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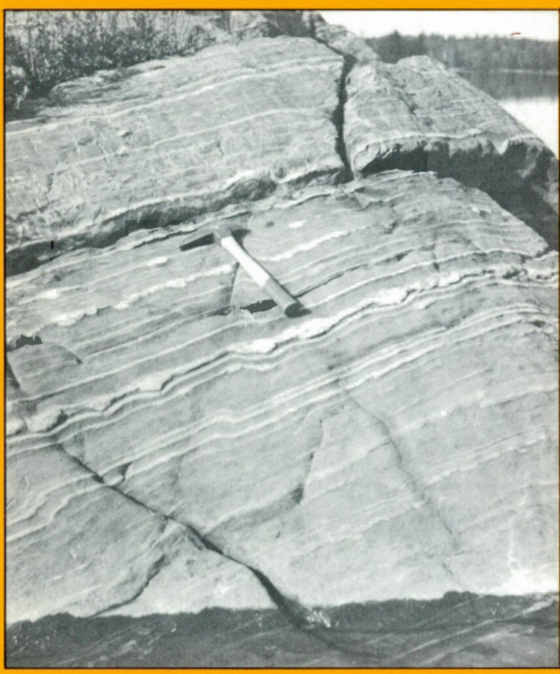

PROTEROZOIC GEOLOGY OF THE LAKE PANACHE-COLLINS INLET AREA, ONTARIO

M.J. FRAREY

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(Top) Load casts in an argillite-siltstone sequence of the Gowganda Formation, Huronian Supergroup, Southern Province. Balsam Lake, Goschen Township. GSC 188848.

(Bottom) Folding of mafic gneiss (amphibolite) and concordant cataclastic pegmatite, Grenville Province. Tyson Lake near Forbes Island, Sale Township. GSC 188951.

Critical Reader

K.D. Card

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PROTEROZOIC GEOLOGY OF THE LAKE PANACHE – COLLINS INLET AREA, ONTARIO

Abstract

The area covers 2330 km^2 of Canadian Shield north of Georgian Bay, Lake Huron, and contains equal parts of Southern and Grenville structural provinces, separated by the northeast-trending Grenville Front.

Southern Province is dominated by 9200 m of Early Aphebian Huronian Supergroup strata (>2300 Ma) that include the Hough Lake, Quirke Lake, and Cobalt groups. Mainly fluviatile crossbedded arenites of the Mississagi, Serpent, Lorrain and Bar River formations make up more than two-thirds of the supergroup. The Ramsay Lake, Bruce and Gowganda formations are of glacial, probably periglacial, origin. The Huronian is cut by sheets of 2115 Ma Nipissing Diabase, by felsic intrusions, and by 1230 Ma Sudbury olivine diabase dykes. Tectonic and possible impact breccias are present. The east-trending McGregor Bay Anticline is the dominant structure: metamorphism ranges up to middle amphibolite grade.

Grenville Province consists of the northeasterly trending 1525-1550 Ma Killarney Batholith (quartz monzonite, granite), remnants of Huronian rocks, paragneisses, a few metamorphosed mafic intrusions, and numerous felsic intrusive gneisses, some probably ca. 1700 Ma old, all cut by olivine diabase (including 1230 Ma Sudbury dykes) and diabase dykes. The Killarney Granite is a high-level potassic intrusion; a major feldspar porphyry component has fragmental border zones suggestive of a subvolcanic origin. The paragneisses are possible time equivalents of the Huronian Supergroup but cannot be correlated with individual formations. The northeast-trending gneisses have undergone polyphase deformation and upper amphibolite to local granulite facies metamorphism. Rocks of the Grenville Province all lie in the Grenville Front Tectonic Zone, and the gneisses are characterized by strong cataclasis and ubiquitous southeast lineation.

The Grenville Front, placed along the northwest margin of the Killarney Batholith, separates east-trending Southern Province regional structures from northeast-trending Grenville Province structures. Faulting is prominent along most of its length.

The reason for the "disappearance" of Huronian strata across the Front remains uncertain.

Résumé

La région, d'une superficie de 2 300 km^2, est située au nord de la baie Georgienne du lac Huron, dans le Bouclier canadien, et comprend des parties égales des provinces structurales du Sud et de Grenville, séparées par le front de Grenville à orientation nord-est.

La province du Sud se distingue par 9 200 m de strates du supergroupe de l'Huronien datant de l'Aphébien inférieur (>2 300 ma), qui comprennent les groupes de Hough Lake, de Quirke Lake et de Cobalt. Des arénites surtout d'origine fluviatile et à stratification oblique des formations de Mississagi, de Serpent, de Lorrain et de Bar River comptent pour plus des deux tiers du supergroupe. Les formations de Ramsay Lake, de Bruce et de Gowganda sont d'origine glaciaire, vraisemblablement périglaciaire. L'Huronien est recoupé par des filons-couches de diabase de Nipissing vieille de 2 115 millions d'années, des intrusions silico-feldspathiques et des dykes de diabase à olivine de Sudbury vieille de 1 230 millions d'années. On y trouve des brèches tectoniques et des brèches d'impact apparentes. L'anticlinal de McGregor Bay, à orientation est, constitue la structure dominante: le métamorphisme atteint le degré moyen de l'amphibolite.

La province de Grenville comprend le batholite de Killarney (monzonite quartzifère et granite datant de 1 525 à 1 550 ma) à orientation nord-est, des restes des roches de l'Huronien, des paragneiss, quelques intrusions mafiques métamorphisées et de nombreux gneiss intrusifs silico-feldspathiques (certains vieux environ de 1 700 ma), tous recoupés par des dykes de diabase et de diabase à olivine (dykes de Sudbury vieux de 1 230 ma). Le granite de Killarney est une intrusion potassique mise en place à un niveau élevé; un important élément de porphyre feldspathique présente des bordures détritiques qui évoquent une origine subvolcanique. Il se peut que la formation des paragneiss soit contemporaine de celle du supergroupe de l'Huronien, mais ils ne peuvent être reliés aux formations individuelles. Les gneiss à orientation nord-est ont subi une déformation polyphasée et un métamorphisme représenté par le faciès supérieur des amphibolites qui passe, par endroits, au faciès des granulites. Les roches de la province de Grenville gisent dans la zone tectonique du front de Grenville; une forte cataclase et une linéation ubiquiste à orientation sud-est caractérisent les gneiss.

Le front de Grenville, qui longe la limite nord-ouest du batholite de Killarney, sépare les structures régionales à orientation est de la province du Sud des structures à orientation nord-est de la province de Grenville. On observe de nombreuses failles le long de presque tout le front.

Des doutes subsistent quant à la raison de la <<disparition>> des strates de l'Huronien en travers du front.

INTRODUCTION

Location and extent

The report area is located (Fig. 1) along the north shore of Georgian Bay of Lake Huron just east of Killarney, in the districts of Sudbury, Manitoulin, and Parry Sound, Ontario. The centre of the area is approximately 48 km southwest of Sudbury and 40 km southeast of Espanola. The Lake Panache and Collins Inlet map areas (NTS 41 I/3, 41 I/14) are contiguous and form a block of about 2330 km^2 bounded by longitudes 81°00' and 81°30' and latitudes 45°54' and 46°15'. The block includes the townships of Stalin, Goschen, Sale, Humboldt, and Carlyle, Indian Reserve 3, most of Killarney and Rutherfold townships, and large parts of Travers, Kilpatrick, Attlee, Halifax, Bevin, Caen, Dieppe, Truman, and Roosevelt townships, and Indian Reserve 6. Geologically (see 1:50 000 scale map, in pocket), the report area comprises the southeastern extremity of the Southern Province, the northwestern margin of the Grenville Province, and the Grenville Front that separates them.

Access

Ontario Highway 637 crosses the middle of the area and provides access to several of the larger lakes, either directly or by means of short sideroads. It joins the Toronto-Sudbury Highway 69 a few kilometres east of the area. Much of the northern part of the quadrangle is reached from Lake Panache (also known locally as "Lake Penage"), which is accessible from the north by Highway 549, a branch road from the Trans-Canada Highway 17. The southern fringe of the area is only reached by boat from Georgian Bay or by air. There are no permanent settlements in the area although the village Killarney lies 1.5 km to the west. Tourist lodges at Lake Panache, Bell Lake, Johnnie Lake, Collins Inlet, French River and Killarney provide accommodation in season, and a large campground is operated in the summer months at George Lake in Killarney Provincial Park by the Ontario Ministry of Natural Resources. The historic canoe route between Lake Panache and Georgian Bay, passing through Balsam, Bell, Johnnie, Carlyle, Kakakise, and George lakes is still in use, mainly by vacationers, and provides access to much of the area. The extreme northeast, southeast, and west-central parts are difficult to access other than by air. Few streams in the area are navigable for appreciable distances, even by canoe.

Previous work

Geological investigations have been carried out intermittently here for over a hundred years. Early geologist-explorers A. Murray (1849, 1857), R. Bell (1878, 1891, 1898) and A.E. Barlow (1893) visited parts of the area in the course of larger surveys. Bell's 1891 and 1898 reports are noteworthy, as they include first geological maps (GSC Map sheets 125 and 130) showing the major rock divisions, i.e., gneiss, granite, diabase and sediments of the report area and of the Sudbury area. Bell (1898, p. 7-8) recognized the post-Huronian age of the granites that separate the sediments from the gneisses east and northeast of Killarney, referring to them as "the Killarney belt of granites". In 1915, Collins (1916) investigated relations between Huronian rocks and granite near Killarney village, and confirmed Bell's conclusions. The first systematic mapping was done in the northern part of the report area by T.T. Quirke in 1915, by W.H. Collins in 1916, and by P. Eskola in 1922 (Collins, 1925). This work established the major stratigraphic and structural relations of the Huronian rocks there. In 1916 and 1917, Collins also investigated a limited part of the granite and gneiss terrane adjacent to the Huronian on the east. The rest of the present area was covered by Quirke in 1923 and 1926. Quirke laid special emphasis on the relationship between the

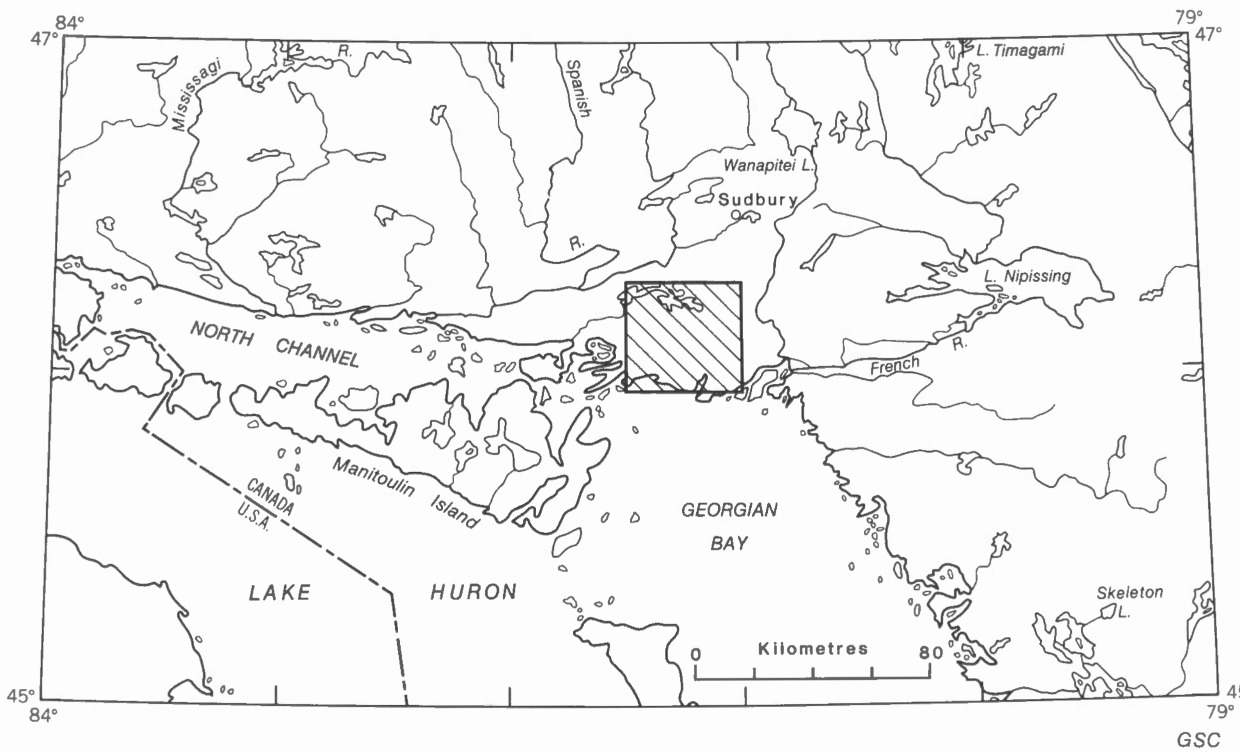

Figure 1. *Index map.*

gneisses of Grenville Province and the Huronian sediments, and published his conclusions in the well-known memoir "The disappearance of the Huronian" (Quirke and Collins, 1930), in which specific gneissic rocks of the Grenville Province were correlated with specific Huronian formations in adjacent Southern Province; the belt of Killarney granites and gneissic granites along the Front was considered (ibid., p. 89) to be metasomatized or melted and remobilized Huronian sediments, mainly quartzite; in particular, a large area of feldspar porphyry near Killarney was thought to be metasomatized Lorrain quartzite. The abundant granitic gneisses intercalated with the metasedimentary gneisses farther southeast were also regarded as the product of in situ metasomatism (ibid, p. 91, 95). To account for the great contrast in metamorphism, the Grenville Front was interpreted as a fault on which great vertical displacement had occurred.

A.C. Lawson (1929) also visited the Killarney area, reaffirmed the post-Huronian age of the granites, argued that they could not be Keweenawan or post-Keweenawan as formerly thought, pointed out the intrusive nature of Quirke's porphyry, and cited evidence to show that it postdated the adjacent coarser grained granite. Lawson (1929, p. 369) was evidently also the first to conclude that the quartz diabase intrusions (Nipissing Diabase) of the district are much older than the Keweenawan rocks of the Lake Superior region, and that many were preorogenic with respect to post-Cobalt folding. Lawson, however, considered other diabases to be pre-Cobalt but intrusive into other Huronian strata, continuing the widely held but erroneous view that there was a great unconformity between the Cobalt and pre-Cobalt Huronian rocks ("Bruce series").

Until the present study, no comprehensive fieldwork was done in the area subsequent to 1926, activity being confined to special studies. The petrography and chemistry of the granitic rocks along the Front in the vicinity of Killarney were studied by W.A. Jones, previously an assistant to Collins (Jones, 1930). Jones refuted Quirke's thesis, later reiterated by Quirke following revisits in 1930 and 1931 (Quirke, 1940), that a continuous in situ transition existed from quartzite to feldspar porphyry to granite. Following this, a long hiatus ensued until E.R. Brooks (1964, 1967) carried out a doctoral dissertation study along the Front in the vicinity of Annie, Bell, and Johnnie lakes, in conjunction with which a master's study was done on gneisses at Tyson Lake (Dollase, 1962). Brooks questioned several of Quirke's conclusions, and suggested (Brooks, 1967, p. 1278) that the Front is the northwest boundary of a zone of intense creep that occurred along restricted shear zones, transposing Huronian stratification and producing horizontal rather than vertical movements. Brooks also thought that granitic intrusions of the Killarney Batholith may have been generated by "shear melting" in this zone; like Quirke, he viewed the granitic gneisses of the Grenville terrane as granitization products. In another doctoral study Henderson (1967, 1972) studied relations along the Grenville Front a short distance outside the area, northeast of Lake Panache in Eden, Broder and Tilton townships. He found little evidence of signficant faulting, described a metamorphic transition between the provinces, and placed the Front (Henderson, 1967, p. 105-106) at the western limit of penetrative mineral lineation, approximately at the west edge of the Chief Lake Batholith. Areas adjacent to the report area on the west and north in Southern Province have been comprehensively studied by the Ontario Division of Mines (Palonen and Mills, 1970; Card, 1976a, b), and considerable university research was also done in the nearby McGregor Bay and Espanola areas to the west and southwest (Young, 1966; Casshyap, 1967; Hadley, 1968; Lindsey, 1967). Lumbers (1971a, 1975) mapped the ground immediately east and northeast of the report area for the Ontario Division of Mines as part of a larger program in the Grenville Province. He concurred with Quirke as to a Huronian or Huronian-equivalent depositional origin for many of the gneisses, but refrained from specific correlations. Northeast of the report area, Lumbers located the Grenville Front at a fault which he considered to be a suitable marker near the northwest margin of an overprinted structural zone that he first recognized (Lumbers, 1971b) between Lake Temiskaming and Sudbury, a zone areally redefined and formally named the "Grenville Front Tectonic Zone" by Wynne-Edwards (1972, p. 268-271). The above position of the Front was adopted by other provincial geologists in regional compilations and was extended along faults through the Lake Panache-Collins Inlet area (Card, 1978a; Ayres et al., 1971; Card and Lumbers, 1977). For the present report area the original position of the Grenville Front (Stockwell, 1961, 1969, 1982) which for the most part follows the northwestern edge of the granites of the Front zone, 1.6 to 4.8 km farther northwest, is retained because, unlike the above position, it is the linear contact that transects the major structures of the Southern Province, and thus satisfies the original and essential criterion for distinguishing structural province boundaries. As discussed later, this boundary is also a fault nearly everywhere.

The present project

Prior to initiation of this project, doubt had been expressed (Thomson, 1961) as to the age of the sediments of the report area and surrounding district between the Sudbury Basin and Lake Huron; these had been mapped by all previous workers as Huronian, and in view of the uranium potential of the latter and the strategic location of the rocks along the Grenville Front, the question of their age and correlation assumed considerable scientific and economic importance. Accordingly, the prime purpose of the project was to establish the identity of the strata as Huronian or otherwise and to revise their stratigraphy and structure. Other principal objectives were to map and investigate in more detail than heretofore the Grenville Province terrane, particularly in view of Quirke's thesis that gneisses there are direct equivalents of Huronian formations and that in places the latter are individually recognizable in the Grenville Province, and to study the nature of the boundary between the two major tectonic domains. Fieldwork was carried out in the four seasons between 1964 and 1967 inclusive and a preliminary report and map were published in 1969 (Frarey and Cannon, 1969). In addition, brief periods were spent in the area in 1968 and 1970. In the second and third seasons the writer was associated with R.T. Cannon, a postdoctoral fellow at McGill University, in the study of the boundary and the Grenville terrane. Cannon mapped most of the Collins Inlet map area, and also the Grenville terrane of the Lake Panache map area lying south and southwest of Johnnie Lake.

The area was mapped by foot traverses, generally spaced from 300 to 600 m apart, from base camps located on Lake Panache, Bell Lake, Annie Lake, Threenarrows Lake, Tyson Lake, Halifax Lake, Collins Inlet, French River, and at Killarney. In addition, the shorelines of the principal lakes were studied in detail by boat or canoe. Geological interpretation and control were aided by air photographs, by aeromagnetic maps (Geological Survey of Canada, 1965a, b) and by a Bouguer anomaly map (Earth Physics Branch, 1971).

In this report, all map units are classified following the time classification of Stockwell (1982).

Physical features

The area is divided into two physiographic domains which correspond to the two structural divisions, Southern Province and Grenville Province. The former is underlain by stratified Huronian rocks and diabase sheets and has essentially an east-west ridge- and valley-topography controlled by bedrock structure and lithology. In the north, local relief is only 30-60 m, the main ridges being underlain by Nipissing Diabase or feldspathic quartzite of the Mississagi and Serpent formations. However, the southern half of this domain is underlain mainly by more resistant siliceous rocks of the Lorrain and Bar River formations, including large areas of orthoquartzite that are flanked by weaker formations; here the topography is rugged and forms the easternmost and highest part of the La Cloche Mountains, which extend westward from the area along the North Channel of Lake Huron for about 80 km. Local relief ranges up to about 275 m. The orthoquartzites form prominent bare white hills and broad ridges which, with their green forested flanks and clear interspersed lakes, create a spectacular scenery unmatched in this part of Canada. In former years, this scenic beauty attracted prominent landscape artists to the area, including members of the Group of Seven, a fact reflected by the names "Artists Creek" and "O.S.A. Lake" (Ontario Society of Artists). The beautiful scenery attracts many tourists and summer residents to Killarney and the area in general, particularly to Killarney Provincial Park. The highest peak is Northeast Hill (also known as Silver Peak) in northern Carlyle Township 550 m above sea level or about 360 m above Lake Huron. Other prominent hills are Gulch Hill, Killarney Peak, and Leading Mark Hill, all about 275 m above Lake Huron. Most of this southern physiographic subdivision is included in Killarney Provincial Park.

The Grenville terrane is a relative lowland of gneiss and granitoid rocks lying between 200 and 275 m above sea level. Its topography too is strongly bedrock-controlled, and characteristically consists of low, narrow, rocky northeast-trending ridges and intervening equally narrow valleys, commonly swamp-covered. Local relief seldom exceeds 45 m. Granite is slightly more erosion-resistant than the gneisses. The granitic intrusions of the Killarney Batholith along the Grenville Front are intermediate in elevation between the Huronian terrane to the northwest and the gneisses to the southeast; along Johnnie Lake and Bell Lake and farther southwest near Killarney, abundant exposures of these red and pink granites contrast sharply with the adjacent white quartzite hills.

The waters of the northwestern, Huronian, part of the area drain westward, entering Lake Huron west of the report area, either at the Bay of Islands or at Narrow Bay. Most of the Grenville terrane drains southwest into Georgian Bay, either at Collins Inlet via Mahzenazing River or Beaverstone Bay via Beaverstone River.

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GENERAL GEOLOGY

Introduction

The area is geologically noteworthy for several reasons. Because it is divided sharply by the Grenville Front into contrasting low- to medium-grade Huronian east-trending sedimentary strata on the one side in the Southern Province, and high grade, complexly deformed and intruded, northeast-trending gneisses on the other in the Grenville Province, it has long been of special interest and a major problem to geologists. This abrupt structural-metamorphic change is the outstanding feature of the area, and, in spite of new information from recent studies, the contrast and the relationship between the two sides of the boundary is a continuing problem. Secondly, the train of narrow felsic intrusions of post-Huronian age emplaced along the Grenville Front between the two structural and metamorphic domains is also of unusual interest; this belt appears to be unique, as such linear intrusions are evidently lacking elsewhere along the northwestern edge of the Grenville Province. These intrusions comprise several lithologically discrete bodies that together were originally termed the "Killarney Granite" (Bell, 1898; Collins, 1916, 1925) and later termed the Killarney Batholith. Along with other bodies in the Huronian near Sudbury and elsewhere, they were thought to represent a wide-ranging orogenic event termed the "Killarnean Revolution" in early accounts. The concept of a Killarnean orogenic event has more recently been revived by Brooks (1967) and by Stockwell (1982). In this report, the term Killarney Granite refers only to the southwesternmost segment of this chain of intrusions, remaining members of the group being given other informal names. The area is also interesting for its thick, well-preserved section of Huronian sediments, which ranges from the Ramsay Lake Formation of the Hough Lake Group to the uppermost Bar River Formation of the Cobalt Group. This section is in the most southerly part of the total distribution area of the Huronian Supergroup and at the eastern end of the Lake Huron fold belt, so that it offers comparison on a formational basis with the same units to the west and north, and interpretations as to depositional conditions and change.

Two islands near the southern boundary of the area are underlain by Paleozoic rocks. These strata are not described in this report.

Of additional interest are numerous remarkable breccias of uncertain origin that have affected the Huronian sediments and Nipissing Diabase of the northwestern (Southern Province) half of the report area. As in neighboring areas (Card, 1976a), many resemble the well known "Sudbury Breccia" that occurs to the north around the Sudbury Basin, ascribed by some to meteorite impact; if related, these breccia occurrences extend the breccia field southward to Lake Huron and the Grenville Front.

The Grenville rocks of the area, most of which had not previously been subdivided, proved amenable to general subdivision at the 1:50 000 scale. These gneisses are fairly well exposed and display in abundance all the features of metamorphism, intense polyphase deformation, and plutonism common to high grade terranes. In addition, widespread cataclastic and mylonitic effects and a remarkably uniform structural style and grain imparted by extremely strong northwesterly directed deformation are distinctive features of these rocks of the Grenville Front Tectonic Zone.

Rb-Sr ages cited in this report were calculated using $\lambda^{87}Rb = 1.42$.

Southern Province

General

The part of the area included in the Southern Province is underlain, in order of decreasing age, by sediments of the Huronian Supergroup, which dominate, by sheets and dykes of metagabbro and related mafic rocks of the Nipissing Diabase group, by small felsic sills, plugs, and dykes, and by numerous amphibolite and posttectonic olivine diabase dykes. All are Proterozoic in age, and all except the Sudbury olivine diabase dykes are Aphebian. The Huronian Supergroup is organized into groups and formations according to the scheme of Robertson et al. (1969) and the section corresponds very closely to Huronian type sections mapped in the Bruce Mines (Frarey, 1977) and Elliot Lake (Robertson, 1971) areas 96 to 160 km to the west. The sections along the Huronian belt not only comprise the same groups and formations, but also show remarkable similarity in lithology, even in detail, of the various units, particularly the thick quartzite formations that constitute the bulk of the supergroup. In the report area the basal Elliot Lake Group is not present; the exposed Huronian strata become younger southward from the Ramsay Lake, Pecors and Mississagi formations of the Hough Lake Group at Lake Panache in the north to the Bar River Formation of the Cobalt Group in the La Cloche Mountains in the south. The detailed succession is shown in the Table of Formations.

Huronian Supergroup

Hough Lake Group

Ramsay Lake Formation (ARL)[1]

Distribution and lithology. The Ramsay Lake Formation is confined to a few small occurrences in a limited area along the northern boundary of the area west of Reef Lake, and is not well exposed. The formation consists mainly of massive and bedded siliceous paraconglomerate, with minor conglomerate, gritty greywacke, and phyllite. At the south end of the large island in Lake Panache 3.2 km west of Reef Lake, where the formation occupies a tight anticline, a small partial section includes (a) about 23 m of sparse boulder conglomerate, (b) perhaps 7.5 m of orthoconglomerate, and (c) another 23 m of paraconglomerate of tillitic appearance. Farther north on this island, gritty greywacke and phyllite appear to be part of the formation; they may mark a transition to the overlying Pecors Formation. The formation is less altered and deformed on the mainland shore just east of the island, where scattered grey granitic and metasedimentary megaclasts up to 0.3 m or more across are contained in a poorly sorted sandy matrix. In all occurrences the matrix is characterized by clear glassy quartz in a wide size range. Just northeast of the most northerly mainland exposure, fragments of the paraconglomerate occur, along with other metasedimentary fragments, in a large breccia thought to be a slump or slide deposit.

In thin section, the paraconglomerate matrix consists of rounded quartz grains up to several millimetres across in a granoblastic mat of smaller quartz grains, chlorite, biotite, plagioclase, potassium feldspar, muscovite, and locally, poikiloblastic epidote.

Contact relations and thickness. Contacts of the Ramsay Lake are not exposed. Elsewhere in this general area the formation is described as having a conformable and gradational contact with the underlying McKim Formation (Card et al., 1975). Because of inadequate exposure and lack of contacts, the thickness is indeterminate, but is probably less than 80 m.

Pecors Formation (AP)

Distribution and lithology. The Pecors occurs only in the northernmost part of the report area, along a 16 km stretch of islands, bays, and peninsulas in Lake Panache that includes Indian Reserve 6, Caen Township, and the western fringe of Bevin Township. In general, the formation is fairly easily eroded, and good exposures are essentially restricted to the shorelines. Systematic study of the formation as a stratigraphic unit is also precluded in this area by numerous folds and large diabase intrusions. Mesoscopic and macroscopic folds are especially numerous at Gabodin Lake, Caen Township.

The formation consists essentially of siltstones, greywacke and subgreywacke, argillite, argillaceous quartzite and arenaceous feldspathic quartzite. "Cleaner" feldspathic quartzite and pebbly conglomerate quartzite occur toward the top and form mappable units (APq) north of Gabodin Lake. The argillaceous beds are commonly metamorphosed to phyllites and to mica schists with or without metamorphic clots or porphyroblasts. Much of the Pecors consists of "dirty" argillaceous sandstone or subgreywacke, commonly interbedded with siltstone or phyllite. These rocks are fine- to medium-grained, grey to brownish weathering, and poorly to well bedded in units up to 1.2 m thick, some of which display excellent large scale crossbedding. Graded bedding is also common. On the island about 1.5 km north of Crean Point, Lake Panache, and on the adjacent mainland, a mainly argillitic subunit (APa), possibly 120 m thick, occurs in the upper half of the formation. This is characterized by even laminations of grey argillite 0.5-2.0 cm thick. Clean, white or cream weathering, coarser grained, feldspathic quartzite or more rarely, glassy quartzite interbeds, increase near the top of the formation, which is arbitrarily placed where the feldspathic quartzite appears to exceed 50 per cent. On either side of the creek emptying into the bay of Lake Panache just north of Gabodin Lake, the mapped feldspathic quartzite member in the pelitic schists of the Pecors includes layers of nonradioactive sparse quartz-pebble conglomerate or conglomeratic quartzite.

The fine- to medium-grained impure sandstones and siltstones consist of about one-half quartz, up to 25 per cent feldspar (plagioclase and potassium feldspar), and variable proportions of muscovite, biotite, and chlorite. No original clastic textures were seen under the microscope. Some specimens are highly muscovitic (up to 30 per cent), and this mineral is late relative to biotite and chlorite. More metamorphosed varieties consist of the same minerals plus porphyroblasts, strongly retrograded as a rule, of andalusite, staurolite, and less commonly cordierite. Andalusite, the most common and prominent of these porphyroblasts, is abundant at Gabodin Lake and in the bay of Lake Panache just north of that lake, where crystals locally exceed 2 cm in length. Staurolite is also prominent in some beds at these localities.

Contact relations, structure, thickness and depositional environment. The contact with the underlying Ramsay Lake Formation was not observed, but elsewhere in the district it is conformable and gradational over an interval of some 6 m (Card et al., 1977). In addition to planar bedding and large- and small-scale crossbedding, the Pecors contains graded bedding, a few load casts, partial Bouma cycles, and sedimentary and tectonic breccias. A sedimentary (slump) breccia is well exposed for 200 m or more on the shore of Lake Panache 3 km west of Reef Lake. It contains fragments up to 6 m long of siltstone and subgreywacke together with some paraconglomerate from the nearby Ramsay Lake Formation. The Pecors also contains numerous mesoscopic folds, and commonly a well developed cleavage. The thickness is difficult to estimate, but appears to be well in excess of 610 m.

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[1] Technical difficulties preclude the use in this text of the specialized symbols found on map 1593A. However, the use of conventional type to approximate these symbols does not seem to introduce any unacceptable problems if the legend of map 1593A is used when referring from text to map.

TABLE OF FORMATIONS

GRENVILLE PROVINCE					
EON	ERA	SUPERGROUP	GROUP	FORMATION	LITHOLOGY
					olivine diabase, diabase
			INTRUSIVE CONTACT		
			KILLARNEY BATHOLITH	ANNIE LAKE COMPLEX	granite, porphyritic granite, pegmatite
	HELIKIAN			BELL LAKE GRANITE	coarse- to medium-grained granite, quartz monzonite and syenite, commonly porphyritic
				KILLARNEY GRANITE	coarse- to medium-grained granite, syenite; fine- to medium-grained porphyry
				TERRY LAKE DIORITE	coarse grained diorite
	INTRUSIVE CONTACT				
PROTEROZOIC	APHEBIAN or HELIKIAN		INTRUSIVE GNEISSES		granite, syenite, monzonite, granodiorite and diorite gneiss
	INTRUSIVE CONTACT				
				NIPISSING DIABASE(?)	amphibolite gneiss, metagabbro
			INTRUSIVE CONTACT		
			SUPRACRUSTAL GNEISSES*		megaconglomerate
					calc-silicate gneiss
	APHEBIAN				amphibolite gneiss
					metaquartzite
					biotite paragneiss, commonly garnetifeous
			COBALT	LORRAIN	quartz-feldspar-muscovite gneiss
				GOWGANDA(?)	paraconglomerate, pelitic gneiss

* Unnamed supracrustal gneisses are not in stratigraphic order

TABLE OF FORMATIONS

SOUTHERN PROVINCE					
EON	ERA	SUPERGROUP	GROUP	FORMATION	LITHOLOGY
	HELIKIAN			SUDBURY DIABASE	olivine diabase
PROTEROZOIC	APHEBIAN		INTRUSIVE CONTACT		
					amphibolite
			INTRUSIVE CONTACT		
					granite, trondhjemite, felsite, pegmatite and diorite dykes and plugs
			INTRUSIVE CONTACT		
				NIPISSING DIABASE	gabbro, diabase, granophyre
			INTRUSIVE CONTACT		
		HURONIAN	COBALT	BAR RIVER	orthoquartzite, siltstone
				GORDON LAKE	argillite, siltstone, cherty siltstone, quartzite
				LORRAIN	orthoquartzite, feldspathic quartzite arkose; minor argillite, pebble conglomerate
				GOWGANDA	paraconglomerate, greywacke, argillite feldspathic quartzite, orthoconglomerate siltstone
			QUIRKE LAKE	SERPENT	feldspathic quartzite, arkose; minor argillite, pebble conglomerate, calcareous quartzite and siltstone
				ESPANOLA	dolomite, limestone, calcareous siltstone, siltstone
				BRUCE	paraconglomerate; minor quartzite
			HOUGH LAKE	MISSISSAGI	feldspathic quartzite; minor argillite
				PECORS	micaceous and feldspathic quartzite, argillite, greywacke, siltstone, mica schist
				RAMSAY LAKE	paraconglomerate, greywacke, phyllite orthoconglomerate

The Pecors was evidently deposited in a fluctuating environment, in part fairly shallow and high energy, as indicated by the large bedding units and crossbeds, "clean" quartzite, and well sorted pebble conglomerate layers. Much of the lower part was probably laid down by turbidity currents in deeper water, and the argillite and siltstone in quiet water. The environment became rapidly shallower, possibly fluvial, near the top of the formation transitional into the feldspathic arenite of the Mississagi Formation.

Mississagi Formation (AM)

Distribution and lithology. The Mississagi occupies most of the south shore of Lake Panache and adjacent islands in a strip up to 3.2 km wide. Although the formation is relatively resistant, extensive exposures are lacking because of forest cover; however, the islands and shorelines provide excellent outcrops.

The Mississagi is composed dominantly of homogeneous feldspathic quartzite. Argillite, siltstone, and a few subgreywacke or arkose beds form volumetrically unimportant intercalations in the quartzite pile. Pebbly and conglomeratic quartzite layers are common but are thin and discontinuous. In a few places, orthoquartzite beds occur. Sedimentary cycles were reported in the formation north of the report-area by Palonen and Mills (1970) and Card et al. (1975). They were not recognized in the present area and if present are poorly developed. No appreciable change in the character of the formation was observed from west to east along Lake Panache.

