blue to green and bronze chatoyance has been observed in all varieties.

As noted above the amount of rock with sufficiently high colour index to be called gabbro is small. Most of the gabbro can be considered simply as local variants that comprise part of an outcrop or perhaps several outcrops in a limited area. The distribution of gabbro is not systematic but it may be somewhat more abundant near the periphery of the anorthosite-leucogabbro body.

Mineral layering on a scale of a few inches to a few feet is present at many localities. Usually it involves only a slight (5 to 10 per cent) variation in colour index. Layered sections have been traced over strike lengths of 100 feet but more commonly, because of outcrop limitations, a few tens of feet is the maximum. In most examples tabular plagioclase megacrysts, when present, are oriented subparallel to the layering. Pyroxenes are typically subophitic and poikilitic crystals of pyroxene and opaque oxide are common. Aggregates or "spots" containing more than one mafic mineral (Figs. 14, 15, 16, 17, see also Fig. 24, Martignole and Schrijver, 1970a) are also widespread. It may be noted here that nearly equidimensional poikilitic crystals or "spots" have been observed in completely recrystallized granular anorthosite indicating that recrystallization was not invariably accompanied by strong deformation. All of these structures and textures are characteristic of rocks formed by crystal accumulation (plagioclase in this case).

Labradorescent plagioclase, although present, is relatively uncommon. It has been found only in primary plagioclase within the main lobe. A patchy pale greenish

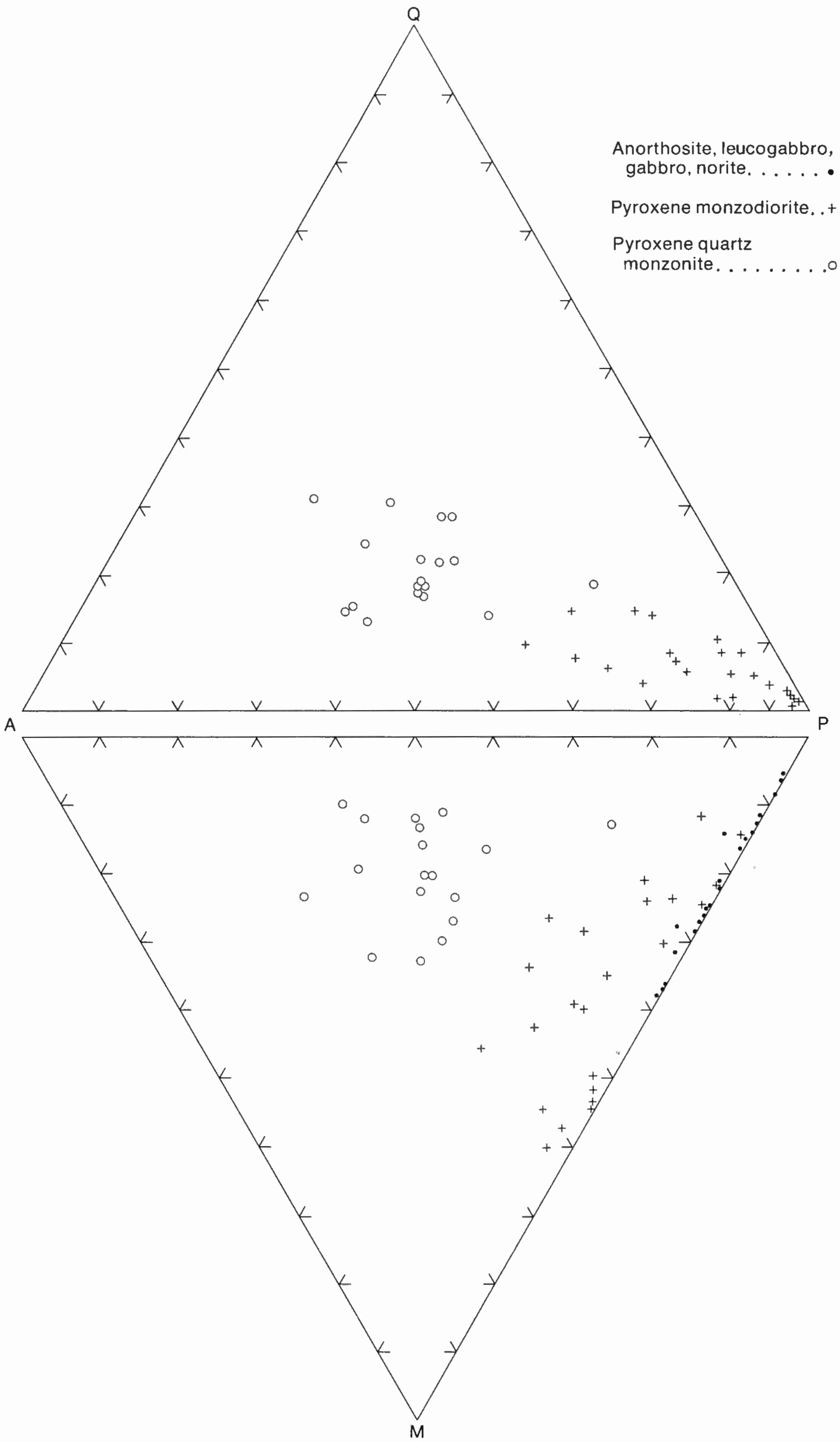

Figure 12. APQM (alkali feldspar-plagioclase-quartz-mafic minerals) projection of modal compositions of rocks of the Morin Complex.

Figure 13. Part of large pod containing giant orthopyroxene and plagioclase. The pyroxene is kink-banded and the plagioclase much fractured. The pod is contained in equigranular coarse leucogabbro (upper part of photograph). Station S64-418.

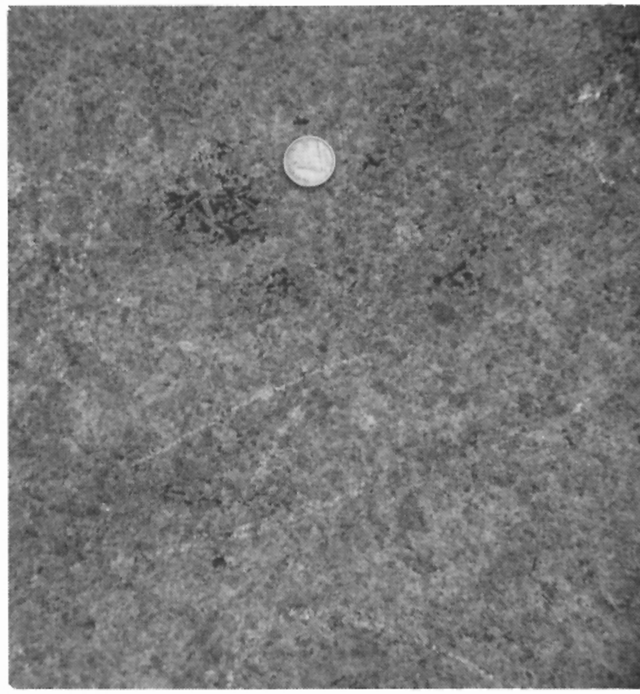

Figure 14. Mafic "spots" with subophitic texture in leucogabbro. Tabular habit of plagioclase within "spot" contrasts with coarser subhedral to anhedral plagioclase in surrounding rock. Station S64-415.

or yellowish-green alteration of anorthositic rocks occurs in many places. It appears to be caused by saussuritic alteration of plagioclase or in some cases zeolitization of plagioclase. This type of alteration is most striking when it occurs in and contrasts with maroon anorthosite.

Many outcrops show extremely complex relations between anorthosite and leucogabbro or gabbro. Angular to subrounded "blocks" (inclusions) of anorthosite in leucogabbro are most common (Fig. 18) but a few examples of the reverse relationship were observed. Thin mafic selvages are sometimes present on inclusions suggesting some sort of reaction relationship with the host. Where crosscutting relationships between anorthosite and leucogabbro are observed, the leucogabbro invariably intrudes anorthosite. Leucogabbro dykes with sharp contacts have been found cutting anorthosite. Pyroxene-rich and pyroxene plus oxide veinlets occur in many outcrops and are clearly late stage fracture fillings.

Inclusions of country rocks are rare in this unit but amphibolite inclusions have been found in anorthosite in several places. An inclusion 15 feet across consisting of quartzite, amphibolite and some calcite is contained within leucogabbro between Val Morin and Val David in the central part of the main lobe. Granite dykes, usually small but sometimes up to several feet thick are widespread but not abundant.

Osborne and Clarke (1960) suggested that all of the mafic minerals were not present when the anorthosite was deformed and recrystallized because in the east lobe large clots of pyroxene occur in fine-grained recrystallized anorthosite (see their Pl. V-B). The locality was visited and the pyroxene although present in large clots, is largely recrystallized, although relict cores remain. The implication is that penetrative deformation was not severe even though the rock was nearly completely recrystallized. Many samples of highly recrystallized anorthosite and leucogabbro from the east lobe have pyroxene augen with residual primary cores.

Petrographic characteristics. In the main lobe of the intrusion the igneous character of the rock texture is largely preserved. Subophitic and poikilitic textures, for example, can be recognized in many exposures even though some recrystallization of the rock has taken place. Commonly the recrystallization is confined to grain margins and is only visible in thin sections. This is in sharp contrast to much of the east lobe in which primary igneous textures are largely or entirely obliterated.

In the main lobe plagiocalse is typically either light grey or maroon in colour. The grey plagioclase commonly contains oriented opaque oxide rods, probably of exsolution origin, a few microns in diameter and up to 30 microns long. Maroon plagioclase is choked with fine red hematite dust but relatively few

Figure 15. Subophitic pyroxene and tabular plagioclase in "spots" show clearly on wall of drillhole in a road-cut. Station E64-310.

Figure 16. Well distributed subophitic "spots" on an outcrop of leucogabbro. Station S64-415.

large discrete opaque inclusions. Where such grains have recrystallized margins the recrystallized plagioclase is clear. Similarly, in much of the east lobe where plagioclase recrystallization is strongly advanced or complete the plagioclase is clear and opaque oxides occur as small granules. Some primary plagioclase is antiperthitic or may have antiperthite margins. Photomicrographs of some of the textural varieties are given by Côté (1960) and by Martignole and Schrijver (1970a).

Traces of quartz are present in many thin sections. Vermicular intergrowths that are partly myrmekite, but may also in part be alkali feldspar - plagioclase intergrowths, are present in many samples.

Both orthopyroxene and clinopyroxene are common mafic minerals. Exsolution lamellae of clinopyroxene occur parallel to (100) in orthopyroxene. Some examples of irregular blebby clinopyroxene exsolution in orthopyroxene are reminiscent of inverted pigeonite textures (i. e. Brown, 1957) but undoubted inverted pigeonite was not identified. Kink bands in pyroxene particularly orthopyroxene, are readily identified in many places in the main lobe especially in the coarser-grained rocks. Olive-green rims of hornblende are common on pyroxene in some places and biotite occurs similarly. Both hornblende and biotite are believed to be largely secondary in these rocks.

Other common secondary minerals in these rocks are clinozoisite, sericite, scapolite, zeolites and carbonate mostly as alterations of plagioclase. Chlorite may occur as an alteration product of pyroxenes.

Opaque oxides seem to be mainly ilmenite-hematite intergrowths with magnetite occurring sporadically. In the main lobe the opaque oxides are texturally subophitic to poikilitic and commonly have small amounts of associated apatite. Garnet occurs locally but is very rare.

Modes of some representative samples of anorthosite, leucogabbro and more mafic members of the Morin Complex are given in Table 1. The gabbros and norites are over represented in the table relative to their abundance in the complex.

Pyroxene monzodiorite group (jotunite) (unit 9)

Field occurrence. This rock-unit is found bordering the anorthosite-leucogabbro in many places. Adams (1897) first suggested the interpretation that dark, mafic "gabbroic rock" is a border facies of the anorthosite found at many places about the circumference of the anorthosite. Although it is not shown as a separate unit surrounding the east lobe, thin selvages are present at many localities as noted by Martignole and Schrijver (1970a). Texturally and mineralogically it is distinct from the anorthosite-leucogabbro and in many places the two units are in sharp contact commonly with monzodiorite having intrusive apophyses into anorthosite. There are, however, other localities where a transitional zone a few tens to a few hundreds of feet wide separates the rock-units.