The feldspathic quartzite is a grey to buff, white to dirty yellow weathering, medium-to coarse-grained sandstone deposited in units 0.3 to 3 m thick. It contains up to 20 per cent feldspar and minor amounts of muscovite or biotite. In places the quartzite is sparsely pyritic, and locally in the eastern part of Lake Panache carries biotite or small garnet porphyroblasts. Accessory minerals are scarce.

Contact relation, structure and thickness. The Mississagi is conformable and gradational with the underlying Pecors Formation. In this area, most of the contact zone is covered by Lake Panache, and only at Burnt Island and Gabodin Lake is the gradation seen whereby the impure argillaceous sandstones of the Pecors become subordinate to feldspathic quartzite. The transition is gradual, occupying a thickness of 60 m or more.

The Mississagi sandstones are crossbedded throughout, and also display ripple marks and graded foresets. Festoon and planar crossbeds are common. No thorough systematic paleocurrent study was done in the formation mainly because of time limitations and the deformed condition of many beds, but a limited number of observations on crossbeds were made at about 20 favourable locations on Lake Panache. Most measurements indicate a northwesterly source, but local current flow from the east, southeast and rarely, southwest, is also indicated. Crossbed orientation tends to be uniform for individual stations.

The Mississagi contains many minor folds and faults so that an accurate estimate of its thickness is difficult. From map relations, minimum thicknesses appear to range from 1500-2600 m, thickening eastward.

Quirke Lake Group

Bruce Formation (AB)

Distribution and lithology. The Bruce Formation is distributed continuously across the northern part of the map area, coextensive with the underlying Mississagi. Good exposures occur north and east of Peter Lake, Goschen Township, and north of Bassoon Lake, Dieppe Township. A narrow slice of Bruce also occurs at the Grenville Front in Sale Township, along the east side of Annie Lake. A small area in the southwest, near Killarney Bay, that was previously identified as Bruce (Quirke and Collins, 1930) was classed by the writer as tectonic breccia.

The Bruce Formation consists essentially of siliceous paraconglomerate. Near the base, and locally at higher levels, the paraconglomerate carries lenses and blocks up to 2-3 m across of feldspathic quartzite similar to that of the Mississagi. No change in the general lithological character of the formation was noted from west to east across the area. With respect to its clast content and siliceous character, the paraconglomerate resembles that of the Ramsay Lake Formation in this area, and is dissimilar to that of the Gowganda Formation of the overlying Cobalt Group.

The Bruce paraconglomerate is a tan, buff or rusty weathering rock characterized by scattered white to grey granitoid, quartz, or feldspar megaclasts set in a quartz-rich, unsorted, commonly pyritic greywacke matrix. Metavolcanic, quartzite, and schist clasts also occur in minor amounts, but by far the majority of clasts consist of granite and quartz. Megaclasts range, evidently randomly, from few to abundant, and from pebble to boulder size, but for the most part they are pebbles that are rather sparsely distributed. The coarse part of the matrix consists of angular feldspar and more-rounded smoky or blue quartz grains, the latter conspicuous in numerous outcrops. The uppermost part of the Bruce is calcareous, a feature that is inconspicuous in the field except where scapolite porphyroblasts have developed, as in the northwest corner of the area. This appears to be a characteristic common to the Bruce Formation along the entire Huronian belt, having been noted in the Elliot Lake area (Pienaar, 1963, p. 31) and between Sault Ste. Marie and Blind River (Frarey, 1977), as well as other parts of the Sudbury-Espanola district (Card et al., 1977, p. 53).

The paraconglomerate matrix consists of subrounded and rounded quartz grains up to 5 mm across, angular plagioclase and potassium feldspar, and a few rock fragments in a much finer sandy to silty paste composed largely of sericite, chlorite and quartz. Pyrite and pyrrhotite blebs and disseminations are common but comprise less than 2 per cent.

Contact relations, structure and thickness. Where the contact can be observed, the Bruce Formation is abruptly gradational with the underlying Mississagi. In the south-central part of Lake Panache, the transition occurs over a few metres, first by the appearance of pyritic beds and pebbly quartzite and then by a matrix change to darker subgreywacke, together with larger clasts. The paraconglomerate is notably massive and structure in the unit is confined to the bedding of the few quartzite lenses.

The outcrop width of the formation shows considerable change from place to place, suggesting similar variations in original thickness. Thus, the unit has apparent thicknesses of more than 1220 m between Bassoon Lake in Dieppe Township and Lake Panache, about 255-300 m to the east along Lake Panache, and 175-340 m farther east near Annie Lake. The area north of Bassoon Lake, however, is at least partly faulted and synclinal, and the actual thickness may approximate 600 m, still an abnormally high figure for this unit. At its easternmost point near Annie Lake, strong deformation, including considerable shearing, makes the estimate there unreliable also. The Lake Panache figure, 255-300 m, is acceptable for most of the area, although, as mentioned, there may be local thickening at Bassoon Lake. This thickness is comparable to the average immediately to the west (Card, 1976b), but is much greater than in the McGregor Bay area some 24 km to the southwest, where an average thickness of only 60 m is reported (Card, 1976a).

Espanola Formation (AE)

Distribution, stratigraphy and lithology. The Espanola forms a belt across the northern part of the map area adjacent to the underlying Bruce Formation, and also occurs in the small fault slice at the east side of Annie Lake at the Grenville Front and in the core of the McGregor Bay Anticline at Threenarrows Lake. Quirke and Collins (1930) mapped a wedge of Espanola at the head of Killarney Bay, but the present study indicates that the patches of calcareous rocks occurring there are part of a large mixed breccia zone. The formation is poorly exposed in general, and sizeable exposures are confined to the western part of its distribution area, northwest of Bassoon Lake and along the south shore of Lake Panache.

In part of this map area, the Espanola, as is common elsewhere in the Huronian belt, is divisible into three stratigraphic members, although these are less clear-cut than in the western part of the belt. The basal and the upper members are much thinner than the middle member and are very discontinuously exposed; they may have been deposited discontinuously, concealed by drift, or obscured by metamorphism and/or tectonism. The three-fold division, corresponding to the limestone, siltstone, and dolomite members of the western Huronian, could only be mapped for a distance of about 11 km, in the strip between Taylor Bay on Lake Panache and Bassoon Lake to the west. The basal member (AEl) consists of thin-bedded, grey, variably siliceous limestone interbedded with lesser amounts of dolomite and calcareous siltstone. The limestone displays the sharply corrugated weathered surface so characteristic of the limestone unit west of Blind River. The middle member (AEs), whose lower boundary is abruptly gradational, consists dominantly of grey- to black-weathering, thinly bedded, variably calcareous siltstone, with numerous thin intercalations of limestone, dolomite, and fine grained arkosic sandstone (Fig. 2). The dark calcareous siltstone is commonly spotted with scapolite porphyroblasts and in places actinolite is prominent in the dolomitic beds. Much of this siltstone is nonreactive to HCl, presumably because of metamorphism. The upper member (AEd), much the thinnest unit, is mainly brown weathering dolomite (dolostone), with subordinate limestone. Not far west of this map area, in the McGregor Bay area, Card (1976a) and Young (1973) described a sandstone member and a thin upper siltstone member above the middle calcareous siltstone member mentioned here; Young (1973) placed these members above the dolostone member as well. These units were not recognized in this map area, and may be confined to the McGregor Bay belt, as suggested by Young (1973). In the northwestern part of the present area, particularly at Ringer Lake, Truman Township, the lower part of the succeeding Serpent Formation contains argillite and silty beds, including a few that are calcareous, and was in part previously mapped as Espanola (Quirke and Collins, 1930). These calcareous strata are, however, subordinate to argillaceous quartzite and "Serpent-type" crossbedded feldspathic quartzite, and are therefore excluded from the Espanola Formation in this report.

The Espanola Formation is everywhere recrystallized and variably metamorphosed, and the original mineral composition correspondingly obscured. Thus, the present variable amounts of carbonate and quartz have wide ranges that do not directly represent original compositions, but vary with the formation of metamorphic calc-silicate minerals. In the siliceous limestones, the carbonate content, mainly calcite, ranges from 5 to 70 per cent and the quartz content is up to 40 per cent (but is commonly less than 20 per cent). Other common constituents are feldspar (0-10 per cent), muscovite (0-10 per cent), together with biotite and chlorite, tremolite, variable amounts of scapolite, and locally, epidote. Sphene and pyrite are common accessories. In the east toward the Grenville Front, for example at Annie Lake, Bevin and Sale Townships, the metamorphism increases, and actinolite, diopside and epidote are locally abundant.

In the siltstones, up to 20 per cent carbonate and 50 per cent quartz were seen, presumably representing minimal original contents. Tremolite or actinolite are common in dolomitic beds (Fig. 3), biotite or chlorite almost ubiquitous, and muscovite, although not common, is abundant in a few specimens. The biotite content is as high as 30 per cent. However, the most prominent metamorphic mineral in many of the siltstones is soda-rich scapolite (marialite) and its wide distribution and abundance are noteworthy. It is common over most of the distribution area of the Espanola, forming white weathering, resistant porphyroblasts up to 5 mm across and also occurring as a matrix mineral. The siltstones are commonly spotted or speckled as a result (Fig. 4). A scapolite content of over 50 per cent is estimated for extreme samples, and a content of 20 per cent is common. Its development is strictly strata-controlled. Scapolite and the micas appear to have had a sympathetic development. In the east, the metamorphism of the siltstones increases in grade, and at Annie Lake and east of Little Gabodin Lake, actinolite, epidote, diopside, augite, and microcline occur, whereas scapolite appears to diminish eastward. The siltstones of the area retain a fine grained granoblastic matrix except in the east where the grain size increases to 1 mm or more.

Quartz veins are common in the Espanola Formation, and at some places large pod-like masses and veins are developed, presumably by secretion during deformation and/or metamorphism. Exposures of such masses reach dimensions of 60 by 23 m.

Contact relations, structure and thickness. The Espanola Formation is conformable above the Bruce Formation. The actual contact was not observed, but successive outcrops at one locality indicate that the change

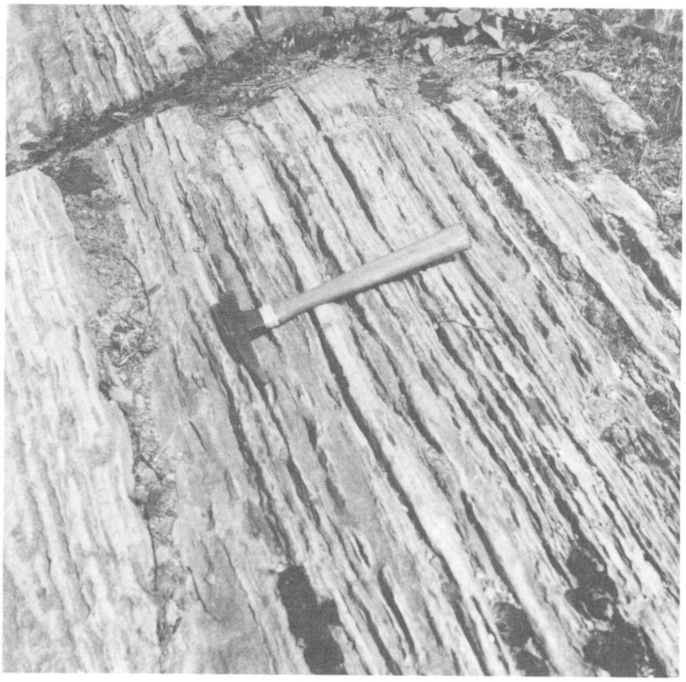


Figure 2. *Thin-bedded siltstone and calcareous siltstone of the Espanola Formation, south shore of Lake Panache, Dieppe Township. GSC 188814*

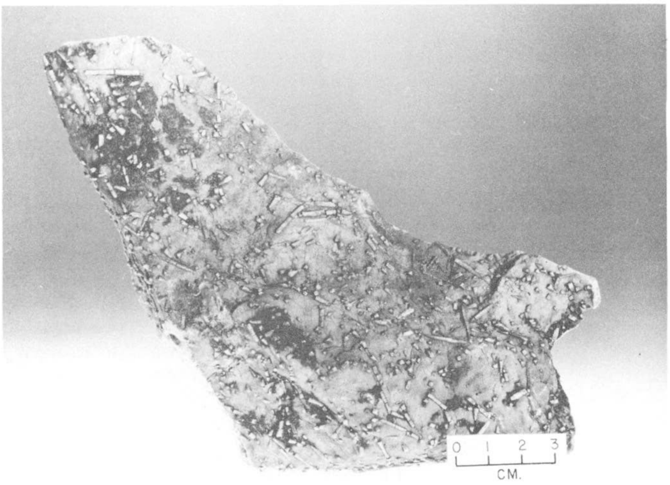


Figure 3. *Tremolite euhedra in dolostone of the Espanola Formation. South shore of Lake Panache near Little Twin Sisters Island, Dieppe Township. GSC 202839B*

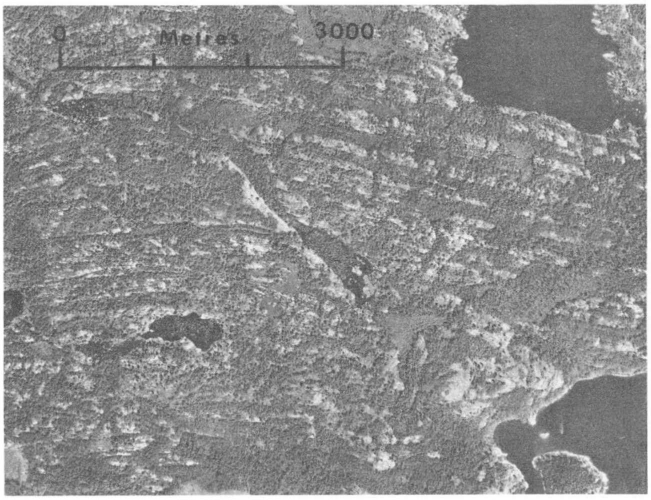


Figure 5. *Aerial view showing gross bedding style of the Serpent Formation in Truman Township northwest of Bear Lake. Each large unit consists of many festoon crossbedded subunits. A disturbed zone resulting from northwest-striking faults is shown lower right. Air photo 59-4609: 54-104, courtesy Ontario Ministry of Natural Resources.*

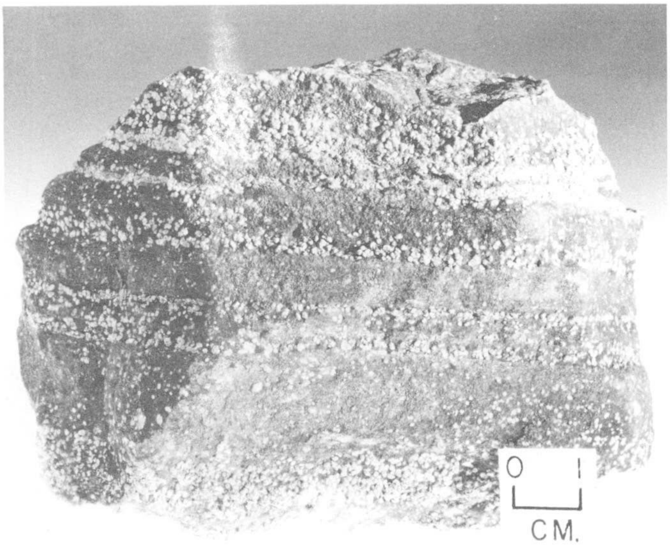


Figure 4. *Scapolite-rich beds in siltstone, Espanola Formation. Lake Panache, Truman Township. GSC 202839F*

in bed form and lithology from massive paraconglomerate to laminated calcareous beds takes place over not more than 6 m; the uppermost Bruce, as noted above, is calcareous in places. No interstratification near the boundary was seen.

The Espanola is the least competent of the Huronian formations and consequently contains numerous mesoscopic tectonic folds and faults. Slump folds are probably also present. Primary structure in the carbonate layers is confined to bedding but the siltstones exhibit load casts, mud cracks, small crossbeds, and ripple marks, in addition to laminated and lenticular bedding.

The original thickness of the Espanola is difficult to estimate because of internal deformation. The best estimate from map relationships is about 430 m, as shown near the south shore of Lake Panache, where deformation appears to be least. The basal limestone member is about 45 m thick, and the upper dolomite member, where recognized, appears to be only a few metres to tens of metres thick.

Serpent Formation (AS)

Distribution, stratigraphy and lithology. The Serpent Formation is coextensive with the underlying formations across the northern part of the map area and in the McGregor Bay Anticline in the west-central sector at Threenarrows Lake. The formation is well exposed in the western part of the area, especially in the northwest, between Bear Lake and Lake Panache. Shoreline exposures are generally bare and clean.

In the Lake Panache-Bear Lake section, the formation is abnormally thick and is divisible into three members, a basal member (ASt) consisting of interbedded quartzite, argillaceous quartzite, argillite and calcareous siltstone or argillite, a thick middle member, dominantly feldspathic quartzite (ASq), and an upper coarse grained arkose member (ASa). The upper and the basal member thin eastward and southward; the former is local to this part of the area and pinches out a short distance east of Bear Lake; the latter is inconspicuous from Goschen Township eastward, except at Annie Lake. Both are absent at Threenarrows Lake, 9 km to the south.

The basal member is well developed at Ringer Lake, Truman Township, and immediately south at Walker Lake. It consists of fine- to medium-grained, well sorted, tan or brown weathering arkosic sandstone, and white weathering, feldspathic quartzite or arkose similar to that in the main part of the formation, interbedded with thick- to thin-bedded argillite and quartzose siltstone. A few spotted, calcareous, scapolitic layers occur at Ringer Lake. At Walker Lake, the unit is noteworthy for its intercalation and for primary sedimentary features.

The overlying member constituting the bulk of the Serpent Formation consists of rather uniform, mostly medium grained, well sorted and well bedded feldspathic quartzite or arkose commonly separated by partings and beds of argillite.

Figure 6. *Graded foreset beds in large scale crossbedding in arkose of the Serpent Formation. Bear Lake, Roosevelt Township. GSC 188787*

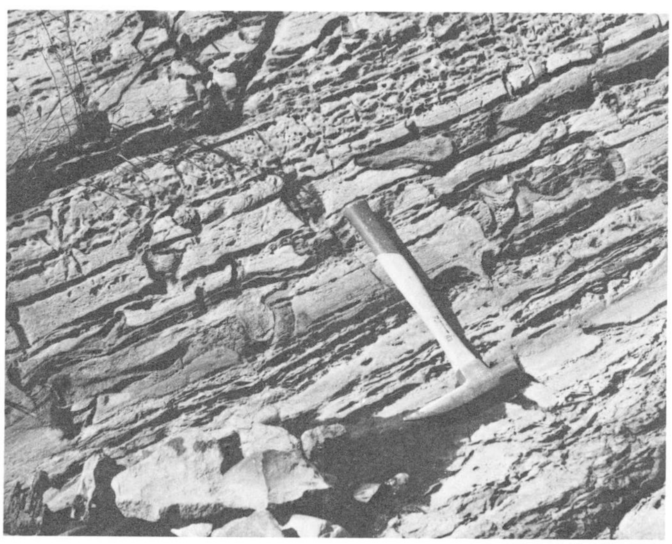


Figure 7. *Load cast structures in argillite-siltstone sequence, lower member, Serpent Formation. Walker Lake, Truman Township. GSC 188776*

Figure 8. *Mudcrack pattern in argillite-siltstone sequence, lower member, Serpent Formation. Walker Lake, Truman Township. GSC 188775*

The large scale bedding, readily visible in air photographs (Fig. 5), is notably regular, forming composite layers up to 90 m thick made up of individual lenticular, crossbedded, massive, or laminated quartzite beds up to 2-3 m thick; the composite units are separated by thin argillitic, largely unexposed layers or composite layers. In outcrop, the quartzite beds commonly appear massive with little visible sign of internal bedding. The texture and high feldspar content give a characteristic dull white, porcelaneous appearance to clean weathered surfaces, a feature noted in numerous other Huronian areas and first described by Collins (1925, p. 56).

The feldspathic quartzite member includes minor amounts of other lithologies in addition to the argillite. Siliceous carbonate or calcareous quartzite layers up to 15 m thick were observed in the upper part of the unit in the eastern narrows of Threenarrows Lake, and isolated occurrences of similar beds were noted in the formation elsewhere. About 0.8 km south of the southeast bay of Peter Lake, Goschen Township, a single outcrop of argillite or siltstone slump(?) breccia was seen, interesting for its calcareous and pyritic matrix. Slumped argillite, small-pebble conglomerate, and paraconglomerate interbeds occur in the formation in the southwest bay of Annie Lake.

Between Harry Lake and Round Otter Lake in Stalin Township, conglomerate and interbedded quartzite and greywacke sequences 60-90 m thick occur at the top of the Serpent Formation. The conglomerate is characterized in some places by sedimentary clasts in a gritty calcareous matrix, in others by clasts of quartz and granitoid igneous rocks. Locally, the conglomerate of this sequence appears to scour the underlying feldspathic quartzite. Previously, these transitional beds were mapped as part of the Serpent (Frarey and Cannon, 1969), but in this report are included in the overlying Gowganda Formation because of the indications of erosion and the appearance of greywacke.

The third, uppermost, arkose member of the formation is, as indicated, restricted to the westernmost part of the area in the vicinity of Bear Lake in Roosevelt Township. It was mapped westward from that lake for 2.4 km to the west boundary of the map area and appears to extend for a limited distance east of the lake. The unit is a distinctive coarse grained, thick-bedded arkose, with a few minor argillite beds.

The arkose bedding units are commonly 3 m or more thick and are characterized by correspondingly large graded crossbeds (Fig. 6). This upper arkose continues westward beyond the limit of the map area (K.D. Card, personal communication, 1974).

Under the microscope, the matrix of the Serpent Formation is seen to be recrystallized, and only in places are relict clastic textures well preserved. The sandstones are commonly made up of a mosaic of angular to shard-like quartz and stubby sericitized feldspar grains; in some sections the latter show rounded forms that may be original grain shapes. Both plagioclase (An_{25-35}) and potassium feldspar (mostly microcline) are abundant, and most of the sandstones are arkoses (>20 per cent feldspar, in places >60 per cent). The proportion of plagioclase is greater in these arenites than in those of the Mississagi or Lorrain formations. Biotite, chlorite, sericite, and accessory pyrite are common and one specimen from Cuckoo Lake, Stalin Township, contains about 15 per cent epidote. The siltstone and argillite interbeds consist of mats of quartz, biotite, and sericite.

Contact relations, structure and thickness. The Serpent Formation is conformable and sharply gradational with the underlying Espanola. The transition is marked by a rather abrupt change from thin grey or brown weathering carbonate beds of the upper Espanola to interbedded siltstones, argillites and thick-bedded quartzites, including white weathering "Serpent-type" quartzite.

The Serpent Formation is marked by large scale bedding and crossbedding in feldspathic quartzite and arkose, by fine lamination in the quartzite in the lower part of the main (quartzite) division, and, in the argillites and siltstones of the lowest member by load structures, sedimentary fissure fillings, slump and flow structures, and mudcracks. The last-mentioned features are well shown at Walker Lake in a sequence of intercalated argillite, quartz siltstone and fine grained quartzite, where a sedimentary breccia has resulted from the fragmentation of quartz siltstone or quartzite beds by mass slumping of the argillite, and where thin argillite and quartzite beds are cut through by load casts and squeezing action from above (Fig. 7). In extreme cases this transection of beds produces a "load breccia". Mudcracks in this assemblage attest to shallow water-emergent conditions (Fig. 8), and deeper fissures that in some cases pass completely through quartzite beds are attributed either to desiccation or to minor movements. These fissures are now filled by argillite from adjacent beds.

The Serpent Formation, as noted above, is abnormally thick at the northwest of the map area between Bear Lake and Lake Panache. Assuming a thirty-degree dip, the basal member there is about 760 m thick, the feldspathic quartzite member 1060 m, and the upper arkose roughly 275 m thick, for a total thickness of 2100 m. 17 km east, between Peter and Deacon lakes, the Serpent appears to be about 1370 m thick. Close to the Grenville boundary, the formation is severely deformed and no thickness estimate can be made. To the south, in the McGregor Bay Anticline at Threenarrows Lake, the Serpent is evidently about 1060 m thick.

Cobalt Group

Gowganda Formation (AG)

Distribution, stratigraphy and lithology. The Gowganda Formation is coextensive with the underlying formations across the north half of the report area, occurs along the Grenville boundary from Annie Lake northward to the north edge of the map sheet, and occupies a large region to the southwest around Threenarrows Lake. A belt previously mapped as Gowganda farther south, between Baie Fine and Norway Lake (Quirke and Collins, 1930), has been reclassified as Gordon Lake Formation by the writer, and a narrow discontinuous belt between George Lake and the northeast end of Kakakise Lake, similarly mapped previously as Gowganda, has also been reclassified, as discussed later. In general, the formation is only locally well exposed, and close to the Grenville Front near Annie and Bell lakes, it is considerably deformed and metamorphosed.

The Gowganda of the map area is generally crudely divisible into three stratigraphic units, but locally as many as nine were recognized. Subdivision of the formation is best shown in the east-west belt between Harry Lake and the west edge of the map area, and also on the shores of Threenarrows Lake. The basal unit (AGp) consists largely of paraconglomerate, commonly referred to as "tillite", with lesser amounts of argillite, quartzite and minor orthoconglomerate. It is overlain by a thick, lithologically heterogeneous, intercalated unit (AGs) comprising laminated siltstone, argillite, white and pink quartz siltstone and fine grained quartzite, arkose, and a few paraconglomerate layers. This middle unit is characterized by interbedded sequences of argillite and fine grained quartzite or quartz siltstone that in many places display prominent load casts and large-scale soft-sediment deformation (slump) features. The boundary between (AGp) and (AGs) is unexposed, but is probably gradational. The third, uppermost member (AGa) consists of distinctive, evenly laminated, black, nonpebbly argillite. It is best exposed at Fish Lake in Stalin Township. A similar but thinner laminated argillite overlies the basal paraconglomerate member at Harry Lake, at Round Otter Lake and at Threenarrows Lake. This lower unit may correspond to Card's "Lower Argillite member" in McGregor Bay to the west (Card, 1976a).

The irregular detailed stratigraphy within the Gowganda Formation is exemplified by the following sections: (1) between Bear Lake and Howry Lake, in the northwest part of the area, and (2) 9.5 km east, south of Cuckoo Lake:

(1) Lorrain Formation

laminated argillite member 90 m

interbedded argillite and quartzite 245 m?

slump zone – quartz siltstone and fine grained quartzite blocks and clasts in argillite. Individual slump deposits may be separated by undisturbed bedded argillite.

argillite-siltstone – quartzite interbedded zone 350 m + paraconglomerate 180 m

lower composite member – paraconglomerate, argillite and quartzite 245 m

(2) Lorrain Formation

laminated argillite and siltstone member (ca. 140 ma)

gap

arkose

gap

arkose

gap

paraconglomerate

thin-bedded siltstone 75 m

paraconglomerate

arkose

thin-bedded siltstone plus sandstone (260 m)

laminated argillite 100 m

basal paraconglomerate member 300 m

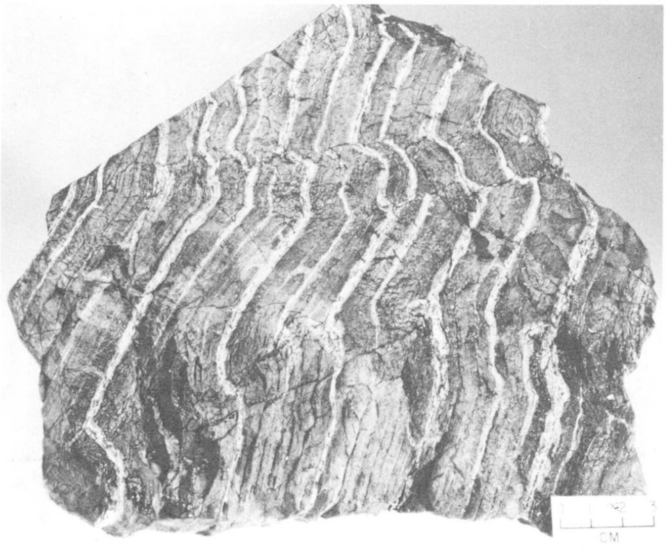


Figure 9. *Rhythmic bedding of argillite and siltstone, kinked and broken by second generation folding. Gowganda Formation, northwest extremity of Balsam Lake, Goschen Township. GSC 202839-G*

The basal member contains a high proportion of paraconglomerate beds but, as indicated, these also appear irregularly throughout the middle member. For example, paraconglomerate near the top of that member was seen on Doris Island, Threenarrows Lake, and on the peninsula to the east. Individual paraconglomerate beds are not traceable due either to lack of outcrop or original discontinuity. The paraconglomerates consist of a matrix of variably grey, unstratified quartzose or feldspathic greywacke sandstone, less commonly siltstone, holding scattered, unsorted clasts mainly of grey granitoid rocks, and a variety of other lithologies: quartz, basic igneous rocks, pink granite, schist, and metasediment. Volcanic clasts and Huronian clasts appear to be rare. Most clasts are pebble-size and many granitic clasts show a fair degree of rounding. The matrix is usually homogeneous for a given layer and grains are generally restricted in size to the medium to coarse range (1-0.25 mm) except for scattered, coarser grains of quartz or feldspar.

The argillites of the Gowganda Formation are grey to black, well bedded rocks. Bedding units range in thickness from 2 m to less than 2 mm. Some units consist of alternating light and dark argillite layers, some are exclusively dark argillite, and other units classed as argillite contain numerous thin layers and lenses of more quartzose silty sediment (Fig. 9). Occasional exotic (granitic) pebbles occur in the argillite horizons, suggesting ice-rafting. These granitic clasts are about 32 km from the closest point along the present southern limit of pre-Huronian basement in Drury Township, and in Gowganda time the distance to granitic basement was undoubtedly much farther, since the underlying Serpent Formation extended at least 80 km north of Lake Panache. The upper argillite member is predominantly black, very evenly and thinly laminated, and appears to lack rafted stones. As in neighbouring areas (Lindsey, 1971; Card, 1978a), varve-like couplets were not observed in the Gowganda argillite, in contrast to areas farther west in this part of the Huronian belt (e.g. the Massey area, Robertson, 1976) and to the western Huronian region (i.e. west of Cutler), where varved Gowganda argillite has been reported from a number of localities (Frarey, 1977; Hay, 1963; Robertson, 1977).

The least altered siltstones and argillites consist chiefly of variable proportions of quartz, feldspar, biotite, muscovite and chlorite. Some layers are relatively magnetite-rich (two to five per cent), accounting for the strong magnetic contrast of the Gowganda with adjacent formations, especially in the Threenarrows Lake area (GSC, 1965, Map 1516G). This magnetite is in part relatively coarse and euhedral, and is of metamorphic or recrystallization origin. In areas of higher metamorphism, the more pelitic layers in these rocks are commonly knotted and spotted by variable amounts of chlorite, staurolite, andalusite, retrograded cordierite, and rarely, garnet porphyroblasts. These minerals are most common in Goschen Township, notably in the north end of Bell Lake and to the north and northeast, but also are found to the southwest in the McGregor Bay Anticline at Threenarrow Lake. Although cordierite itself was not positively recognized by the writer, it was identified previously at Bell Lake by Brooks (1964, p. 30), and the large ovoid retrograded spots made up of quartz, sericite, and biotite prominent in some of these rocks evidently represent original cordierite porphyroblasts. Andalusite is much the most abundant and widespread porphyroblast, whereas staurolite and cordierite in the Gowganda are relatively scarce and evidently only occur at Bell Lake and at Gabodin Lake. Garnet is even scarcer. Although porphyroblastic Gowganda rocks are especially prominent around the northern part of Bell Lake in Goschen Township, near the Bell Lake Granite of the Killarney Batholith, they also occur at much greater distances from Front granites: 4.8 km away at Deacon Lake, 8 km distant in southeastern Caen Township, and 9.6 km distant at Threenarrows Lake, farther southwest. Thus the widespread development of these minerals in the Gowganda and other Huronian rocks is not a contact metamorphic product of the granite intrusion, but, like that of scapolite in the Bruce and Espanola formations, is an earlier regional thermal effect. Outside the report area, Card (personal communication, 1982) has interpreted andalusite near the Front granites to be of later, contact metamorphic origin.

A variety of sandstones occur in the Gowganda Formation, including gritty to medium grained arkoses and greywackes and medium- to fine-grained silty, feldspathic quartzites. The various types can occur in thinly intercalated sequences, commonly with argillite and siltstone, or form thicker (tens of metres) individual layers. Silty sandstone occurs extensively in the middle part of the formation as disrupted blocks in argillite and siltstone, particularly north of Fish Lake, Stalin Township.

A few thin beds of polymictic orthoconglomerate occur, mainly in the lower part of the formation. These consist of close-packed rounded pebbles, largely granitic, in a dark greywacke matrix.

Contact relations, structure and thickness. The Gowganda Formation overlies the Serpent Formation conformably. At several places, notably on islands in Bear Lake, the contact is abruptly gradational and characterized by the presence of lenticular grit and gravelly orthoconglomerate beds interbedded with feldspathic quartzite. This transitional assemblage resembles Pleistocene outwash deposits.