A variety of inclusions has been found in monzodiorite, and they are both abundant and widespread Quartzite, paragneiss, amphibolite and fine-grained

Table 1

Modal analyses of the anorthosite-leucogabbro group

	E64 -40	E64 214	E65 -72	S64 161	S64 112	S64 364	E65 -59	S64 270	S64 291	E65 -37	E64 325	E64 -17	E64 -37	E64 249	E65 -63	E65 -41	S64 306	E64 -22	E65 -50	E65 125	E64 200
plagioclase	94.0	93.7	90.2	88.3	87.1	84.5	83.7	82.5	81.1	77.9	77.6	75.3	74.7	72.9	72.3	71.1	68.6	66.8	62.7	62.5	61.5
alkali feldspar	0.3		tr	0.2		0.9	tr	0.6	3.9	0.8							2.9	1.0		tr	0.1
quartz	0.5	tr	1.5	0.3	tr		2.7	0.8	1.1	0.3	0.4	0.1			2.2	0.2	0.9	0.7	0.5	1.5	0.7
clinopyroxene	4.4	3.3	1.9	0.8	2.7	6.1	2.6	6.4	6.5	1.2	11.4	1.8	17.3	2.0	14.3	4.5	16.4	15.3	2.9	1.4	4.1
orthopyroxene		2.5	6.2	10.1	9.9	4.3	9.5	3.5	0.3	15.5	7.1	21.2	7.1	24.4	10.3	23.0	1.8	8.8	31.4	32.3	32.0
hornblende								3.6	0.3	0.4					tr		0.7	0.3		tr	
biotite			tr			3.2		2.3	1.3	3.8	0.8	1.4			tr	0.5	2.3		2.3	1.7	
opaques	0.8	0.5	0.2	0.3	0.3		1.5	0.3	5.0	0.1	2.7	0.2	0.9	0.7	0.9	0.7	6.2	5.5	0.2	0.6	1.6
apatite						0.6	tr		0.5								0.2	1.6			
sphene						0.6															
rutile	tr	tr										tr		tr							tr
garnet																	tr				
	100.0	100.0	100.0	100.0	100.0	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
plagioclase composition	An43			An44	An45	An44	An49	An44	An45	An50		An45*	An46	An51*	An53		An47				
orthopyroxene composition																	En56				

*determined by flat stage extinction angle measurement others by refractive index of cleavage fragments

Table 2

Modal Analyses of the Pyroxene Monzodiorite Group

	E64 362A	E64 274	E64 254	E64 251	S64 504	S64 -25	S64 269	S64 444	S64 442	S64 521	E64 373	S64 439	E64 -60	S64 224	S64 229	S64 -48	S64 496	S64 386	S64 302	E65 212	E64 -86	E65 306	E64 362
plagioclase	45.0	45.4	76.4	82.6	73.8	46.0	46.4	34.0	35.5	62.5	66.5	37.5	50.8	80.1	67.2	48.8	45.6	65.5	42.3	55.6	47.6	45.5	33.5
alkali feldspar	0.3	0.7	0.9	1.1	1.2	1.6	2.5	2.5	3.1	3.1	5.3	6.1	7.8	8.0	8.3	8.3	9.4	10.0	13.3	13.8	17.5	17.7	17.8
quartz	0.7	1.1	1.2	2.5	0.4	1.8	2.5	4.3	2.1	6.1	6.6	3.4	10.5	0.8	1.1	5.1	9.3	4.6	3.6	2.8	11.3	5.0	5.3
clinopyroxene	27.5	18.4	19.5	6.4	11.1	25.7	18.3	23.3	21.5	6.3	6.2	17.4	13.9	7.7	12.0	7.4	14.3	6.7	18.6	8.5	7.0	9.1	19.1
orthopyroxene	12.6	15.8	1.2	1.2	6.3	2.9	11.0	5.5	7.6	8.5	4.9	12.9	4.6	3.1	6.2	9.1	2.8	7.3	10.5	3.3	3.5	6.0	5.5
hornblende						0.7	1.1				6.9	tr	0.5		0.1	1.5		0.4		tr	7.1	0.5	
biotite		1.7										tr											
opaques	13.7	14.5	0.8	5.2	6.0	15.6	10.3	18.4	20.2	3.9	2.1	11.7	7.1	0.5	4.8	13.2	4.0	4.5	10.2	5.1	4.8	7.1	16.8
apatite	0.2	2.4		0.7	1.2	2.1	2.5	2.3	2.8	0.7	1.5	1.5	1.8		0.3	2.0	0.7	1.0	1.2	0.9	1.2	0.9	2.0
zircon															P					P	P		
rutile																							
garnet				0.3		3.6	5.4	8.7	7.2	8.9		9.5	3.0		tr	4.6	13.9		0.3	10.0		8.2	
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	100.0	100.0	100.0	100.0	100.0	100.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
plagioclase composition	An48	An43*						An46			An44		An42		An46	An39*		An35*		An37*			
orthopyroxene composition	En62							En54	En64		En57		En56		En53								

*determined by flat stage extinction angle measurement others by refractive index of cleavage fragments

Figure 17. Ellipsoidal mafic "spots" in leucogabbro of west lobe. Station E64-228.

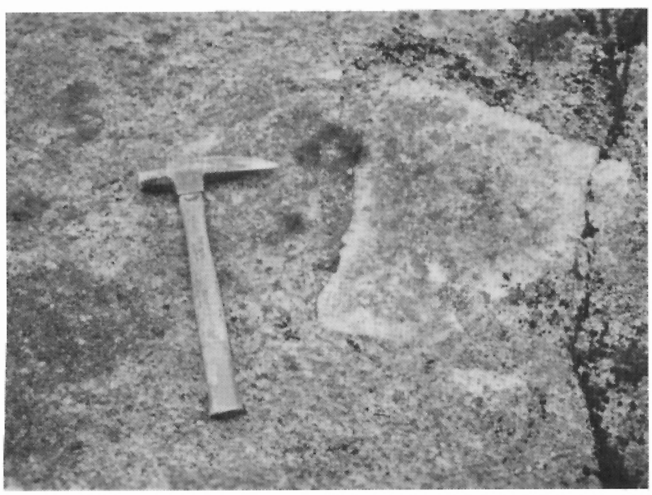

Figure 18. Angular block of anorthosite in leucogabbro. Note white rim of recrystallized plagioclase. Station E64-242.

mafic granulite are the most common country rock inclusions; quartzite being the single most common type presumably because of its refractory nature. Country rock inclusions are usually small, sometimes only a few inches across, but inclusions several feet or more in diameter are not uncommon.

Mineral layering is present in this unit in some localities. Commonly it is on a scale of a few inches and tends to be diffuse rather than sharply defined (Figs. 19, 20; see Fig. 9, Martignole and Schrijver, 1970a).

Angular to subrounded inclusions of anorthosite and leucogabbro are common near contacts with these rocks (Figs. 21, 22, 39, 40, 41). At some localities the inclusions are massive and coarse-grained but some are highly recrystallized or strongly foliated varieties. The latter types clearly indicate that some deformation took place, at least locally, during emplacement of the complex.

Along the south margin of the main lobe about two miles northwest of Morin Heights one passes from coarse-grained anorthosite through about 100 feet of garnetiferous pyroxene diorite full of fine-grained paragneiss inclusions into banded paragneiss dipping 75 degrees south. About one and one-half miles west of this locality a wollastonite-marble inclusion several feet in diameter occurs in mafic pyroxene diorite. Small forsterite-bearing marble inclusions are present in pyroxene monzodiorite north of Piedmont.

Petrographic Characteristics. Plagioclase may comprise as much as 80 per cent of these rocks but most commonly it is below 65 per cent. Plagioclase compositions range from about An_{35} to An_{48} so that, although the colour index is commonly more like gabbro, plagioclase compositions are in the diorite range. Dark grey plagioclase megacrysts commonly range from 0.5 to 5 cm (Fig. 23). They are often antiperthitic sometimes with strongly antiperthitic rims that may grade to mesoperthite. White or light grey recrystallized rims on dark plagioclase megacrysts are a common and distinctive feature. Alkali feldspar is usually present in amounts up to 10 per cent and rarely ranges up to nearly 18 per cent. It is mesoperthite to microperthite. The quartz content is typically about 5 per cent or less but ranges up to about 10 per cent.

The colour index of the rocks is commonly in the range 25 to 45 but may reach as high as 60. Orthopyroxene and clinopyroxene are present in most samples but clinopyroxene is usually by far the more prevalent. Exsolution lamellae have been noted in both clinopyroxene and orthopyroxene and a few examples of inverted pigeonite were found. Olive-green to olive-brown amphibole commonly occurs on pyroxene and is probably of metamorphic origin but some large poikilitic amphibole plates may be primary. A little red-brown biotite may be present usually associated with opaque oxide minerals or with orthopyroxene.

Opaque oxide minerals are typically abundant and are usually present in amounts between 5 and 15 per cent. Apatite is also common and closely associated with opaque oxide minerals. Euhedral to subhedral zircon crystals were observed in some thin sections.

Garnet is visible in most exposures but its distribution is highly erratic. Irregular garnet-rich patches several inches across may be widely dispersed through rock in which garnet can scarcely be detected. In some outcrops the garnet is clearly related to fractures which presumably allowed migration of components or access of volatiles to promote reaction. The garnet-forming reaction is clearly related to plagioclase-orthopyroxene and plagioclase-oxide consumption. Some

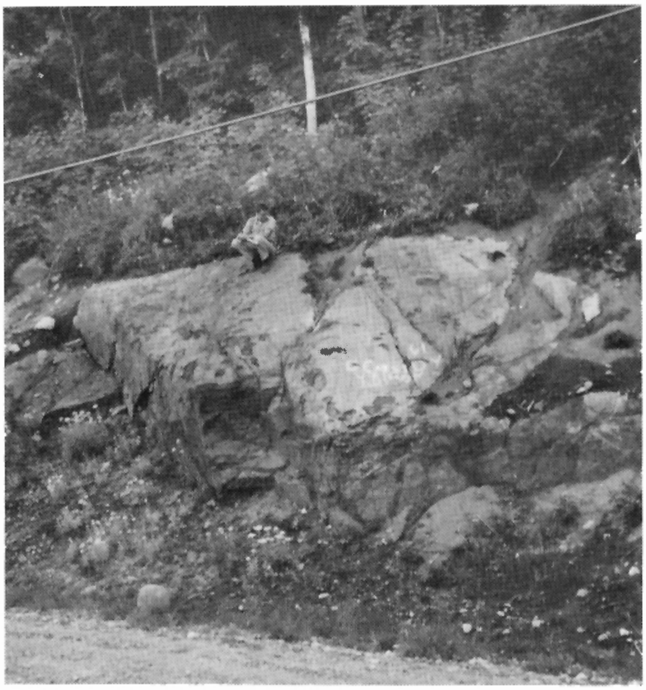

Figure 19. Steeply-dipping weakly developed mineral layering in pyroxene monzodiorite. Station S64-443.

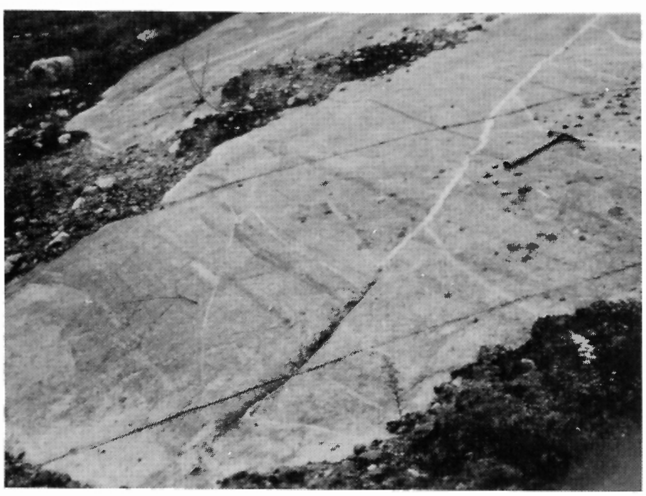

Figure 20. Oxide-rich pyroxene monzodiorite with well developed thin lensy layering. Some layers suggest a graded effect. Cut by narrow pyroxene quartz monzonite dykes. Station E64-349.

Figure 21. Elongate angular to subrounded anorthositic fragments in oxide-rich pyroxene monzodiorite. Station E64-349.

Figure 22. Subrounded inclusion of leucogabbro in oxide-rich pyroxene monzodiorite. Station E64-362.

specimens show beautiful, delicate necklaces of fine garnet surrounding plagioclase megacrysts. Martignole and Schrijver (1973) have commented on the occurrence of garnet in the Morin Complex and related it to bulk rock compositions.

Modes of the pyroxene monzodiorite group are listed in Table 2. They range in composition from diorite (with possibly some gabbro) through monzodiorite to quartz monzodiorite. The relative richness in pyroxenes, opaque oxides and apatite is characteristic of this group of rocks.

Pyroxene quartz monzonite group (unit 10)

Field occurrence. These rocks occur in large masses closely associated with the Morin Complex but extending well away from the anorthosite-leucogabbro. Some smaller satellitic masses occur in country rocks at a

Figure 23. Large dark grey plagioclase megacryst with white recrystallized rim in pyroxene monzodiorite. Station E65-248.

Figure 25. Angular oxide-rich pyroxene monzodiorite fragments contained in lighter coloured pyroxene quartz monzonite. Station E64-362.

Figure 24. Finer-grained pyroxene quartz monzonite with streaky layers rich in coarse augen. Cut by diabase dyke at left. Station E64-109.

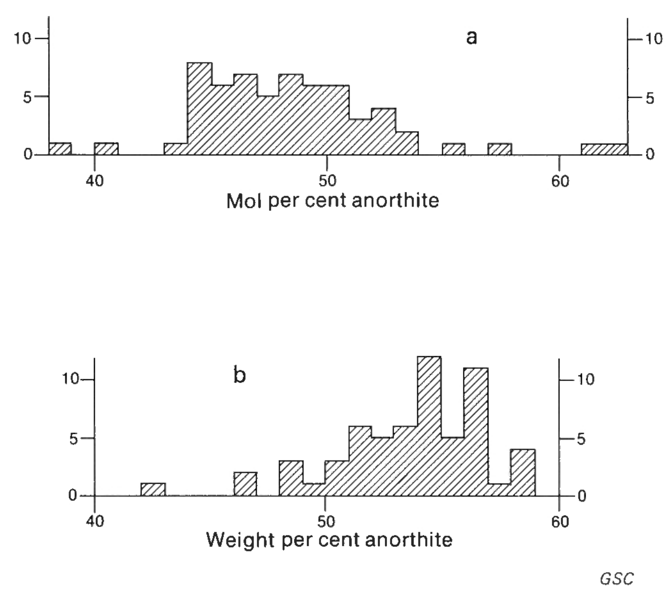

Figure 26. Compositions of plagioclase in anorthosite-leucogabbro. (a) by measurement of refractive index of α on (001) cleavage fragments. (b) by refractive index of fused plagioclase.