Structures in the Gowganda Formation include bedding, crossbedding, grain gradation, mud cracks, load casts and slump breccia. Interbedded argillite – siltstone – fine grained quartzite sequences are characterized by load casts in many places (Fig. 10 and 11), and rarely loading has produced extreme ball-and-pillow structure in sandstone beds (Fig. 12). The middle member of the formation is characterized by sliding and slumpage, resulting in some places in a chaotic mixture of fine grained or silty quartzite blocks in dark argillite. Differing from relatively simple two-component slump breccias are polymictic sedimentary breccias resulting

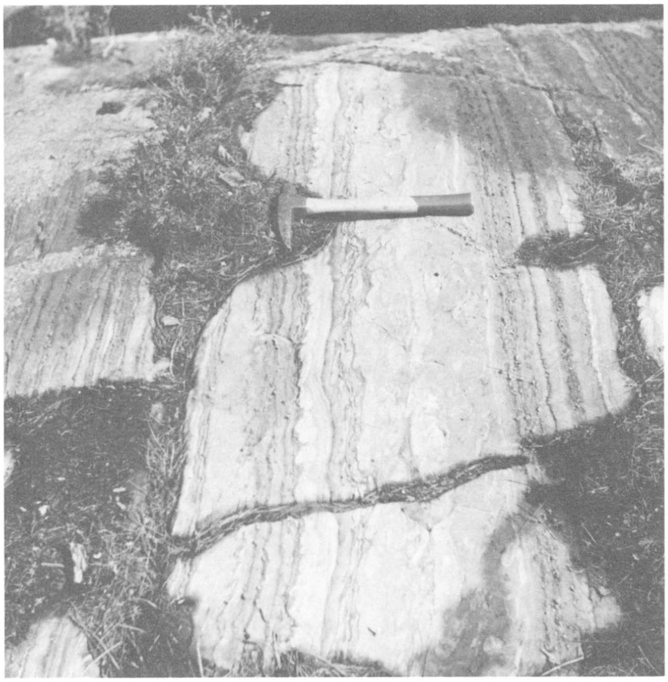


Figure 10. *Sedimentary structures in vertical hornfels beds, Gowganda Formation. Load casts occur in a disrupted siltstone horizon overlain by slumped mudstone bed (under hammer handle). Andalusite porphyroblasts are prominent in argillite beds above slump deposit. Bell Lake, Goschen Township. GSC 188841*

Figure 11. *Load casts in argillite-siltstone sequence. Gowganda Formation. Balsam Lake, Goschen Township. GSC 188848*

from more extensive and destructive subaqueous movements or slides. An outstanding example of this type occurs near the base of the formation in Roosevelt Township, on the southeast shore of Bear Lake (Fig. 13). This breccia exposed over an area roughly 60 by 16 m, is underlain by unstratified greywacke paraconglomerate and overlain by undisturbed, well bedded arkose. It consists of large (up to 8 m across) and small rounded sedimentary blocks lying randomly in a pebbly greywacke matrix with well marked flow lines. The larger fragments are of feldspathic quartzite somewhat similar to that of the Serpent Formation, and others consist of various types of laminated argillite and mudstone (the majority) and, rarely, paraconglomerate. Since argillaceous strata similar to the blocks do not appear in the section in this vicinity, or elsewhere in the Gowganda at or below this level, the argillite blocks appear to represent remnants of former deposits now removed, that travelled unknown but probably short distances downslope without disintegrating or deforming, as indicated by their sharp regular boundaries and preserved lamination. This would only have been permitted in such incompetent beds by partially consolidated or frozen conditions, conditions also indicated by the rounded quartzite blocks. Similar sedimentary breccia is exposed on the large island in Annie Lake.

The Gowganda Formation is estimated to be about 1220 m thick in Stalin Township near Harry Lake and 760 to 920 m thick at Threenarrows Lake farther southwest. Between Bear Lake and Howry Lake in the northwest part of the report area, in the same section where the Serpent Formation is thickest, the Gowganda also appears to have been greatly thickened, to roughly 2100 m.

<u>Lorrain Formation (AL)</u>

Distribution, stratigraphy and lithology. The Lorrain is the most widely distributed, most resistant, thickest, and best exposed of the Huronian formations. It forms many of the hills and ridges of the La Cloche Mountains that stretch along the North Channel of Lake Huron from the Spanish River eastward to the Grenville Front. Many of the crests and upper flanks of these hills are almost devoid of vegetation, so that numerous excellent exposures are available.

The area is advantageous for study of the Lorrain, for complete and reasonably continuous stratigraphic sections exist on either flank of the McGregor Bay Anticline, i.e. on the north and south ranges of the La Cloche Mountains. Innumerable cross faults, fractures, and shears have disturbed the strata, obscuring local relationships, altering textures, and deforming primary sedimentary structures locally or over larger areas, but these have not, with a few exceptions, seriously interrupted the internal succession or caused major dislocations within or at the contacts of the formation.

The Lorrain is almost exclusively arenaceous sandstone, either quartzite or arkose, and considering its great thickness, represents an enormous rapid and uninterrupted accumulation of quartz and feldspar debris from the source area. Pelitic beds or even thin interbeds are virtually absent. The upward lithological trend in the formation is from coarse grained arkose to feldspathic quartzite to medium grained orthoquartzite to fine- or very fine-grained orthoquartzite.

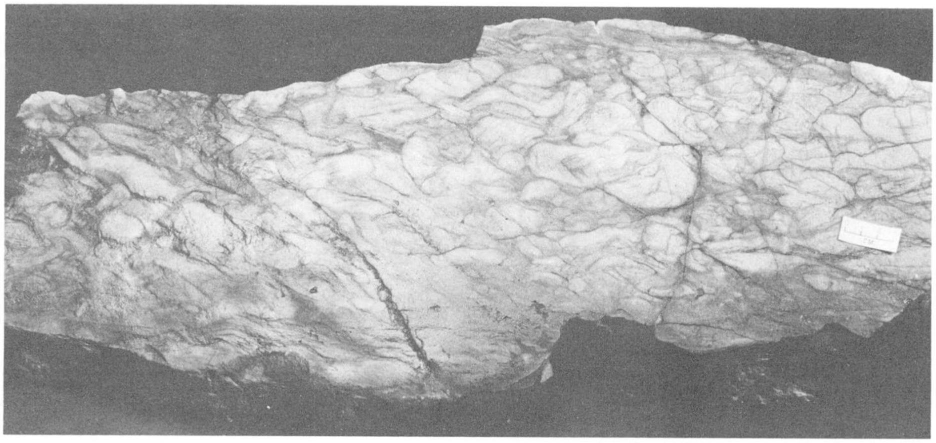


Figure 12

Aggregation of detached sand pillows (sedimentary pillow structure), Gowganda Formation. Bear Lake, Roosevelt Township. GSC 202839-D

Figure 13. *Sedimentary breccia, Gowganda Formation, Bear Lake, Roosevelt Township. Quartz-rich siltstone and sandstone blocks (white areas) and argillite blocks randomly oriented in mudstone-greywacke matrix. GSC 188791*

Figure 14. *Thick-bedded arkose, basal member, Lorrain Formation, on the south limb of the McGregor Bay Anticline. Threenarrows Lake, Killarney Township. GSC 188886*

This is expressed in the following subdivision scheme employed in mapping the formation:

Lorrain Formation

Member	Lithology
Member 4:	fine grained orthoquartzite
Member 3:	medium- to coarse-grained orthoquartzite; quartz-pebble beds
Member 2:	medium- to coarse-grained, green to white feldspathic quartzite and arkose, minor orthoquartzite
Member 1:	basal medium- and coarse-grained granular or pebbly arkose; includes basal transition zone

The contacts between these members are gradational and are generalized on the accompanying map (in pocket).

To the west of the report area, different subdivisions have been employed. In the Whitefish Falls area, Hadley (1968) used a three-fold scheme, combining the two orthoquartzite units listed above, and Card (1976a) described six lithostratigraphic units in the McGregor Bay-Bay of Islands area. In addition to those shown above, Card (ibid, p. 17) distinguished a relatively thin mixed basal member of micaceous and feldspathic sandstone, siltstone and greywacke, and a ferruginous member located above the green member of this scheme. The first of these is included by the writer in the basal arkose member and the second evidently does not exist throughout most of the report area as a separate entity, although some hematitic beds were observed at this stratigraphic level. Hadley's (1968) account, a doctoral dissertation on the Lorrain of this and other regions, provides numerous detailed petrographic and sedimentological data of the various Lorrain lithologies, many of which are applicable to the present area.

Member 1 (ALa). The basal member consists predominantly of medium grained to gritty and pebbly buff, pink, greenish or brownish weathering, massive to strongly crossbedded arkose. Locally, siltstone is interbedded with the arkose at its base, and in a number of sections a thin but appreciable succession, up to 150 m thick, of siltstone and finer grained grey arkosic sandstone occurs between the coarser, coloured arkoses and the uppermost laminated argillite of the Gowganda Formation. As mentioned, these beds have been accorded member status in the Lorrain by some authors (Card et al., 1977; Card, 1976a, b).

The arkose is well bedded in lensoid to tabular units up to two or three metres thick (Fig. 14), commonly made up of trough crossbeds which may comprise individual foreset

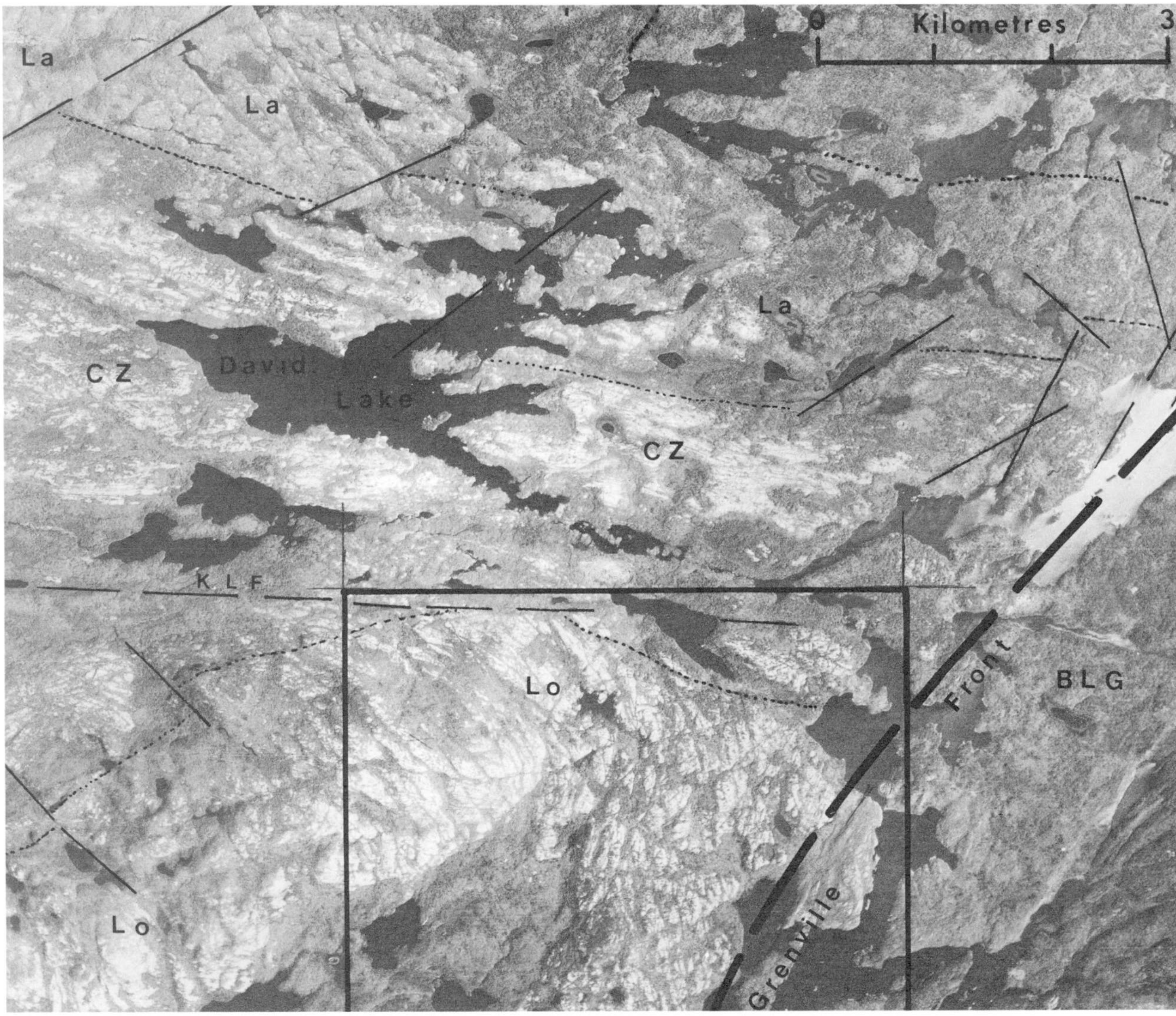


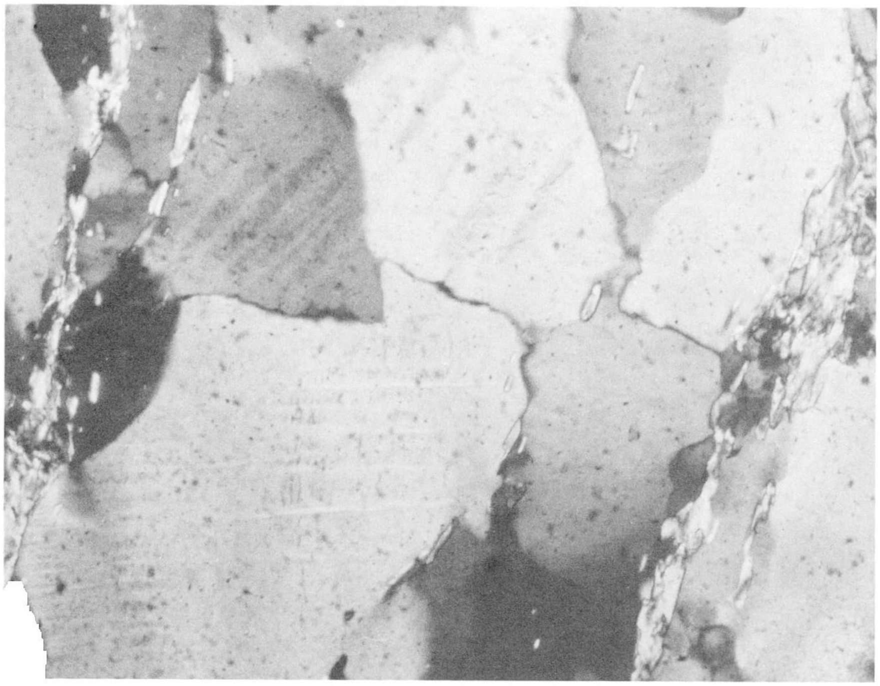
Figure 15. *Aerial photograph showing terrane around David Lake (centre). Features visible from north to south are: basal arkose member of the Lorrain Formation (La), cataclastic, faulted zone (cz) in middle Lorrain beds flanking David Lake, the Kirk Lake Fault (KLF), and Lorrain orthoquartzite (Lo) of the South La Cloche range. BLG = Bell Lake Granite. The outlined area shows the profusion of faults in the upper Lorrain Formation that result in pseudostratification in aerial view. Bedding strike in these fault blocks is east-southeast. Air photo A13020-48, National Air Photo Library.*

layers two to several centimetres thick. Sorting is poor, and granules and small pebbles less than 2 cm across, many of which are simply large potassium feldspar crystals or parts of crystals, or vein quartz, occur in isolation. The member appears to lack conglomerate horizons. Graded bedding is common in the arkose both in plane beds and in the foresets of crossbeds.

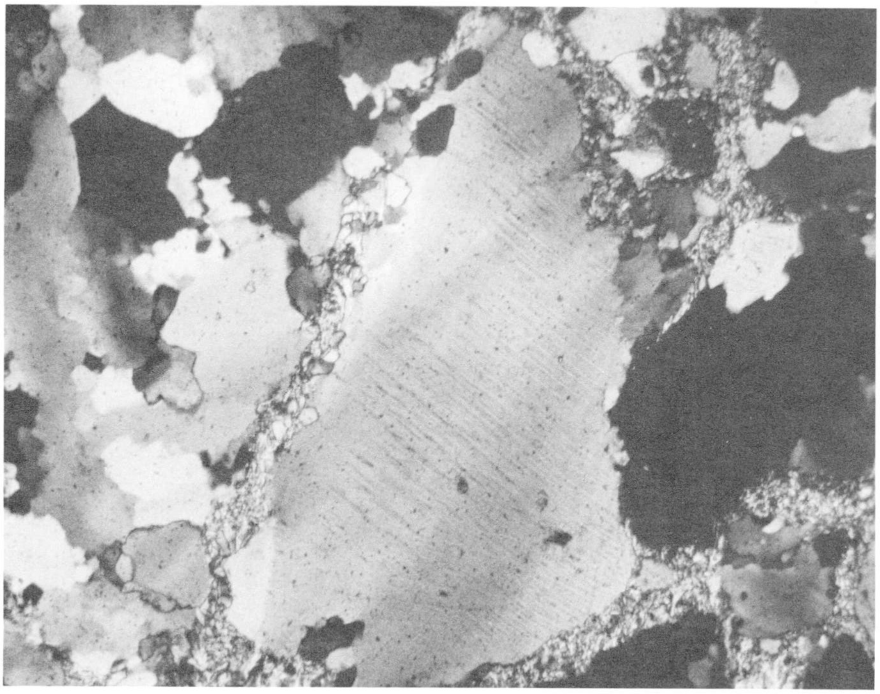
Petrographically the sandstones of the basal member are arkosic arenites (Williams et al., 1954), inasmuch as they evidently contained little clay matrix. The rocks consist of up to 50 per cent feldspar (K-feldspar exceeding plagioclase), up to 70 per cent quartz, and a fine "matrix" or mat of sericite commonly amounting to 5-10 per cent. Most samples are metamorphosed and cataclased to some degree and a considerable proportion, possibly all, of the sericite is secondary, for the most part replacing quartz. Epidote and/or biotite appear in finer grained basal arkose at Balsam Lake. Original matrix textures and grain shapes are not preserved.

Member 2 (ALf). This member consists of medium- to coarse-grained, green to white arkose, feldspathic quartzite, and orthoquartzite. These rocks are more uniform and better sorted than those of member 1, mostly consisting of quartz and white weathering feldspar in a fine grained matrix that is commonly a sea-green due to the presence of ferruginous muscovite. Chrome mica (fuchsite) has been identified by Card (1976a, b) in similar rocks in the adjacent area to the west. The green arkose beds are thin to absent in some sections, possibly due to faulting. Some of the arkose at this level is pink, as in the basal member; near the north end of Johnnie Lake the member contains a mappable zone of orthoquartzite. Quartz granules are common and isolated quartz pebbles and pebble lenses occur. The feldspar content, largely plagioclase, is generally under 25 per cent and the quartz content is consistently greater than in the underlying member. The proportion of matrix also has increased (up to 35 per cent) but again because of cataclasis and alteration an indeterminate amount of the mica is secondary, replacing quartz and feldspar.

Member 3 (ALo). The third member is characterized by a marked decrease in feldspar and matrix content and comprises a rather monotonous succession of mostly medium grained white orthoquartzite (quartz arenite) with numerous thin quartz-pebble beds and lenses and rare pelitic beds. Near David Lake, the member includes a zone of peach to flesh quartzite (ALop) containing both plagioclase and potassium feldspar. In scattered localities, streaks and pods of hematite appear in the quartzite. Vein-like shear layers a few centimetres thick containing andalusite or epidote occur in a few places near David Lake.



A. Cataclastic orthoquartzite showing deformation lamellae controlled crystallographically and foliation defined by muscovite layers (left and right). x60. GSC 203843-B



B. Strain lamellae in single grain of cataclastic orthoquartzite. x40. Characteristic features seen in A and B are development of inclusion-rich and clear lamellae, discontinuity of lamellae, and gentle curvature of lamellae (lower right in B). 1.6 km north of Norway Lake, Killarney Township. GSC 203843-G

Figure 16. *Planar strain lamellae in quartz, Lorrain Formation.*

Member 4 (ALof). The fourth, uppermost unit of the Lorrain consists almost entirely of pure, very fine- to medium-grained, white orthoquartzite. A few scattered quartz pebbles or layers containing pebbles less than 25 mm in length occur. Unsheared orthoquartzite beds are composed of well rounded quartz grains in a quartz cement with minor sericite, and commonly contain over 90 per cent quartz. Similar beds in the Lorrain Formation are quarried for silica at Whitefish Falls, 18 km west of the report area. The unit contains a few feldspar-bearing beds and silty intercalations that are less than 15 cm thick. Where cataclased, the orthoquartzite displays excellent microscopic layering and sericite, although still inconspicuous megascopically, is much more abundant, forming clusters and rows of tiny platelets.

Most samples of the Lorrain Formation show cataclastic effects. These are particularly prominent in a large east-west zone through Great Mountain Lake and David Lake to Bell Lake, and to the southeast toward the Grenville Front (Fig. 15). In many places primary features are obscured or obliterated by shearing and crushing. Under the microscope, cataclasis is reflected by crushed grains, mortar structure, serrate grain boundaries, strained, broken, bent or elongated quartz, and flaser or augen structure. In some thin sections quartz has a crude banded extinction, and in several, fine deformation lamellae are developed. These Boehm lamellae include both inclusion-free and inclusion-rich lamellae that display characteristic undulating borders and discontinuity of the lamellae pattern within the grains (Fig. 16). Quartz deformation lamellae have not been previously reported from rocks of the Sudbury-Lake Huron district, except those near Sudbury attributed to shock metamorphism (French, 1972).

Contact relations, structure and thickness. The Lorrain Formation conformably overlies the Gowganda Formation. Contact relations are well shown just east of Fish Lake in Stalin Township, in the central part of Balsam Lake, Goschen Township, and along the northern and southern reaches of Threenarrows Lake in Roosevelt, Stalin and Killarney townships. The laminated dark argillites or pelitic siltstones of the uppermost Gowganda are directly followed without interbedding by medium grained arkose, subgreywacke, and arkosic siltstone that rapidly give way upward to the coarse grained to pebbly arkose that constitutes the bulk of the basal Lorrain member. The change in depositional environment, transport energy, and provenance material from the uppermost Gowganda into the Lorrain is notably sharp and rapid.

The Lorrain is characterized throughout by crossbedding and to a lesser extent by graded crossbedding. Bedding units in the formation become thinner upward, from the thick-bedded basal arkose to the upper orthoquartzite member, where beds are generally less than 0.6 m and commonly less than 0.3 m thick; the scale of crossbedding decreases accordingly. Crossbedding in thin-bedded orthoquartzites, although abundant, is commonly inconspicuous and also is commonly deformed, so that in many outcrops facing directions are not obvious. Ripple marks are not common, although excellent asymmetrical marks were observed at the top of the Lorrain near Norway Lake. Gradational grain size is best shown in the planar beds and foresets of the basal arkose member and the medium grained orthoquartzite.

The Lorrain Formation, from map relations on the flanks of the McGregor Bay Anticline, has an estimated thickness of 2140 to 2740 m, neglecting internal deformation effects. In a section between Threenarrows Lake and Artists Creek, Killarney Township, estimated thicknesses of members from the base upward are roughly 765 m, 610 m, 455 m and 365 m respectively, for a total of 2195 m.

Gordon Lake Formation (AGL)

Distribution and lithology. The Gordon Lake Formation occurs in the southwestern part of the report area in a belt 900 to 2100 m wide, extending for 17 km from the western boundary to the western part of Carlyle Township, where it is faulted out. The formation occupies a valley between the more resistant quartzites of the underlying Lorrain Formation and the overlying Bar River Formation, and is only locally well exposed. Prior to the present investigation, this belt was mapped as Gowganda Formation (Quirke and Collins, 1930). The Gordon Lake Formation also underlies part of Killarney Bay in the extreme southwest, where the upper part is well exposed on headlands along the southeast shore near the boundary of the report area and beyond.

The Gordon Lake consists mainly of variably argillaceous, feldspathic, and siliceous siltstones, with lesser amounts of argillite, fine grained quartzites and cherty beds. It may also include minor dolomite and calcareous siltstone beds at Killarney Bay, a problematic question discussed later. The strata of this formation are characteristically thin-bedded, regular, and distinctively varicoloured. Many of the weathered surfaces, particularly between O.S.A. Lake and Norway Lake, are spotted due to metamorphic clots of micaceous minerals up to 10 mm across. The argillites and siltstones are grey or greenish grey, weathering white, grey, greenish grey, buff, or brown. They are commonly layered in units less than 2.5 cm to several centimetres thick. The fine grained quartzites appearing irregularly among the siltstones and argillites are grey to pink and somewhat thicker bedded, although rarely more than 10 cm thick. Cherty beds are locally abundant on islands in the western part of O.S.A. Lake, where green, black and brownish varieties are intercalated in the upper part of the formation. Most of these cherty beds display very fine grained clastic textures. Aside from the thin basal transition zone, no internal stratigraphy is discernible and the formation was not subdivided.

The quartzites and siliceous siltstones of the Gordon Lake consist of up to 75 per cent subangular quartz, 5 to 10 per cent feldspar (K-feldspar > plagioclase), and variable amounts of matrix up to 35 per cent, composed of micas, chlorite, quartz and feldspar. In the argillaceous rocks the micaceous matrix exceeds 50 per cent. In areas to the west, Card et al. (1977) reported up to 5 per cent carbonate cement in some Gordon Lake samples. The metamorphic clots consist of a fine grained mat of sericite, minor biotite, chlorite and quartz.

Contact relations, structure and thickness. The Gordon Lake is abruptly conformable with the underlying Lorrain. The change from white fine grained Lorrain orthoquartzite to siltstone and grey quartzite of the Gordon Lake is well shown at Baie Fine in Killarney Township, and takes place by interbedding of the lithologies over about 15 stratigraphic metres. In places, such as along O.S.A. Lake, the Lorrain-Gordon Lake contact zone is sheared and may be the locus of appreciable displacement.

Sedimentary structures in the formation include ripple marks, mud cracks, crossbedding, slump structures and load casts. The Gordon Lake was evidently deposited during an extended period of tectonic quiescence in the source area, in a shallow to very shallow low-energy environment. The formation has suffered considerable internal deformation and contains minor folds, faults, breccia zones, and numerous shear zones. Divergent strike trends due to tectonism are well shown in the southern part of Killarney Lake. Penetrative deformation or recrystallization, however, has not been widespread and even delicate primary structures are well preserved.

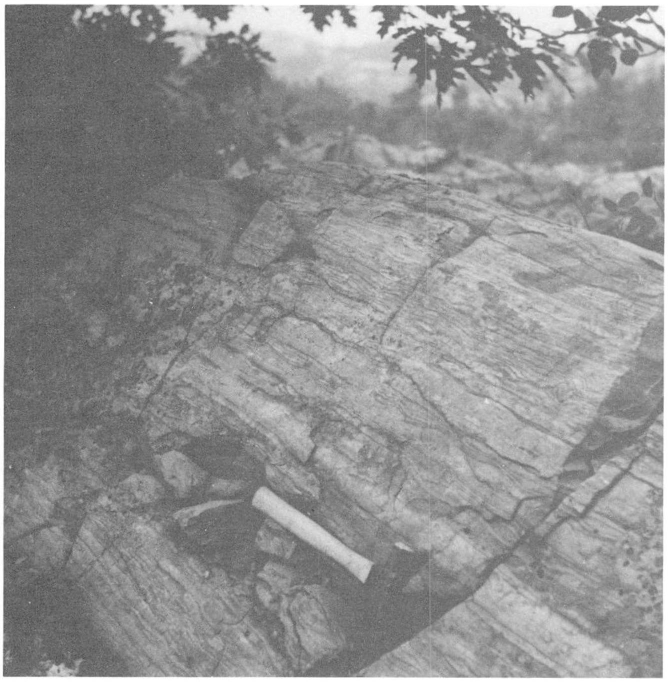


Figure 17. Variegated siltstone and fine grained sandstone of the Bar River Formation, commonly intercalated with orthoquartzite and commonly displaying tectonic and soft sediment deformation. Near Lumsden Lake, Killarney Township. GSC 188939

The thickness of the Gordon Lake is estimated at 1060-1280 m. The abnormal width of the formation at Killarney Lake is probably due to local folds and faults.

Bar River Formation (ABR)

Distribution and lithology. The Bar River Formation occupies a belt adjacent to the underlying Gordon Lake Formation extending from Killarney Bay on Lake Huron northeastward to western Carlyle Township, where it is faulted out. The formation is ridge-forming and includes some of the highest hills of map area – Leading Mark Hill (445 m), Gulch Hill (460 m) and Killarney Peak (415 m). Much of it carries only sparse vegetation or none, and the formation is abundantly exposed. It is conveniently crossed by well-used trails from Lamorandière Bay to Baie Fine, from the southwest end of George Lake to Baie Fine, and the portage trail between George Lake and O.S.A. Lake; the first and second of these trails traverse complete sections of this unit as preserved. The top of the formation is not preserved because of granite intrusion and/or faulting.

The Bar River, formerly mapped as Lorrain and Gordon Lake ("Banded cherty quartzite"; Quirke and Collins, 1930) consists of orthoquartzite and subordinate siltstone and argillite. The orthoquartzite is white weathering and almost uniformly fine grained, resembling the uppermost Lorrain member. It comprises practically all of the lower 640 m of the formation, in beds 0.6 to 1 m thick, interrupted at irregular intervals by more pelitic partings and thin interbeds. A few bluish, hematite-bearing orthoquartzite beds also occur in this member, and in the syncline just south of Baie Fine and Cave Lake, fine grained red quartzite forms a horizon near the top.

The upper half, approximately, of the formation is varied, consisting in large part of orthoquartzite similar to that below interrupted at several levels by closely intercalated sequences (ABRi) of grey, buff, red, pink, and greyish blue layers of siltstone, fine grained quartzite, and argillite (Fig. 17). Repetitions of such intercalations, capped by white orthoquartzite, lend a rough cyclicity to this part of the Bar River Formation. Individual layers in these intercalations range from mere laminae to several tens of metres in thickness, and form aggregates up to several hundred metres thick, particularly prominent north, west, and southwest of George lake and in the syncline south of Baie Fine. Commonly, the thin-bedded siltstone and fine grained quartzite of these zones are strongly deformed by folding that obscures their real thickness, or are squeezed out between orthoquartzite masses so that particular layers or sequences are difficult to define or trace from one section to another. Areas of the intercalated rocks shown on the map (ABRi) are somewhat generalized. The intercalated sequences in the Bar River appear to decrease in volume northeastward from George Lake. The bluish quartzite and siltstone contain matrix hematite, usually in minor quantities, but ranging in selected samples up to 15 per cent iron (Young, 1968). In places the iron has been mobilized into veins and shear zones that in past years attracted prospecting, but neither the sedimentary layers nor the veins are of economic interest.

Contact relations, structure and thickness. The contact of the Bar River with the underlying Gordon Lake Formation is conformable and gradational. The change takes place by interbedding of siltstone and white orthoquartzite over a thickness of about 30 m. Sedimentary structures in the formation are festoon crossbedding and ripple marks in the white orthoquartzite and small scale current bedding, including ripple drift crossbeds, in the siltstones. The formation is strongly faulted throughout and in many outcrops bedding and original texture have been obscured by intricate fracturing, strong cataclasis, and/or recrystallization. In many places a rubble of fractured quartzite blocks has formed over outcrops. The preserved thickness of the Bar River is obscured by its deformation, but appears to be roughly 910 to 1220 m.

The uppermost Bar River Formation is bounded on the southeast by a largely covered valley for about 16 m northeastward from Killarney Bay, much of it occupied by George Lake, Freeland Lake, Kakakise Lake and their connecting streams, but small patches of sediments, unlike those of the Bar River Formation described above but possibly representing higher parts of the formation, occur at the northeast end of George Lake, the northeast end of Kakakise Lake, and along the southeast shore of Kakakise Lake. Just beyond the northeast end of Kakakise Lake, Carlyle Township, a sequence of grey metaquartzite, metasiltstone, meta-argillite and minor white orthooquartzite totalling possibly 150 m thick, bounded on the north by drift, dips southeastward against the Terry Lake Diorite of the Killarney Batholith, and thinner remnants continue on strike for about 1.5 km beyond the lake. Remnants of grey metaquartzite that occur in granitic rocks and in amphibolite along the southeast shore and on islands of Kakakise Lake probably also belong to this sequence, which lacks the close intercalation and the hematitic beds of the sequence described in the upper Bar River. The stratigraphic position of these varied strata at Kakakise Lake is uncertain because of the lack of top determinations and the probability that they are in fault contact with both the Bar River beds to the northwest and the Killarney Batholith to the southeast. Their relationship is further complicated by the fact that four large xenoliths up to two hundred metres across in the diorite within 150 m of the contact with these beds consist entirely of white orthoquartzite. These xenoliths, however, may be interpreted as having been derived from lower parts of the Bar River, and the mixed sequence in question and also the smaller remnants along Kakakise Lake are tentatively assigned to that formation.

Apparent stratigraphic anomalies and uncertainities exist at other points along the margin of the Killarney intrusions. Another group of strata of similar position to that at Kakakise Lake occurs on the low peninsula at the northeast end of George Lake, between the Front granite on the southeast and the orthoquartzite hills of the Bar River Formation on the northwest side of the lake. Here the beds, comprising siltstone, argillite and dark quartzite, are altered, locally contorted and brecciated, lack top determinations, dip southeast, and are possibly entirely fault-bounded, obscuring their stratigraphic position. The writer (Frarey and Cannon, 1969) and Card (1978a) included these beds in the Bar River Formation and on the accompanying map (in pocket) they are shown as questionable Bar River. However, in addition to the above lithologies, scapolitic calcareous beds occur near the northeast corner of George Lake, and dolomite or crystalline limestone blocks were found in a poorly exposed breccia near the inlet to the lake. These calcareous occurrences render the correlation with the Bar River equivocal, as no such rocks appear elsewhere in that formation.

Restricted occurrences of carbonate rocks elsewhere along strike are likewise problematic. Isolated dolomite and scapolite-bearing blocks also occur 8 km farther southwest in the large breccia at Lamorandière Bay, Lake Huron, and similar rocks occur at the boundary of the report area, in breccia and bedded outcrops near the head of Killarney Bay. The writer left the beds at Killarney Bay unclassified in the preliminary report on this area (Frarey and Cannon, 1969); later, from relationships in the adjoining area, Card (1978a) included them in the Gordon Lake Formation, and this is followed here. Again, however, the carbonate rocks are anomalous. Finally, near the southwest end of Kakakise Lake, a large dolomite block several metres wide and possibly 40 m long lies adjacent to the Killarney Granite at its sheared northern contact. Its contacts are unexposed. Although this dolomite is also strongly deformed, it possesses a layering that may represent stratification. These indications are far from conclusive, but all point to the possibility that the deposition of white, crossbedded orthoquartzite and its associated argillite-quartzite-hematitic siltstone intercalations in the upper part of the Bar River was succeeded by a new regime in which pelitic beds, mineralogically immature sandstones and siltstones, and calcareous rocks were deposited. These rocks may have constituted an additional Huronian sedimentary formation above the Bar River. Correlation with the Gordon Lake or Bar River requires a distinct and sudden southward facies change from the closest lithologies of these formations, in particular to account for the carbonate. An additional complication is that hydrothermal(?) dolomite lenses were observed in a fault at the granite contact near the outlet of Kakakise Lake, and at least some of the breccia dolomite blocks mentioned may be similarly derived. Their origin remains uncertain.

Volcanic rocks

In Killarney Bay, at the western edge and immediately west of the report area, small areas of porphyritic, massive and amygdaloidal mafic metavolcanic rocks were observed by the writer on Pine Island, Sheep Island, Partridge Island, and on three smaller unnamed islands. Aside from the phenocrysts (plagioclase) and amygdules (quartz) they are featureless in outcrop. In thin section they consist of plagioclase, quartz, biotite, epidote, muscovite, sphene, and iron oxide minerals, and from normative calculations the flows are meta-andesites (Card, 1976a). Interestingly, a chemical analysis of a sample of these volcanics given by Card (ibid., p. 28-29) shows an abnormally high tin content, 300 ppm.