Table 3

Modal analyses of the pyroxene quartz monzonite group

	E65 −208	S64 −168	E64 -63	E65 −102	E65 −136	E65 −270	E64 -27	S64 −287	E64 -356	S64 −298	S64 − 508	E65 -205	S64 −518	E64 -78A	E65 -322	E65 289	S64 509	S64 263
plagioclase	57.2	29.9	32.2	35.3	30.0	45.1	34.8	32.7	23.3	35.1	37.1	37.3	37.6	18.1	34.5	29.0	33.6	31.2
alkali feldspar	15.8	24.3	24.5	27.0	28.4	28.7	31.0	31.0	32.3	32.9	34.9	35.8	36.7	38.9	39.1	41.6	44.4	47.0
quartz	16.6	21.7	22.5	17.6	13.1	12.0	17.3	18.1	18.1	15.1	14.9	16.0	15.9	25.9	17.8	12.6	11.7	13.5
clinopyroxene	3.3	4.8	3.3		14.5	5.2	2.5	2.6	8.8	8.8	1.7	2.7	1.4		1.4	5.0	2.5	1.3
orthopyroxene	1.9		6.7		6.4	1.4	0.3	6.0	8.8	2.3	6.8	2.2	6.1		3.0	4.6	4.6	3.4
hornblende	3.2	13.6	5.5	11.6	tr		11.5					2.8		11.7	tr	0.9	0.7	2.1
biotite				3.6				tr			0.2		tr	1.4	tr			
opaques	1.0	3.8	5.1	3.1	2.4	2.3	2.0	2.6	3.7	3.5	3.6	1.0	1.5	3.0	1.4	5.6	2.0	1.0
apatite	0.3	1.9	0.2	0.7	tr	0.3	0.6	0.9	0.4	0.8	0.8	tr	0.8	1.2	0.5	0.7	0.5	0.1
zircon	P	P	P	P		P	P			P	P	P	P	P	P	P	P	P
garnet	0.7			1.1	5.2	5.0		6.1	4.6	1.5		2.2			1.8			0.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.2	99.5	100.0	100.0	100.0
plagioclase composition	An40*			An35*	An28*	An38*						An34*		An38	An38*			An30
orthopyroxene composition														En48				En39

*determined by flat stage extinction angle measurement others by refractive index of cleavage fragments

Table 4

Sample	Mol % An	Si/Al	2θ131 2θ131	Sample	Mol % An	Si/Al	2θ131 2θ131
E64 - 40	43	1.80	1.77	E65 - 16	52	1.64	1.85
- 96	44	1.78	1.86	19	38	1.90	1.77
162	49	1.68	1.80	26	48	1.70	1.87
167*	51	1.65	1.88	28*	46	1.74	1.89
169A*	53	1.62	1.83	37*	50	1.67	1.88
171*	55	1.58	1.90	59*	49	1.68	1.84
207	47	1.72	1.82	63*	53	1.62	1.86
219	44	1.78	1.81	81*	53	1.62	1.83
240	49	1.68	1.78	85*	49	1.68	1.92
270	49	1.68	1.83	92*	47	1.72	1.84
362A	48	1.70	1.83	97*	50	1.67	1.82
371	46	1.74	1.83	121*	50	1.67	1.84
				135*	48	1.70	1.85
S64 - 23	45	1.76	1.76				
S64 - 37	46	1.74	1.83	187	44	1.78	1.82
59	50	1.67	1.82	236*	48	1.70	1.79
88	45	1.76	1.82				
112	45	1.76	1.81	238*	51	1.65	1.82
161	44	1.78	1.77	239*	62	1.47	2.01
306	40	1.86	1.80	243*	52	1.64	1.87
330	46	1.74	1.77	293	48	1.70	1.81
342	44	1.78	1.82				
364	44	1.78	1.81				
415	50	1.67	1.78				
456	49	1.68	1.82				
465	46	1.74	1.81				
467	46	1.74	1.86				

*strongly recrystallized samples from east lobe

distance from the complex. These rocks in outcrop appear to be completely transitional into pyroxene monzodiorite which borders the anorthosite-leucogabbro but the transition is rapid and not well defined by the modal analyses (see p. 26)

West, north and south of the main lobe, the rocks are typically coarse grained and porphyritic with megacrysts of plagioclase and perthitic alkali feldspar. Feldspar megacrysts tend to be blocky, tabular or somewhat rounded forms. Small lath-shaped plagioclase crystals are commonly abundant but they rarely if ever, have a preferred orientation. Few examples of mineral layering were observed within the pyroxene quartz monzonite. Some layer-like textural variations occur (Fig. 24). East of the main lobe moderate to strong foliation is typical and many of the rocks are augen gneisses.

Dark grey, large (up to 5 cm long) euhedral plagioclase crystals are commonly found singly or sparsely distributed in outcrops not far from anorthosite-leucogabbro contacts. These could be xenocrysts but in view of their euhedral shapes it seems more likely they were in equilibrium with the enclosing magma.

Inclusions are widespread and quartzite is most common. In addition, inclusions of calc-silicate rock, marble, granulite and paragneiss have been identified. Many inclusions are small but quartzite inclusions up to 10 feet by 3 feet have been observed. Pyroxene quartz monzonite has been observed to cut and contain inclusions of pyroxene monzodiorite (Fig. 25) and it has been found as dykes within anorthosite-leucogabbro.

Dykes of granite up to several feet thick have been found cutting pyroxene quartz monzonite but most are only a few inches thick. The source of this granite is unknown.

Petrographic Characteristics. The textures of these rocks are commonly porphyritic or, where deformed and partly recrystallized, augen textures are formed. Megacrysts of plagioclase and alkali feldspar are present and on the average about equally abundant. Plagioclase compositions range from about An_{25} to An_{40}

TABLE 5

Partial chemical analyses of feldspars

	E64 160 wt %	E64 169 wt %	E64 171 wt %	E64 219 wt %	E64 223 wt %	S64 270 wt %	S64 291 wt %	S64 440 wt %	S64 444 wt %	E64 -1 wt %	E64 -77 wt %
CaO	7.28	9.31	9.18	8.27	7.56	7.30	8.50	9.05	9.17	1.22	0.56
Na_2O	4.23	3.94	4.06	4.09	4.01	4.66	5.06	5.35	5.56	2.14	2.26
K_2O	0.50	0.20	0.15	0.70	0.70	0.83	1.14	0.76	0.65	11.78	12.45
	mol %	mol %	mol %	mol %	mol %	mol %	mol %	mol %	mol %	mol %	mol %
An	46.9	55.9	55.0	50.0	48.4	43.6	44.8	46.1	45.9	6.4	2.9
Ab	49.1	42.8	44.0	44.9	46.2	50.3	48.1	49.3	50.1	20.2	21.0
Or	4.0	1.3	1.0	5.1	5.4	6.0	7.1	4.6	3.9	73.3	76.1
An*	48*	53*	55*	44*	46*	44*	45*	44*	45*		

* from refractive index measurements of α on 001 cleavage fragments

TABLE 6

	E64-96 (1)		E64-160 (1)		S64-342 (1)		E64-17 (1)		E65-63 (2)		E65-41 (2)		E65-187 (3)		E65-135 (3)		E65-238 (3)	
	opx	cpx	opx	cpx	opx	cpx	opx	cpx	opx	cpx	opx	cpx	opx	cpx	opx	cpx	opx	cpx
SiO_2	50.5	50.3	52.7	51.4	51.0	51.3	51.5	50.2	49.2	47.7	51.1	49.6	50.4	50.0	52.7	52.1	52.7	50.9
Al_2O_3	2.0	2.5	1.4	2.7	1.3	2.2	1.3	2.3	1.8	3.9	1.7	3.0	1.8	2.9	2.0	2.5	1.8	3.5
FeO*	24.7	10.8	20.4	7.9	23.6	9.0	21.4	7.9	22.8	9.0	23.4	8.3	22.2	8.6	19.9	6.6	18.4	6.1
MgO	21.7	13.0	24.1	14.1	21.6	13.5	22.9	14.0	23.2	13.5	22.4	13.5	22.6	13.6	25.0	14.8	25.5	14.3
CaO	0.6	20.8	0.5	22.2	0.6	21.2	0.9	21.7	0.4	21.5	0.4	22.7	0.4	21.9	0.4	22.6	0.4	21.8
Na_2O	0.3	0.8	0.0	0.2	0.0	0.4	0.0	0.6	0.0	0.9	0.0	0.4	0.0	0.5	0.0	0.3	0.0	0.6
TiO_2	0.5	0.2							0.1	0.5							0.2	0.6
	100.3	98.4	99.1	98.5	98.1	97.6	98.0	96.7	97.5	97.0	99.0	97.5	97.4	97.5	100.0	98.9	99.0	97.8
Mg	60.4	38.3	67.1	41.3	61.3	39.9	64.4	41.1	63.9	39.6	62.5	39.1	63.9	39.9	68.5	42.6	70.6	42.8
Fe	38.4	17.7	31.8	12.8	37.6	14.9	33.7	13.0	35.3	14.8	36.7	13.6	35.2	14.1	30.7	10.7	28.6	10.2
Ca	1.2	44.0	1.0	45.9	1.1	45.2	1.8	45.9	0.8	45.3	0.8	47.3	0.9	46.0	0.7	46.7	0.7	47.0
$\frac{Fe}{Fe+Mg}$	0.389	0.316	0.322	0.236	0.380	0.272	0.344	0.240	0.356	0.272	0.370	0.258	0.355	0.261	0.309	0.201	0.289	0.192

* - total Fe as FeO
(1) - rock not recrystallized
(2) - plagioclase recrystallized, pyroxenes partly recrystallized
(3) - plagioclase and pyroxenes recrystallized

and it is commonly antiperthitic. Alkali feldspars are microperthite and mesoperthite.

Quartz comprises about 10 to 25 per cent of the rock. Large single grains are commonly strained and strain effects are frequently visible even in recrystallized aggregates. Myrmekitic intergrowths are common.

Colour index is generally in the range 10 to 25. Orthopyroxene and clinopyroxene are present in most samples. A few examples of inverted pigeonite were found in relatively undeformed rocks but deformation and recrystallization has probably obliterated such delicate textures in many places. Olive-green to olive-brown amphibole and deep brown to red-brown biotite are common mafic minerals with amphibole being the more abundant. Both minerals tend to have poikilitic habits in the least deformed rocks. Small amounts of opaque oxides, zircon and apatite are ubiquitous accessory minerals. Garnet is widespread but sporadic in occurrence and smaller in amount than in rocks of the pyroxene monzodiorite group.

Modal analyses of the rocks are listed in Table 3. Although the rocks range up to granite in composition they are dominantly quartz monzonites.

Dykes

Mafic dykes ranging in thickness from less than 2 cm to more than 5 m are widely distributed in the anorthosite-leucogabbro. Most are small and irregular and their locations are indicated by symbols on the map. Most are oxide-rich with chemical compositions very similar to the pyroxene monzodiorites to which they are undoubtedly related (see Table 8 and Fig. 32). Mineralogically they are closely similar as well and many are garnet-bearing.

There are also some small mafic dykes with distinctly different compositions (see Table 8 and Fig. 32). They are poor in oxides, most are olivine normative with calcic normative plagioclase and relatively low Fe/mg ratios. They are also low in K_2O and TiO_2. It is uncertain whether these dykes have any genetic relationship to the Morin Complex.

The metatroctolite that occurs along the southwestern contact of the east lobe has been described by Osborne (1949) and interpreted as an intrusion predating the anorthosite. The main evidence is that two fine-grained white anorthosite dykes occur within the metatroctolite. Martignole and Schrijver (1972) however, assumed that the metatroctolite is genetically related to the Morin Complex an assumption based on its similarity to some other anorthositic complexes in Quebec and Labrador that have associated troctolitic rocks. At the present time there is no clear evidence to establish or refute a genetic relationship. It might be suggested that the small olivine normative dykes mentioned above are related to the metatroctolite. They postdate consolidation of the anorthosite-leucogabbro.

Mineralogical Studies

Feldspars

The essential mineral of the anorthosite-leucogabbro group is, of course, plagioclase. Optical determinations of anorthite content were carried out on a number of samples to establish the range of compositional variation. No claims can be made that the sampling represents the total range of plagioclase compositions present in the complex.

Measurements of α' on (001) cleavage fragments by the dispersion method (Morse, 1968) were made to determine the anorthite content. The compositions determined are plotted in histogram form in Figure 26a. Most compositions lie in the range of about An_{42-54} with a mean value around An_{48}. The plagioclases measured are powders from bulk rocks, that is rocks which commonly contain some megacrysts as well as groundmass plagioclase.

A number of plagioclase compositions were also determined by measurement of the refractive index of plagioclase glass formed by fusion of grains in a carbon arc. These samples are all of plagioclase megacrysts which were convenient to sample directly on the outcrops. These compositions are shown in the histogram of Figure 26b. The entire distribution is shifted to about 5 per cent more An-rich compositions relative to Figure 26a. Note that the abcissa is weight per cent An in Figure 26b which accounts for about 1.0 - 1.5 per cent higher An contents in this compositional range. Megacrysts of plagioclase typically have abundant Fe-Ti opaque exsolution rods which upon fusion would tend to increase the refractive index of the glass and indicate higher An values. The results presented in Figure 26b therefore are presented mainly for the sake of interest - their true significance is not understood. It is possible that megacrysts are in fact more calcic on the average than groundmass plagioclase but there are insufficient data checked by both methods to establish this.

Many attempts have been made to derive useful petrological conclusions from measurements of the structural state of plagioclase without notable success. Philpotts (1966) reported low transitional structural states in anorthositic rocks regardless of whether they were primary or recrystallized. Romey (1969) reported low transitional structural states of plagioclase from several anorthositic bodies.

In Figure 27 structural states of plagioclase from anorthosite and leucogabbro of the Morin Complex are indicated on a plot of $2\theta(131) - 2\theta(1\bar{3}1)$ against plagioclase composition as determined by refractive index of cleavage fragments (data from Table 4). The plagioclases may be described as having low transitional structural states. Samples from the southern part of the east lobe are completely or nearly completely recrystallized and show some tendency to have higher $2\theta(131) - 2\theta(1\bar{3}1)$ values than plagioclase from the western lobe where recrystallization is much less severe. There is, however, considerable overlap. Recrystallized plagioclases are not antiperthitic and are commonly accompanied by discrete separate grains of K-feldspar. Bérard (1971) noted that the amount of K-feldspar visible in thin sections appeared to increase with the amount of recrystallization. It is possible that recrystallized plagioclases are lower in Or than primary plagioclases. If this is true they should be referred to different low curves according to Bambauer et al. (1967). This may largely account for the apparent differences in structural state between east and west lobe plagioclases. It is of interest that plagioclases from the Michikamau intrusion in Labrador, covering a similar compositional range to those from the Morin Complex were run at the same time as the Morin samples. The Michikamau plagioclase all yielded apparent substantially lower structural states. This was a surprising result for it was anticipated that high grade metamorphism superimposed on slowly cooled coarse plagioclase of the Morin Complex would enhance an existing high degree of ordering.

Partial chemical analyses by atomic absorption of eleven feldspars from the Morin Complex are given in Table 5. The analyses have been recalculated into end members and are plotted in Figure 28. The two alkali

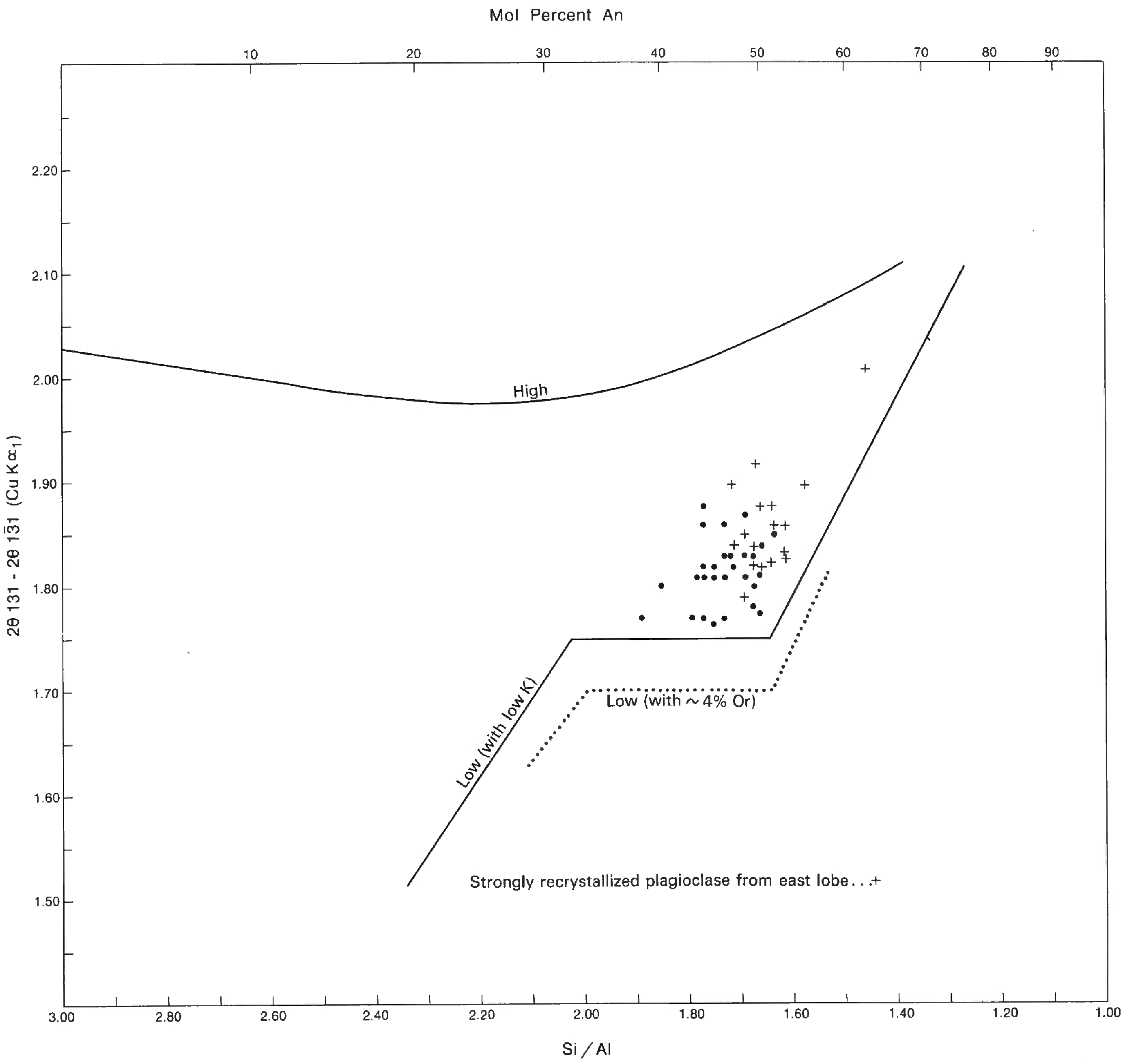

Figure 27. Structural slates of plagioclase in anorthosite-leucogabbro.

feldspars are from pyroxene quartz monzonites. Most of the plagioclases average about 5 mol per cent Or except for two samples with very low Or contents. These two are from the east lobe near the junction with the west lobe and have strongly recrystallized plagioclase although they contain relict augen of pyroxene. The fact that these two plagioclases are slightly more calcic is consistent with exsolution of several mol per cent of an alkali feldspar.

Pyroxenes

Nine pairs of Ca-rich and Ca-poor pyroxenes from anorthosite-leucogabbro were analyzed by electron microprobe with the assistance of Dr. A. G. Plant. The results are listed in Table 6. Each analysis represents the average of 4 grains with 10 readings per grain. The data were corrected and reduced using the University of Toronto's EMPADR VII program. The pyroxenes are from rocks with textures ranging from not recrystallized, through partly recrystallized to completely recrystallized.

Coexisting pyroxenes and their tie lines are shown on the pyroxene quadrilateral of Figure 29. Also shown on the figure are optically determined (γ-index of 210 cleavage fragments) compositions of orthopyroxenes including some from pyroxene monzodiorites and pyroxene quartz monzonites (data listed in Table 7). The optically determined pyroxenes are arbitrarily plotted at the 1 per cent Ca level in Figure 29.

The tie lines in Figure 29 do not show marked differences in orientation. This suggests that the equili-

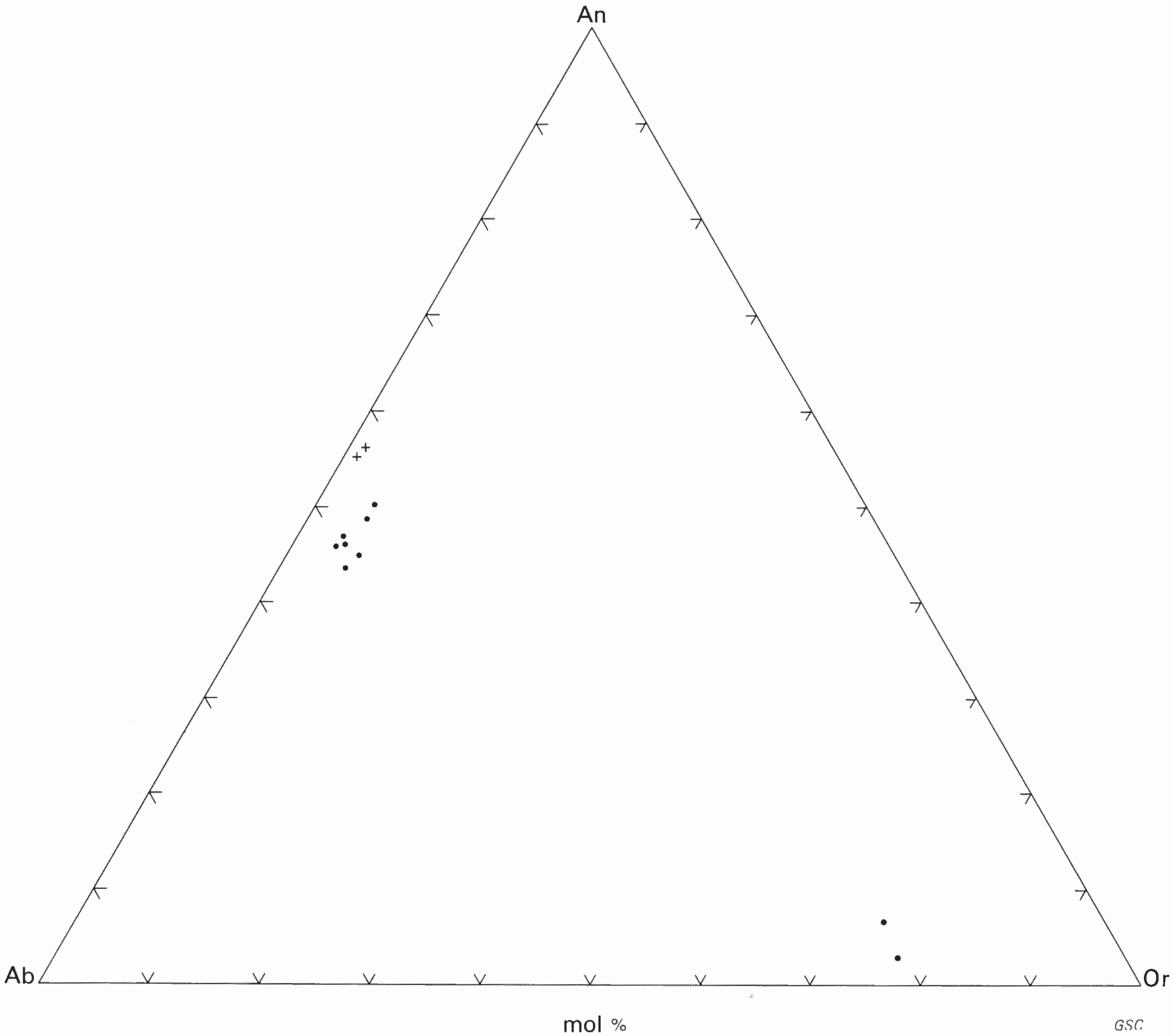

Figure 28. Molecular proportions of An, Ab, and Or in feldspars from recrystallized (+) and unrecrystallized anorthozite-leucogabbro and from pyroxene quartz-monzonite.

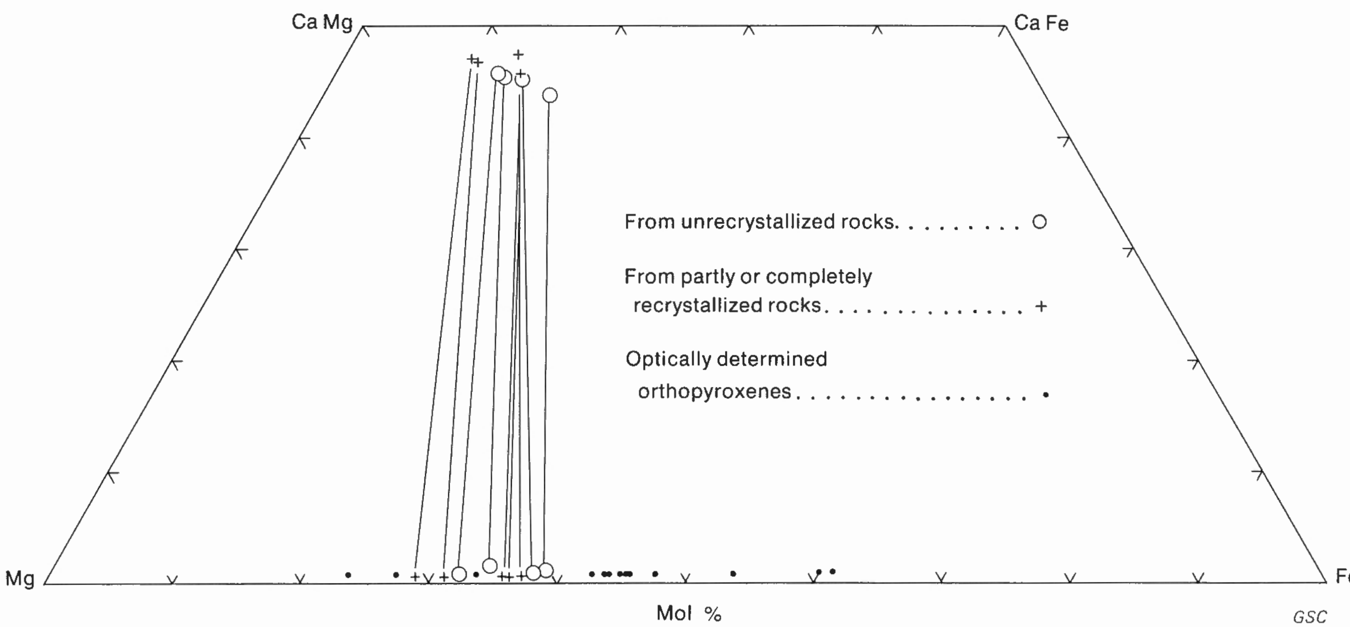

Figure 29. Analyzed coexisting pyroxenes from anorthosite-leucogabbro. Also plotted are optically-determined orthopyroxene compositions from Table 7.