As mentioned by Card (ibid.), who mapped this adjacent area, no contacts between these rocks and Huronian formations are exposed. The volcanic rocks are intruded and isolated by granite and agmatite of the Killarney complex so that their age and stratigraphic position are obscure, except that they must be earliest Helikian or older (i.e. pre-Killarney granite). From their position, they are probably not Archean or part of the basal Huronian Elliot Lake Group, so that they are either younger Huronian rocks, and almost certainly younger than the Bar River Formation, or are of indeterminate post-Huronian pre-granite age.

A clue to their age may be provided by a small body of such rock occurring within the report area at the northern tip of the small island southwest of the entrance into Lamorandière Bay, at the head of Killarney Bay. This part of the island, informally called "Ashtree Island" by the writer, appears to be formed of breccia that includes the volcanic rock but is otherwise similar to, and possibly continuous with, breccia on the southwest shore opposite, shown on the accompanying map. If these breccias are "Sudbury breccia", the volcanics are, from relations in the Sudbury area, pre-Whitewater Group and pre-Sudbury Irruptive (i.e. pre-1850 Ma), both of which are post-Sudbury breccia. As there is no evidence that pre-Whitewater, post-Huronian supracrustal rocks were ever deposited in this region, this would indicate that the metavolcanics are Huronian, possibly intercalated with the sediments suggested above to be post-Bar River.

Summary of Huronian stratigraphy and deposition

The Huronian Supergroup of the report area ranges from the Ramsay Lake Formation of the Hough Lake Group to the Bar River Formation of the Cobalt Group, with an estimated total thickness of more than 9200 m. Virtually the entire succession (>95 per cent) is clastic and deposited directly by paleocurrents from the north (Young, 1968). The arenaceous Mississagi, Serpent, Lorrain and Bar River formations make up approximately two-thirds of the thickness. The Huronian succession of the report area does not include the Elliot Lake Group, which lies between the northern boundary and the south edge of the Sudbury Irruptive; including this group, the complete north-south Huronian section between the Irruptive and the Grenville Front at George Lake totals about 12 200 m, by far the thickest sequence in the entire Huronian belt.

As mentioned earlier, the stratigraphic succession of formations in the area is identical to, and their lithologies are generally, and in most cases closely, similar to those in the Huronian successions westward in the Espanola-Whitefish Falls (Card, 1976b), Elliot Lake-Flake Lake (Robertson, 1978) and Bruce Mines (Frarey, 1977) districts, demonstrating the remarkable overall stability and tectonic unity of the Huronian depository from west to east along Lake Huron, a distance of some 320 km (Table 1). Important changes in the Huronian succession from west to east are, as noted earlier, essentially confined to the basal Huronian Elliot Lake Group in the Sudbury area. These are: (1) a general thickening of formations, most notably the McKim Formation of that group, and the presence of substantial volcanic units in the group, (2) increased volumes of pelite and "impure" sandstone, manifested in the Stobie and McKim formations (and the Pecors Formation of the succeeding Hough Lake Group) and (3) an interval of largely pyroclastic felsic volcanism, unique in the Huronian belt, represented by the Copper Cliff Formation. Aside from these, the lateral continuity and similarity of formations, and their identical

Table 1. Depositional characteristics of Huronian formations

Formation	Lithological change eastward	Thickness change	Depth* of environment	Lithology and thickness compared with western Huronian region
Ramsay Lake	–	–	shallow, possibly surficial in part	more sandstone, less argillite; much thicker
Pecors	–	–	shallow to deep	less argillite, more sandstone, much thicker
Mississagi	none	thickens eastward	very shallow	thicker, lithologically similar
Bruce	none	thins eastward	shallow to surficial	thicker
Espanola	–	thins eastward	moderate to shallow	more mixed lithologically; thicker
Serpent	none	none	shallow	much thicker; lithologically similar
Gowganda	possibly more pelitic	little or none	shallow to deep	less variable in lithology, similar thickness
Lorrain	none	none	shallow	thicker; more coarse arkose; no jasper conglomerate; no red deposits
Gordon Lake	none	none	shallow to moderate	thicker; more siliceous, no red deposits, no evaporite features
Bar River	none	none	shallow	apparently thicker, with additional siltstones, mainly in upper part; may be due to erosion in the west

* (deep = below wave base)

Table 2. Chemical composition of granite and porphyry, Killarney Granite (reproduced from Jones, 1930)

	A	B
SiO_2	72.39	73.83
TiO_2	0.31	0.13
Al_2O_3	13.78	12.91
Fe_2O_3	1.14	0.98
FeO	1.28	0.55
CaO	0.74	0.32
MgO	0.78	0.60
MnO	0.09	0.07
Na_2O	3.74	3.37
K_2O	5.10	5.65
H_2O	0.46	0.44
CO_2	0.16	0.13
P_2O_5	0.13	0.06
TOTAL	100.10	100.04

A – Average of 7 analyses of coarse grained granite gneiss.
B – Average of 7 analyses of fine grained granite gneiss (porphyry).

sequence from one end of the belt to the other, show that tectonic movements in the Archean provenance area to the north and in the Archean basement within the belt were regionally consistent and regular from Lake Superior eastward, except that the thicker sequence of the report area and environs indicates that the tectonic pulses controlling sedimentation in the east were more rapid and extreme compared to areas to the west. Notable in this thick succession south of the Sudbury Irruptive is the absence of any significant unconformity; even erosional disconformities are minor and of limited extent in spite of the very shallow environment of the bulk of the supergroup. This emphasizes that the history of the deposition area, while cyclical, was essentially one of long-continued, steady subsidence interrupted occasionally by emergence and erosion and uninterrupted by intrabasin tectonism. Features such as clastic dykes and slump deposits in formations above the Elliot Lake Group are probably not indicative of important diastrophism.

The crustal instability manifested by the basal Huronian Elliot Lake Group in the Sudbury area in early Aphebian time may not be unrelated to pre- and post-Huronian crustal events in that area, including late Archean – earliest Proterozoic faulting, formation of the Sudbury structure, extensive brecciation, deposition of the Whitewater Group and the emplacement of the Sudbury Irruptive. These features of Sudbury geology have been described in detail elsewhere (e.g. Card et al., 1972; Card et al., 1978).

Since more than two-thirds of the Huronian sequence in all areas consists of relatively coarse crossbedded arenites, mostly feldspathic, rapid uplift of the provenance block must have been dominant, chemical weathering minimal, and the transport and deposition of sediments must have been generally rapid and under strong current conditions. From consideration of their lithology, thickness, crossbedding, and paleocurrent data, the writer considers these arenites to be dominantly fluvial, as has been proposed previously (Young, 1968; Roscoe, 1969; Frarey and Roscoe, 1970); others (Card, 1970, 1978a; Pettijohn, 1970) have argued for a marine origin. The pelite-poor, carbonate-poor character of the Huronian sequence as a whole, the great thickness of coarse crossbedded arenites, and the essentially unidirectional nature of sedimentary current directions militate against a general marine environment, the marine-regressive cycle interpretation of each of the Huronian groups suggested by Pettijohn (1970), and Sims et al. (1981), or deposition of the presently exposed Huronian rocks at a continental margin. The most likely product of marine deposition, the carbonate-bearing Espanola Formation, shows by its wholly clastic nature and its sedimentary structures that transgression, although widespread, was shallow; Young (1973) has described typical fluvial deposits immediately above the uppermost carbonate at McGregor Bay.

Paleocurrent studies show that the arenites comprising the bulk of the Huronian Supergroup were carried from the source and deposited by essentially southerly directed currents (Young, 1968; Card et al., 1972; Card, 1976a, b). As these arenites are relatively clean, submature to mature quartzofeldspathic deposits, the provenance lithology was dominantly granitic, but appreciable areas of Archean metavolcanics and metasediments, some possibly contiguous with greenstone belt remnants now preserved to the north and northwest, must have supplied the coarse immature detritus and lesser pelitic material for the Pecors, Gowganda and parts of other formations. Judging from the report area, iron formation, such as supplied the jasper fragments abundant in the Lorrain Formation and to a lesser degree in the Mississagi Formation in the western Huronian region, appears to have been lacking in the eastern provenance. The erosion products of the Archean provenance were directly and rapidly transported and deposited to form the present stratigraphic units, as shown by the lack of second-cycle deposits and by the feldspathic nature of the bulk of the succession.

The Ramsay Lake, Bruce and Gowganda formations are considered to be largely of glacial origin. The Ramsay Lake and Bruce formations are almost entirely paraconglomeratic, and their thickness, continuity and lateral extent along and across strike throughout the Huronian belt are difficult to explain by any other hypothesis, as are the unsorted exotic granitic clasts and megaclasts so abundant and indiscriminately widespread in the paraconglomerates of all three units. Slump and load structures commonly seen in the Gowganda would be natural features of mixed glacial deposits rapidly laid down in a subglacial, proglacial, or periglacial environment and require no special explanation. Further, indisputable evidence for a glacial environment in Gowganda time exists in the western Huronian area (e.g. Frarey, 1977, p. 40-42). The Gowganda may be largely glaciomarine in this district, as argued by Lindsey (1967, 1971).

Reference has been made to marked facies changes in Huronian formations in this general vicinity and to changes in depositional environment as the Grenville Front is approached and crossed from the west (Lumbers, 1975, 1978; Card et al., 1975; Card and Lumbers, 1976; Sims et al., 1981). The typical coarse clastics of the Huronian sequence in easternmost Southern Province were described as diminishing southward and eastward, becoming more pelitic in those directions, reflecting deep water "eugeosynclinal" conditions (Lumbers, 1975, p. 48-49). These suggestions were offered in explanation of the regional contrast in sedimentary type, described by Lumbers (ibid.), between dominantly well sorted, siliceous or feldspathic arenaceous sections in the Huronian terrane of Southern Province and the abundant dark, biotitic gneisses classed as metagreywacke and meta-argillite in the Grenville Front Tectonic Zone in the adjacent areas across the Grenville Front. This lithological contrast is evident in the relatively small part of the Grenville Front Tectonic Zone contained in the report area, particularly in the south where metaquartzites are volumetrically unimportant among the paragneisses, whereas quartzites, largely orthoquartzites, dominate the Huronian sequence immediately to the west of the Front. Unless the Grenville Front Tectonic Zone is allochthonous or large scale horizontal or vertical fault motions occurred at the Front, a sharp change in sedimentary facies seems a plausible, in fact necessary, explanation for the observed contrasts across the Front if the sequences on either side are correlative, but the present study and comparison with areas farther west do not support the suggested facies change within the Huronian of Southern Province, as very little eastward change in facies or thickness of the formations occurs as the Front is approached. In particular, the feldspathic and quartzose arenites of the Mississagi, Serpent, Lorrain and Bar River formations, forming the bulk of the sequence, show practically no change in lithology near the Grenville Front in the report area, i.e. show no evidence of becoming "eugeosynclinal". Table 1 shows, for each formation of the sequence, those changes discernible to the writer across the report area, the probable environment of deposition, and a regional comparison with the same units in the western part of the Huronian belt. No significant facies change from feldspathic quartzite or orthoquartzite to greywacke or pelites is shown near the Grenville Front. The table shows that several formations thicken eastward regionally. Apparent thinning of the Bruce and Espanola formations in the report area is probably due in part to structural disturbance near the Front where faults are numerous. Possible direct Huronian antecedents for the widespread pelitic paragneiss or metagreywacke in the Grenville part of the area appear to be restricted to the greywackes and pelitic rocks of the Elliot Lake Group and possibly the Pecors Formation of the Hough Lake Group. How these would have become distributed as far south as Georgian Bay in the Tectonic Zone, and the concomitant exclusion of Cobalt Group rocks in quantity, is problematic, as is the apparent absence of equivalents of Elliot Lake Group volcanic rocks, abundant in this region of Southern Province.

Lumbers (1975, 1978) and Sims et al. (1981) also speculated that the Grenville Front Tectonic Zone in this region may represent a diagonally trending (northeast-southwest) geosynclinal hinge line separating essentially miogeosynclinal sediments of the Huronian Supergroup in the Southern Province from thicker, largely eugeosynclinal sediments of the same age to the east in the Grenville Province. The eugeosynclinal trough is further suggested as having formed along a late Archean – early Aphebian northeast-trending continental margin, an idea previously advocated by Dietz and Holden (1966) and by Krogh and Davis (1971). As outlined above, however, the Huronian basin and its sediments continue eastward largely unchanged in trend, lithology (except for the basal group), and sequence, to the northwestern margin of the Tectonic Zone. Presumably, its Archean sialic basement continues as well. A continental margin underlying or bordering the present Huronian belt almost certainly would have had a similar east-west orientation. A sudden change at the Grenville Front from an easterly to a northeasterly tectonic-sedimentary strike seems unlikely. Also, the fluvial interpretation for the Huronian quartzite formations requires that the continental margin be located south of the present belt. In western Quebec, northeast of Sudbury, late Archean and older rocks, including rocks of the east-west Abitibi and Pontiac belts, are known to extend or occur eastward into the Grenville Front Tectonic Zone and beyond for considerable distances

(Deland and Grenier, 1959; Doig, 1975; Frith and Doig, 1975; Wynne-Edwards, 1972), and it seems questionable whether any northeast-trending continental margin existed along the Zone in late Archean – early Aphebian time either in Ontario or western Quebec. The problem of contrasting sedimentary lithofacies in the eastern part of the Southern Province and the northwestern part of the Grenville Province in Ontario appears to remain unsolved. If otherwise acceptable, the hypothesis of T.T. Quirke (Quirke and Collins, 1930, p. 94-95; Quirke, 1940) that Huronian quartzites of this region were granitized on a large scale and thus "removed" from the section in the Grenville Front Tectonic Zone might offer an explanation for the above contrast, but this concept has not met with general acceptance and is not supported by the present study.

Nipissing Diabase (AN)

Distribution and form

Included here are essentially sheet-like mafic (metagabbro) intrusions that form part of a widespread regional swarm along the north shore of Lake Huron and in the Cobalt district. In total, these numerous intrusions represent a very substantial volume and constitute a major Aphebian magmatic event. In earlier work in the vicinity of the Sudbury Basin north of the report area, the intrusions were given the name "Sudbury Gabbro", now obsolete. In the Sudbury-Killarney district the Nipissing Diabase intrusions are preferentially emplaced in the lower half of the Huronian succession, i.e. up to the level of the Gowganda Formation. Consequently, Nipissing intrusions are essentially confined to the northern third of the present area, north of a line between Howry Lake and the northern part of Bell Lake. Possible and probable equivalents have been identified farther east in Grenville Province, but within this map area and also over a wider area of the Grenville Province, these equivalents appear to be of notably lesser areal extent than in the adjacent parts of Southern Province (Card and Lumbers, 1977).

Within the stratigraphic interval mentioned, the Nipissing sheets show no particular preference as to host rocks, large intrusions occurring in the Pecors, Mississagi, Bruce, Espanola, Serpent and Gowganda formations. Some are in part located at or close to formational contacts. There is no indication that the Nipissing intrusions are related either temporally or spatially to known faults in the area.

The Nipissing Diabase intrusions mapped in this area comprise five or six large sheets and a few small crosscutting bodies. In places, adjacent sheets appear to be connected across the stratigraphy by short, dyke-like arms. Small dykes of Nipissing Diabase are rare. The most persistent of the metagabbro sheets are followed continuously for at least 15 km from the west boundary of the report area eastward; beyond that they become discontinuous because of increased tectonism, but at least two of them probably continued originally for the remaining 7 or 8 km to the Grenville Front. The dip of these sheets, and hence their real thickness, can only be inferred, but assuming a rough concordance with their host strata, they are commonly of the order of 300 m thick, and in places exceed 500 m. Sheets may continue for 7 or 8 km at the same stratigraphic level, as for example within the Serpent and Gowganda formations in the vicinity of East Howry Lake and Bear Lake. Two northeast-trending mafic dykes (ANp), one feldsparphyric, were observed between Round Otter Lake and Lake Panache in the northwestern part of the area; they could not be traced through Nipissing Diabase sheets in the interval, but as one transects the post-Nipissing breccia zone north of East Howry Lake, they are appreciably younger. In turn, they are cut by northwest-trending, posttectonic olivine diabase dykes.

Lithology

Outcrops of Nipissing Diabase are unlayered, rather featureless except for joints, and tend to form low, hummocky, steep-sided ridges. Borders of the intrusions are commonly sheared and some bodies are foliated throughout. In hand specimen the Nipissing Diabase is typically massive, medium- to coarse-grained, grey, grey-green, or mottled grey and black, the colour depending on texture and feldspar abundance. It consists dominantly of sodic to calcic plagioclase and tremolite-actinolite or hornblende, depending on metamorphic grade, together with minor amounts of quartz, epidote, chlorite and/or biotite, apatite, sphene, ilmenite, sulphide and carbonate. Plagioclase is altered to sericite, biotite and scapolite. In contrast to areas in the western part of the Huronian fold belt (Frarey, 1977), granophyric differentiate of the diabase in this area is rare; it is evidently not common or abundant in the Sudbury district generally. No mappable granophyre occurs in the report area except for a thin layer at the north end of Bell Lake (ANg); granophyre does, however, form local patches in the metagabbro sheets, and some are very coarse grained to pegmatitic, as just north of Ringer Lake in the northwest corner of the area. Granophyre contains appreciable quartz, microcline and hornblende. Because of their lack of magnetite, the Nipissing intrusions have little or no magnetic expression on aeromagnetic maps.

Details of the mineralogy, petrology, petrography and chemistry of the Nipissing rocks southwest of Sudbury have been given by Card (1978a) and for a larger area by Card and Pattison (1973). Chemical and modal analyses of eleven intrusions from the McGregor Bay-Bay of Islands are immediately west of this report area, have been compiled by Card (1976a). These results show the intrusions to have been tholeiitic, quartz-bearing, one- or two-pyroxene or hornblende gabbro originally, and that metamorphism to metagabbro was essentially isochemical except for the addition of water and sulphur. The Nipissing of the report area probably differs in no important respect from that elsewhere in the region except that metamorphism is more extensive. No primary pyroxene remains in specimens examined from the present area.

Age and emplacement

The Nipissing intrusive event has been dated by the Rb-Sr whole-rock isochron method, using granophyric samples from the Bruce Mines-Blind River area and from the Cobalt area, by Van Schmus (1965) and by Fairbairn et al. (1969) at about 2115 Ma ($\lambda = 1.42$). The first author (ibid.) also obtained a Rb-Sr date of about 2135 Ma on biotite from Cobalt. These results all confirmed an earlier K-Ar determination (2095 Ma) on primary biotite collected by C.H. Stockwell from Cobalt (Lowden et al., 1963).

Although diabase contacts are in place discordant at various angles with the host sediments, the large sheets are generally subconcordant, at least in plan, with the strata of the report area and with major folds of the Huronian belt, as at Bruce Mines, Elliot Lake, and elsewhere. This suggests that diabase emplacement occurred relatively early in the deformational history of the Huronian belt, possibly coincident with or immediately after initial folding and early faulting of the Huronian sediments, as suggested for the Blind River-Elliot Lake district by Eisbacher and Bielenstein (1969) and by Robertson (1973). Crosscutting bodies connecting sill-like masses on individual fold limbs or homoclines may have been early connections between flat or gently inclined sheets, but other crosscutting masses that link sheets on opposite limbs of major folds, as in the McGregor Bay Anticline west of the report area, were apparently intruded during or after the formation of such major folds. Subsequent deformation in the area has likely contributed to discordances, particularly of smaller intrusions. In an attempt to determine paleomagnetically the time of intrusion relative to folding of the anticline north of Gabodin Lake, the concordant diabase sheet in the fold was drill-sampled on either limb and tested for magnetic properties. The test was unsuccessful as pole positions could not be determined, presumably due to post-diabase tectonism and metamorphism (A. Larochelle, personal communication, 1967).

Isotopic ages for the Nipissing intrusions, as mentioned above (2115 Ma), for Huronian (Gowganda) sedimentation (2235 ± 87 Ma) as determined and interpreted by Fairbairn et al. (1969), and for intrusion of the post-Huronian Creighton Granite near Sudbury (ca. 2335 Ma; Frarey et al., 1982), leave a considerable time gap prior to diabase emplacement, enhancing the idea that major Huronian folding preceded diabase intrusion in the Huronian belt, an idea originally expressed by Church (1968). Indeed, since the Creighton pluton accompanied or followed deformation of Huronian strata, the earliest folding, from the numbers just cited, must have long preceded the Nipissing event. On the other hand, the general concordance or subconcordance of some large diabase sheets in the belt, even at fold noses, suggests that intrusion accompanied or preceded that folding. Huronian Supergroup deposition has heretofore been bracketed between the Nipissing intrusive event and the Archean age of the pre-Huronian basement, which remains to be well dated but is evidently ca. 2500 Ma old (Stockwell, 1982). It is now bracketed between the Creighton intrusion and the age of that basement, an interval of about 165 Ma. The total time span of deposition is unknown, but is unlikely to approach this figure; much of the early part of the Aphebian Era is apparently unaccounted for in the geological record of Southern Province.

It has been stated (Card and Pattison, 1973; Card, 1978a) that on a regional scale the distribution and access channels of Nipissing Diabase bodies are related to major regional faults. Inspection of 4-mile compilation maps of the Huronian belt (Giblin and Leahy, 1979; Card and Lumbers, 1977) indicates to the writer that these intrusions are not controlled by the faults now mapped but that the diabase rose along basement fractures not now evident. As in the case of other extensive sheet intrusions, e.g. in the Labrador Trough, access channelways may have been relatively local, the wide lateral extent of sheets being attributable to prolonged spreading of magma along favourable lithological, structural, or hydrostatic levels. In the present map area, these levels did not extend stratigraphically above the lower part of the Gowganda Formation.

Felsic intrusions (Afi)

Felsic intrusions, including a few sill-like bodies but mostly dykes too small to map at this scale, appear in the eastern reaches of Lake Panache and environs, and similar rocks also appear at Kakakise Lake and Killarney Lake near the Grenville Front. In addition, a single stock of dissimilar muscovite granite occupies an oval-shaped area about 1.6 km in length at Balsam Lake, Goschen Township.

In the first area, the largest mappable bodies are north-trending, sill-like masses in sediments near Gabodin Lake and Little Gabodin Lake and another narrow body about 0.8 km long in Nipissing Diabase just west of Reef Lake. Others form irregular patches, possibly subconcordant. These larger bodies are dioritic and trondhjemitic to granitic and are biotitic and/or muscovitic. They are unfoliated to poorly foliated but most are moderately cataclastic, resulting in a streaky appearance. In addition, a variety of narrow, fine- to medium-grained, felsic dykes occur in this part of the area, trending in various directions. Some have unusually shallow dips. Most are biotitic. A distinctive buff weathering grey type is low in quartz but rich in sodic plagioclase (75 per cent or more), corresponding to the larger trondhjemitic intrusions mentioned; these dykes may carry zoned plagioclase phenocrysts and some are garnetiferous. These felsic rocks are relatively unaltered and evidently postdate all but the latest deformation (and metamorphism) of the Huronian sediments. The garnet content in some of the intrusions, noted also north of the area by Henderson (1967, p. 26) may indicate an appreciable contribution of assimilated sediments in the magma.

At Kakakise Lake, the intrusions are small pods or dykes of buff weathering felsic material generally less than 6 m wide. Most of the dykes strike 50 to 70 degrees east of north. These small intrusions are dissimilar to the more potassic granitic rocks of the Killarney Batholith on the opposite side of that lake. Small trondhjemitic dykes resembling those in the northern part of the area cut the Bar River Formation near Killarney Lake.

The intrusions near Lake Panache become more numerous and larger north of the report area and merge there with a mainly trondhjemitic igneous terrane termed the Eden Lake Complex (Henderson, 1967; Card et al., 1972) or Eden Lake intrusions (Card et al., 1975). In that area, these Eden Lake intrusions were mapped separately from the nearby Chief Lake Batholith (Henderson, 1967; Card et al., 1975); the age relationship of the two intrusive groups is evidently not shown by field relationships. Likewise, in the report area the age relationship of the small Eden Lake bodies to the Killarney Batholith is not directly shown in the field. If, as stated by Davis et al. (1970) and Card et al. (1975), the Chief Lake Batholith actually comprises intrusions of two distinctly different ages, one alternative is that the Eden Lake intrusions may be coeval with the older of these, which in turn are thought to be part of, or correlative with, intrusions in nearby Grenville Province dated at about 1700 Ma (Krogh and Davis, 1969), and thus predate the Killarney Batholith. Dissimilarities in lithology, form, and deformation, compared to the components of the Killarney Batholith, support the idea that they are appreciably different in age from the batholith. In the report area, field relations show that the Eden Lake felsic intrusions postdate the Nipissing Diabase and the folding of their host rocks; they predate their own foliation and cataclasis, as well as the northwest-trending olivine diabase dykes ("Sudbury swarm") that are the only rocks seen to cut them. That is, the felsic intrusions and their weak foliation and cataclasis are younger than, or possibly synchronous with, the general north to northeast structural trend at the southeast end of Lake Panache, which is probably a post-Nipissing feature, but older than the Killarney Batholith. Geochronologically, the Eden Lake intrusions are very loosely bracketed between 2115 Ma (Nipissing Diabase) and 1550 Ma (U-Pb age of the Killarney Batholith, see Appendix), but a closer indication of their age may be shown by the fact, mentioned previously, that the Eden Lake complex appears to occupy the core area of one of the metamorphic nodes of the district, as depicted by Card (1978a, b). According to data of Fairbairn et al. (1969), this regional metamorphic pattern probably developed about 1900 ± 100 Ma ago and from the apparent genetic relationship this would be an approximate age for these intrusions. Accordingly they are herein classed as Aphebian.

The small muscovite granite stock at Balsam Lake (Afim) intrudes the Gowganda Formation and is cut by an olivine diabase dyke. Little or no effect of the intrusion is shown by the adjacent sediments which are cut by small granite dykes and apophyses. The muscovite granite is a medium grained pink to grey mass consisting of orthoclase, plagioclase, quartz, muscovite, minor biotite, and accessories including epidote. For the most part homogeneous, it becomes pinker toward the margin, evidently due to increased potash feldspar content. A sample from near the west end of the body shows good alignment and streaking of the muscovite as well as moderate cataclasis. A K-Ar isotopic date of 1215 ± 45 Ma was obtained from the muscovite (Wanless et al., 1974, p. 41), but because of the petrographic evidence of deformation, this date is not a reliable indicator of the age of intrusion. It may, however, indicate that later thermal effects from the Grenville Province extended over 3.2 km into Southern Province, and modified the argon isotopic content. Similar K-Ar muscovite ages were determined from Reef Lake to the north and from the Killarney area to the southwest (Wanless et al., 1974).

Amphibolite dykes and Grenville Front amphibolite

In the southwest quarter of the report area, a few very narrow, north- or northwest-trending, near vertical amphibolite dykes, not plotted on the accompanying map, were encountered in trench-like depressions transecting the quartzites of the Bar River and Lorrain formations. They are poorly exposed, fine- to medium-grained bodies less than 30 m wide, that weather to a salt and pepper texture and are generally sheared or foliated. They consist of plagioclase, actinolite or hornblende, epidote, and a few accessories. Drift-covered depressions of similar trend probably contain more of these dykes.

In view of their sheared and metamorphosed condition, there were no obvious field criteria in this area to distinguish these small dykes from metamorphosed Nipissing Diabase intrusions. However, according to descriptions of neighbouring areas where amphibolite dykes are more numerous (Card, 1976a, b), such dykes are seen to cut Nipissing Diabase. While younger than the main fold deformation and the Nipissing intrusions, and older than the shearing episode probably associated with late faulting in the southern part of the area, and also older than the olivine diabase dykes of the area, their precise age is unknown. They were not observed in the Front granites or the Grenville gneisses.

From limited chemical and mineralogical data (Card, 1976a), the amphibolite dykes differ distinctly from posttectonic olivine diabase, being poorer in magnesium, titanium and calcium, and richer in silica, iron, alkalis, and aluminum. The dykes are tholeiitic.

In addition to the narrow northerly trending dykes, a different type of amphibolite (ANa) occurs, apparently confined to a linear zone adjacent to the Front granite at several localities: on islands and on the southeast shore of Kakakise Lake, beside the short creek from Freeland Lake into George Lake, westward on islands and the shore of George Lake near its inlet, and at the entrance from Killarney Bay to Lamorandière Bay. This rock is rough weathering, black, coarse to very coarse-grained, nonfoliated to moderately foliated, and in a few places is sparsely chalcopyritic. In places it approaches hornblendite in composition. At places on Kakakise Lake, the amphibolite is composite, containing well defined patches or blocks of fine grained amphibolite and also irregular small-scale segregations of granophyric composition. Epidote-rich veins and patches were seen, and on the islands near the inlet into George Lake, the amphibolite contains large, football-like aggregates composed mainly of epidote (Fig. 18). On the shore opposite the easternmost island, the amphibolite is cut by a 0.3 m wide amygdaloidal mafic dyke, possibly a type of lamprophyre or possibly a basalt dyke related to the amygdaloidal and porphyritic metavolcanic remnants in Killarney Bay, mentioned above. If there is a temporal relationship between this basalt dyke and the metavolcanics, then the stratigraphic position and age of the flows would be post-Huronian and post-regional deformation of Southern Province rocks, and pre-Killarney Granite, i.e., late Aphebian to early Helikian. The amphibolite is also cut by olivine diabase just above the inlet to George Lake, and probably also at the southwest end of Kakakise Lake. At Kakakise Lake it is also invaded by Killarnean granite dykes and is chilled against and forms intrusive breccia with metasediments, commonly siltstone. The precise age of this amphibolite is uncertain. It may be Nipissing Diabase, although at Kakakise Lake it is dissimilar texturally and mineralogically to a nearby Nipissing body on the northeast side of that lake and is probably younger. It may be a postmetamorphic intrusion unrelated genetically to the small amphibolite dykes mentioned above. For convenience it is shown on the map and legend as a Nipissing subunit.

Olivine diabase (Ndb)

Dykes of mildly alkaline Neohelikian olivine diabase belonging to the northwest-trending "Sudbury swarm", so called because of their regional distribution, distinct trend, and common chemical and paleomagnetic properties, are numerous in the north half of the report area, and sparse in the southern part. Only the largest are shown on the accompanying map, as the dykes range from a few centimetres to 90 m in width. A few dykes of identical appearance trending northeast to east are assumed to be coeval. The olivine diabase dykes are vertical or near vertical, and though poorly exposed, larger ones are traceable for long distances, up to 15 km within the area and regionally for as much as 160 km (Card, 1976b). Some dykes are composed of en echelon segments. Because of their magnetic character the larger ones can commonly be traced through large covered areas by means of positive linear anomalies on aeromagnetic maps. In detail, however, the dykes are not uniformly magnetic; one, crudely tested by Brunton compass, was found to comprise 3 magnetic and 2 nonmagnetic zones across strike. The Sudbury olivine diabase cuts all other rocks and structures of the Southern Province, except for minor offsetting late faults. At or near the Grenville Front, one or two dykes assigned to this group locally show moderate to strong deformation (Brooks, 1976). Others cross the Front without apparent change, cross the Killarney intrusive complex and, unlike the situation northeast of the area as described by Lumbers (1975, p. 109), extend into the

Figure 18. *Epidote-rich segregations in metagabbro dyke. Rims are hornblende-or actinolite-rich. George Lake, Killarney Township. Photo R.T. Cannon. GSC 188986*

gneisses of the adjacent Grenville Front Tectonic Zone of the Grenville Province (Frarey and Cannon, 1969; Palmer et al., 1977), where they may change strike abruptly, as at Tyson Lake. Problems arise elsewhere in the Grenville terrane in distinguishing the Sudbury dykes from other diabase dykes; their occurrence in Grenville Province is discussed in a later section.

The olivine diabase outcrops are usually small, but are readily recognized by their magnetic character, their tyical rusty tan to rich brown weathering, a friable surface rind, and an ellipsoidal pattern controlled by closely spaced rectangular joints. The dykes are easily eroded and are largely concealed by drift or water along linear valleys. Internally, the diabase is remarkably fresh, ophitic, and composed of unaltered intermediate to calcic plagioclase, titaniferous augite, and small amounts of olivine (commonly <10 per cent) plus minor but ubiquitous biotite and accessory apatite, magnetite, ilmenite, and rare sulphides. Some dykes are in part markedly porphyritic, carrying plagioclase tablets commonly 1 to 2 cm, and in places several centimetres, in length. A peculiar feature is their abrupt textural change from equigranular to megaporphyritic in certain portions along their length or across their strike. These zones have no gradational borders but appear abruptly.

Various paleomagnetic studies on the Sudbury diabase dykes have been carried out by Sopher (1963), Fahrig et al. (1965), Larochelle (1967) and Palmer et al. (1977), and have shown the pole position of the Sudbury dykes of this region to lie at approximately 165° west longitude and between 0° and 10° south latitude. The study by Palmer et al. (1977) included numerous sample sites from the eastern part of the report area, some 20 within the Southern Province and 6 within the Grenville Province. They found that 5 of those within the Grenville Province gave a different declination and inclination from those typical of the Sudbury dykes, and accordingly classified them separately. Of the 20 sites northwest of the Grenville boundary, 12 failed to provide useful paleomagnetic information, either because there was no clear end point of demagnetization, or because after AF treatment they gave scattered results anomalous with respect to the two classes recognized. More specifically, no Sudbury dyke directions were obtained in a section about 10 km wide between the Grenville Front at Bell Lake and Lake Panache, and in general the anomalous sites appear to form a zone several kilometres wide parallel to the Front (Palmer et al., 1977, p. 1874, Fig. 2). Their apparent zonal distribution suggests that these anomalous paleomagnetic results may be due to geological causes, possibly late faulting, late cataclasis, or rise in temperature in the host rocks of that general area rather than to fortuitous lightning strikes as suggested by Palmer et al. (1977, p. 1879), even though only locally are the dykes in the vicinity visibly faulted, crushed or altered.

The most commonly cited age for the Sudbury diabase dykes is about 1250 Ma. Rb-Sr mineral analyses by Patchett et al. (1978) derived an age of 1200 ± 20 Ma. K-Ar whole-rock determinations by Palmer et al. (1977) on dykes of the report area were excessively high in the Bell Lake-David Lake sector: as high as 1838 Ma (see Appendix). As surmised by those authors (ibid., p. 1870), these anomalously old ages may be due to excess argon resulting from a post-dyke heating episode, presumably Grenvillian, and these ages appear to be essentially meaningless. Of the five paleomagnetically anomalous sites dated four have relatively high K-Ar ages (ibid., Table 3). Anomalously young (Ordovician-Silurian) ages derived from a dyke in the same sector are difficult to explain; while the samples dated appear to be tholeiitic and yielded a different paleopole position, suggesting a separate age and origin (Palmer et al., 1977, p. 1884, 1886), the "young" intrusion probably is not Paleozoic. No dykes are known to cut Ordovician or Cambrian rocks of the northern Lake Huron region, the pole position of the samples is unlike the established positions for these periods (ibid., p. 1886), samples collected by the writer contain olivine, unlike the late quartz diabase Grenville Province dyke swarm (Murthy, 1971), and age determinations farther northwest along what is evidently the same dyke gave "normal" Sudbury diabase results (Palmer et al., 1977, Table 3 and Fig. 2).

Structure

Folds

Introduction

The part of the area northwest of the Grenville Front lies in the eastern extremity of the "Penokean Fold Belt" (Stockwell, 1961) of the Southern Province and the dominant structural pattern is similar to that of the region farther west, which is made up of very large-scale, upright, gently plunging, east-west folds with moderately to vertically inclined limbs. In this area these major structures are affected by faults, cataclasis, and smaller folds, particularly in the south and southeast.

From evidence within the area and the region, at least three separate deformations affected this terrane or parts of it. The oldest produced the regional east-west upright open "megafolds" of the Huronian fold belt, including the La Cloche Syncline and the McGregor Bay Anticline, which occupy much of the Huronian terrane of the report area. From field evidence, it preceded or overlapped the intrusion of the Nipissing Diabase, as discussed; if also older than the Creighton Granite north of the area, as seems evident because the Creighton was emplaced into inclined Huronian strata (Card, 1968; Dutch, 1979), this episode much preceded Nipissing intrusion because the Creighton, as mentioned earlier, has given a U-Pb zircon age of ca. 2335 Ma (Frarey et al., 1982). Stockwell (1982) has recently named syn- or pre-Creighton folding in this part of Southern Province "Blezardian" in his expanded time-classification. In this region, the La Cloche Syncline and McGregor Bay Anticline have been later modified by steepening, faulting and in places by imposition of smaller parallel, upright folds. This deformation, accompanied or followed by regional metamorphism, probably occurred about 1900 Ma ago during the Penokean Orogeny (Card, 1978b). Products of this metamorphism are mesoscopically folded and foliated along northeasterly trends in the eastern part of the area, and along the Grenville Front still later minor folds parallel the Front, sharply transverse to earlier structures.

East-west folds

The major folds of the area are east-west to east-northeast upright structures that are eastward continuations of the same large structural elements to the west. They belong to the set of large, gently plunging folds that individually persist for many kilometres along the north shore of Lake Huron in both the western sector, i.e. from Sault Ste. Marie to Cutler, and the eastern sector from Cutler to the Grenville Front. Examples in the west are the Bruce Mines Anticline, the Chiblow Anticline, and the Quirke Lake Syncline, and in the east the McGregor Bay Anticline and La Cloche Syncline. Thus the first-order Huronian fold pattern in the report area is very simple, comprising three principal elements from north to south (Fig. 19). In the north, a belt some 13 km wide is underlain by consistently south-dipping, successively younger Huronian strata, and is here informally termed the "Lake Panache homocline". It is bounded in the adjoining area to the north, at Lake Panache itself, by the Lake Panache Fault (Card et al., 1975) and by a major antiformal structure identified by Card (1978a) as the "Lake Panache Anticlinorium". Except for a large warp west

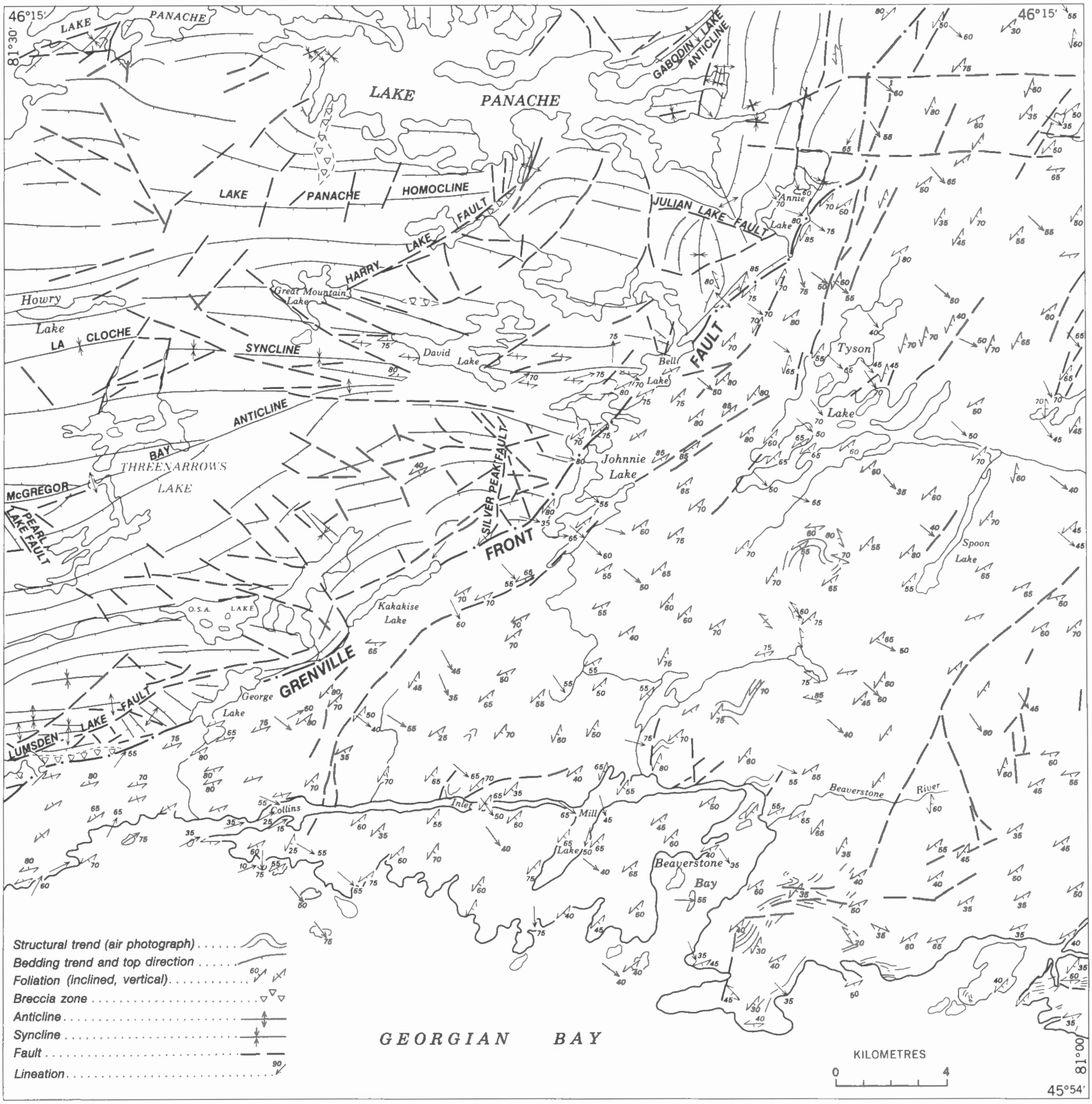


Figure 19. *Structural features, Lake Panache-Collins Inlet area.*

of Crean Point in Lake Panache, the homocline is fairly regular along strike for about 19 km from the western boundary of the area to a north-south line through Jackdaw Lake and Reef Lake, but eastward from there in the next 11 km it is interrupted by a series of north- to northeast-trending warp-like structures of intermediate scale, and by numerous faults of similar trend (Fig. 19). Finally, at the eastern end of Lake Panache, approximately 3.2 km from the Front intrusions, the entire Huronian succession turns abruptly north-northeast, parallel to the trend of the intrusions and the adjacent Grenville gneisses. North to north-northeasterly superimposed folds in the Huronian rocks of this zone are cut off by the Front intrusions at the eastern extremity of this belt.

The homoclinal belt is followed southward by the eastern extremity of the La Cloche Syncline, the largest fold in the Huronian fold belt, which extends westward for about 80 km from the present area, as shown on the compilation maps of Card and Lumbers (1977) and Giblin and Leahy (1979). In the report area, the syncline forms a highly constricted, isoclinal, westerly plunging trough in the Lorrain Formation, whose axial trace passes through Nellie Lake in Roosevelt Township. The La Cloche Syncline is traceable eastward, wholly within the Lorrain Formation, for about 15 km, ending in a strongly faulted and cataclased zone near the west end of David Lake in Stalin Township. Succeeding the syncline southward is the contrastingly broad McGregor Bay Anticline, an east-northesterly plunging structure that occupies about half the Huronian terrane of the area, exposing formations from the Espanola to the top of the Huronian Supergroup. This regional structure extends some 40 km west of the report area to the vicinity of Birch Island and the North Channel of Lake Huron (Card and Lumbers, 1977). It evidently plunges and/or is faulted out just south of David Lake. Thus all three major fold elements of the area are disrupted or terminate as the Grenville boundary is approached.

The limbs of the McGregor Bay Anticline and La Cloche Syncline generally dip steeply from 60 to 90 degrees, with local overturning common. They were probably steepened by the second deformation. Despite widespread shearing on bedding planes, the folds are clearly indicated by numerous top determinations from crossbedding. On the south limb of the McGregor Bay Anticline, the quartzites of the Bar River Formation are folded into several subsidiary east-west structures between Baie Fine and the Grenville Front. The age of these smaller folds is uncertain; they may be synchronous with the larger parallel structures, or may be the product of Penokean refolding.

North-northeast, northeast, and northwest folds

Regional compilations (Card and Lumbers, 1977) show that fold axes in the easternmost part of the Huronian fold belt between longitude 82° and Wanapitei Lake swing northeasterly as compared to the almost 90° strike farther west and in the south near Lake Huron; this change is evidently manifested in the report area by the curved axial trace of the McGregor Bay Anticline and by the orientation of smaller structures in the northeastern part of the area, notably the Gabodin Lake Anticline (Fig. 19). Theoretically, this regional swing may be attributed to primary control by structures in the Archean basement, to northeasterly directed forces associated with Penokean or earlier tectonism, or to later tectonism in Southern and/or Grenville Province. Card et al. (1975, p. 57) report that east-west foliation and related lineation in rocks immediately north of the report area are deformed by later east-northeast foliations congruent with prominent east-northeast folds, indicating that these folds were superimposed on an original easterly trend that extended to the Grenville Front. Furthermore, as the regional northeast structural grain (N 45-70 degrees E) extends for 45 km or more northwest of the Grenville Province boundary, and is actually at an appreciable angle to the Front and to the Grenville trends (N 15-50 degrees E) southwest of Sudbury (Card and Lumbers, 1977), it is probably an early feature, i.e. early Penokean or Hudsonian, or perhaps even earlier, rather than one related to existing Grenville Province structures including the Grenville Front. This reasoning is confirmed by the crosscutting relationship with the northeast fold trend shown by node metamorphism of the district, considered to be of Penokean age (Card et al., 1978).

As mentioned above, several relatively small folds, striking 0 to 50 degrees east of north and mostly south-plunging, are present along the main homocline in the northern part of the report area. East of a line through Harry Lake, the homocline is segmented by these smaller folds and associated faults (Fig. 19). Axial traces of these folds are 800 m – 3.2 km in length. They are, from west to east, a group of small anticlines and synclines at Potato Point on Lake Panache, a compressed, faulted and brecciated anticline at Jackdaw Lake, a fairly large anticline north of Gabodin Lake (Gabodin Lake Anticline), smaller folds at the east end of that lake, and prominent buckles northeast of Bell Lake. The relationship of these structures to the regional northeast pattern north of the report area is uncertain.

Figure 20. *Mesoscopic northeast-trending folds in gneissic Lorrain quartzite. Grenville Front Zone at Bell Lake, Goschen Township. GSC 188834*

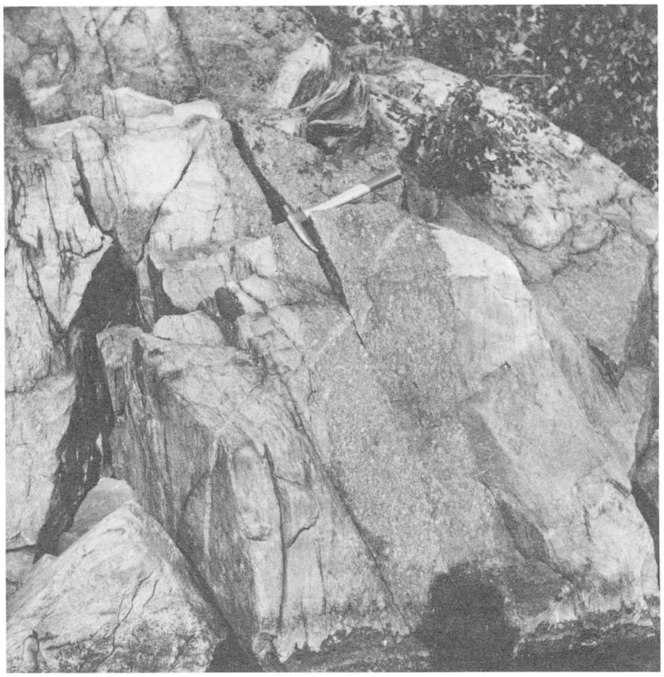


Figure 21. *Dykes of Bell Lake Granite cutting refolded gneissic Lorrain quartzite. Bell Lake near Grey Lake portage, Goschen Township. GSC 188835*

The secondary folds between the east end of Lake Panache and Bell Lake, and perhaps all the secondary folds along the homocline, appear to be related to the larger-scale structure at the end of Lake Panache, where the entire Huronian sequence changes direction from east-west to north-northeast about a northwest axis passing through the south-easternmost bay of Lake Panache (Fig. 19). This new north-northeast trend of generally east facing Huronian formations near the Grenville Front continues well beyond the north boundary of the report area, vestiges of the Cobalt Group being found at Chief Lake in Tilton and Broder townships 16 km to the northeast (Card and Lumbers, 1977). The forces that produced this major change in trend are not well dated, except that they are older than the Front intrusions, i.e. pre-1550 Ma, and younger than the main east-west structures of the district, which are pre-Penokean (pre-1800 Ma). A minimum age is also indicated by small felsic dykes and sills that intrude north- and northeast-trending structures near the east end of Lake Panache; as mentioned, these dykes probably belong to the Eden Lake intrusive complex that may be as old as 1900 Ma. Thus the north-northeast trend is middle to late Aphebian and the forces are presumably related to early westward-directed tectonism from the east in what is now Grenville Province that appears to have formed an early "proto-Grenville Front" at that time. Immediately west of the present Front at Annie Lake, two generations of north-northeast to northeast foliations and small-scale folds are exposed, showing that repeated deformation affected the Huronian rocks there, some probably after the "proto-Grenville" event. Thus some of the secondary folds mentioned above along the homocline, as well as small structures near the Grenville boundary at Annie Lake and Bell Lake, may be younger than others; some may have been produced by late events (e.g. intrusion) more closely related to the present edge of the Grenville Front Tectonic Zone.

It will be noted from the map and Figure 19 that in contrast to conditions in eastern Lake Panache and north of Bell Lake, the Huronian strata and structures along other stretches of the Front zone maintain their eastward trend almost to the contact of the Front intrusions, as in the main body of Bell Lake, at Johnnie Lake, and at George Lake. At Bell Lake, small northeast fold structures are found (Fig. 20), but only in a narrow zone 100-200 m wide adjacent to the contact of the Bell Lake Granite. Field relations show that these folds are pre-granite (Fig. 21), and muscovite in pegmatite cutting one such structure at Bell Lake yielded a Rb-Sr minimum age of approximately 1450 Ma (Krogh and Davis, 1970, p. 312). Strictly speaking, the Grenville boundary should include this narrow zone, but it has not been delineated accurately in this study, and at the present scale the boundary would only be slightly altered.

Northwest folds and trends are confined to the southern part of the area, where they occupy fault-bounded and rotated blocks in the Lorrain and Bar River formations on the south limb of the McGregor Bay Anticline as at Killarney Lake and in a large block adjacent to the contact of the Killarney Batholith between George Lake and Lamorandière Bay of Lake Huron, where strata of the Bar River Formation strike northwest on either side of an anticlinal axis passing through Lumsden Lake. These latter structures abut sharply against the Killarney intrusions. The rotated structures are attributed to faults distinctly younger than the major east-west deformation, but of otherwise uncertain age. Those southwest of George Lake are presumably related to important strike-slip movement on the Lumsden Lake-Frazer Point Fault and faults marginal to the Killarney Batholith.

Minor structures

Late small-scale folds, kinks, crenulations, cleavage, faults, and lineation occur along the boundary of Southern Province and in the eastern part of Lake Panache, where, for example Gowganda rhythmites are kinked and broken (Fig. 9). At Annie Lake, north- and northeast-striking folds and cleavage produced in retrograded Gowganda biotite and andalusite schists by post-Penokean deformation are strongly refolded and crenulated parallel to the boundary. Postmetamorphic refolding and imposed northeast cleavage is also shown by schists of the Pecors Formation (Fig. 22) and by Nipissing Diabase at and near Gabodin Lake, where for example retrograde cordierite clumps are flattened in the new cleavage planes, and by Gowganda laminated, knotted schist near the narrows of Bell Lake. Kink bands in siltstone along the southern fringe of the Bar River Formation near Lamorandière Bay may be the youngest structures in the Southern Province terrane, related to movement on the adjacent post-Killarney Granite fault (R.T. Cannon, personal communication, 1965).

The relatively few lineations recorded in Huronian rocks near the boundary of Southern Province were measured on wrinkles crossing cleavage surfaces, or on intersections of cleavage and bedding planes. They vary in orientation, plunging north, northeast, southwest, and, close to the Grenville boundary, southeast.

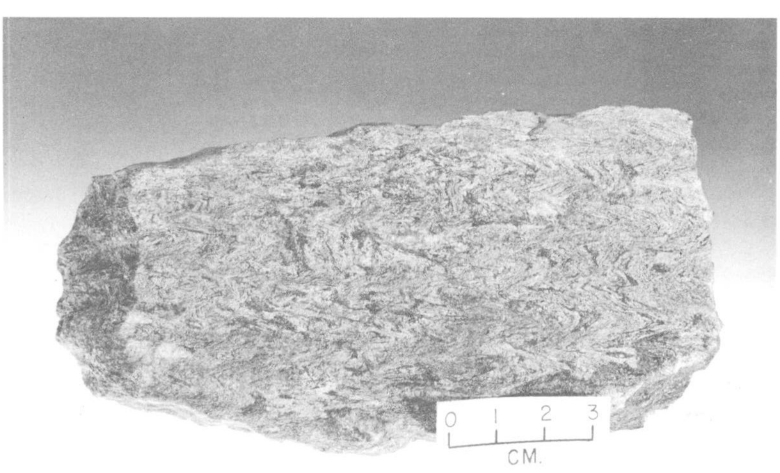


Figure 22

Folded foliation in biotite schist of the Pecors Formation. Gabodin Lake, Bevin Township. GSC 202839A

Faults

The accompanying map and Figure 19 show that faults of various orientations are numerous throughout the area. Most are identified by displacement of contacts, sheared or unsheared lineaments, or brecciation; few are directly visible. Faults strike northwest, northeast, north, and east, in decreasing order of abundance. Many appear to be vertical normal faults of limited displacement, some are small thrusts, but others discussed below are of regional or major importance.

The most important faults and fault zones in terms of displacement, with their trends, are as follows: Lumsden Lake (Frazer Point) Fault (northeast), Harry Lake Fault (northeast), Pearl Lake Fault (northwest), Kirk Lake Fault (east), Julian Lake Fault (east-southeast), Northeast Hill (Silver Peak) Fault zone (north) and the Grenville Front faults (northeast). The last are intermittently observed along the entire length of the Front as breccia, cataclasite, or shear zones and appear to be parts of a continuous break.

The fault sets, all of which had post-Nipissing Diabase movement, mostly formed during or immediately following the main folding process or during the second deformation. However, some east-trending faults are clearly much younger, displacing second generation folds near the Grenville Front as well as Front intrusions and Grenville gneisses farther east. Also, a few young (Grenvillian?) faults, mostly northeasterly, offset olivine diabase dykes slightly, and late movement on the Grenville Front faults has brecciated Killarney intrusions locally. The Front zone is evidently the locus of a pre-Killarnean boundary fault, renewed after the intrusions were emplaced.

The competent Bar River and Lorrain formations in the ridges of the South La Cloche Mountains that form the limbs of the McGregor Bay Anticline are cut by a multitude of closely spaced northwesterly and northeasterly faults, most of which appear to have produced only limited displacement; some of the northwest faults have shifted member contacts within the Lorrain Formation 300 m in either direction. In a zone west of Johnnie Lake (Silver Peak Fault zone), northwest to north faults are so closely spaced and conspicuous as to resemble gross stratification on the air photographs (Fig. 15) but are actually at a large angle to the bedding. The combined effect of the faults in this zone has been to shift blocks of the Lorrain Formation southward about 1.6 km, cutting off the northeast-striking Gordon Lake and Bar River formations. In this displacement zone, parts of the upper two members of the Lorrain are repeated by branching east- and southeast-trending faults, resulting in apparent thickening of these units. Precise relations where the Lorrain white quartzite is brought into juxtaposition with similar strata of the Bar River Formation were obscured and complicated by numerous local faults, by the similarity in rock type, and by shearing over a considerable area. The position of the faulted boundary between the two quartzite formations as shown on the map is necessarily interpreted, but is believed to be reasonably accurate. The northeast faults complementary to the northwest set in the La Cloche ridges are essentially bedding plane slips and faults which are less well defined and consequently appear to be less numerous from the accompanying map. Actually on the ground they are extremely numerous and conspicuous and have converted the quartzite to sericite schist along many bedding planes.

The Lumsden Lake Fault, striking northeast in the southwest corner of the report area, is a probable continuation or branch of the Frazer Point Fault mapped to the west (Card, 1976a). It appears to transect northwest faults and is thus presumed to be younger. Together with a presumed companion parallel fault to the south, close to the Grenville Front, it has evidently formed a couple that, as mentioned earlier, rotated a large block of the Bar River Formation southwest of George Lake from a westerly to a northwesterly orientation. The intercalated siltstones and quartzites of the formation within this zone are severely crumpled and sheared. North of Lumsden Lake, Z-shaped drag folds in siltstones of the Bar River on the north side of the fault indicate dextral strike-slip displacement along that boundary of the block.

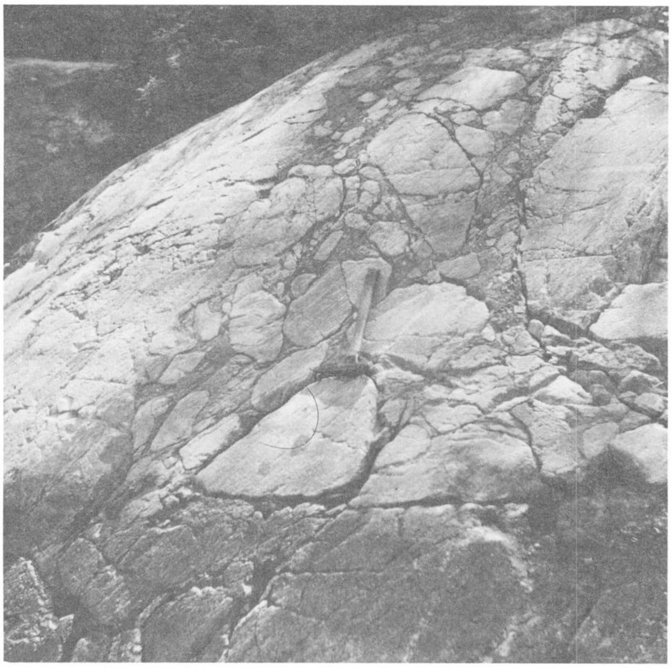
The Pearl Lake Fault, named after a small lake near the southwest end of Threenarrows Lake, is the easternmost of several north to northwest block faults located west of the report area (Card, 1976a) that displace parts of the Huronian sequence into anomalous stratigraphic positions along the central or core zone of the McGregor Bay Anticline. The block bounded on the east by the Pearl Lake Fault has moved down relative to adjoining blocks, and has also undergone clockwise rotation.

The Harry Lake Fault or fault zone is accompanied by extensive brecciation. It is curvilinear, extending from Great Mountain Lake in Stalin Township northeasterly and northerly to Taylor Bay of Lake Panache. At Harry Lake, left hand strike-slip has displaced the Gowganda-Lorrain contact by approximately 2.3 km. Northeast of Harry Lake the fault divides within the zone of secondary north-trending folds near Jackdaw Lake mentioned above, with which it is probably contemporaneous. Between Harry Lake and Jackdaw Lake these faults produced a large breccia zone described later. Both breccia zone and fault are cut by olivine diabase dykes.

The Julian Lake Fault is a small, probably steep fault about 4 km long between Peter Lake and Annie Lake. It moved Gowganda and Serpent strata against older beds, slicing or eliminating the Bruce and Espanola formations. It postdates and cuts the large secondary north and northeast folds involving the Serpent and Gowganda rocks between Peter Lake and the Grenville Front. In the east the fault may merge with northeast faults running through Annie Lake.

As indicated, northeast faults recognized sporadically along the northwest boundary of the Killarney intrusive complex (Grenville Front) are probably parts of a single major structure. Shearing and cataclasis in adjacent rocks on one side or the other are common along water or drift-covered portions, and the fault zone is directly observed at several places. These include Annie Lake, where noncataclastic Huronian units are in sharp contact with mylonitic granite, and Johnnie Lake, where a spectacular breccia zone is developed for more than 3.2 km, a late diabase dyke is disturbed, and complexly folded muscovite-biotite gneiss derived from Lorrain quartzite is juxtaposed against well preserved crossbedded Lorrain quartzites. As mentioned earlier, Brooks (1967, Plates 4, 5) has previously described this strongly foliated, crenulated and cataclastic gneiss, carrying mafic boudins, in the contact zone at Johnnie Lake. Also, at Kakakise Lake and George Lake the Killarney intrusive rocks are sheared, and at the former, breccias of probable fault origin occur on the northeast side of the contact. Near the dam at the outlet from Kakakise Lake, intense faulting at the contact has produced a crush breccia consisting of a swarm of orthoquartzite platelets, oriented vertically, in a biotite schist matrix. Blocks or lenses of dolomite, presumed to be hydrothermal, also occur in this fault. Finally, the large breccia zone extending for about 3.25 km east from Lamorandière Bay at the extreme southwest end of the Front may be the manifestation of the fault segment between Killarney Bay and George Lake. Alternatively, as discussed below, this zone may represent a diatreme or Sudbury-type breccia.

Shearing and cataclasis along the northwest margin of the Killarney Batholith appears to have resulted mainly from dip-slip movement, judging from the lack of northeast-trending slickensides. At one point near Bell Lake, vertical lineation occurs in the contact zone. The fault movement



A. Rounded to angular orthoquartzite clasts in milled micaceous matrix. GSC 188932

B. Pelitic fragments of uncertain origin, forming a separate zone in the breccia. Photo I.F. Ermanovics. GSC 188968

Figure 23. *Fault breccia at the Grenville Front, Johnnie Lake, Carlyle Township.*

involved unknown aggregate vertical displacement, but since movements postdating the olivine diabase dykes were minor, the bulk of the movement and resulting deformation along this zone was evidently pre-Grenvillian, as discussed further below.

Breccias

This area is noteworthy for its large number of breccias, of which there are four types: intrusion breccia, sedimentary breccia, "Sudbury-type" breccia of problematic origin, and fault breccia. Principal examples, mainly of the last two types, are shown on the accompanying map and Figure 19.

Structural breccias, then, are of two types: those clearly related to secondary folds and faults, and the more complex breccias of "Sudbury-type" of obscure origin that characterize the whole district southwest of the Sudbury basin. The former are relatively few, narrow, linear, and predominantly contain only local fragments, whereas the latter are very numerous, irregular, range from a few centimetres to hundreds of metres wide and may include fragments foreign to the host rock.

What appears to be the largest fault breccia occurs at the Grenville Front, extending irregularly southwest along the Bell Lake Granite-Lorrain quartzite contact for about 3.6 km from a point just west of the portage between Bell Lake and Johnnie Lake to Ruth-Roy Lake. Excellent exposures of the brecciated white quartzite occur on a hill west of the portage, and again on the shores of Johnnie Lake to the southwest. At Johnnie Lake, the breccia consists dominantly of angular to rounded blocks of white orthoquartzite (Fig. 23A), but locally darker metasediments of a type not seen in the Lorrain Formation were observed (Fig. 23B). Brecciation of the adjacent granite was only seen in one small area and is much less conspicuous because of the lack of colour contrast between fragments and matrix. The obvious high degree of milling and the mixing of fragments at Johnnie Lake may have been produced by repeated movements in the fault zone.

A second major fault breccia zone occurs in the north-central part of the area, trending northeast for about 1.6 km between Harry lake and Jackdaw Lake. Depending on the rocks intersected, it contains fragments of the Espanola Formation, Serpent Formation, or the Nipissing Diabase. The adjacent rocks are strongly sheared and in places fractured, with quartz-tourmaline fillings or quartz veins or boxworks. This zone formed contemporaneously with the north-south crossfolds in this part of the area. Smaller oligomicitic breccias along the Front at Kakakise Lake may be simple fault breccia, although some involving amphibolite matrix may be intrusive breccia.

The Sudbury-type breccias are of enigmatic origin as various authors have noted. They are abundantly scattered, large and small, throughout the Southern Province terrane. Hypotheses of origin previously suggested have included diatreme activity (Thomson, 1957; Fairbairn and Robson, 1942; Frarey and Cannon, 1969; Dupuis et al., 1982), and meteorite impact (Dietz, 1964; Dence, 1972; French, 1972). No relationship to folding is shown, and while some are located close to faults many are randomly located and have evidently formed indiscriminately.

Perhaps the best example of a large Sudbury-type breccia zone is located near the north edge of the map area, extending for 2.4 km northward from the south shore of East Howry Lake to the bay of Lake Panache south of Potato Point. It attains a maximum width of 620 m in the central part, narrowing in both ends. First seen at its northern end at Lake Panache, it was thought to be a simple fault breccia because of its monomict fragments of quartzite and restricted width there, but mixing of clasts, including numerous diabase fragments, was seen in the much broader continuation farther south. The breccia zone is post major folding and perpendicular to the structural trend, crossing Huronian formations from the Mississagi to the Serpent, as well as the Nipissing Diabase sheet within the Serpent at East Howry Lake.

It is inhomogeneous in that areas within it, possibly very large blocks, appear to be unbrecciated. Except at the ends of the zone, most of the clasts consist of fragments of Espanola rocks with which are mixed pieces of quartzite and Nipissing Diabase. However, Mississagi quartzite or Nipissing Diabase blocks predominante where these units are transected at the north and south ends respectively.

There has been little or no mixing where the diabase sheet is transected, whereas diabase blocks are very common northward from the sheet to the level of the Mississagi Formation, suggesting northward transport, as do Espanola fragments distributed north of Espanola wall rocks. Strangely, there is little sign of the Bruce Formation in this breccia zone; breccia dominated by Espanola and diabase fragments occurs on strike with the Bruce on the flanks. Contrasting evidence of transport within the breccia is provided at the southern extremity of the zone on the south shore of East Howry Lake, where the breccia cutting the Serpent Formation includes Nipissing Diabase and Espanola fragments as well as the Serpent quartzite, suggesting significant transport southward or upward. There is some suggestion of displacement of rocks on either side of the breccia zone, in that the Bruce-Espanola contact west of the zone is about 300 m farther north than on the east side. Other contacts are little displaced.

The breccia matrix is variable. In quartzite, it is siliceous, consisting of milled quartzite or vein quartz, and in the Espanola it is dark, altered and graphitic. In diabase it appears to be merely crushed diabase. None of the matrix in this occurrence or others of this group of breccias is pseudotachylyte, as to be expected, since pseudotachylyte is not found in the Sudbury breccias anywhere south of the Sudbury Basin (K.D. Card, personal communication, 1976). In places, the matrix shows well-marked flow lines.

Tentatively assigned to this class is an even larger breccia zone along the Grenville Front at the northeast of Lamorandière Bay. From its position it might be suspected of being a fault breccia but this seems questionable because of its size and its mixed clasts. It has a minimum length of 3.2 km and a width of up to 310 m. Fragments in the breccia are dominantly sedimentary, varied, and in places quite large, which, together with the indifferent to poor quality of exposure, probably accounts for previous identification of various parts of the breccia zone as in situ Huronian formations, chiefly Bruce and Espanola (Bell, 1878; Quirke and Collins, 1930).

The breccia contains blocks of white orthoquartzite and a variety of silty, micaceous, dark grey fragments, some scapolite-bearing and spotted similar to metamorphosed Espanola siltstone, as well as grey to brown weathering crystalline dolomite; in addition, it carries pebble-size, cherty (silicified?) clasts of uncertain origin in a dark, pinkish weathering, micaceous greywacke-like matrix, forming a pseudoconglomerate. The presence of these lithologies undoubtedly accounts for Quirke and Collins assigning the rocks in the vicinity to the Bruce conglomerate, Espanola siltstone and limestone, and Lorrain quartzite (Quirke and Collins, 1930). Westward extensions of the Lamorandière Bay breccia zone occur intermittently at the entrance to the bay, on the small islands just west of the entrance, on the south shore of Killarney Bay opposite the islands, and on the hillside extending up from the south shore. All these contain calcareous or dolomite fragments. East of Lamorandière Bay, brecciated diabase was seen in two or three poorly exposed places, indicating that the zone is not a large sedimentary breccia. At one point close to the northeast end of the zone, brecciated granitic rocks occur in an isolated outcrop near its south margin. If the granitic blocks are from the Killarney Batholith, dated at 1550 Ma, the breccia cannot be correlated with the Sudbury Breccia, which is pre-Sudbury Irruptive, i.e. pre-1850 Ma. In that case the Lamorandière Bay breccia must be a younger diatreme or a giant fault breccia containing a mixture of clasts, including carbonate clasts.

Other smaller breccias of this group are confined to single stratigraphic units. Many are in quartzite, such as those at Bear Lake (Serpent Formation) and those in the south-central and eastern parts of Lake Panache (Mississagi and Pecors formations). They vary widely in form and size from irregular patches a few centimetres to a few metres across to well defined dyke-like masses a few metres across. In quartzites, oligomict breccia lacking colour contrast between matrix and fragments is commonly difficult to recognize, particularly where exposure is obscured by vegetation, even small growth such as lichens. Others are more readily seen because of the inclusion of argillite or conglomerate fragments. Mixed quartzite-argillite breccias are prominent on Sentinel Island and islands farther south in Lake Panache north and northwest of Archie Bay. There appears to be no overall stratigraphic or structural control for these small breccias, which show evidence of later deformation. In one small but noteworthy occurrence on the shore of Lake Panache near the north edge of the report area, brecciation is confined to a single bed one or two metres thick in a series of regularly bedded, unsheared, and crossbedded subgreywacke beds near the top of the Pecors Formation.