TABLE 7

Sample	Mol % Mg	Mol % An	Rock
E64-219	76	51	leucogabbro
E64-169A	73	61	leucogabbro
E64-160	68	52	leucogabbro
E64-171	66	57	gabbro
S64-442	64	-	pyroxene monzodiorite
S64-440	63	46	pyroxene monzodiorite
E64-362A	62	50	pyroxene monzogabbro
E64-373	57	44	pyroxene monzodiorite
E64-60	56	42	pyroxene monzodiorite
E64-306	56	47	leucogabbro
S64-467	55	46	pyroxene monzodiorite
S64-505A	55	42	pyroxene monzodiorite
S64-444	54	48	pyroxene monzodiorite
S64-299	53	46	pyroxene monzodiorite
S64-40	46	-	pyroxene quartz monzonite
S64-263	39	30	pyroxene quartz monzonite
S64-79	39	31	pyroxene quartz monzonite

bration temperatures of Fe-Mg exchange were not drastically different even though the rock textures range from fresh igneous to polygonal metamorphic. In Figure 30 the distribution of Fe and Mg between Ca-rich and Ca-poor pyroxenes is shown on a diagram similar to that used by Philpotts (1966) and his data from two small anorthosite suite complexes east and southwest of the Morin Complex are included. The slopes of lines labelled "Higher T" and "Lower T" define limiting values of distribution coefficients (K_D) which bound the field of points. Maximum temperatures tend to approach a line with slope 1. Philpotts interpreted his data as defining an igneous temperature and two different lower metamorphic temperatures. An alternative interpretation can, however, be suggested. From the distribution of data in Figure 30 it may be inferred that some higher temperature pairs are preserved (falling close to the Higher T line) and these may represent an approach to "igneous" temperatures of equilibration. There are also a number of pairs lying on or close to the Lower T line and these may represent the lowest temperatures of "metamorphic" Fe-Mg equilibration. The scatter of points between the lines therefore presumably represents pairs that either only partially re-equilibrated to lower temperatures or that completely re-equilibrated at a series of different temperatures. More data are required to establish which of these alternatives is correct although the former seems more likely because the composition range is not large. It is clear, however, that there is not a simple correlation between rock textures and temperatures of Fe-Mg equilibration in the pyroxenes.

Primary igneous orthopyroxenes contain 1.0 to 1.8 mol per cent $CaSiO_3$. Orthopyroxenes from partly or completely recrystallized rocks contain 0.9 mol per cent $CaSiO_3$ or less. This suggests lower temperatures of equilibration for the metamorphic orthopyroxenes. The metamorphic clinopyroxenes tend to have slightly higher $CaSiO_3$ contents than the igneous clinopyroxenes which is also consistent with lower temperatures of equilibration. The calcium contents of the pyroxenes are therefore in general agreement with the Fe-Mg distribution data.

The orthopyroxenes contain 1.3 to 2.0 weight per cent Al_2O_3 and, except for one, the igneous samples are lower. The clinopyroxenes range in Al_2O_3 content from 2.2 to 3.8 weight per cent and again the igneous ones are at the lower end of the range. If the alumina content of orthopyroxene is mainly a function of pressure (Boyd and England, 1960) it would imply that metamorphic recrystallization took place at higher pressures than igneous crystallization. However, if the solubility of Al_2O_3 in orthopyroxene is primarily a positive function of temperature as suggested by Anastasiou and Seifert (1972) it is difficult to believe that metamorphic temperatures could have exceeded the igneous temperatures of crystallization and this is contrary to the Fe-Mg distribution data for the pyroxenes. Because the bulk compositions of the rocks are similar it is difficult to ascribe variation in Al_2O_3 content of orthopyroxenes to differences in availability of Al_2O_3. Reactions of pyroxene with plagioclase to produce aluminous pyroxene from less aluminous or non-aluminous pyroxene involves an increase in density and thus should be favoured by an increase in pressure and/or a decrease in temperature. Therefore it seems likely that either recrystallization took place at higher pressure and lower temperature than igneous crystallization or at lower temperature and constant pressure. The former condition might be expected if prograde metamorphism took place during an event postdating emplacement and cooling of the complex whereas it might be argued that the latter condition could accompany retrogression during cooling and deformation of the complex. In any case the relatively low levels and small differences in Al_2O_3 content between igneous and metamorphic pyroxenes suggests that the differences in pressure were not of great magnitude and that the pressures were not high. It should be borne in mind that recrystallization took place for the most part under "dry" conditions. It is possible that under these conditions reaction between pyroxenes and plagioclase was inhibited even though the minerals recrystallized and some measure of Fe-Mg re-equilibration was established between coexisting pyroxenes. Fe-Mg equilibration

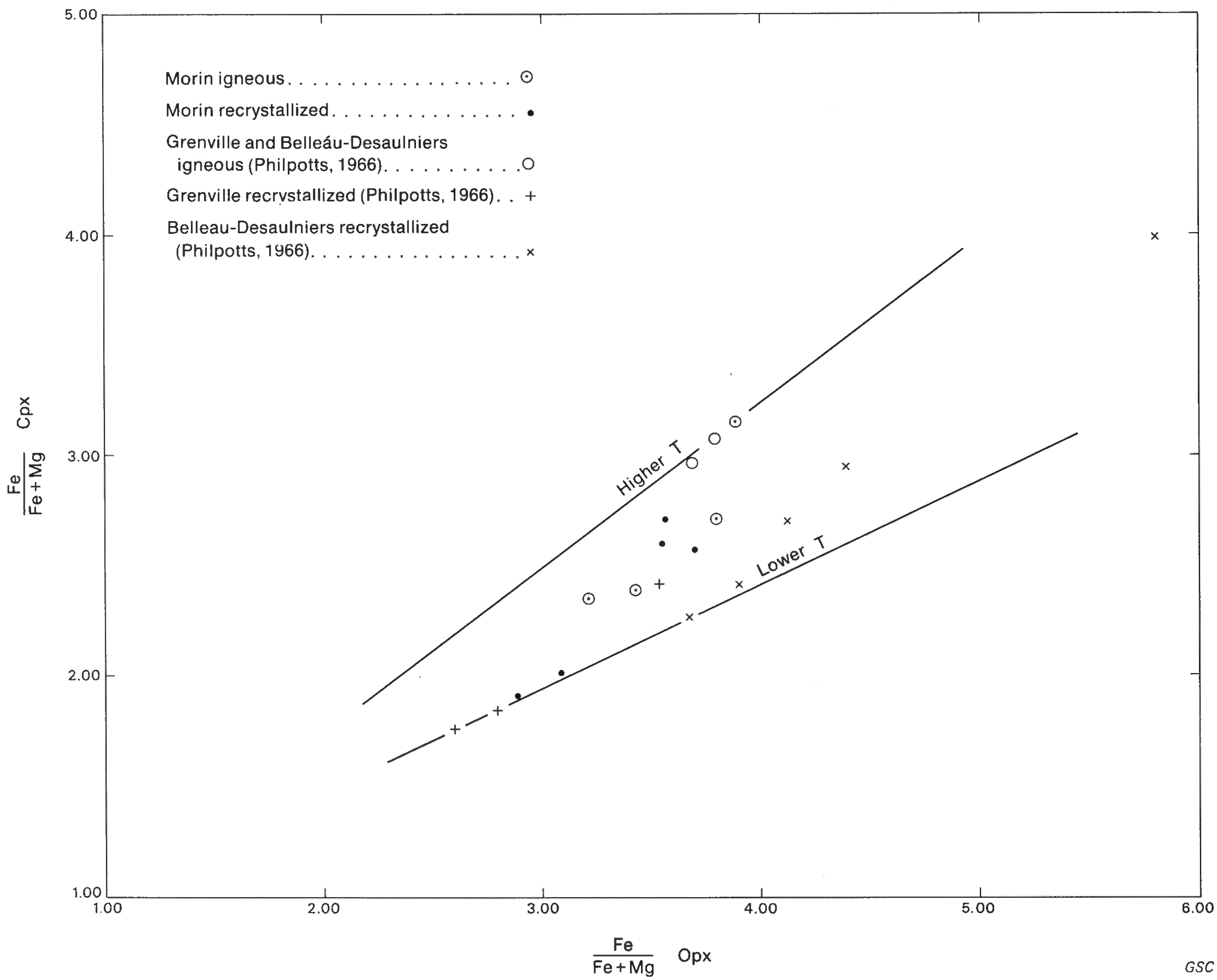

Figure 30. Distribution of Fe and Mg between coexisting pyroxenes from anorthosite-leucogabbro.

TABLE 9

Measured densities of rocks of the Morin Complex and country rocks

Rock-unit	Avg. density gm/cc	Range gm/cc	N
anorthosite	2.69	2.61 - 2.75	245
leucogabbro	2.81	2.65 - 3.11	289
pyroxene quartz monzonite	2.84	2.66 - 3.30	266
pyroxene monzodiorite	3.14	2.77 - 3.66	105
quartz monzonite, granite	2.70	2.60 - 2.76	35
granite, granitic gneiss	2.63	2.55 - 2.85	47
paragneiss	2.86	2.60 - 3.35	122
marble	2.78	2.58 - 3.07	34
quartzite	2.70	2.61 - 2.94	29
granulite	2.67	2.60 - 2.92	93
		Total	1265

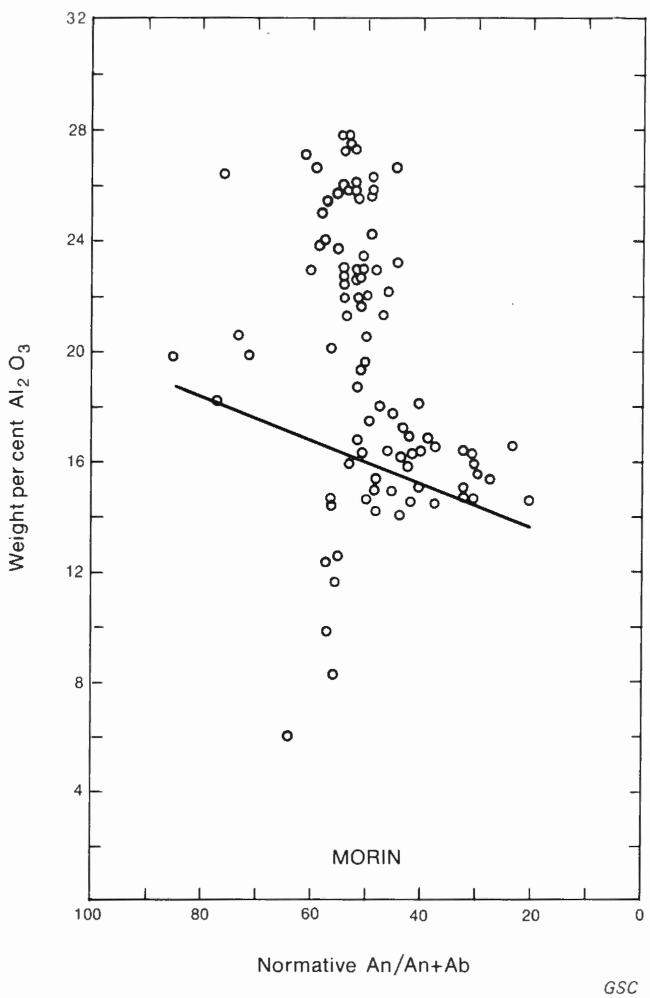

Figure 31. Weight percent Al_2O_3 vs. normative An/An + Ab of plagioclase for rock of the Morin Complex.

requires only exchange of ions in existing lattice sites whereas Al substitution requires reconstitution of the pyroxene structure involving breaking of Si-O bonds.

The optically-determined compositions of orthopyroxenes plotted in Figure 29 indicate that relatively iron-rich compositions are present in pyroxene monzodiorites and pyroxene quartz monzonites. None of these specimens shows microscopic evidence of having formed by inversion from pigeonite.

Chemistry of the Rocks

Although the close spatial association of the main rock-units is undoubted and a temporal alliance is inferred, a good deal of uncertainty surrounds their genetic relationships. The anorthosites and leucogabbros are almost certainly formed by the accumulation of plagioclase crystals cemented by adcumulus overgrowths and small amounts of interstitial pyroxenes and opaque oxides. The composition of the liquid that coexisted with these crystals at the time of accumulation is a matter of some conjecture. The pyroxene monzodiorites may also have formed in part by crystal accumulation of heavy mafic minerals (see p. 26). Of the three main rock groups the pyroxene quartz monzonites show least evidence of crystal accumulation processes and their compositions may be expected to approach most closely the liquids from which they crystallized.

Chemical analysis by rapid methods of 34 rocks from the Morin Complex are listed in Table 8 along with computed norms. A substantial number of analyses of anorthosite and leucogabbro from the Morin Complex are available from Papezik (1965) and no additional examples of these rocks were analyzed during the present study.

Most analyses of Morin anorthosites and leucogabbros from the literature carry small amounts (up to about 3%) of quartz in their norms. A few have larger amounts of quartz, a few have small amounts of corundum and two analyses have traces of nepheline. The Fe/Mg ratios of the anorthositic rocks are high, mostly greater than 1.5 (Emslie, 1973, Fig. 5).

In Figure 31 rocks of the complex are shown on a plot of weight per cent Al_2O_3 against normative plagioclase composition (An/An+Ab). The anorthosites and leucogabbros (with Al_2O_3 > 20 weight per cent) are clearly defined in an elongate cluster whose axis is located at about An_{50-55}. These intersect another trend which contains the intermediate and silicic rocks of the complex. Assuming that the anorthositic rocks are plagioclase crystal cumulates with variable amounts of interstitial material, chiefly pyroxenes, a possible interpretation is that the liquid from which the plagioclase cumulate formed lay at the intersection of the trends i.e. it had an Al_2O_3 content of about 17-18 per cent and normative plagioclase near An_{50}.

The group of points along the same trend as the anorthositic rocks but extending to low levels of Al_2O_3 are rocks carrying substantial amounts of Fe-Ti oxide minerals, some of which are from substantial oxide-rich deposits. The fact that the normative plagioclase compositions of these rocks are similar to those of the anorthositic rocks suggests that either the oxides are genetically related to the anorthositic rocks or, if they were introduced at a later time it was without causing chemical alteration of the host rock. Because all gradations from oxide-poor to very oxide-rich rocks occur and typically have good igneous textures the former interpretation seems more likely.