North of the report area and closer to the Sudbury structure, shatter cones occur in the various brecciated formations within 16 km of the irruptive (Guy-Bray et al., 1966), and shock features have been described in the breccia fragments (French, 1972), lending weight to the impact hypothesis of origin for the breccias there. No shatter cones were found in the report area and it is evident that the shatter-coned aureole around the Sudbury structure is very much smaller than its breccia field.

Cataclasis

As mentioned, large areas of the Lorrain Formation and to a lesser extent the Bar River Formation are cataclased toward the south. The major zone of cataclasis, about 4.8 km wide, extends from the west edge of the report area eastward to Bell Lake. It includes the tightly compressed La Cloche Syncline and the faulted culmination of that fold and the McGregor Bay Anticline. The entire zone is dissected by innumerable faults (Fig. 15) and the normally highly competent Lorrain arenites are in many places severely crushed and reduced to quartz-sericite schist (± feldspar). The strain is taken up in numerous strongly sheared horizons a few metres to hundreds of metres wide between which are beds that are cataclastic but in which bedding and cross-bedding are preserved to varying degree.

The timing of the cataclasis is of interest. It obviously preceded Sudbury diabase intrusion (ca. 1230 Ma) and succeeded the formation of major folds. It presumably resulted from the coaxial refolding of the major structures by strong north-south stresses that compressed and steepened those structures. Some northeast faults are evidently younger, as at David Lake where a fault breccia strikes across the zone. The zone of cataclasis and its foliation strike east-southeast with the bedding strike, and are evidently unrelated to, and probably earlier than, northeast faulting, cataclasis and refolding at the Grenville Front and to the tectonic grain within Grenville Province.

Metamorphism

Except for late diabase dykes, the Southern Province rocks have been regionally metamorphosed under conditions ranging from upper greenschist to middle amphibolite facies. Chlorite, biotite, muscovite, garnet, andalusite, cordierite, staurolite and magnetite have developed in the immature sandstones and pelitic rocks, notably in parts of the Pecors and Gowganda formations, while quartz, muscovite, phlogopite, biotite, tremolite, clinozoisite, epidote, pyrite, scapolite, diopside, actinolite, plagioclase, and microcline have formed in the calcareous rocks of the

Espanola Formation. Scapolite is also prominent in the Bruce Formation in the northwest corner of the area, where the upper part of that unit is evidently calcareous. Elsewhere, this mineral is lacking in the upper Bruce although it is conspicuous in adjacent Espanola beds, indicating that the top of the Bruce is not everywhere calcareous. Except for ubiquitous sericite (5-30 per cent), regional metamorphism is relatively inconspicuous in the psammitic rocks, particularly in the orthoquartzites that underlie a large proportion of the area; however, biotite is common and garnet occurs locally in the Mississagi Formation in the northeastern part of the area, and muscovite and locally epidote are found in the Lorrain and Bar River quartzites in the south. The orthoquartzites of the Lorrain and Bar River also contain megascopic aluminosilicate metamorphic minerals, andalusite and chiastolite, in veins and partings. West of this area, kaolinite, kyanite, pyrophyllite, and andalusite are reported (Card, 1976a, b) to occur as microscopic porphyroblasts and as patches interstitial to the quartz grains in the upper Lorrain. These minerals were not seen in thin sections of Lorrain from the report area, but may have been obliterated by cataclasis. The secondary aluminosilicate minerals in the Lorrain are regarded as metamorphic after kaolinite and/or diaspore in the original sediment (Church, 1967; Young, 1973).

Regional metamorphic effects are most apparent in the calcareous Espanola Formation across the northern part of the report area, and in pelitic and semipelitic parts of the Pecors and Gowganda formations around the east end of Lake Panache, the northern part of Bell Lake, and at Threenarrows Lake. There, andalusite, cordierite, staurolite and garnet have formed megascopic euhedral to anhedral knots and porphyroblasts. Andalusite is by far the most widespread and abundant product in these rocks; it is for the most part retrograded, like cordierite and staurolite, to quartz, sericite, biotite and chlorite. Staurolite is much less abundant than either cordierite or andalusite. The size, number, and composition of the porphyroblasts and knots are strictly controlled by the composition of the beds. In favourable beds, andalusite crystals reach 10 cm in length, and staurolite, andalusite and cordierite are preferentially developed in separate beds or in the upper and lower parts respectively of a single bed (Fig. 24). Locally, cordierite knots are rimmed by apparently younger andalusite. The plagioclase in most pelites is in the oligoclase-andesine range. Brooks (1967) reported albite near Harry Lake. Chloritoid was not recognized and garnet is uncommon in the pelitic rocks. Minor tourmaline was seen in several thin sections and occurs megascopically with quartz at Gabodin Lake.

The metamorphic character of the Espanola Formation changes about halfway across the northern part of the area. To the west, carbonate beds consist of calcite (dolomite) – quartz – muscovite (phlogopite) – biotite – chlorite – ± tremolite ± minor pyrite assemblages locally containing large tremolite porphyroblasts (Fig. 23) and the siltstones carry scapolite, plagioclase, microcline and epidote in addition; eastward, carbonate, chlorite and the micas decrease, scapolite decreases and disappears, feldspar and amphiboles increase, and diopside and possibly garnet appear. There is evidence of two generations of amphibole at Annie Lake near the Front.

The abundance of scapolite in the area is unusual, as it is not a commonly reported mineral in low- to medium-grade regionally metamorphosed Shield rocks, nor is it a product of contact metamorphosed Espanola beds in the Huronian, as far as is known to the writer. In contrast to some areas where scapolite has been reported in higher grade zones (e.g. Westra, 1978; Dimroth and Dressler, 1978), in this area it is abundant in zones of greenschist grade as defined by the pelitic rocks. It is very abundant in calcareous siltstone of the middle Espanola member, exceeding 50 per cent in extreme examples (Fig. 4). The scapolite is generally anhedral but may be euhedral and forms prominent polycrystalline white spots up to 3 or 4 mm across. It is commonly zoned into soda-rich (marialitic), poikilitic cores containing "beads" of biotite, muscovite, quartz, and carbonate, and calcic rims, or vice versa, or consists of alternating sodic and calcic layers. The abundant chlorine and soda may indicate a highly saline environment of deposition or may be due to metasomatism of unknown origin, as suggested by Card (1976b). The change in the Espanola Formation to higher grade coincides approximately with the appearance of abundant alumina-rich porphyroblasts in the pelitic rocks. Thus a large zone in the northeastern part of the area was metamorphosed to lower to middle amphibolite grade. A smaller and more inconspicuous zone at Threenarrows Lake was correspondingly metamorphosed. Both zones extend beyond the report area and form part of a regional nodal metamorphic pattern in this part of Southern Province (Card, 1978b). Data from this report area indicate that the northeastern zone or "Eden Lake node" extends considerably farther south than previously shown, at least to the main body of Bell Lake.

Age of metamorphism

The western edge of the Eden Lake node strikes south-southeast, transecting the major structural trend, and thus the node is post major folding. Node metamorphism took place under static conditions, as shown by a general lack of cleavage in porphyroblastic strata that, while possessing a weak bedding-plane foliation best seen in thin section, retain excellent primary (sedimentary) structures (Fig. 10). The metamorphism, however, preceded a later strong but irregularly developed deformation, as knotted beds at Gabodin Lake, Bell Lake and elsewhere are schistose and at

Figure 24. *Andalusite-cordierite hornfels, uppermost Gowganda Formation. The photograph shows compositional control over the crystallization of cordierite (under hammer head) and andalusite. Bell Lake, Goschen Township. GSC 188839*

those lakes are cut by northerly to northeasterly cleavage subparallel to secondary folds, and in a few places metamorphic knots have been flattened in the plane of that cleavage, as mentioned previously, or rotated. Knotted strata are also clearly folded in places in the eastern part of Lake Panache and at Annie Lake. The Eden Lake metamorphic node includes the felsic intrusive rocks of the Eden Lake Complex, suggesting a possible genetic relationship. Although the metamorphic rocks in the Gabodin Lake Anticline are cut discordantly by felsic dykes, the interval between metamorphism and felsic dyke intrusion may have been brief, and if so the age of the metamorphism may be roughly that of the Complex. As mentioned earlier, Fairbairn et al. (1969) obtained Rb-Sr isotopic ages from Huronian metasedimentary rocks in this general district that in composite suggested a metamorphic event at 1910 ± 100 Ma. This is probably the best available estimate of the approximate age of the regional metamorphism of the area, and generally corresponds to the age of Penokean orogeny tectonism south of Lake Superior (Cannon, 1973; Van Schmus, 1976). In summary, the metamorphic (thermal) peak followed the main deformation stage in the area, was possibly synchronous with the Eden Lake intrusions, but preceded secondary deformation around the eastern end of Lake Panache.

The Eden Lake node abuts against the Grenville Front intrusive belt (Killarney Batholith) in Goschen, Bevin, and Sale townships, and near Bell Lake its formation was formerly attributed to heat from those intrusions (Brooks, 1967); subsequent work has shown it to be broader than thought, and to be older than and truncated by the intrusive belt. However, late microscopic growth of cross-cutting muscovite, biotite, and chlorite in the pelites near Bell Lake and at Annie Lake is probably due, as suggested by Brooks (1967) to Killarnean intrusion.

The Killarnean Grenville Front intrusions, furthermore, have evidently produced a zone of low grade contact metamorphism along their entire length (see Card, 1978b, Fig. 3). It is not distinguishable in the orthoquartzites or meta-arkoses, even immediately adjacent to the intrusions, but is conspicuous in the siltstones of the Gordon Lake Formation beyond, particularly around Killarney Lake, O.S.A. Lake, Baie Fine, and Killarney Bay. These beds are now hornfelses spotted with clots rich in quartz, sericite, biotite or chlorite. Some are blade-like and may represent retrograded andalusite. According to Card (personal communication, 1982), cordierite-andalusite hornfels is well developed at the Killarney Granite contact in Killarney Bay.

Grenville Province

Grenville Front

Following the criteria customarily and originally used in defining structural province boundaries in the Canadian Shield (Gill, 1949; Stockwell, 1961, 1969, 1973, 1982), the Grenville Front in this area is the line or zone along which major structures of the Southern Province are transected by structural trends of the Grenville Province or along which contrasting major structures of the two provinces are juxtaposed. Generally, the Grenville boundary is most readily drawn on large-scale regional maps, but in smaller areas and on more detailed scales the structural change is commonly transitional to varying degree except where marked by a major fault. In this area the most obvious change in regional structural trend and style occurs at or close to the northwest margin of the Killarney Batholith which, except in the northeast, clearly transects the major east-west structures in the Huronian Supergroup, separates different structural styles, and parallels adjacent Grenville gneiss trends. Accordingly, it is taken as the Grenville Front following Quirke and Collins (1930), Brooks (1967, 1976), and Stockwell (1969, 1982). As mentioned earlier, much or all of this boundary is also a fault, although the presence or absence of a fault is not critical in positioning the Front. East of Lake Panache, Southern Province trends are subparallel to the boundary because of the large-scale swing in strike of the Huronian Supergroup described earlier, but there too the boundary separates sharply differing fold styles.

Provincial compilers (Ayres et al., 1971; Card, 1978a; Card and Lumbers, 1977), in depicting the Grenville Front in this area selected a line following faults, lineaments, and/or augen gneiss and mylonite zones up to 4.8 km farther southeast, a line that for the most part lies along the opposite side of the Killarney intrusions; as a result, those intrusions were included in the Southern Province on their compilations. This departure is questionable and in the opinion of the writer undesirable, because, while the line in question follows conspicuous structural features, it does not satisfy the basic criterion applied to structural province boundaries, i.e. the separation of large-scale, regional structural units.

General

Grenville Province rocks occupy the triangular area comprising the southeastern half of the report area. In the south, it extends for 48 km from Killarney Channel along the north shore of Georgian Bay to the French River, tapering to a width of 9.5 km at the northern boundary. The Grenville terrane consists of roughly 60 per cent igneous and metaigneous rocks (orthogneisses), dominantly felsic, and 40 per cent metamorphosed supracrustal rocks. The latter comprise mainly biotite paragneiss and metaquartzite, lesser amounts of stratiform amphibolite, and minor metaconglomerate and calc-silicate or calcareous gneiss. All the gneissic rocks are cut by poorly-exposed, east- to southeast- or northeast-trending mafic dykes.

The supracrustal gneisses are recrystallized and lack primary structures; consequently, no stratigraphic ordering is possible. The earlier conclusions of Quirke in this respect (Quirke and Collins, 1930), based on his correlation of individual gneisses or associations of gneisses with known Huronian formations or sequences, could not be substantiated; nor could the felsic orthogneisses be sequentially ordered from field relations because of their concordance. As mentioned later, isotope dating indicates that orthogneisses southwest of Tyson Lake are circa 1700 Ma old; this provides a minimum age for the supracrustal rocks, and in this report they are classified as Early Aphebian.

Because of the scale of mapping and the intercalation and intergradation of gneisses, the representive map units are necessarily generalized and their contacts approximated for the most part.

Supracrustal gneisses

Biotite paragneiss (A'p)

Biotite paragneisses form the bulk of the metasedimentary assemblage in the Grenville terrane of the report area; they are particularly dominant south of Highway 637. Commonly they are migmatitic, a granitic or pegmatitic (feldspar-quartz ± biotite or muscovite) leucosome occurring as layers, lenses, or streaks, or they are variably feldspathized. Near Attlee and Broker lakes they are pinker or more feldspathic, more homogeneous, and form a relatively uniform assemblage (**A'pg**) of thinly layered stratiform gneisses (Fig. 25) with minor amphibolite and metaquartzite gneisses. The biotitic gneisses apparently represent original greywacke, argillite, and impure sandstone (Lumbers, 1975), and the layering presumably represents original bedding in a

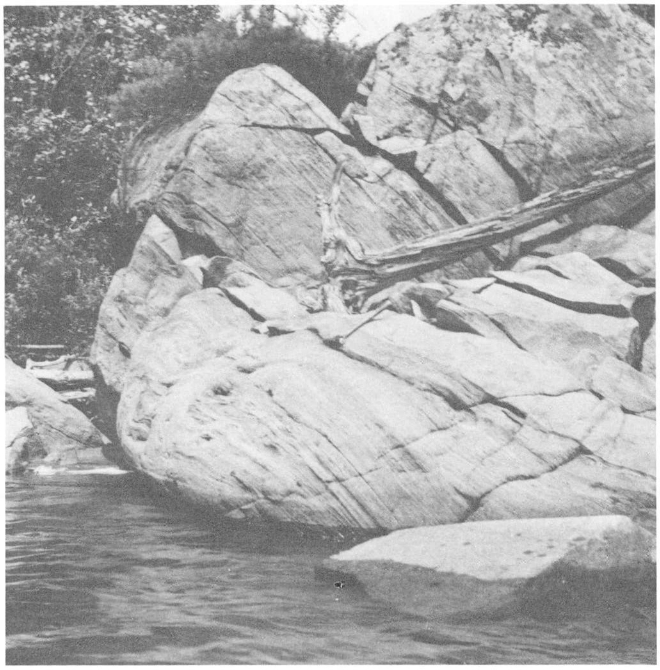


Figure 25. *Biotite paragneiss showing scale of layering and migmatitic injections. Attlee Lake, Attlee Township. GSC 188919*

gross way although individual layers are not necessarily or even probably equivalents of individual beds. Some amphibole-bearing varieties may represent mafic tuffaceous beds. No primary structures remain and the metasediments are completely recrystallized. They have undergone polyphase deformation, although they now display a remarkably strong uniform structural attitude.

The biotitic paragneisses are highly varied but, in general, most correspond with the Type 1A, Type 1B and Type 2 metasedimentary gneisses listed as metagreywackes by Lumbers (1975, p. 32) for the adjacent area. They are light to dark to pinkish grey, and consist essentially of plagioclase, quartz, and biotite, in decreasing order of abundance, plus or minus variable potassium feldspar. Garnet is a common additional constituent, occasionally forming euhedral crystals up to 5 mm across, hornblende is fairly common, and megascopic sillimanite appears in some specimens in needle-like clusters. Graphite was reported by Quirke and Collins (1930, p. 71) near the former Collins Inlet settlement. Knots and single crystals of potassium feldspar commonly form porphyroblasts and small lenses, and magnetite porphyroblasts occur in a few places. Thin zones composed largely of coarse biotite flakes form along local shears that parallel the gneissic layering. Macroscopically prominent garnet-rich biotite paragneiss zones were observed along the Mahzenazing River, around Tyson Lake, on Philip Edward Island, at Mill Lake, and northeast of Grondine Point, coast of Georgian Bay. Layering in these biotite paragneisses is defined by sharp changes in the ratio of mafic to leucocratic minerals along contacts that are prominent parting surfaces, and by the presence of conformable quartzofeldspathic layers of variable thickness (generally less than 10 cm) that represent "sweats" of late metamorphic origin. Thin layers and boudins of dark amphibolite of questionable origin are also found. Paler (more felsic) layers or sequences may represent less argillaceous siltstones or impure quartzites, as suggested by Lumbers (1975, p. 33).

Microscopically, the biotite paragneisses consist essentially of a granoblastic aggregate of relatively fresh poikiloblastic plagioclase (An_{20-40}), potassium feldspar, and strained quartz, together with well-oriented to clustered biotite that contains pleochroic haloes around small zircon grains. Amphibole is blue-green or brown hornblende, also oriented in the foliation. Apatite and iron oxide are minor but consistent accessory minerals; epidote is sporadic. The garnet (almandine) is also poikiloblastic, enclosing quartz, biotite, and/or iron oxide. Clinopyroxene appears in some specimens.

Metaquartzite (A'q)

Three main lithological types of metaquartzite gneiss are present: a) those consisting almost entirely of glassy quartz, b) those containing significant amounts of potassium feldspar and/or plagioclase, and c) recognizable Lorrain metaquartzite. The most abundant are medium- to coarse-grained quartz-plagioclase-potassium feldspar metaquartzite gneisses widely interlayered with other components of the supracrustal and igneous gneiss complex, particularly biotite paragneiss and amphibolite. In the field the glassy varieties, from their composition (but not their volume), resemble metamorphosed Lorrain or Bar River orthoquartzite, and the others resemble metamorphosed feldspathic quartzite or arkose of other Huronian formations.

a) Glassy metaquartzite

Most occurrences of this type, too small to map at 1:50 000 scale, were seen in and near the southern reaches of Tyson Lake and to the northeast, north of Lone Lake. One is well exposed in a roadcut on Highway 637 about 600 m northeast of the northeastern tip of Mahzenazing Lake, or about 2.3 km east of the junction of the highway and the access road to Bell Lake. Farther south, glassy metaquartzite forms a relatively thick layer west and southwest of Bijou lake and another lies on the northwest shore of Beaverstone Bay (Quirke and Collins, 1930, p. 76). These rocks consist almost entirely of layers of medium- to coarse-grained, recrystallized, glassy quartz, with thin muscovite or biotite partings. Some occurrences display euhedral red garnets that at one locality reach a diameter of 15 mm. Sillimanite was also observed at some localities. Commonly, layering defined by grain size or micaceous partings is also marked by a reddening of the quartz in some layers, apparently due to their iron content.

The glassy quartzite is difficult to trace for appreciable distances and some outcrops form isolated pods or lenses enclosed by biotite gneiss. These may be large boudins. In contrast, one narrow band of largely glassy quartzite, including the roadcut mentioned, is more or less continuous for some 4 km between Mahzenazing Lake and Tyson Lake. In this and some other examples, the glassy quartzite appears to be interlayered with, or to pass on strike into, the feldspathic quartzite, but their relationship is uncertain. In the roadcut, the glassy quartzite forms layers less than 30 m thick separated and flanked by thicker, dark biotite and biotite-amphibole paragneisses containing sillimanite. While superficially similar in isolated outcrop, these glassy layers cannot be correlated with the thick Lorrain or Bar River orthoquartzites of the Huronian Supergroup because of their restricted volume, apparent gradation to feldspathic quartzite, and the intercalations mentioned. Like the associated feldspathic quartzite gneiss, their parentage is indeterminate.

Figure 26. *Metaquartzite gneiss with biotite gneiss interlayers. Near Forbes Island, Tyson Lake, Sale Township. GSC 188911*

b) Feldspathic metaquartzite gneiss

These rocks dominate the metaquartzite category. They are widespread and form numerous mappable units north of Highway 637, particularly in a belt from Tyson Lake northeastward, but they are scarcer and form much smaller units south of the highway. Although strongly and repeatedly deformed, they are in general more homogeneous and less migmatitic than the biotite paragneiss group described above. Nevertheless, they contain numerous intercalations of biotite paragneiss (Fig. 26), amphibolite, "granite" and pegmatite, and the map units shown are actually composite and generalized.

Feldspathic metaquartzite is a typically medium grained, dirty cream, grey to yellow-brown weathering, well layered rock; where strongly feldspathized, it assumes a pink, igneous appearance. It consists of variable amounts of potassium feldspar and plagioclase (up to 30 per cent) quartz, biotite (chlorite), and/or sericite. Garnet and sillimanite are common. Microcline is not common in the thin sections examined. All textures are granoblastic to mylonitic, and foliation, defined by biotite orientation, is normally distinct.

Most of these metaquartzite gneisses, where mapped around Tyson Lake, Mill Lake, and Beaverstone Bay, were correlated by Quirke (Quirke and Collins, 1930) with the Mississagi Formation of the Huronian Supergroup. Others, at Tyson Lake, were equated with the Serpent Formation. The correlations at Tyson Lake were largely dependent on Quirke's identification in the central part of that lake of a substantial conglomeratic gneiss unit which he correlated with the Bruce Formation; the extent of the conglomerate and its correlation were not confirmed in the present study, as discussed below. Thus the correlations with the Mississagi formation, while possibly correct, are not adopted in this report. At Mill Lake and Collins Inlet settlement correlation of the metaquartzite with the Mississagi Formation was simply based on overall similarities with metaquartzite at Tyson Lake and at intervening localities, and at Beaverstone Bay it was largely based (ibid., p. 76) on identification of nearby amphibolite gneisses as Espanola equivalents, and supposed resemblances, including primary features, with Mississagi strata of Southern Province, also unconfirmed in this study. The correlations of these metaquartzites are not followed in any of these localities in this report, although it appears reasonable to relate these arenaceous metasediments to the Huronian Supergroup.

Considering the high degree of tectonism that has affected these rocks, particularly those in the belt through Tyson Lake, the grade of metamorphism, and pervasive effects of the voluminous intercalated felsic intrusions, now orthogenisses, it is highly unlikely that any of the textural features, including grain size, are primary, and the degree to which compositions represent primary composition in problematic. Most of them, however, were probably rather "clean" arkosic or subarkosic sediments. The intercalations of amphibolite and biotite paragneiss, some relatively thick, in these metaquartzite units, if representative of original interbeds, are a problem if the metaquartzites are to be directly correlated with the Mississagi or Serpent formations of the adjacent Huronian Supergroup. Across the Grenville Front, a scant 3.2 to 4.8 km distant, intercalations in these formations, as in the Lorrain, are thin and inconspicuous in comparison. The contrast would require a very sudden eastward change in depositional conditions along strike, at the Front or, alternatively, a significant tectonic transport of the rocks in question from a site of differing depositional regime.

c) Lorrain metaquartzite

Differing from the groups of gneisses just described is an irregular area of Lorrain metaquartzite (**A'**ql) extending for 3.2 km westward from the most southwesterly bay of Tyson Lake to the edge of the Bell Lake Granite and for a maximum of 5 km along the regional strike. This area, which lies west of the highly tectonized zone through Tyson Lake, is somewhat varied lithologically but consists in large part of relatively well preserved meta-arkose and metaorthoquartzite that is unmistakably Lorrain equivalent. Smaller remnants of like origin were observed by A. Davidson between Billy and Tyson lakes and by the author northwest of Strata Lake. While cataclased, sheared, and partly converted to micaceous gneiss and igneous-looking products, particularly at the southern, northern and eastern borders, these rocks are less deformed, richer in quartz, less feldspathized in general, and lack pelitic or other mafic intercalations compared to the above group. In places, in the central and southern portions, they display remnant bedding, even crossbedding. Where most altered, especially at the margins, they are characterized by complex intrastratal folding, thin concordant biotite seams and flecks, abundant and ubiquitous muscovite, granite dykes, pegmatite pods and dykes, and feldspar porphyroblasts. Much of this more altered material closely resembles the quartz-rich "streaky gneisses" described below. At the margins, this relatively large area of metaquartzite grades irregularly into varied granitoid rocks and pegmatite. Most of the recognizable bedding and some of the foliation in this enclave strikes 50 degrees or more east of north, appreciably more easterly than the regional Grenville trend (north 40 degrees east). The presence of this large, disoriented, semipreserved block of Lorrain in Grenville Province southeast of the Bell Lake Granite of the Killarney Batholith, surrounded by a complex of granite, pegmatite and gneiss, is enigmatic, but it emphasizes the complicated history of the zone now occupied by the batholith. The enclave is presumably a continuation of the Lorrain terrane to the west that was detached and rotated by faulting in this zone prior to or possibly during the intrusion of the 1525 Ma old Bell Lake Granite, which in its margins contains numerous Lorrain xenoliths in various states of preservation. Thus, tectonic activity in the Grenville Front fault zone long predated the Grenvillian Orogeny.

Intrastratal minor folds in the enclave are of uncertain age, except that they preceded the intrusion of post-Bell Lake equigranular granite and pegmatite that cut them. Some show dextral shear movement.

An irregular area over 300 m across of similar muscovitic white metaquartzite mixed with pegmatite, biotite gneiss, and granite occurs in the extreme southeast corner of Bevin Township and the northeast corner of Sale Township, 1.2 km northwest of Strata Lake.

Certain biotitic, quartz-rich gneisses were distinguished separately by Cannon (unpublished report) as "streaky biotite gneisses" (**A**'ql). Cannon recognized these at two localities, firstly in a narrow strip along the northwest edge of the Bell Lake Granite between Johnnie Lake and Ruth-Roy Lake (i.e. at the Grenville Front), where they were previously recognized by Brooks (1967, p. 1267, Plates 4 and 5) and named informally the "Brushcamp Lake Granitic Gneiss" (Brushcamp Lake is an obsolete name formerly applied to an adjacent part of Johnnie Lake), and secondly on islands at Mill Lake, an enlargement of Collins Inlet. At Johnnie Lake, this gneiss is granular (cataclastic) and consists of quartz, plagioclase, biotite, and muscovite, with or without potassium feldspar, plus accessory minerals. The biotite and muscovite are concentrated in thin layers separating siliceous, quartzose, layers that form the bulk of the rock, and this assemblage has been intricately folded (see Fig. 27; Brooks (1967) Plate 5). The "streaky gneiss" is well exposed on a ridge about 150 m west of the portage into Ruth-Roy Lake, immediately west of equally well exposed breccia of Bell Lake Granite and quartzite.

The high quartz content, muscovite content, and low biotite content readily distinguish this gneiss from the more feldspathic, or more biotitic varieties described above. At Johnnie Lake, it carried boudins and inclusions of much less foliated amphibolite and amphibolite-quartzite aggregates, and at least one sizeable mass of garnetiferous metagabbro. In places, according to Brooks (1967, p. 1267), it becomes more feldspathic and grades into patches of granite mineralogically resembling adjacent Bell Lake Granite. This narrow band of streaky biotitic gneiss at Johnnie Lake, which lies between large masses of Bell Lake Granite and Lorrain orthoquartzite, clearly represents highly altered and deformed Lorrain quartzite caught in a tectonically mobile zone of repeated movement that was also affected by granitic metasomatism or "soaking". The source of the biotite is unclear, as it is completely lacking elsewhere in Lorrain quartzites, except in the narrow transposed zones along the Front. Deformation preceded and followed biotite crystallization and probably also followed "granitization" (feldspar metasomatism), i.e. followed emplacement of the Bell Lake Granite. The layering does not represent original bedding.

At Mill Lake, Cannon (unpublished report) noted that the gneiss is similar texturally, is intercalated with quartzite and pelitic gneiss, carries amphibolite boudins, and is similarly high or higher in quartz but lower in muscovite content. Biotite is sparse, but sillimanite, reoriented into the cataclastic foliation, is abundant. This gneiss also probably formed from an orthoquartzite parent with biotite forming during late tectonism but prior to cataclasis.

*Amphibolite (**A**'a)*

In this report all metamorphic rocks consisting essentially of plagioclase and amphibole are termed amphibolite. Rocks of both sedimentary and igneous origin are included. These are commonly difficult to distinguish from one another in the field, but some occurrences resemble metagabbroic rocks and are discussed later. Those amphibolites thought or known to be of intrusive origin are so designated (**A**'mg) on the accompanying map.

Amphibolites intercalated with biotite paragneisses and metaquartzite form a subordinate but appreciable portion of the Grenville Province gneiss complex from Tyson Lake northeastward. At Tyson Lake they commonly make up thick to thin layers, in places only centimetres thick, flanked by metaquartzite units. These amphibolites continue in a narrower belt southwestward to Mahzenazing Lake. Like other gneisses, most if not all of the stratiform amphibolite units shown on the map are to a degree composite, as they include unmappable layers of biotite paragneiss, biotite-amphibole gneiss, and metaquartzite, as well as pegmatitic and granitic masses. Amphibolite layers themselves are rather poorly exposed in the area.

These stratiform amphibolites taken to be of supracrustal (sedimentary?) origin are fine- to medium-grained and moderately to well layered or foliated. They are consistently concordant with adjacent members of the gneiss complex and lack inclusions in all observed outcrops. Weathered surfaces are dark grey to black, or speckled. Plagioclase and garnet are megascopically porphyroblastic in some examples. The rocks consist of approximately equal amounts of calcic plagioclase and brown hornblende, with or without an appreciable biotite content (up to 10 per cent). Magnetite is relatively abundant and epidote and apatite are other accessories. In addition, Dollase (1962) identified diopside, tremolite and sillimanite in various amphibolite samples from Tyson Lake. Sizeable areas of amphibolite at Tyson Lake and Beaverstone Bay were correlated with the Espanola Formation by T.T. Quirke (Quirke and Collins, 1930, p. 61-64, 77-80). The stratiform amphibolites are presumably formed from limy argillites or siltstones, but their common intercalation with sizeable metaquartzite layers is puzzling, as far as seeking Huronian antecedents is concerned, particularly in the Espanola Formation. As Tyson Lake, much of Quirke's Espanola unit consists of biotite paragneiss indistinguishable from many of those of unit (**A**'p) of this report, and in this report the correlations are not followed at either locality.

Figure 27. *Cataclastic quartz-biotite-muscovite "streaky gneiss" derived from Lorrain quartzite. Grenville Front at Johnnie Lake, Carlyle Township. Photo R.T. Cannon. GSC 188989*

Calcareous gneiss (A'cq)

Restricted occurrences of calcareous gneiss were observed with associated biotitic paragneisses in two localities: on shores and peninsulas in the northern part of Tyson Lake and to the north between Duplex Lake and Strata Lake. Those at Tyson Lake were noted by Quirke and Collins (1930, p. 61-63) who correlated them, along with large nearby areas of amphibolite, with the Espanola Formation of the Huronian sequence. Those east of Duplex Lake were previously unrecognized.

The Tyson Lake gneisses form one or more thin layers at the north end of the large, highly indented peninsula in the northern part of the lake and in the bay east of the peninsula. They are mostly fine grained, grey, pinkish or rusty weathering, thinly layered rocks that are characteristically friable. They contain thin (<5 mm) streaks of potassium feldspar and quartz but are not particularly migmatitic. Compared to "common" biotite paragneisses, calcareous gneiss and intercalated noncalcareous gneisses are finer grained but granular, less biotitic or lack biotite, are thinly layered, and display somewhat corrugated weathered surfaces; calcite-bearing members are readily recognizable in the field by reaction to dilute hydrochloric acid. One shoreline exposure includes one or two thin layers of dirty white marble. Other outcrops contain diopside porphyroblasts. These thin calcareous gneisses are closely associated with much more abundant fine grained, more biotitic, sedimentary gneisses that are also thinly layered, but the calcareous rocks are not intercalated with amphibolite.

The carbonate-bearing component of the gneiss at Tyson Lake is a granoblastic assemblage of highly variable amounts of quartz, garnet (up to 30 per cent), calcite or dolomite (up to 15 per cent), diopside, and epidote ± andesine, hornblende, actinolite, and microcline. Carbonate-free specimens contain up to 15 per cent pyroxene or amphibole and 50 per cent plagioclase. The marble contains small amounts of pyroxene, quartz, epidote and sphene, in addition to calcite and dolomite (90 per cent). Graphite was reported in these rocks by Quirke (Quirke and Collins, 1930, p. 62) but was not observed in this study.

The second calcareous gneiss unit, as outlined east of Duplex Lake, is interpreted from a few relatively small outcrops extending southeastward for about 300 m from a point located about 1.4 km southwest of the southern tip of Strata Lake. Further outcrop tracing is hindered by poor exposure, and in addition the unit may be thinned or eliminated along strike by tectonism and/or intrusion. At one place the outcrops are separated from metaconglomerate to the east only by about 60 m of cover. These calcareous rocks are similar mineralogically to those on Tyson Lake. They contain variable amounts of quartz, calcite, biotite, epidote, diopside, actinolite, microcline, and plagioclase. One outcrop displays metacrysts of diopside up to 6 cm across, rimmed by actinolite and surrounded by coarse plagioclase and quartz.

Metaconglomerate (A'mc)

Previously, Quirke (Quirke and Collins, 1930) reported occurrences of metaconglomerate in the Grenville terrane at Tyson Lake, Broker Lake and Beaverstone Bay, and correlated them with the Bruce, Gowganda and Mississagi formations respectively. In the present study it was hoped that these occurrences could be verified and extended, so as to provide evidence for correlation with the Huronian strata and/or for the stratigraphy within the sedimentary gneisses. If, as Quirke believed, the gneisses of this part of Grenville Province are correlative on a formation to formation basis with Huronian units, one might expect that the abundant boulder-bearing conglomeratic rocks of the Ramsay Lake, Bruce and Gowganda formations would be well represented and recognizable on the other side of the Grenville Front. Such is not the case, however, and the present study indicates that either the Huronian conglomerates have been obliterated by metamorphism, metasomatism, and tectonism, or that they were not deposited in this part of the area. At most of the localities mentioned by Quirke, identifications were found to be highly questionable or untenable and the correlations consequently suspect. Instead, the most unequivocal conglomerate observed does not occur at any of the localities mentioned in Memoir 160.

On the large peninsula in the northern part of Tyson Lake, Quirke identified and described at length (ibid., p. 59-61) his most extensive conglomerate unit, which forms a series of outcrops said to extend for over 1.6 km; this he correlated with the Bruce Formation, inasmuch as it lies in part adjacent to calcareous rocks he considered to represent the Espanola Formation.

The description noted that the most diagnostic outcrops were to be seen on the west side of the northern portion of the unit in question, where "grey granite" pebbles were reported. Re-examination of this map unit showed that clean exposures suitable for close study are small and essentially confined to the lakeshore, and confirmed that only in one or two outcrops at the northern locality are there rocks that can be said to resemble conglomerate. The writer considers even these doubtful, however, and except for one narrow layer shown on the map as questionable conglomerate, mapped the unit formerly shown as Bruce conglomerate as porphyroblastic and migmatitic biotite paragneiss. Supposed conglomerate outcrops in Tyson Lake and Collins Inlet were examined by Dollase (1962), who also considered them questionable.

In the present study, unequivocal conglomerate was seen only in the unit extending southwest from Strata Lake in Sale Township. Small isolated outcrops occur at the outlet of that lake and elsewhere, the best exposures lying within a section about 300 m wide about 1600 m southwest of Strata Lake. Rounded grey granite pebbles up to 7.5 cm in long direction (horizontal surface) lie in a brownish biotitic matrix that resembles metagreywacke. These clasts are greatly elongated in third dimension, down plunge. As mentioned, at one point this conglomerate lies close to calcareous gneiss outcrops to the west, a situation suggestive of an Espanola-Bruce association. Other metasedimentary outcrops within the unit shown are not conglomeratic or unequivocally conglomerate, and the unit, like others in this part of the area, also includes a considerable proportion of intercalated pegmatite and granite.

An isolated outcrop of probable conglomerate was observed by J.B. Henderson in Halifax Township, about 1.6 km northwest of the west end of Halifax Lake. Rounded and elongate granitic pebbles lie in an indurated metasiltstone matrix. Problematic examples resembling greywacke conglomerate lie near the southwestern extremity of Tyson Lake and on the south shore of Broker Lake.

On the Bell Lake access road, which was completed subsequent to the systematic mapping, a small but well preserved outcrop of typical Gowganda-like paraconglomerate was observed in northeastern Carlyle Township during a revisit to the area. Exposures on strike to the southwest, at the northeastern extremity of the southeast bay of Johnnie Lake, proved on re-examination to be Gowganda-like pelitic schist, although nonconglomeratic. It is tentatively concluded that a thin slice of Gowganda rocks (A'pq) extends northeast from this bay of Johnnie Lake for 1.6 km or more, intertonguing with granitic gneiss, pegmatite, and Lorrain metaquartzite remnants.

Figure 28. *Blastomylonitic pseudoconglomerate interlayered with leucocratic mylonite layers. The notebook is about 16 cm across. Broker Lake, Attlee Township. Photo I.F. Ermanovics. GSC 188958*

Pseudoconglomerates consisting of subround to elongate porphyroblastic feldspar and quartz in a dark matrix, or produced by boudinage of thin pegmatite or quartzite layers, are widely scattered over the area. Prominent occurrences of the first type lie along the southern shore of Broker Lake (Fig. 28). Local examples of blastomylonitic pseudoconglomerate occur along the shores of Tyson Lake southwest and west-northwest of Forbes Island, in the stretch between Collins Inlet and Lyle Lake, at Mill Lake, at Beaverstone Bay, and on the Georgian Bay coast near the southeastern corner of the report area. Most, if not all, of these occurrences lie at or near prominent faults or mylonite zones along which intense cataclastic deformation has taken place. Some are quite deceptive, however, because of their resemblance to paraconglomerate, particularly that of the Huronian Gowganda Formation.

Amphibolite (metagabbro): (A'mg)

Amphibolite of intrusive origin occurs in small patches and intercalations, mainly in a belt through Tyson Lake. Where less deformed, it resembles Nipissing Diabase. Large mafic bodies, like those of Nipissing Diabase in the adjoining Southern Province to the west, or those provisionally correlated with the Nipissing by Lumbers (1975) in Grenville Province east and northeast of the report area in Struthers, Halifax, Tilton and Secord townships, are not present in this area. The amphibolite is dark grey to black, medium- to coarse-grained, and foliated to massive. Outcrops are usually small and only rarely are intrusive contacts or metasedimentary inclusions shown; most occurrences are too small to map. The largest outcrop areas lie in Tyson Lake west and southwest of Lone Lake; they were formerly correlated with the Espanola Formation (Quirke and Collins, 1930). A smaller body of metagabbroic amphibolite is exposed on the Killarney road (Highway 637) at the junction of the sideroad to Mahzenazing Lake. These rocks consist dominantly of plagioclase and hornblende, with or without appreciable biotite. A poorly exposed, sill-like mass of amphibolite west of the central part of Spoon Lake is magnetite-rich, disturbs the compass, and is at least partly responsible for a well defined magnetic anomaly (Geological Survey of Canada, 1965, Map 1516G).

The relatively early age of these bodies is shown by the fact that aside from their foliation and metamorphism they are invaded by granitic and pegmatitic veins and dykes that have been sheared, folded and cataclased by subsequent deformation. Boudins of amphibolite enclosed in paragneiss or orthogneiss were seen at many places in the report area.

Intrusive gneisses (orthogneisses)

General

Gneissic intrusive rocks underlie most of the Grenville terrain. North of a line through Tyson Lake they constitute at least half the gneiss complex and south of the line their proportion increases to perhaps 75 per cent. The volume of intrusive rock is appreciably greater than in the western part of the adjoining Burwash area of Lumbers (1975); this increase may be related to increased tectonism as the northwest margin of the Grenville Front Tectonic Zone is approached. Discrete plutons are difficult to outline in this area because these orthogneisses have assumed an extremely regular, linear, "strung out" trend and form due to strong tectonic overprint; as shown by Figure 29, some have been reduced by tectonism to swarms of lenticular slices. Only in a few places in the southern part of the area is their original shape partly retained, as for example by the crudely ovoid body east of Mahzenazing Lake.

While amphibolite gneiss of intrusive origin is clearly older than adjacent felsic orthogneisses, age relationships among the latter could not be determined in the field. Since local gradation from one petrographic type to another can be observed, it is assumed that many of the orthogneisses are approximately the same age.

The orthogneisses are generally somewhat more erosion-resistant than the other rocks and form either low elongate ridges bounded by swampy valleys, as in the northeast, or border low areas of little relief, as in the south. Exposure is generally good to excellent, particularly in the extreme southeastern part of the report area, as southwest of Beeftea Lake, on Philip Edward Island, and along the Georgian Bay coast, where the proportion of bedrock may exceed 50 per cent (Fig. 29).

These rocks are classified and described separately from the felsic intrusions of the Killarney Batholith of known Helikian age along the Grenville Front because they are in general more biotitic, lack inclusions, are more migmatitic and pegmatitic, more varied petrologically, more metamorphosed and much more deformed, are intercalated with paragneisses, and from isotopic evidence are at least in part significantly older. From Annie Lake northeastward the structural distinction between the two intrusive groups is more difficult, because there the Front intrusions are also strongly deformed in places. The actual contact or boundary zone between the groups is unfortunately nearly everywhere covered, and further, it has been the locus of strong late deformation, so that age relationships of the two groups are not shown in the field directly.

Like the associated paragneisses, the orthogneisses are nearly everywhere deformed by at least one period of shearing and cataclasis that has obscured their original igneous textures to varying degree. Commonly, cataclasis and shear have reduced the rocks to variably micaceous porphyroblastic, porphyroclastic or augen gneiss, or to mylonite, which also has the effect of obscuring their original composition. These cataclastic rocks are especially prominent in a broad zone extending southwest and northeast from Tyson Lake, and also in a parallel one flanking Spoon Lake.

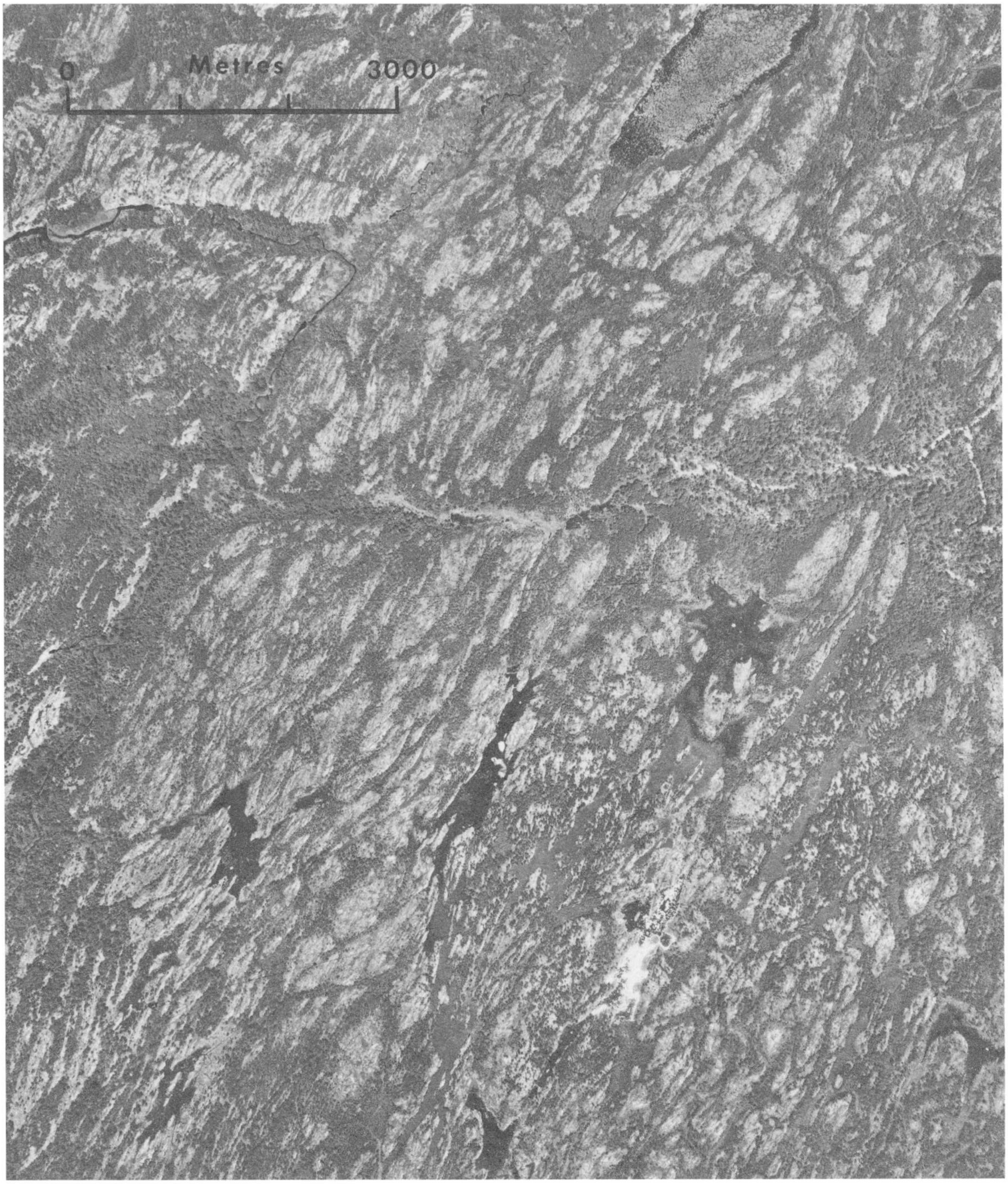


Figure 29. *Aerial view of Grenville terrane near Beeftea Lake, Kilpatrick Township, illustrating the dominant northeast foliation and later lenticular fault pattern imposed on monzonite and granite orthogneisses of the Grenville Front Tectonic Zone. The stream-occupied northeast lineament (left) offsetting the east-west lineament is the Beaverstone River Fault, a late or late-activated structure. Air photograph 59-4602: 2-77, courtesy Ontario Ministry of Natural Resources.*

Felsic orthogneiss (fo)

The felsic orthogneisses of the area (aside from pegmatite) are a varied group that includes diorite, granodiorite, trondhjemite, monzonite, hornblende and quartz monzonite, minor syenite, and granite, but consist mostly of pink, medium- to coarse-grained, equigranular to porphyritic or porphyroblastic, gneissic quartz monzonitic rocks. Quartz monzonite and hornblende-bearing quartz monzonite from sizeable areas south of Tyson Lake and Tyson Channel. Other large areas farther west appear to be more granitic. Classification of the pinkish potassic gneisses is largely based on field estimates and a relatively limited number of thin sections. Further mapping, sampling, and petrographic study is necessary to more accurately classify and delineate them, particularly since they are gradational and also have been severely deformed, in places to strongly lineated gneiss and augen gneiss. Gneissic grey granodiorite, diorite, and trondhjemite are readily distinguished from the more potassic rocks; they are confined to areas north of Broker Lake (part of the "Broker pluton" of Lumbers (1975)) and south of Beeftea Lake, where, together with adjacent masses of granite and monzonite, they form the southwestern extension of Lumbers' "Francis Lake Batholith". Lumbers (ibid.) classified these two bodies as "Middle Precambrian" (pre-1600 Ma).

These gneisses are almost all biotitic and are garnetiferous in places. Perthite and antiperthite are common and locally the gneisses are megascopically magnetite-rich. Aeromagnetic maps 1515G, 1516G, and 7067G (Geological Survey of Canada, 1965a, b) show a broad, northeast-trending zone of positive anomalies extending through the report area in ground largely underlain by felsic orthogneiss, indicating that many of these rocks are relatively magnetite-rich. Near Collins Inlet, at Tyson Lake, and probably elsewhere, the felsic gneiss also contains allanite sufficient to produce above-background scintillometer or geiger counts.

On the accompanying map, a narrow ill defined unit near the eastern boundary, extending from Spoon Lake northward across Highway 637, is classed as "granulite gneiss" (fop); it is of uncertain origin, but is included with the orthogneisses because of its generally coarse grained texture. In the field the rock displays the yellowish brown weathering of feldspar that is common among granulite grade gneisses, and in places it is friable and deeply weathered. Samples consist of scant to abundant quartz (up to 50 per cent), plagioclase, hornblende, biotite, with in some cases up to 15 per cent clinopyroxene and lesser amounts of orthopyroxene (hypersthene), together with accessory garnet, rather abundant apatite and iron oxide. The pyroxenes are largely altered to hornblende. Rocks of similar megascopic appearance outcrop locally farther southwest along Highway 637.

The orthogneisses appear to grade into coarse grained, feldspathized or recrystallized biotite paragneiss in places, especially in the Tyson Lake zone, where many outcrops are difficult to classify. While potash metasomatism was evidently extensive in the area, the range of composition, the discrete form and nature of some orthogneiss bodies, textures, and local crosscutting relationships, indicate that they are predominantly of magmatic and intrusive origin.

The age of the felsic orthogneisses is indicated in the field only by their intrusion of the supracrustal gneisses and gabbroic amphibolite and by crosscutting mafic dykes probably 1200 to 1250 Ma old. Since some of the bodies are, however, directly traceable into the neighbouring Burwash area, the felsic orthogneisses of the two areas are very likely contemporaneous, and as reviewed by Lumbers (1975, p. 67), regional field relations and isotopic dating indicate a late Aphebian to early Paleohelikian age for some and possibly most of these rocks. Typical granitic orthogneiss sampled in the report area between Johnnie Lake and Mahzenazing Lake gave a two-point U-Pb concordia age from zircon of 1730 Ma (Krogh et al., 1971). At the map scale, the felsic orthogneisses are nearly everywhere concordant with adjacent supracrustal gneiss, but one large dyke-like mass clearly transects folded gneisses near the former Collins Inlet settlement (see map in pocket), suggesting a younger age, possibly syn-Killarnean (ca. 1550 Ma), for some of these rocks. Bodies that show the effects of repeated deformation are probably Aphebian.

Pegmatite (pm)

Pegmatite is common in the Grenville terrane, cutting all the above-described gneisses. Only west of Tyson Lake are there large areas of this rock, however. Near the south shore of that lake and north of Attlee Lake, two small but mappable pods of pegmatite occur. West of Tyson Lake, the pegmatite is intimately mixed with granite, metaquartzite, and paragneiss, but probably constitutes well over 50 per cent of the bedrock. In some sizeable outcrops it amounts to 70 per cent. Elsewhere, pegmatite forms dykes, sheets, and pod-like masses normally only a few metres wide. The pegmatites are simple mineralogically, consisting of alkali feldspar, quartz, and muscovite or biotite. Some also contain minor hornblende or conspicuous amounts of garnet or magnetite. Only unzoned pegmatite was observed. As remarked by Quirke and Collins (1930, p. 110), pegmatite appears to be preferentially developed within the supracrustal gneisses and to be distinctly lacking in the orthogneisses, suggesing that it formed more or less in situ as a metamorphic product. Pegmatite between Tyson Lake and the Bell Lake Granite of the Killarney Batholith, however, contains angular and rotated inclusions and crosscuts its wall rocks, indicating considerable mobility. The relatively late age of some of the pegmatite in this zone is shown by the fact that it invades boudined amphibolite, and cuts across granite dykes that cut refolded folds in the enclave of Lorrain Formation. Nevertheless, the pegmatite is itself crumpled, sheared, and in places crushed and boudined. It appears to have been very incompetent, displaying crushing and shearing even where bounded by relatively massive granitic host rock. It may have developed contemporaneously with late deformation.

Most if not all of the observed pegmatites are deformed in some fashion – by folding concordant with adjacent gneiss (Fig. 30), cataclasis, or shearing, and while there is evidence of more than one stage of pegmatite generation, as discussed later, the massive, undeformed, late (posttectonic) pegmatites that occur east of the report area (Lumbers, 1975, p. 103-104) are lacking; the observed pegmatites all preceded some stages of the tectonic overprint that structurally dominates the Grenville rocks of the area. The age of pegmatite folded with gneiss is suggested by the work of Krogh and Davis (1970), who reported a U-Pb zircon age of "between 1600 and 1700 Ma" from pegmatite concordant with folded paragneiss of the Grenville Front Tectonic Zone southeast of Sudbury, and who interpreted that as the time of plastic deformation in the Zone.

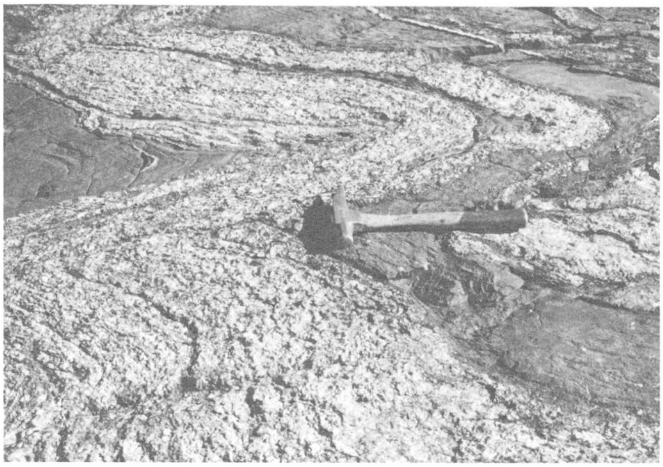


Figure 30. *Folding of mafic gneiss (amphibolite) and concordant cataclastic pegmatite. Tyson Lake near Forbes Island, Sale Township. Photo I.F. Ermanovics. GSC 188951*

The Killarney Batholith (PK-PAL)

General

References to the "Killarney belt of granites", "Killarney Granite" and "Killarney Batholith" appear in the literature from the time of Robert Bell (e.g. Bell, 1878, 1898; Collins, 1914, 1916, 1925; Miller and Knight, 1914; Quirke, 1927; Lawson, 1929; Quirke and Collins, 1930; Brooks, 1964, 1967). From the first, its great importance as a feature separating two major, markedly different geological terranes was recognized. It was also recognized early (Bell, 1898) that is coincided with a major dislocation (fault) and Bell (ibid.) also established the post-Huronian age of the granites. At the time, this latter was a significant conclusion because for decades there were considered to have been only two periods of granite intrusion ("Laurentian" and "Algoman") in the eastern Canadian Shield, both pre-Huronian in age. This was due in part to erroneous early correlations with the "original" Huronian, but consequently the post-Huronian age of the Killarney granites appears not to have been readily accepted in some quarters; Collins, for example, designated them pre-Huronian in 1914 (Collins, 1914, p. 16, 17, and correlation chart) as did Miller and Knight (1914) and although Collins soon altered this designation after visiting the Killarney area (Collins, 1916), as late as 1928 A.C. Lawson felt it necessary to visit Killarney to confirm the relationship. Lawson (1929, p. 369-370) also confirmed and stressed other relationships earlier described by Collins (1925), namely that the post-Huronian Killarney intrusions also postdate the quartz diabase (Nipissing Diabase) of Southern Province but predate the olivine diabase dykes, which he and others considered as a manifestation of Keweenawan magmatism; consequently, although based on this somewhat tenuous correlation, Lawson correctly concluded that the Killarney intrusions could not be Keweenawan or post-Keweenawan as had been believed. His important additional conclusion, that the Nipissing Diabase is also pre-Keweenawan, was unfortunately ignored for many years, with the result that Nipissing Diabase bodies were designated "Keweenawan" on some maps for a considerable time. Lawson (1929) also disputed Quirke's theory of a metasomatic origin for the Killarney Granite.

Originally (Bell, 1898), the "Killarney granite belt" extended only from Killarney Bay of Lake Huron in the southwest to Bell Lake (called "Three-mile Lake" in Bell's reports) in the northeast, a distance of about 32 km. By 1925 it had been further extended to the vicinity of Sudbury (Collins, 1925, p. 101), and Collins (ibid, p. 103) had also suggested that "Killarnean diastrophism", manifested by the granites, extended along the entire fringe of Huronian sediments from Lake Huron to Lake Temiskaming. Bell's northeastern termination at Bell Lake arose because, as noted above, the felsic intrusions beyond that are less uniform, particularly near Annie Lake, and are in part more strongly deformed (Bell termed them "Laurentian gneiss"); as a result they are not as clearly distinguishable from the gneisses to the southeast in the Tectonic Zone as are the intrusions farther southwest in the Batholith.

In this report the Killarney Batholith is divided into the following components, from the southwest to northeast; the Killarney Granite, including a closely associated, finer grained, younger phase informally called the "Lighthouse porphyry", the Terry Lake Diorite, the Bell Lake Granite, and the Annie Lake complex. Beyond this last, most of the felsic intrusive rock resembles the Bell Lake porphyritic granite, and is so designated provisionally on the map. Except for the Annie Lake complex, these components are distinctive, well defined, and nongradational; there are probably slight differences in age among them, although there is limited field evidence to confirm this. A six-point Rb-Sr isochron plot giving a recalculated age of 1625 ± 47 Ma was derived from analysis of samples of Killarney Granite and one sample from the Bell Lake Granite (Wanless and Loveridge, 1972); earlier, samples from the batholith fell on a reference isochron giving an age of 1540 Ma (Krogh and Davis, 1970). Zircons from Bell Lake Granite gave a U-Pb concordia age of 1523 Ma (Krogh et al., 1971). The preferred age of the batholith is 1525-1550 Ma.

Killarney Granite (PK)

This body extends for 20.8 km from Killarney Channel and George Island almost to Johnnie Lake, where it lenses out by intertonguing with the Bell Lake Granite and the Terry Lake Diorite. A short distance east of Killarney Channel it has a maximum width of about 4 km. The Killarney Granite is exposed southwestward beyond the report area on islands in Killarney Bay and on Badgley Island about 6.4 km distant (Card, 1976a). Beyond that it is covered by Paleozoic rocks. It is best exposed at Killarney and on numerous low bare ridges between the village and George Lake. This being the original area, the term "Killarney Granite" is retained for this component of the batholith to avoid introduction of a new name.

Granite member (PKc)

Excluding the Lighthouse porphyry, described later, the Killarney Granite member of the Killarney Batholith consists of coarse grained red granite or quartz monzonite that is massive to moderately foliated. Its brick-red weathered surface is distinctive and attractive. The rocks consist of orthoclase, microcline, oligoclase, quartz, and up to 5 per cent biotite (chlorite) which imparts the generally weak foliation. Accessories are sphene, apatite, iron oxide, rare pyrite, and zircon. No pegmatite was seen in the body. A petrographic description by R.T. Cannon (unpublished report), who studied the Killarney area in detail, reads as follows:

"The granite is extremely leucocractic, the sporadic mafic minerals usually consisting of biotite (often chloritised) associated with sphene and iron oxides. Occasional large zircons occur, small zircon crystals often core the pleochroic halos in biotite, and small apatites are present. Plagioclase, usually finely twinned and saussuritised, occurs as irregular crystals or well developed euhedra. The latter may be oscillatorily zoned; the zoning is picked out by alternating bands of alteration products. The plagioclase is usually oligoclase and the zones are little different in composition. The saussuritised plagioclase is often surrounded by a clear rim of K-feldspar producing a rapakivi effect which, however, cannot be seen on outcrop. The K-feldspar may be orthoclase, untwinned perthite, often irregularly microclinized, or microcline. Microcline replaces plagioclase and has grown the latest. The quartz forms irregular aggregates interstitial to the feldspar." Jones (1930, p. 49) described microscopic evidence of strain in the granite, in the form of bent or broken feldspars, undulatory and granulated quartz, and wrap-around structure of micas.

Cannon (unpublished report) found the Killarney Granite to become more gneissic (foliated) from northwest to southeast across strike, grading successively into a "coarse-grained, pink biotite gneiss" and then into porphyritic "fine-grained biotite gneiss" which is the informally termed "Lighthouse porphyry" (PKp) of this report. Card (1976a) reported a similar change. These rocks are gneissic in the sense of possessing a layering only in the extreme southeast near the Georgian Bay shore; elsewhere the "gneissosity" consists of a rather inconspicuous biotite orientation that in many places in not visible megascopically. The granite and the "coarse-grained pink biotite gneiss" are not readily distinguished and in this report are treated as a unit. The gradation mentioned is more or less in accord with Quirke's (1940) interpretation of the nature and relationship of the coarse grained granite at Killarney village and the associated fine grained porphyritic member to the southeast of it, which contains altered quartzite remnants near its southeastern margin. Quirke postulated, as discussed below, that a transitional series from quartzite to granite formed in situ and is represented in the section between Georgian Bay and Killarney Bay.

The Killarney Granite has an irregularly developed agmatite zone along its northwestern margin for about 9.6 km from Killarney Channel to beyond Lamorandière Bay. Small agmatite patches also occur on the margin of the granite at George Lake and Kakakise Lake. The agmatite was studied by R.T. Cannon and most of this account is from his description; it applies particularly to the Killarney Bay zone near Sheep Island immediately west of the report area, where the agmatite fragments are abundant and best exposed.

Fragments in the agmatite range from a few centimetres to (rarely) 7 m across, are angular and disoriented, and include the following rock types:

1. Amphibolite
2. Calc-silicate rock
3. Feldspar porphyry
4. Gneiss and schist

The amphibolite lacks schistosity and gneissosity and consists of blue-green hornblende, plagioclase and a little quartz. Its origin is unknown but is probably igneous and the fragments may be derived from a diabase dyke or dykes. The feldspar porphyry blocks are black or dark grey, medium grained, and display well-formed plagioclase phenocrysts and scarcer quartz phenocrysts; in places they appear to be amygdaloidal. They may be derived from volcanic rocks related to those on Pine Island, Sheep Island and other islands in Killarney Bay, mentioned earlier in this report (see "Volcanic rocks"). Calc-silicate inclusions, restricted to Killarney Bay, are medium grained, grey to green, consisting of irregular aggregates of hornblende and/or tremolite, diopside, and biotite in a matrix of quartz and plagioclase. They may be equivalents of the calcareous beds seen on islands in the bay, also mentioned earlier (see "Bar River Formation"). The gneiss and schist fragments at Killarney Bay are sparse in the agmatite. According to Cannon, most of them resemble coarse grained biotitic, foliated granite, while others are leucocratic garnetiferous and micaceous schist of unknown origin. As well as agmatite that grades into non-agmatitic granite, Cannon observed small agmatite dykes in the granite near Killarney Bay, indicating a stage of agmatite mobility.

To the northeast the coarse grained Killarney Granite differs from that near Killarney. At George Lake it is pale pink, in part porphyritic, foliated, and contains irregular strongly cataclastic zones, indicating increased tectonism there. Farther northeast, toward Kakakise Lake and Terry Lake, the granite is foliated variably, and is hornblende-bearing, with salmon-red feldspar.

Lighthouse porphyry member (PKp)

The Lighthouse porphyry member of the Killarney Granite everywhere flanks the rest of the formation on the southeast and actually exceeds it in volume. Opposite George Lake it is almost 3.2 km wide. The contact between the two members crosses Highway 637 about 4.8 km east of the west edge of the report area and about 6.4 km east of Killarney village, and from there to Carlyle Lake there are many good roadside exposures and rockcuts. The rock is dominantly fine grained, pinkish grey to red, and contains abundant K-feldspar phenocrysts up to 8 mm but usually less than 3 mm across that weather paler pink to white. Toward the southwest near Killarney, the porphyry, unlike the granite, forms low narrow parallel ridges trending northeast, but this aspect diminishes northeastward around George Lake and beyond. Except near Georgian Bay most outcrops are massive and structureless except for jointing and some variation in grain size. In places, presumably near faults, they are sheared and display good cleavage and foliation. Near Georgian Bay the porphyry is cataclased, lineated, and generally more foliated than elsewhere, especially marked where streaks of quartz or quartzite exist. The composition of the porphyry is closely similar to that of the granite, consisting of a fine mosaic of potassium feldspar, sodic plagioclase, quartz, small amounts of biotite and, near the quartzite xenoliths, abundant muscovite. Accessory minerals include pyrite, ilmenite, epidote, apatite and sphene. Analyses published by Quirke and Collins (1930) and by Jones (1930), who studied the Killarney Granite in some detail, are reproduced in Table 2* and show the close chemical similarity between the porphyry and the granite.

The occurrence of remnants or inclusions of altered white orthoquartzite in the porphyry along Killarney Channel near the east lighthouse and of white weathering quartz-rich patches along the Georgian Bay coast for about 1.6 km has led to differing views on the origin of the porphyry. On small islands near the east end of Killarney Channel are unequivocal orthoquartzite remnants that retain sedimentary features yet contain euhedral pink potassium feldspar and muscovite porphyroblasts, and at many places near the shore northeastward from the nearby lighthouse there are grey, white and green zones, lenses and streaks, variably rich in quartz and muscovite, that strongly resemble altered quartzite, although they have lost all sedimentary aspects. The largest is a mappable white weathering, quartz-rich area beginning about 1 km northeast of the lighthouse. Surrounding some of these occurrences or occurring separately in this interval along the coast are zones a few metres

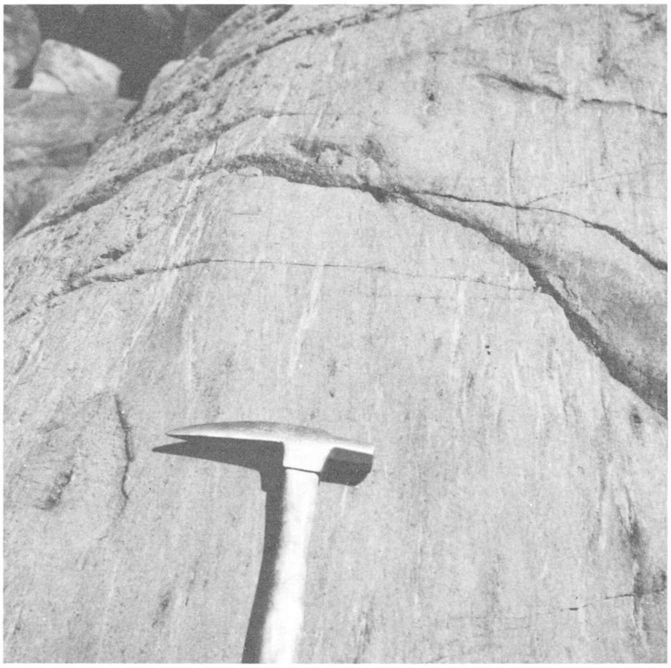


Figure 31. *Tectonic, deformed quartzite remnants in cataclastic "Lighthouse porphyry" of the Killarney Granite. Coast of Georgian Bay east of Killarney Channel, Rutherford Township. Photo R.T. Cannon. GSC 188980*

* For table 2 see page 20

wide of fairly massive rock that weathers grey rather than pink or white and grades into "normal" pink porphyry. Viewed by themselves, the separate masses are problematic, but are probably altered quartzite; an alternative is that they are silicified porphyry. The considerable tectonism in this zone along Georgian Bay has streaked out the quartz-muscovite masses and strongly cataclased both them and the porphyry (Fig. 31), complicating rock relationships. Several kilometres to the northeast, on the rocky point dividing the campground beach at George Lake, outcrops within the porphyry include areas similar to some of those just mentioned, i.e. dense, massive to streaky or patchy, grey weathering material that resembles altered quartzite (see Quirke, 1940, Plate 1).

The intimate association of altered, metasomatized quartzite and the porphyry in outcrops of the lighthouse zone (undoubted quartzite inclusions are absent or rare elsewhere in the porphyry), together with his petrographic observations and interpretations (Quirke and Collins, 1930, p. 46-53) led Quirke to postulate that all the fine grained porphyritic rock is metasomatized quartzite, and in his various publications he became a vociferous advocate of the theory that the entire Killarney Granite, indeed all granite in the area, originated through metasomatism, and that the section from Georgian Bay to Killarney Bay represents a progressive transition series, ending in coarse grained massive granite. Because of clearly discordant contacts with unaltered quartzite at Killarney Bay, he was forced to add that the granite end product became mobile there. Quirke's thesis was rejected on field and chemical evidence by Jones (1930), who reported an apparent chilled contact between porphyry and granite, and who analyzed a series of samples across the section and found no chemical transition. Lawson (1929, p. 363) also rejected it on field evidence, citing the presence of porphyry dykes cutting quartzite and granite, and of granite inclusions in the porphyry. In response, Quirke (1940) disputed the evidence of Jones and Lawson, and reiterated his arguments for metasomatism.

R.T. Cannon (unpublished report) identified a matrix microtexture in the coarse grained "granite gneiss" of the Killarney Granite and in the porphyry that he considered characteristic of and inherited from feldspathized quartzite, and he endorsed Quirke's metasomatic concept for the section near Killarney. The writer suggests that the textures in common are the result of late cataclasis affecting all these rocks.

As unaltered orthoquartzite of the Lorrain and Bar River formations is over 90 per cent silica, it can readily be seen that enormous quantities of potash, soda, and aluminum would have to have been introduced on a regional scale and similar quantities of silica removed in the process visualized by Quirke. The writer agrees with Jones, who suggested that the porphyry and the adjacent coarse grained granite are comagmatic igneous products. It is fair to note, however, that at the time of Quirke's study (1923-26), the work of European geologists who were strong advocates of metasomatic granite was exerting considerable influence on geological thought in many quarters.