Analyzed rocks listed in Table 8 together with a few from the literature are shown on an AFM projection in Figure 32. The pyroxene quartz monzonites form an elongate field trending toward the A apex. This is principally a reflection of the range of K_2O contents (due to K-feldspar) in the rocks. The pyroxene monzodiorites cluster toward the F apex together with most of the oxide-rich dyke rocks. These compositions have been referred to as ferrogabbro by Papezik (1965). The rocks are indeed high in iron chiefly because of their richness in Fe-Ti oxides but since a large proportion (1/3 to ½ commonly) of the iron is ferric it seems incorrect to term the rock ferrogabbro as pointed out by Anderson (1966). Note that there is an indication of a compositional gap where few points fall between the cluster of pyroxene monzodiorites (excluding oxide-rich dykes) and the pyroxene quartz monzonites. This is in agreement with the gap previously noted in

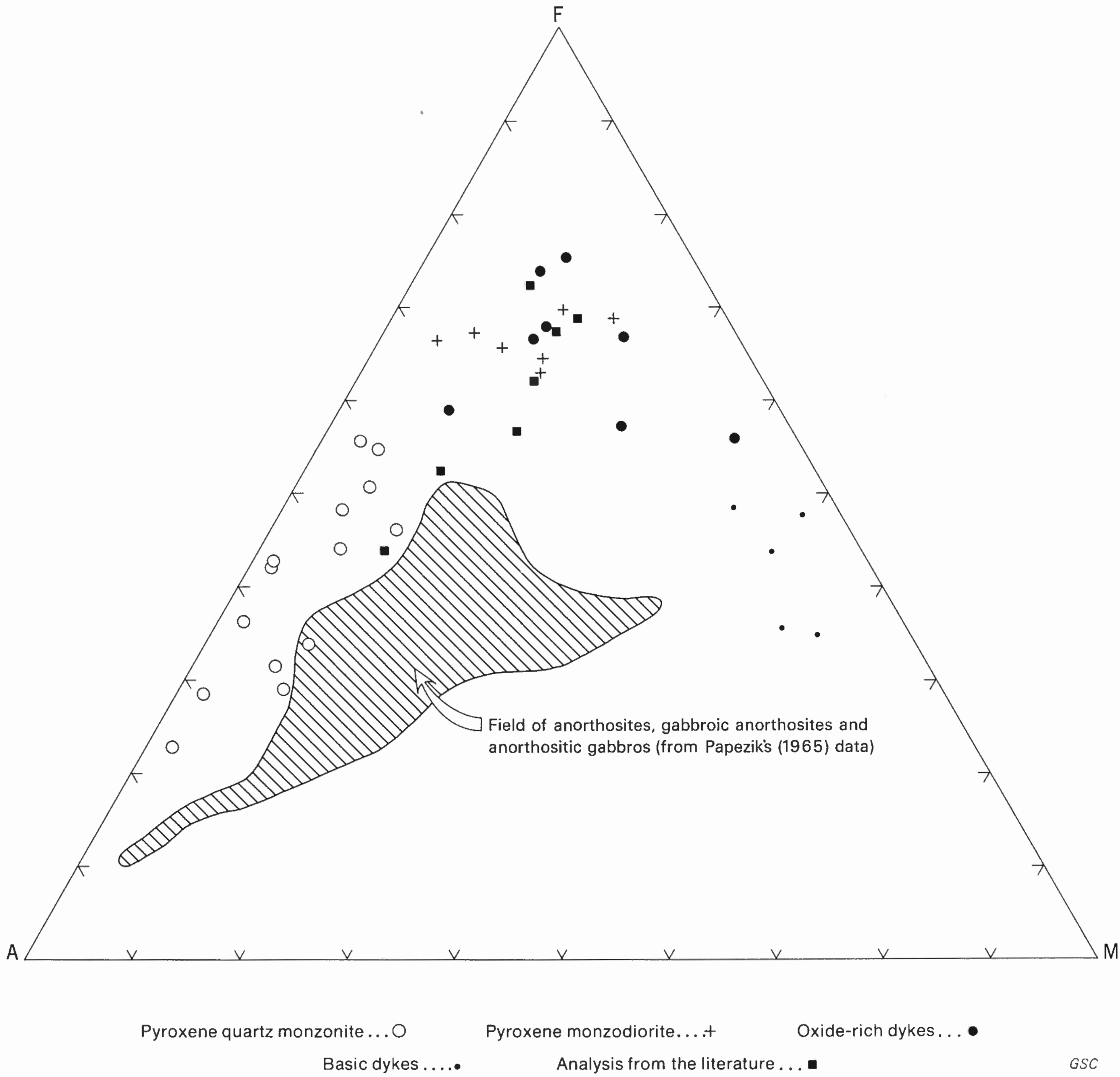

Figure 32. AFM projection of rocks of the Morin Complex excluding anorthosite-leucogabbro. Analyses from the literature are from Côté (1960), Osborne (1949) and Papezik (1965).

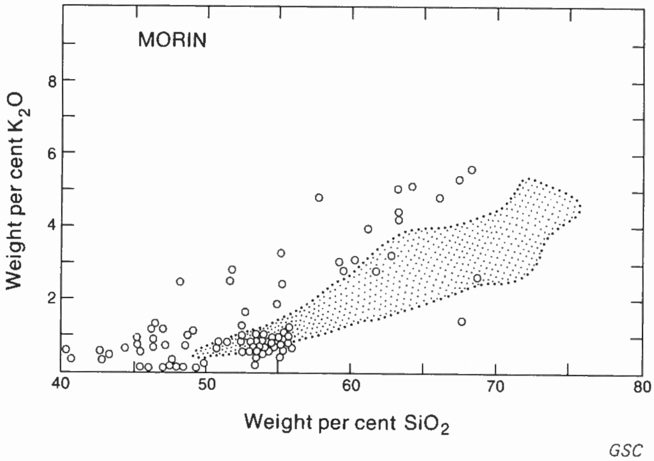

Figure 33. K_2O vs. SiO_2 for rocks of the Morin Complex.

modal compositions of these two groups. If it is not simply a sampling gap it adds support to the interpretation that the pyroxene monzodiorites are products of enrichment in mafic silicates and oxide minerals that settled to the base of the pyroxene quartz monzonite. Efficient segregation by settling could result in two groupings with only a relatively small volume of intermediate types.

The five metabasic dyke rocks lying near the F-M sideline are low in Fe-Ti oxides and generally have small to moderate amounts of olivine in their norms. They have less than 0.2 per cent K_2O and are low in TiO_2 and P_2O_5. As pointed out previously these metabasic dykes may be related to the Morin Complex but there is no guarantee that this is true. Several of the dykes have calcic normative plagioclase (up to An_{77}) a feature unlike any other rocks of the complex. Apart from these dykes there are few analyses distributed along the F-M sideline which might be interpreted as indicating a lack of evidence for basic magmas associated with the Morin suite. An explanation for this is not difficult to suggest, however. Anorthosites and leucogabbros (anorthosites, gabbroic anorthosites and anorthositic gabbros of Papezik, 1965) projected onto this diagram occupy a broad field in the central part of the triangle and trend toward the A apex. Assume that these rocks are essentially plagioclase cumulates with varying amounts of trapped interstitial liquid that subsequently crystallized chiefly as pyroxenes, oxides and plagioclase that was added to the cumulus plagioclase. On the AFM projection plagioclase lies at the A apex. Subtraction of plagioclase from these plagioclase cumulates (anorthosite and leucogabbro) would be equivalent to projecting these rocks toward the F-M sideline from A. If sufficient plagioclase is removed to result in a reasonable alumina content for the interstitial liquid (say 20% Al_2O_3 or less) these liquids would lie in an elongate field subparallel to F-M and extending from the pyroxene monzodiorite group toward M. The metabasic dyke rocks plotted in Figure 32 fall within this fictive field and it is possible that they represent residual liquids squeezed or otherwise concentrated from the plagioclase cumulates although olivine and calcic plagioclase in their norms is not readily explained.

A plot of K_2O against SiO_2 for the Morin suite is shown in Figure 33. The shaded area indicates the range of compositions for calc-alkaline intrusive and extrusive rocks of the western United States from Dickinson (1969). The anorthositic rocks form a tight cluster at SiO_2 - 55-56 weight per cent and K_2O - 0.5-1.0 weight per cent. The majority of the other rocks of the suite are significantly more K_2O-rich at a given SiO_2 level than the western United States suites. In this respect it is similar to most other anorthositic rock suites (Emslie, 1973). Correlations have been drawn relating K_2O/SiO_2 ratios to depth of origin of calc-alkalic magmas (Dickinson and Hatherton, 1967) and one possible interpretation is that Morin magmas were derived from greater depths than most calc-alkaline suites.

Rock Densities

While gravity observations were being made over parts of the Morin Complex in 1968 many samples were collected for density determinations. In addition, densities were measured on existing rock collections. A total of 1, 265 specimens were measured by weighing in water and in air. These included all of the major rock-units of the complex and most of the country rocks although the latter are less well represented.

Histograms of the density distributions for the major rock-units are illustrated in Figure 34 and the data are tabulated in Table 9.

The 245 anorthosite specimens have a symmetrical distribution with a well-defined mode closely corresponding to the mean of 2.69. Leucogabbro specimens numbering 289 have a mean density of 2.81 but the distribution shows some positive skewness (a small number of specimens with densities above 2.95 are probably gabbro). A mean value for the anorthosite plus leucogabbro of 2.75 is close to the average density of 2.72 that Simmons (1964) estimated for the Adirondack anorthosite. Thompson and Garland (1957) calculated a weighted mean density of 2.72 for the Morin anorthosite.

The densities of pyroxene quartz monzonite samples have a fairly marked positive skewness with a mean density of 2.84. Rocks of the pyroxene monzodiorite group have as their chief characteristic a richness in mafic silicate minerals and opaque oxides (which accounts for some of the extremely high density values). The density distribution of these rocks has a broad range and does not show a well-developed mode. The mean density is 3.14.

Rocks indicated separately as quartz monzonite in Table 9 are believed to be facies of pyroxene quartz monzonite but they lack pyroxenes and are rather more leucocratic. The mean density of these rocks is 2.70.

For the country rocks the following average densities were determined: granite and granitic gneiss: 2.63 (n=47); paragneiss: 2.86 (n=122); marble: 2.78 (n=34); quartzite: 2.70 (n=29); granulite: 2.67 (n=93).

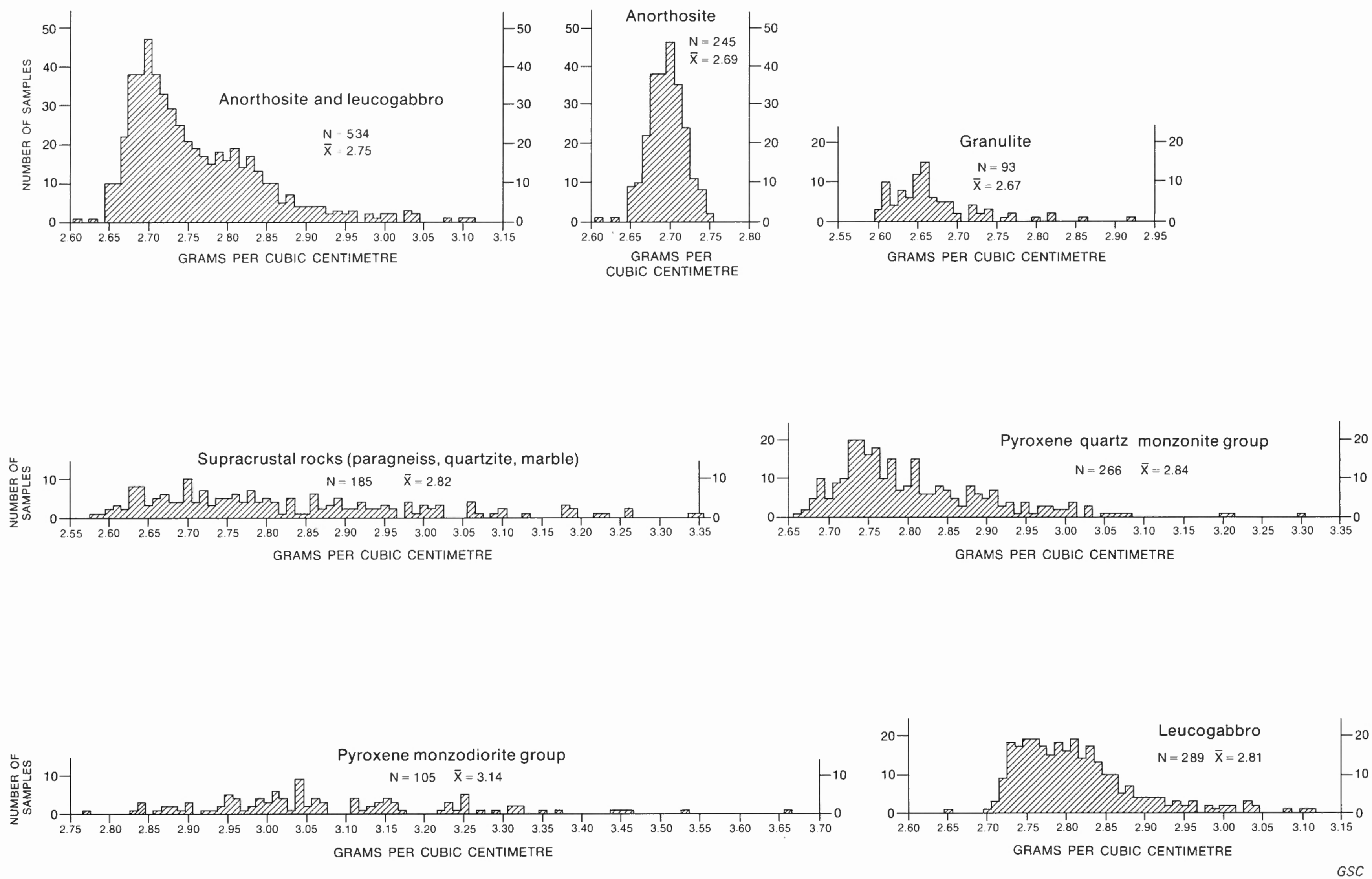

Figure 34. Histograms of distribution of rock densities for the major units in the Morin area.

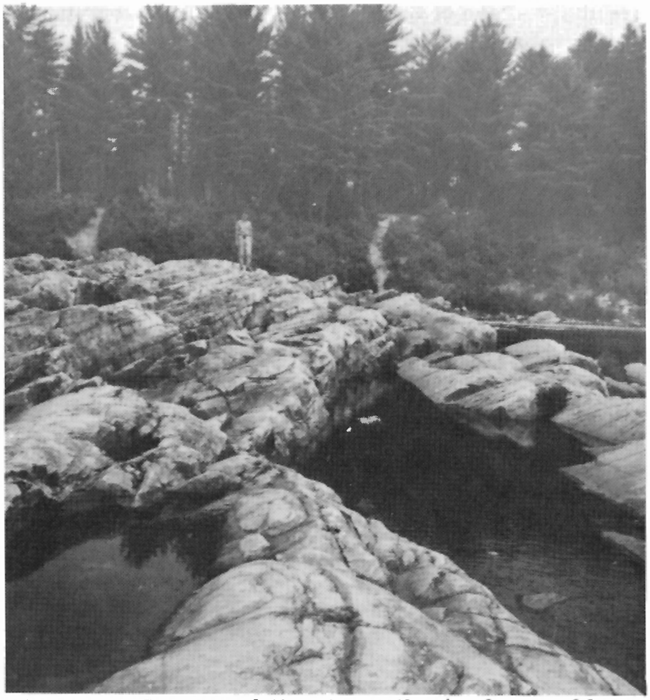

Figure 35. Strongly foliated anorthosite-leucogabbro at Pontbriand Falls. Station E65-86.

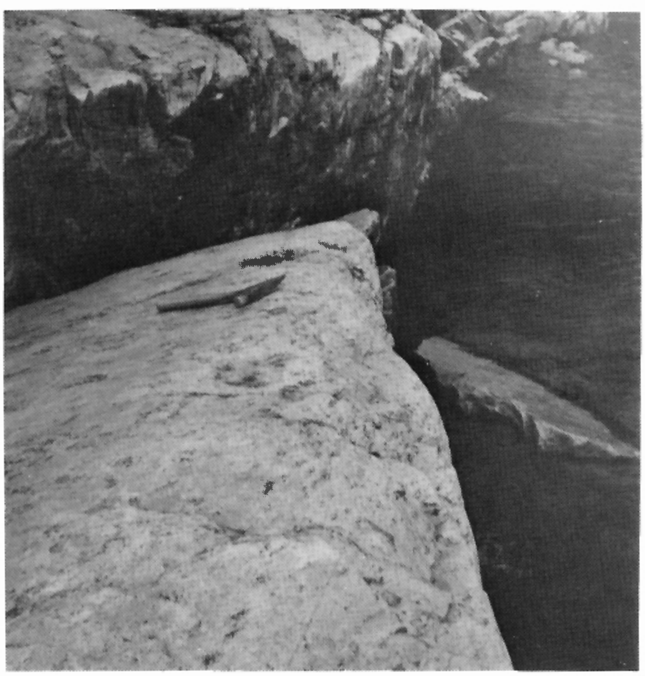

Figure 36. Elongated mafic "spots" in strongly foliated recrystallized leucogabbro. Hammer handle lies in foliation plane and is parallel to lineation formed by elongation of "spots". Station E65-86.

Figure 37. Elongated mafic aggregates in strongly foliated recrystallized leucogabbro. Station E65-86.

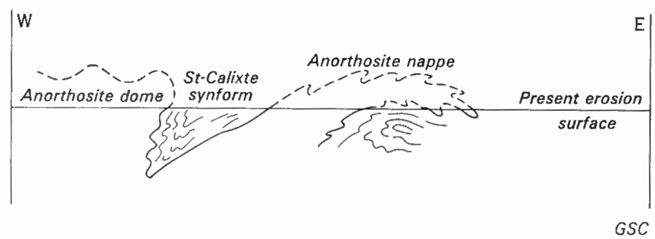

Figure 38. Interpretation of a structural cross-section at about 46^{o}N latitude according to Martignole and Schrijver (1972). Section passes from the west lobe dome across pyroxene quartz monzonite synform (St. Calixte synform) and the anorthosite nappe into country rocks.

It is, of course, not possible to argue that these measured densities are closely representative of the units, especially intrinsically heterogeneous units such as paragneiss. However, it is interesting that the grand mean (unweighted) density of all country rock-units is 2.73, slightly less than the anorthosite-leucogabbro mean (2.75). If it were assumed that these average densities are in fact representative of the rock-units it would be impossible to reconcile them with the pronounced negative gravity anomaly over the anorthosite-leucogabbro (Thompson and Garland, 1957). This would require that the source of the anomaly be sought at depth. On the other hand, if the leucogabbros represent a border or roof facies as has been suggested for the Adirondack anorthosite, then the 2.69 density of the anorthosite may be more representative of the rocks present at depth.

Deformation and Regional Metamorphism

There can be no doubt that the Morin Complex has undergone severe regional metamorphism and deformation after crystallization. There are extant, however, two main opinions concerning the timing of the igneous event of emplacement of the anorthosite suite and the last major regional deformation and metamorphism (the Grenvillian Orogeny). These are: 1) the Morin Complex was emplaced and crystallized long before (perhaps several hundred million years) being deformed and metamorphosed by the Grenvillian Orogeny (Emslie, 1970; Wynne-Edwards, 1972) or 2) the complex was emplaced, deformed, and metamorphosed during the latest stages of the Grenvillian Orogeny (Martignole and Schrijver, 1970a).

The deformational and metamorphic history of the Morin Complex has been discussed in several recent papers by Martignole and Schrijver (1970a, 1970b, 1971, 1972). In these papers the authors have developed an evolutionary scheme based on rising and partial spreading of the anorthosite-leucogabbro mass in an environment with ambient granulite facies P-T conditions. The resultant shape of the upper surface of the anorthosite-leucogabbro is interpreted as being domed in the western lobe, a diapir in the northern part of the east lobe and a nappe overturned toward the east in the southern part of the east lobe. A domical shape for the west lobe was originally suggested by Osborne (1956) and is supported (or at least not negated) by the present study. Martignole and Schrijver have provided good arguments for the nappe-like form of the southern east lobe but the evidence for a diapir to the north is less well founded as they recognize. Although steep foliations are not uncommon in the "diapir", lineations are mostly subhorizontal and there is little evidence to support penetrative vertical tectonic movement of material either within the "diapir" or around its margins.

The steps leading from definition of the shape of the upper surface of the anorthosite-leucogabbro to determination of the processes involved in the evolution of that shape necessarily follow a more treacherous path. Martignole and Schrijver have argued that the shape of the upper surface of the anorthosite-leucogabbro has been formed entirely by buoyant uprise and spreading of the mass. Indeed, they have gone

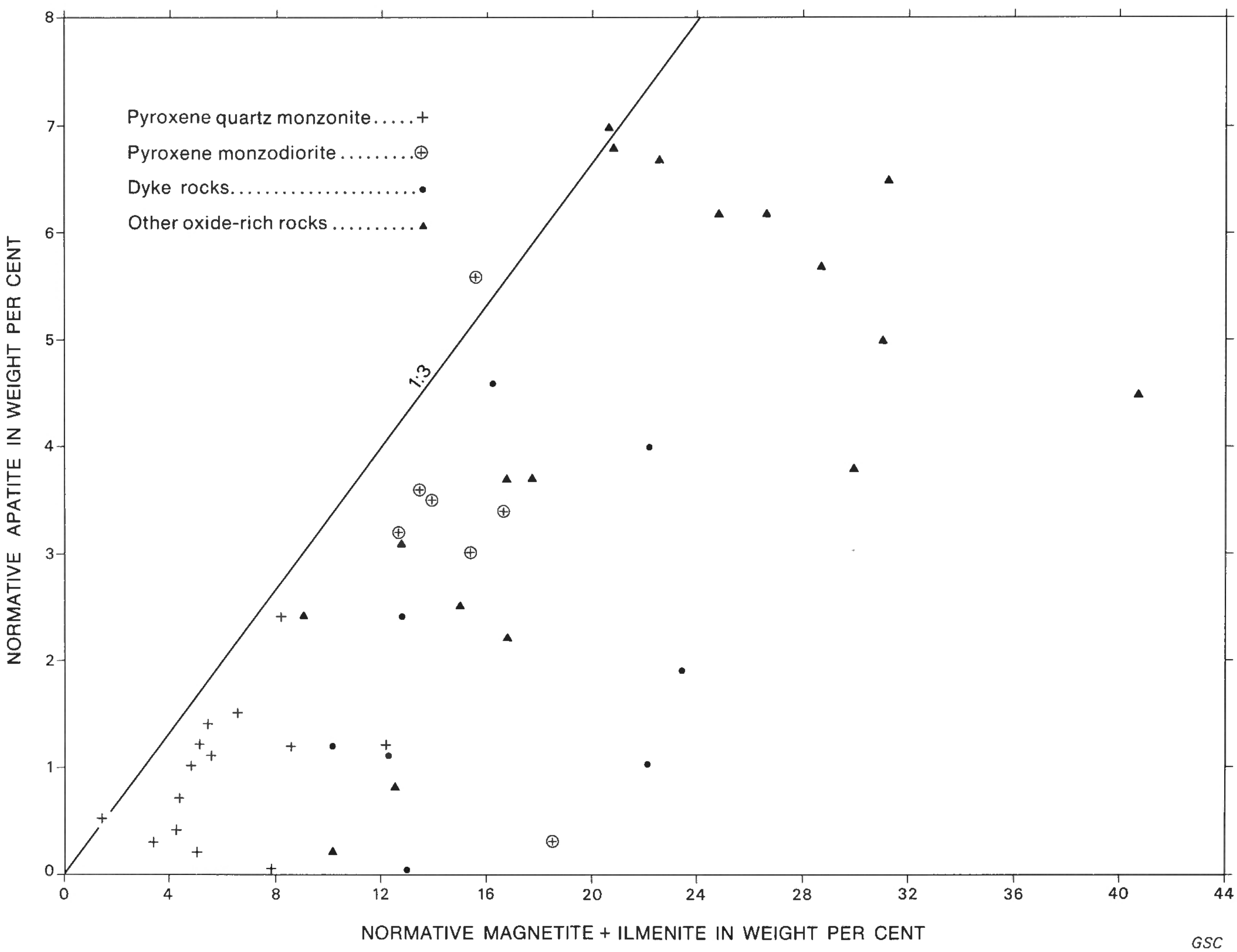

Figure 39. Plot of normative apatite vs. normative magnetite plus ilmenite in oxide-bearing rocks of the Morin Complex.

farther and suggested that all deformation of the anorthosite-leucogabbro and surrounding country rocks was due to this buoyant uprise. Some objections to Martignole and Schrijver's model of structural evolution are:

1. The large western lobe or dome has, for the most part, well-preserved subophitic and poikilitic textures that are undeformed or only slightly deformed except in local zones. There is no evidence within the west lobe or around its margins of penetrative vertical tectonic movements. This is also true of the east lobe "diapir".

2. The southern part of the east lobe, presumed to be the core of a nappe (see Fig. 38), contains within it widespread elongate and flattened bodies (Figs. 35, 36, 37) believed to represent original poikilitic crystals or polymineralic aggregates formed by diffusion within the plagioclase cumulate. These are typically, but not invariably, subequidimensional (Fig. 16) in most of the west lobe as pointed out by Martignole and Schrijver (1970a, see Fig. 24). In the east lobe, however, these bodies form flattened and elongated aggregates (aptly termed "knife-blades" by Martignole and Schrijver, 1972) lying in the plane of foliation. Within the foliation plane they are elongated in a north-south direction to several times their width, that is they form a lineation with subhorizontal plunges (see also Martignole and Schrijver, 1970a). In the nappe interpretation these are assumed to be "B-lineations" parallel to fold axes in the country rock gneisses to the east. If the buoyant upward flowage of large volumes of material took place through the preserved nappe core into the now eroded nappe one might expect to find structures analogous to those in the cores of salt domes. In salt dome cores strong elongation of crystal forms and of inclusions parallel to the direction of flow are typical (Balk, 1949; Kupfer, 1963). Such lineations appear to be absent in the east lobe and one must assume that either they did not exist or they were subsequently obliterated by the later "B-lineations".

3. A zone of large patches of supracrustal rocks extends south and east from Lac Ouareau to the tip of the east lobe. Several of these masses occur within anorthosite-leucogabbro and may reasonably be interpreted as roof pendants. These have normal igneous contacts and not tectonic contacts with anorthosite. In addition, inclusions of supracrustal rocks, although rare, are present within anorthosite-leucogabbro. Therefore the anorthosite-leucogabbro must have existed in at least partly magmatic form at the same crustal level as the supracrustal rocks. The Martignole and Schrijver model proposes that buoyant uprise took place when the anorthosite-leucogabbro was in a solid or near solid condition. Deformation and recrystallization of pre-existing igneous structures and textures also clearly requires that these effects postdate solidification. However, an anorthosite-leucogabbro crystal-liquid mush would have had its lowest possible density prior to solidification and should have reached its level of buoyant equilibrium in the crust. After crystallization the increased density of the mass would decrease effective buoyancy forces.

4. Martignole and Schrijver (1970a, 1972) have pointed out that there are no identifiable fold hinges within the east lobe but that small folds occur in the margin of the anorthosite and are consistent in attitude with folds in the supracrustal rocks and gneisses to the east. The lineation described above within the east lobe is subparallel to the axes of these folds. for this reason folding of the country rocks and deformation of the east lobe are probably contemporaneous as Martignole and Schrijver recognized. They have argued however, that the sole cause of deformation was buoyant rise of the anorthosite-leucogabbro mass. Northerly-trending structures are typical of the region for nearly 100 miles to the north and for several tens of miles to the west of the anorthosite mass (Wynne-Edwards et al., 1966; Katz, 1973). These can hardly all be caused by buoyant uprise of the Morin anorthositic rocks. They seem more likely to have resulted from regional deformation and it follows that deformation of the complex may also have resulted from applications of these regionally-applied external forces.

5. The St. Calixte synform (Fig. 38) lying between the east lobe and the west lobe is strongly overturned toward the east like the proposed east lobe "nappe" of anorthosite-leucogabbro. If deformation were due entirely to buoyant rise of anorthosite-leucogabbro in the east lobe while the western dome remained relatively stationary as postulated by Martignole and Schrijver, one might expect the synform to be overturned toward the west. The very marked easterly vergence of both the proposed "nappe" and the synform is strongly suggestive of externally operative lateral compressive forces.

To the present author the evidence outlined above brings into serious question a model of structural evolution based entirely on buoyancy forces generated by a low density crystalline mass of anorthosite-leucogabbro. The evidence is compatible, however, with deformation of a solid anorthositic mass by external forces as has been recognized but rejected by Martignole and Schrijver (1972). The time gap separating solidification of the complex and subsequent deformation is open to question.

The metamorphic grade of the Morin Complex and its surroundings is upper amphibolite to granulite (Martignole and Schrijver, 1970a, 1971). These authors have sketched "isograds" between which rocks of the anorthosite suite (chiefly pyroxene monzodiorites and pyroxene quartz monzonites) contain garnet. They have discussed the garnet-forming reactions and implied that clinopyroxene is an additional product of the reactions. Although it is true that clinopyroxene occurs in many garnet-bearing rocks the present study has not uncovered any confirming textural evidence that it participates in the reactions. Instead, clinopyroxene appears to occur either as relict igneous grains or as simply recrystallized material or more commonly, a combination of both.

Figure 40. Oxide-rich veinlets intrude and enclose angular and subangular leucogabbro fragments. Desgrosbois Quarry.

Figure 41. Angular and subangular fragments of anorthosite and leucogabbro in oxide-rich matrix. Desgrosbois Quarry.

In the present study garnet has been found in pyroxene quartz monzonite along the eastern margin of the east lobe north and south of Rawdon. This is well to the east of the Martignole and Schrijver "isograd". Martignole and Schrijver (1973) have since demonstrated the bulk compositional control on the occurrence of garnet so that the existence of garnet "isograds" is cast into doubt. Schrijver (1973) has also commented on the probable invalidity of these "isograds".

There is no convincing evidence now available of a regional metamorphic gradient across, within, or related to the Morin Complex.

Although there are no published dates available for the Morin Complex itself, recent isotopic dating in the region has provided some interesting results. Barton and Doig (1972) have determined Rb-Sr isochrons on several units of the Lac Croche Complex of anorthosite suite rocks about 10 miles northeast of the Morin Complex. The average whole rock isochron age was 1124±27 m.y. and this was interpreted by the authors as representing the time of crystallization, deformation and metamorphism of the complex. Low initial ratios of Sr^{87}/Sr^{86} suggest no significant pre-history for the rocks, however the range of Rb^{87}/Sr^{86} is low in all of the units measured and rehomogenization of the Rb-Sr systems within a few hundred million years of crystallization would not significantly increase the initial ratios.

Barton and Doig (1973) have also measured some Rb-Sr isochrons in the area immediately east of the east lobe of the Morin Complex. An isochron on Grenville Group paragneisses yielded a metamorphic age of 1094±43 m.y. Another isochron on the Lac Quinn Formation (recognized only adjacent to contacts of the Morin Complex) yielded an age of 1576±19 m.y. This latter metamorphic age is referred by the authors to some earlier unidentified "thermal event". Because the rocks occur in close proximity to the Morin Complex it seems not unreasonable to suggest that the "thermal event" may reflect thermal metamorphism caused by emplacement of the plutonic complex. It may also be noted that about 150 miles to the northeast Frith and Doig (1973) determined a Rb-Sr whole rock isochron age of 1482±72 m.y. on paragneisses at the contact of the Lac St-Jean anorthosite which they interpret to be the age of thermal metamorphism by the anorthosite.

The 1124 and 1094 m.y. old ages determined by Barton and Doig would be interpreted by most workers as manifestations of Grenvillian metamorphism. The fact that older isotopic ages are recognizable in the vicinity of the Morin Complex suggests that it should be possible to determine the primary igneous age of the complex whether that age be Grevillian or older.

Martignole and Schrijver (1970a) have argued strenuously for emplacement of the Morin Complex during late stages of the Grenvillian Orogeny as the "simplest interpretation". Nevertheless these authors and Schrijver (1973) recognize that the severity of the Grenvillian deformation and metamorphism in the region makes difficult recognition of pre-existing structural, stratigraphic and intrusive relations so that a pre-Grenvillian history for the Morin Complex cannot yet be discounted on the existing geological evidence.

Figure 42. Large angular anorthosite fragment in oxide-rich matrix that contains abundant plagioclase megacrysts. Desgrosbois Quarry.

The only significant late igneous activity to affect the region of the Morin Complex was emplacement of diabase dykes. These range in thickness from a few inches to several hundred feet. They are fresh undeformed rocks commonly with dense, aphanitic chilled margins. Many of the dykes have an approximately east-west strike and are probably part of a swarm that strikes across eastern Ontario and western Quebec, concentrated north of the Ottawa River and dated at about 790 m.y. (K-Ar whole rock). Other fresh diabase dykes with a variety of strikes may or may not be of similar age.

Along Highway 11 on the northern outskirts of Ste-Adele greenish dykelets up to ¼ inch thick fill fractures in anorthosite. The dykes consist largely of carbonate and chlorite but stubby pyroxene pseudomorphs can be identified. The dykelets may be related to Cretaceous Monteregian igneous activity.

Fe-Ti Oxide Deposits

The occurrence of titaniferous magnetite and ilmenite deposits in the Morin Complex has been known for many years. In addition to the well-known deposits at Ivry and Desgrosbois, there are numerous small showings. All of these have been reviewed and discussed in recent years by Rose (1960, 1969) and no further description is necessary here.

Philpotts (1967) pointed out that some oxide-rich deposits associated with anorthositic rocks contain apatite, commonly present in proportions of 1 apatite to 2 opaque oxides by volume. With the help of some experimental results he suggested that the constant proportions were due to formation of an apatite-oxide immiscible liquid that formed at an advanced stage of fractional crystallization of the anorthosite suite.

In Figure 39 normative apatite is plotted against the normative magnetite + ilmenite contents of rocks of the Morin suite excluding anorthosite and leucogabbro. Although there is considerable scatter it is clear that there is a rough positive correlation between the variables. The normative values are in weight per cent and taking into account the differing densities of apatite and magnetite-ilmenite the ratio of 1: 2 in volume per cent recalculates to about 1: 3 in weight per cent terms. This ratio is shown as a dashed line in the diagram. Nearly all of the points lie to the right of the line, that is they have apatite: oxide ratios less than 1: 3 although it could perhaps be argued that they approach it as a limit.

An alternative to liquid immiscibility is accumulation of apatite and oxide minerals by crystal settling. Because the oxide minerals are about 50 per cent more dense than apatite one would expect that, given comparable crystal sizes and shapes, oxide minerals would settle more rapidly. This would result in rocks with a range of apatite: oxide ratios with the more oxide-enriched samples nearer the base. The distribution of normative apatite and opaque oxides in Figure 38 is consistent with accumulation of coprecipitating oxide and apatite crystals with differential settling rates. It is inconsistent with formation of an immiscible apatite-oxide liquid that crystallized to give fixed proportions of those minerals.

If the base of the magma body were in contact with anorthosite which had already solidified then fracturing of the anorthosite could result in infilling by an apatite-oxide-rich crystal mush in the manner of clastic dykes. On the other hand, deformation and recrystallization at a later time could cause flowage of oxide-rich material into brittle-fractured anorthosite (Figs. 40, 41, 42). As pointed out previously, the typically oxide-rich pyroxene monzodiorite lies adjacent to anorthosite in most places and grades outward (upward) into pyroxene quartz monzonite as if it were a mafic basal zone of that unit.

SUMMARY AND CONCLUSIONS

The rock-units of the Morin Complex are grouped into three major units; anorthosite-leucogabbro, pyroxene monzodiorite (jotunite), and pyroxene quartz monzonite (farsundite). Modally and chemically there appear to be gaps between the groups where transitional rock types are sparse. Primary textures of the anorthosite-leucogabbro are characteristic of plagioclase cumulates. These rocks form the oldest established unit of the complex. Pyroxene monzodiorite is texturally and mineralogically more akin to the pyroxene quartz monzonite than to the anorthosite-leucogabbro and may form a mafic-enriched basal facies of that unit. Dykes of pyroxene monzodiorite in anorthosite-leucogabbro and inclusions of anorthosite-leucogabbro in pyroxene monzodiorite demonstrate that the latter existed in fluid form after solidification of the anorthosite-leucogabbro. Existence of liquids more basic than monzodiorite in the complex is not directly demonstrated but Fe/Mg ratios of anorthosites and leucogabbros strongly suggest that such liquids existed.

Measured plagioclase compositions in anorthosite-leucogabbro range from about An_{42-54} with a mean of An_{48}. Measurements of $2\theta(131) - 2\theta(1\bar{3}1)$ suggest low transitional structural states. Recrystallized plagioclase appears to be markedly lower in Or and slightly higher in An than igneous plagioclase.

Distribution of Fe and Mg between Ca-rich and Ca-poor pyroxenes suggests that the final temperatures of equilibration of "igneous" and recrystallized pyroxenes may not have been greatly different. A range of temperatures is indicated however, that may be real or may represent incomplete re-equilibration to metamorphic temperatures. Ca contents of the pyroxenes are in agreement with the Fe-Mg data. The Al_2O_3 contents of recrystallized ortho- and clinopyroxenes appear to be consistently but only slightly higher than "igneous" ortho- and clinopyroxenes. The Al_2O_3 contents do not suggest high pressure crystallization under either igneous or metamorphic conditions.

Approximations of the shape of the upper surface of the anorthosite-leucogabbro can be suggested but virtually nothing is known of the 3-dimensional shape or extent. Mineral layering occurs most commonly within the anorthosite-leucogabbro but even in these rocks it is too rare (or too rarely exposed) to define internal structure in detail.

The Morin Complex has undergone severe deformation and metamorphism of upper amphibolite to granulite facies after crystallization. There is no well defined contact aureole around the complex. This may be explained as having been erased by the high grade regional overprint.

Several lines of evidence call into question Martignole and Schrijver's (1970a) model of deformation due to buoyancy forces generated by lighter anorthosite-leucogabbro and point instead to deformation by externally imposed lateral forces.

Rb-Sr isotopic dates have confirmed that the last major metamorphism to affect the Morin Complex can be related to the Grenvillian Orogeny (1094-1124 m.y. ago in this area). Existence of some relict older ages in the vicinity of the complex and the severity of the Grenvillian metamorphism suggest to this author that it would be premature to rule out a pre-Grenvillian primary igneous age for the complex.

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APPENDIX

Universal Transverse Mercator (UTM) coordinates of sampling localities.
All are located in Zone 18.

Station	UTM Coordinates
E64-1	249076
E64-8	378059
E64-17	404055
E64-22	416030
E64-27	378058
E64-28	386073
E64-40	548008
E64-60	407003
E64-63	397009
E65-77	297005
E64-78A	294015
E64-86	386090
E64-93	437078
E64-96	623115
E64-109	811892
E64-160	490003
E64-162	473010
E64-167	732187
E64-169	728173
E64-169A	728173
E64-171	731149
E64-187A	527948
E64-200	473963
E64-207	650075
E64-214	611978
E64-215	521925
E64-219	494901
E64-223	472902
E64-226A	502893
E64-228	497888
E64-240	682908
E64-242	687936
E64-249	671895
E64-251	675871
E64-254	657854
E64-270	555842
E64-274	537027
E64-279	542038
E64-306	605937
E64-310	609910
E64-325	580130
E64-342	824016
E64-349	761038
E64-356	731044
E64-362	757035
E64-362A	757035
E64-371	456169
E64-373	452172
S64-23	448062
S64-25	416029
S64-31	423012
S64-37	532980
S64-40	373066

Station	UTM Coordinates
S64-44	364064
S64-44A	364064
S64-48	484141
S64-59	518093
S64-79	321072
S64-88	524891
S64-102	610960
S64-112	500162
S64-127A	317087
S64-161	554027
S64-163	551041
S64-168	347943
S64-224	612976
S64-227A	398052
S64-261	400945
S64-263	406945
S64-269	422942
S64-270	424942
S64-287	404915
S64-291	417914
S64-298	426878
S64-299	429882
S64-302	434884
S64-306	439883
S64-330	541898
S64-342	467922
S64-364	482866
S64-386	630848
S64-415	612898
S64-418	582867
S64-439	739884
S64-440	743902
S64-442	738921
S64-443	739924
S64-444	740926
S64-456	693957
S64-465	723852
S64-467	718846
S64-496	764833
S64-504	602061
S64-505A	592065
S64-508	571178
S64-509	572181
S64-518	550176
S64-521	545181
E65-3	544061
E65-9	636242
E65-16	732197
E65-19	763237
E65-26	773314
E65-26A	773314
E65-28	842087
E65-29	835105

Station	UTM Coordinates
E65-37	872093
E65-41	847063
E65-50	706210
E65-59	870046
E65-63	900104
E65-72	915049
E65-81	947033
E65-85	933006
E65-86	917006
E65-92	891000
E65-92A	891000
E65-97	917034
E65-97A	917034
E65-98A	876002
E65-102	842970
E65-121	935973
E65-125	982963
E65-135	980998
E65-136	991015
E65-178	582134
E65-179	514115
E65-187	843312
E65-205	837866
E65-208	855852
E65-212	877875
E65-236	924843
E65-237A	937852
E65-238	948847
E65-239	960836
E65-243	900809
E65-248	389063
E65-262	525030
E65-270	871837
E65-277	874802
E64-289	583197
E65-293	603982
E65-306	580224
E65-309A	579232
E65-322	844795
E65-360	592169
E65-384	440078
E65-429	654874
E65-433A	564087
E65-437	801863
E65-446	497888
E65-451	746040