As indicated, early workers in the area disagreed as to the mode of origin of the porphyry body, which is unique along the Grenville Front in this region; its temporal relationship with coarse grained Killarney Granite was consequently also controversial (Lawson, 1929; Quirke and Collins, 1930; Jones, 1930; Quirke, 1940). The following field evidence, in part noted much earlier by Lawson (1929) and by Jones (1930), indicates that the porphyry is essentially of magmatic origin and somewhat later than the adjacent granite:

1. At a few places porphyry dykes cut the granite in the contact zone, although elsewhere, and more commonly, no dykes are seen and there appears to be an intergradation.
2. The textural change from porphyry to coarse even-grained granite is generally abrupt.
3. Within the porphyry body there are irregular variations in grain size.
4. A large area of the granite is entirely enclosed in porphyry near the mouth of Collins Inlet (see accompanying map, in pocket). It appears to be a large enclave caught up in the porphyry, a situation not in keeping with the concept of progressive transition.
5. In several places along the Georgian Bay shore northeast of the lighthouse and also at the west end of Collins Inlet, the porphyry has a fragmental appearance given by swarms of elongate lenses or sliver-like streaks up to a few centimetres long consisting of similar material to their porphyry matrix (pinkish to grey, felsic, fine grained), but slightly paler on weathered surfaces. Unless these are of tectonic origin (much of the porphyry here is cataclastic), they suggest that the porphyry in this zone is, in part at least, an intrusive (subvolcanic?) breccia. The fragmental aspect (PKpf) of the lighthouse zone is confined to the vicinity of the shoreline. Near the mouth of Collins Inlet, Cannon (unpublished report) observed pink lenses up to one or two metres long for which he favoured a tectonic origin.
6. Although time did not permit a complete study of the large metaquartzite enclave east of the lighthouse, some detail was observed there that showed no evidence of metasomatic generation of porphyry or a transition from metaquartzite to porphyry. In places, thin, streaky, pink, rhyolitic layers are intercalated with green or white quartz-muscovite schist (metaquartzite) and thin sections were cut from one hand sample containing both (collected by A. Davidson). Each type is well foliated, especially the schist, which under the microscope shows matrix folia bending around scattered large quartz grains, some of which are subhedral, suggesting that they are porphyroblasts. The schist matrix is a fine grained, recrystallized, feldspar-free mosaic of equant quartz grains (cf. Quirke and Collins, 1930, Fig. 3) in which are numerous, strongly aligned muscovite aggregates. The immediately adjacent rhyolitic layer carries potassium feldspar phenocrysts or porphyroblasts in addition to those of quartz, and the matrix, which is a finer grained, less micaceous mosaic than that of the schist, contains feldspar including plagioclase. In both rock types, the large grains have ragged or shredded borders, matrix embayments, and interior muscovite-quartz patches. The line of demarcation between the layers is sharp even under the microscope, with no transition. The metaquartzite layer, like others in the enclave, is intensely cataclastic, more so than the rhyolitic porphyry layer; elsewhere in the enclave cataclasis has fragmented quartzite masses to the point of producing the appearance of a stretched oligomicitic breccia or conglomerate. Cataclasis may have both preceded and followed porphyry intrusion.

Rb-Sr data from two samples of porphyry fall on a straight line isochron plot that included coarse grained granite samples, indicating no great genetic difference between the two rock types but favouring neither mode of origin. One porphyry sample from close to the granite contact showed markedly different $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios from the others, for unknown reasons (Wanless and Loveridge, 1972). The low initial strontium ratio (0.7019) obtained from the plot indicates that there was no significant sialic contribution to the porphyry or the granite. The age given by the isochron is 1625 ± 47 Ma.

Detailed study of the contact zone between coarse granite and the Lighthouse porphyry shows interesting features in the Killarney Provincial Park campground, at the outlet bay of George Lake. This locality ("Tyson Bay") was discussed at some length in Quirke's 1940 paper reaffirming a metasomatic origin for the porphyry. At the northwest end of the outlet dam, the porphyry is sheared and evidently faulted. On the second ridge top a short distance beyond, varied layering appears, and the rock contains numerous lenticular and streaky, oriented clasts or inclusions at first thought in the present study to be stretched clasts in a thin metaconglomerate (see GSC Map 21-1968 in Frarey and Cannon, 1969), largely because near the shoreline at the end of this ridge there is a well stratified or layered section about 8 m thick, largely consisting of dark, micaceous, thinly laminated, pelitic or tuffaceous, sedimentary looking beds, together with coarser streaky fragmental layers resembling the type just mentioned. The whole ridge resembled a large metasedimentary xenolith within the porphyry. Further study has shown the matrix and the streaky clasts of the fragmental layers to be all igneous, mainly porphyritic, and rather restricted in composition. In the small stratiform section mentioned, many of the fragments in the coarse clastic layers are fine grained, pink, felsic (rhyolitic) and nonporphyritic. Except for the small laminated section, the zone resembles a strongly foliated, igneous, subvolcanic breccia although Quirke (1940) considered it a Gowganda remnant. The breccia interpretation is strengthened by details on the next ridge to the northwest, where the above foliated breccia has given way over the first few metres to a fairly uniform, layered to unlayered pink porphyry that carries blocks of cherty or rhyolitic, pale pink- to creamy-weathering porphyry up to one metre long. These cherty blocks have ragged borders and tails. On the upper part of the ridge the contact between fine grained porphyritic rocks and coarse grained granite, largely also porphyritic, is exposed and here narrow irregular fine grained apophyses and dykes of porphyry and felsite invade the granite with knife-sharp contacts. Some dykes show layering or colour banding parallel to the contacts and one carries a splinter of wall rock granite. This outcrop area provides the best evidence seen by the writer that the "Lighthouse porphyry" is post-granite.

At the northeast end of the outlet bay of George Lake, on strike with the above zone, a similar assemblage of fragmental layered and unlayered porphyritic rocks (**P**Kpf) occupies a small wedge near the margin of the Lighthouse porphyry, but its contacts are not exposed. Noteworthy, however, are enigmatic laminated, dark phyllitic or phyllonitic, almost certainly metasedimentary rocks in a section about 23 m thick at its southeastern edge. In places, rounded (in plan) quartzofeldspathic aggregates resembling granitic pebbles occur in this stratiform section, which is reminiscent, superficially at least, of local sections in the Gowganda Formation, explaining Quirke's (1940) Gowganda correlation of the zone. The phyllitic layers and contained quartz veins or segregations are strongly deformed into mesoscopic folds striking northeasterly and plunging subvertically. The presence of metasedimentary beds in this position is difficult to explain.

The narrow stratiform agglomeratic or breccia zones suggest extrusive conditions on the one hand, but the complete absence of extrusive characteristics elsewhere in the lighthouse porphyry, on the other, indicates strongly that the porphyry is a late, high-level intrusive component of the Killarney Batholith. Although they differ markedly in texture, the chemical and mineralogical similarity of the porphyry and granite members of the Killarney Granite and their apparent gradation in places indicate a common magmatic source and a close temporal relationship, and the agmatite border zones of the granite, like the fragmental porphyry, suggest that the Killarney Granite as a whole invaded at a relatively high crustal level.

*Terry Lake Diorite (**PTL**)*

This relatively small component of the Killarney Batholith forms an irregular area about 4 km in maximum dimension between Carlyle Lake and the Grenville Front. The diorite intertongues with coarse equigranular pink Killarney Granite and with the coarse porphyritic Bell Lake Granite that succeeds it to the northeast. The diorite has abrupt contacts with these granites and is probably faulted against the sediments to the northwest. Locally it is sheared and foliated.

The Terry Lake Diorite is coarse- to very coarse-grained and weathers mottled white, grey and black, in contrast with the bordering pink granites. It consists of blue-green hornblende, biotite, zoned altered plagioclase, minor quartz, and accessory iron oxide, sphene, epidote, and apatite.

At its margin east of Terry Lake, biotite gneiss and diorite fragments occur in adjacent coarse grained granite resembling Killarney Granite, and at a second locality farther east along the contact the diorite appears to be transected and included by Bell Lake Granite. Therefore it is considered somewhat older than these granites. Near its northeastern edge, the diorite contains large (mappable) and small ortho-quartzite xenoliths assumed to be derived from the Bar River Formation and near its southeastern margin local igneous breccias carry small pieces of black amphibolite and quartzite.

*Bell Lake Granite (**PBL**)*

This granite forms an elongated lensoid mass that extends northeastward from Carlyle Lake for 17.6 km to Annie Lake, where it pinches out between a Grenville Front fault and the Annie Lake granitic complex. It has a maximum width of about 1.9 km. The Bell Lake Granite (Brooks, 1964, 1967) is a coarse grained pink biotitic granite or quartz monzonite characterized in most places by prominent euhedral feldspar phenocrysts. It is readily distinguished from other granitic bodies in the report area

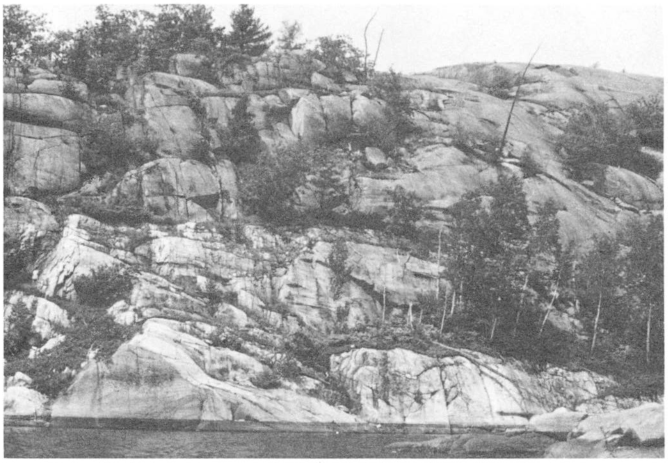


Figure 32. *Xenolith of Lorrain quartzite enclosed by Bell Lake Granite. Bedding is parallel with the jointing common to both rocks. Johnnie Lake, Carlyle Township. Photo I.F. Ermanovics. GSC 188974*

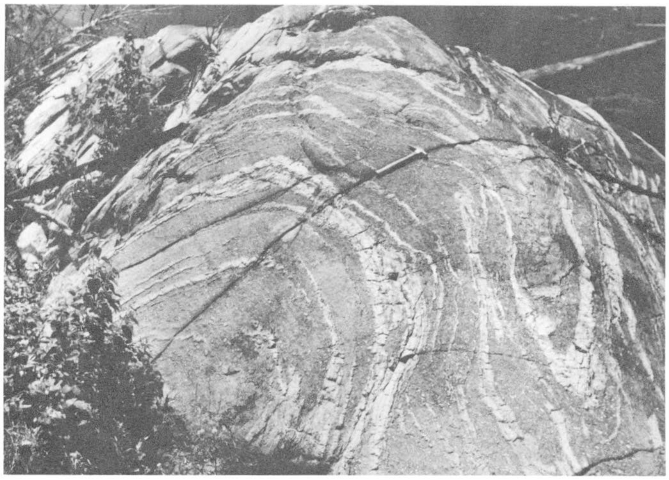


Figure 33. *Deformation of Bell Lake Granite and shredded quartzite inclusions at the southeastern margin of the Killarney Batholith. Grey Lake, Sale Township. GSC 188825*

Figure 34. *Folding of cataclastic Bell Lake Granite and mylonitic quartzite. Note ribbed foliation on crest and limbs, transverse to axial plane of fold. Scale in centimetres and inches. Grey Lake, Sale Township. GSC 203084-A*

except where it is nonporphyritic or strongly cataclased. Its distinctive texture was noted briefly by Collins (1925, p. 86) but it was not studied or described prior to Brooks' (1964) thesis study, and not fully mapped until the present study.

The Bell Lake Granite is the coarsest, most mafic (biotitic) and most strikingly porphyritic granite of the Killarney Batholith and of the entire area. It normally consists of a matrix of quartz, microcline, perthite, oligoclase-andesine and up to 15 per cent biotite, in which are microcline, perthite or oligoclase euhedral phenocrysts commonly 1-4 cm long. The granite is in places cataclastic, with a porphyroclastic texture, and is foliated commonly by alignment of biotite and/or quartz, even where it is deceptively massive looking. Locally, the phenocrysts are also aligned, possibly a primary feature. Like the Killarney Granite, the Bell Lake Granite is nonmigmatitic and pegmatite is not abundant. For an apparently high-level intrusion, it does not have an abundance of xenoliths. At the northwest margin, however, which is well exposed at Johnnie Lake and Bell Lake, small mafic inclusions mostly a few centimetres across are locally numerous, and large (Lorrain) quartzite and smaller amphibolite remnants occur in a linear zone subparallel to the margin and 150 to 450 m southeast of it (Fig. 32). At the opposite margin, inclusions of quartzite are conspicuous where the granite is in contact with the large Lorrain enclave described above. Elsewhere in the granite inclusions are small and scattered and other Huronian formations appear not to be represented. The quartzite inclusions are usually not feldspathized, but in the northern part of Johnnie Lake and at the west end of Grey Lake, xenoliths of amphibolite, dioritic rock, and unidentified mafic schist are "granitized", showing "dents de cheval" porphyroblasts of potassium feldspar.

The Bell Lake Granite has clearly defined margins and there appear to be virtually no dykes or satellite masses in the bordering rocks. Along Bell Lake and Johnnie Lake its northwesterly margin is in fault contact with Huronian rocks of Southern Province, and is well foliated; locally, as at Johnnie Lake, it is brecciated. If different levels of erosion are exposed across this fault, it may partly account for the absence of dykes of the granite in adjacent Huronian rocks. Where it tapers out southwestward at Carlyle Lake, the Bell Lake Granite is strongly cataclased along with other rocks, but in general it is readily distinguished by its texture and lithology from the Terry Lake Diorite, Killarney Granite, and the orthogneisses to the southeast. Most of the southeastern contact of the Bell Lake Granite against orthogneiss, augen gneiss, metaquartzite, and the Annie Lake granites, is covered but is probably also faulted. There has been tectonism involving plastic deformation along this important contact, as is shown at Grey Lake, where outcrops of cataclased Bell Lake Granite with shredded orthoquartzite inclusions are complexly folded (Fig. 33, 34). Simple, straightforward field evidence for intrusion of the Bell Lake Granite into the gneiss complex is lacking, except that it clearly crosscuts, includes, and "soaks" the margin of the large enclave of Lorrain Formation metaquartzite east of Grey Lake and Turbid Lake. Only one dyke of the granite was recognized in the mixed gneisses west of Tyson Lake, and it was not traceable into the main body of the intrusion. Others may be obscured by cataclasis or drift cover.

The Bell Lake Granite is cut in numerous places by other felsic intrusions of relatively minor extent. These are finer grained, porphyritic or nonporphyritic, less biotitic, and generally less foliated compared to their host. The largest volume of "new granite" in the intrusion lies between the Bell Lake road and the east-west narrows of Johnnie Lake, where it occurs extensively intercalated with large amounts of the porphyritic host granite. A strip of finer grained, sheared to unsheared younger muscovite granite (Ang) borders the Bell Lake pluton along Bell Lake from the Johnnie Lake portage northeastward for about 4 km; it then curves through the pluton to Grey Lake. Farther east along Grey Lake, the Bell Lake Granite is cut successively by: (1) the above muscovite granite, accompanied by pegmatite and aplite; (2) medium grained porphyritic granite; and (3) a second pegmatite. All have been sheared and show a penetrative foliation. Medium grained porphyritic or porphyroblastic leucocratic granite similar to the second of these phases ("Grey Lake phase") occurs extensively northwest of Tyson Lake in the Annie Lake Complex, outside the Bell Lake intrusion; its correlation with the Grey Lake occurrences is probable though not unequivocal. A few small pink or chalk-white aplite dykes also cut the Bell Lake Granite. Because of their relatively restricted volume and distribution within the Bell Lake pluton, these later phases are not thought to be significantly younger. Zircons from porphyritic Bell Lake Granite have been dated at 1523 Ma (Krogh et al., 1971, recalculated by Stockwell, 1982) and Rb-Sr analyses from a similar sample, as well as one from the Killarney Granite, plotted on a reference isochron indicating an age of 1540 Ma (recalculated from Krogh and Davis, 1970); four K-Ar biotite ages from the pluton, including younger phases, fall beween 886 and 1055 Ma (see Appendix).

As mentioned, the Bell Lake Granite terminates at Annie Lake where it is succeeded for about 4.8 km along the Front by the Annie Lake Complex. Beyond that, in the extreme northeastern part of the area, foliated, coarse, porphyritic biotite granite, very similar to the Bell Lake body, reappears; on the accompanying map, it is tentatively given the same designation. It intercalates on the west with Huronian sediments, and on the east is flanked by nonporphyritic granitic gneisses that are intercalated with biotite paragneiss, metaquartzite gneiss, and amphibolite gneiss. Its eastern limit is not accurately determined, but is arbitrarily placed along a line in eastern Bevin Township and western Halifax Township, beyond which contrasting granite gneiss and the layered gneiss prevail. In the area immediately to the north, it has been included in the Chief Lake Batholith (Card et al., 1975).

The Bell Lake Granite is more deformed than the Killarney Granite and Terry Lake Diorite, much of it being foliated to some degree by the alignment of biotite. The pluton contains numerous faults, shears and cataclastic zones, the largest of which lies along its southeastern margin, exceeding 0.75 km in width southwest of Ned Lake. As also mentioned, along this same margin near Grey Lake, the cataclased granite has been plastically folded (Fig. 33, 34). This post-Bell Lake deformation preceded intrusion of the unaltered olivine diabase dykes that cross the Bell Lake Granite from the Southern Province.

Annie Lake complex (PAL)

Along the Grenville Front northeast of the Bell Lake Granite, an elongate area extending from Billy Lake in Sale Township northeastward for 8 km or more into Bevin Township is made up of a varied assemblage of gneissic to massive granites, fairly abundant pegmatite, and wedges and inclusions of paragneiss. It is well exposed east of Annie Lake and hence has been informally called the Annie Lake complex. Most of the following details are from the careful observations of A. Davidson, who mapped it for the writer.

The Annie Lake complex is separated from the Huronian rocks, and in the south from the Bell Lake Granite, by a fault or group of faults that have produced a narrow but conspicuous mylonite zone, well exposed on the southeast shore of Annie Lake. In the south, granite of the complex invades the streaky gneiss developed from Lorrain meta-arkose, and also, near Ned Lake, is seen to cut the Bell Lake Granite. To the east, near the Duplex Lake lineament, the rocks become highly cataclastic and the boundary of the complex is indeterminate. It may concide with the west boundary of supracrustal gneisses mapped near the northwest shore of Tyson Lake and west of Strata Lake, or as depicted here, it may lie farther west, at the lineament. In the north the complex wedges out between faults and presumed Bell Lake equivalents.

At least three types of granite and two ages of pegmatite are included in the complex. They all appear to be younger than the Bell Lake Granite, and may be the youngest intrusions of the Killarney Batholith. The granitic phases, which although not synchronous were probably intruded in close succession, are: a fine- to medium-grained, equigranular, pale pinkish grey, two-mica granite, possibly the youngest; a medium grained nonporphyritic to subporphyritic phase, and a highly porphyritic (or porphyroclastic) medium- to coarse-grained granite closely resembling the post-Bell Lake Granite seen in the vicinity of Grey Lake, referred to earlier and termed the "Grey Lake phase" for descriptive and mapping purposes. In the western part of the Annie Lake complex, all these granites are intermingled, but farther east and southeast the Grey Lake porphyritic phase forms a mappable zone between Duplex Lake and Billy Lake.

A short distance east of Annie Lake, the grey granite was seen to cut pink, fine-to medium-grained granite, the second phase mentioned. The latter transects pegmatite that cuts a Bell Lake Granite inclusion. The younger granites are in turn intruded by numerous small pegmatites that are commonly sheared and locally folded by what appears to be the latest pre-diabase deformation of the report area. The granites in the western half of the complex are erratically foliated, and near the north end of Ned Lake this foliation is folded about southeasterly plunging axes.

A variable and indistinctly bounded agmatite zone in the Annie Lake complex extends northeast from Ned Lake for about 3.2 km. It contains disoriented blocks of Bell Lake Granite, metamorphosed Lorrain Formation (near Ned Lake), unidentified metasediments including biotite schist and amphibolite (metadiabase?). The zone is most conspicuous near Ned Lake, where in some places inclusions equal or exceed the amount of granite exposed.

Late mafic dykes (Ndb)

At least two petrographic types of late mafic dykes cut the gneisses and granites of the Grenville terrane. Their relative ages are uncertain as crosscutting relations were not observed. All the late mafic dykes are narrow and poorly exposed but are persistent, either in a west-northwest direction following prominent fractures or, less conspicuously, northeasterly along the general structural trend. As in Southern Province, only the more prominent of the observed mafic dykes are shown on the accompanying map.

It is clear that olivine diabase dykes of the "Sudbury swarm", so numerous in Southern Province, continue east-southeastward into Grenville Province at least as far as Tyson Lake and possibly much farther. Four have been traced continuously to that point (see map, in pocket), and the most northerly of these appears to continue, after interruption or apparent interruption at Tyson Lake, for an additional 8 km to the eastern edge of the report area at Broker Lake. The dyke has a known length of 6.4 km in Southern Province, for a total of 19 km. Olivine diabase typical of the Sudbury dykes also trends northeastward north of Tyson Lake between Scar Lake and the Mahzenazing River, along the northwest shore of Tyson Lake, and southwest of the bay of that lake. At one locality, the change in trend from east-southeast and northeast was traced in outcrop. Fresh northeast-striking olivine diabase dykes were also mapped just south of Sunfish Lake in northeastern Humboldt Township. As mentioned previously, the olivine diabase Sudbury dykes have a isotopic age of 1200-1250 Ma; thus their straight course through the Killarney Batholith, dated at 1550 Ma. Their persistence into gneiss beyond the batholith eastward to Tyson Lake testifies to the pre-Grenvillian age of deformation of the gneiss or, put another way, the lack of significant post-1200 Ma Grenvillian folding in that interval. The same relationship between the dykes and "Grenvillian" deformation was noted north of the report area by Henderson (1967, p. 46). It is noteworthy, however, that in the central part of Tyson Lake, some large mafic dykes have curved traces, suggesting late folding that presumably is Grenvillian, and in places large dykes are evidently interrupted by late faulting. Eastward from the Tyson Lake-Collins Inlet zone, the few dykes mapped generally follow straight east-southeast trends.

In mapping the much larger Burwash area adjacent to the east and northeast, Lumbers (1975, p. 109-110) recognized a petrographic group of west- to northwest-trending diabase dykes (nonalkaline) different from the Sudbury dykes and suggested a younger, post-Grenvillian age for them. They may belong to the regional diabase swarm in southern Grenville Province investigated paleomagnetically by Murthy (1971). These dykes, according to Lumbers, are distinguished by their lack of olivine, their discontinuity, and their weak aeromagnetic expression, in contrast to the 1250 Ma old Sudbury dykes of Southern Province. Lumbers identified a number of these between the east boundary of the present area and the Wanapitei River, and if indeed they are part of a separate group this group probably occurs in the report area as well; the thin sections examined in this study included a few unaltered specimens with no olivine and both types could coexist in the eastern part of the report area. While all the mapped dykes, including known Sudbury dykes, lack aeromagnetic expression in Grenville Province, this is probably due to higher magnetic intensities of the Grenville Province host rocks compared to those of Southern Province, resulting in the lack of comparable linear dyke anomalies (see Geological Survey of Canada, 1965, aeromagnetic map 1516G). The supposedly younger dykes just east of the report area were interpreted differently by Palmer et al. (1977) who studied them paleomagnetically and petrographically and concluded that they are probably metamorphosed Sudbury dykes. Except for a more mafic appearance they look much like Sudbury dykes in the field, especially in weathered exposures. Insufficient data are available from the present study to confirm or negate the existence of two sets of megascopically similar diabase dykes.

A distinctly different type of diabase does occur sparingly in the report area. It is distinguished by phenocrysts or large aggregates of black plagioclase that reach a length of 7.6 cm set in a fine grained matrix that evidently lacks olivine and primary biotite. An outstanding example of these megacrystic dykes occurs in an abandoned rock quarry on Highway 637 about 350 m northeast of the Mahzenazing River bridge. Small exposures of this type of dyke were seen on Tyson Lake and near Halifax Lake. All are less than 30 m wide and are subvertical. None was traceable for more than one to two hundred metres along strike. In the quarry the dyke can be seen to have sheared margins. Some phenocrysts are rounded, suggesting resorption. In contrast with these dykes, phenocrysts in porphyritic olivine diabase are greenish grey.

In thin section, all the mafic dykes are gabbroic in composition, consisting of unaltered plagioclase (An_{50}) and augite, with variable olivine (0-10 per cent), biotite, and iron-titanium oxide content (up to 5 per cent). Diabasic texture is well developed but becomes obscured in strongly cataclased dykes. One unusual specimen from just southeast of the Grenville Front at Johnnie Lake contains completely serpentinized olivines; elsewhere olivine is relatively fresh and unaltered.

It is interesting to note that thin sections from throughgoing diabase dykes from various places on Tyson Lake, and from Broker Lake, Attlee Lake, West Tanner Lake, and the quarry on Highway 637 all show moderate to severe cataclasis that is not apparent megascopically (Fig. 35). In an extreme case from Attlee Lake, the pyroxene is mostly crushed into small granules, which in places are forced into cracked and split plagioclase crystals. The pyroxene in this case is also extensively altered to brown hornblende, serpentine, and iron oxide. One small dyke close to the Front on Johnnie Lake shows strong megascopic lineation and cataclasis as well (Fig. 36; Brooks, 1967, p. 1276; 1976) along with adjacent Bell Lake Granite. As mentioned, some dykes are faulted, some have sheared margins, and at Tyson Lake some apparently have been folded. Unlike the situation in Southern and Superior provinces, where dyke emplacement followed complete posttectonic stabilization of the crust so

Figure 35. *Photomicrograph showing cataclasis in diabase dyke crossing structures of the Grenville Front Tectonic Zone. Crossed nicols, X10, Highway 637, Humboldt Township. GSC 203843-J*

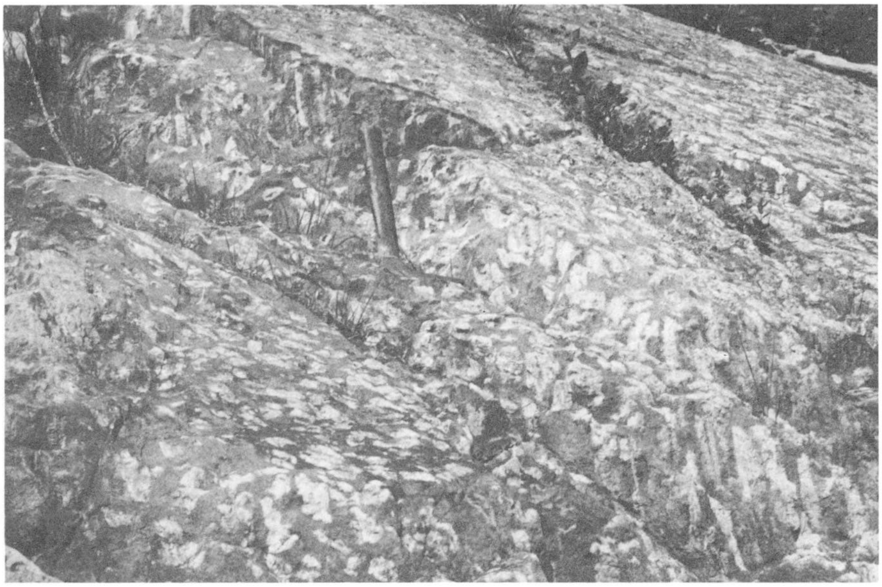


Figure 36

Cataclastic, lineated portion of a porphyritic olivine diabase dyke at Johnnie Lake near the Grenville Front. Photo I.F. Ermanovics. GSC 188971

that original textures are perfectly preserved, a restricted episode of deformation clearly postdated dyke intrusion in parts of the Grenville Front Tectonic Zone.

Palmer et al. (1977, p. 1871-1877) showed that diabase dykes in the Grenville Province between the Front and Tyson Lake have different paleomagnetic properties from their extensions in Southern Province. In the latter the pole position is 160°W, 2½°S and in Grenville Province it is 16½°W, 4°S. Based on K-Ar whole-rock age determinations from four dykes in that part of the area (see Appendix) and three others outside the report area, they attributed this change to moderate reheating at about 1000 Ma that left the mineralogy and petrography of the dykes unchanged. The cataclasis, faulting and minor folding mentioned above presumably took place at the same time.

In addition to the above types of mafic dykes, a few small, fresh-looking, basaltic dykes were observed in the Killarney Granite near its northern margin about 0.8 km east of Lamorandière Bay of Lake Huron. Their age and relationship to other dykes are not known.

Structure and metamorphism

General

The rocks southeast of the Grenville Front all lie within the Grenville Front Tectonic Zone and have undergone deformation from Aphebian to late Neohelikian time. In this report, usage of the term "Grenville Front Tectonic Zone" follows that of Wynne-Edwards (1972, p. 269-271), and more recently of Stockwell (1982), namely to designate a structural subprovince of the Grenville Structural Province. Hence, by this definition, the Tectonic Zone is restricted to the Grenville Province. Different usage has been employed by Lumbers (1975, 1978), inasmuch as he included in the Tectonic Zone that part of Southern Province he considered to have been involved in "Late Precambrian" (i.e. post-1600 Ma) deformation.

In this part of the Tectonic Zone, all early, macroscopic folds, except for a few remnants, have been obliterated by the strong overprinting that developed the consistent northeasterly trend and southeasterly dip of the gneisses. Widespread, strong late cataclasis has followed this overprinting, further obscuring previous events.

In many gneiss outcrops, only the attitudes of the dominant northeast-southwest foliation, minor fold axes, and southeast-plunging lineation can be seen, and the structural aspect of the rocks is deceptively simple in appearance. No anticlines or synclines can be recognized since no top determinations are possible, and only small antiforms and synforms appear in the predominantly isoclinal layered gneisses. However, polyphase deformation is shown megascopically at various places by relatively small, complex folds, including refolded folds, by crosscutting relationships, intrusive relationships, and by deformation of intrusions cutting older gneisses. From the aggregate of observations, a general interpretation of the structural history can be attempted.

Folds

As indicated, in most of the area only small folds a few centimetres to a few metres in width or length are observable. Along Collins Inlet and east of Beaverstone Bay, however, remnants of much larger folds are discernible on air photographs, although these structures are not obvious or even apparent on the ground due to overprinting and cataclasis. Their trend lines shown on the map and Figure 19 are taken from air photographs. East of Beaverstone Bay, the preserved trends suggest that the related folds were oriented easterly or east-northeasterly. These remnants represent relatively early structures; they are sharply sliced and truncated by faults and northeasterly trending cataclastic zones, and in places clearly overprinted by northeast foliation or gneissosity. Since northeasterly-trending gneiss units contain small folds and refolded folds, also northeasterly, the event producing the large structures was presumably followed by more than one later episode of folding. On the other hand, the larger structures involve granitic bodies as well as layered paragneiss, and therefore postdate at least the earliest granites.

The mesoscopic folds that characterize the Grenville gneisses are typical of the plastic deformation shown in metamorphic complexes. They are best shown in metaquartzite layers (Fig. 37) and in gneisses that contain contrasting thin, conformable felsic, pegmatite, amphibolite, or quartzite layers (Fig. 30, 38 to 45). The folds in the gneisses range from symmetrical to asymmetrical and from open to isoclinal, but are mostly overturned northwestward and are isoclinal, dipping and plunging southeastward.

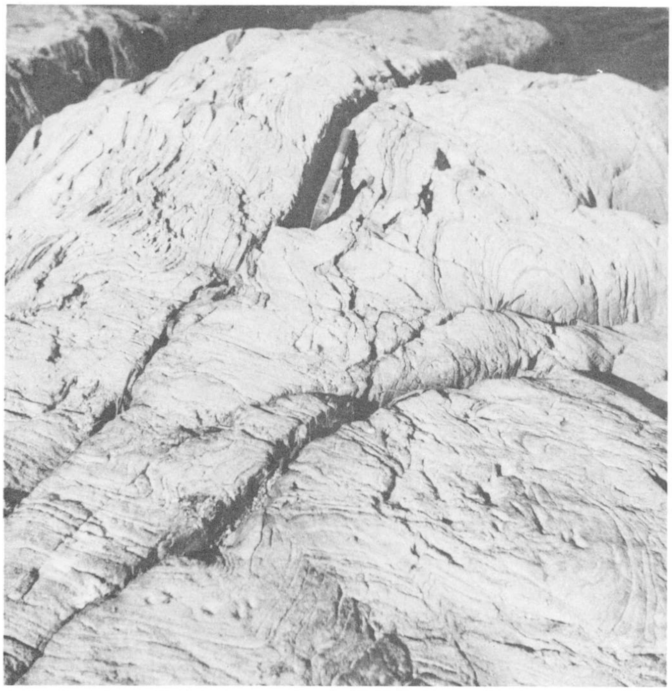


Figure 37. *Flow folds in metaquartzite gneiss, plunging steeply southeast. Lone Lake, Sale Township. GSC 188903*

Figure 39. *Open fold in mafic paragneiss, granite, and pegmatite, with small internal folds. Beaverstone Bay, Lake Huron. Photo R.T. Cannon. GSC 189047*

Figure 38. *V-shaped second or third generation folds in well-foliated migmatitic biotite gneiss. Beaverstone Bay, Lake Huron. Photo R.T. Cannon. GSC 189029*

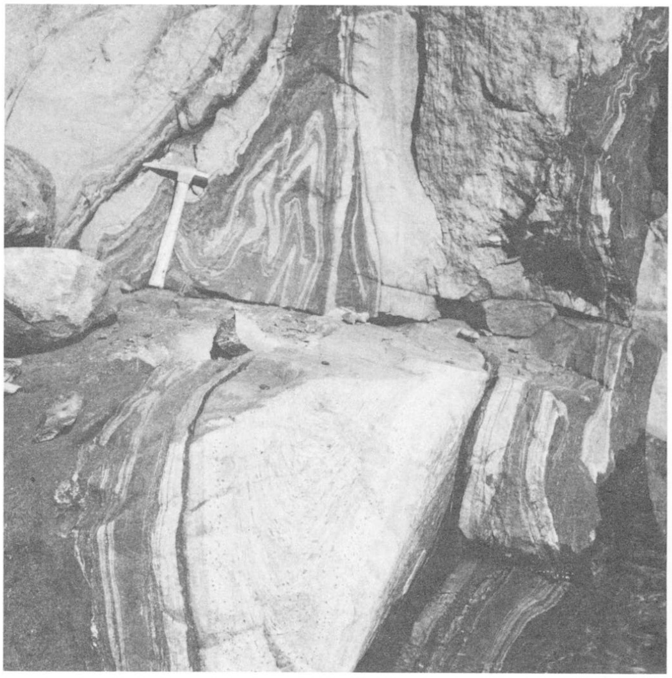


Figure 40. *Tight Z-shaped folds in biotite paragneiss and interlayered quartzofeldspathic (ortho?) gneiss. Beaverstone Bay, Lake Huron. Photo R.T. Cannon. GSC 189068*

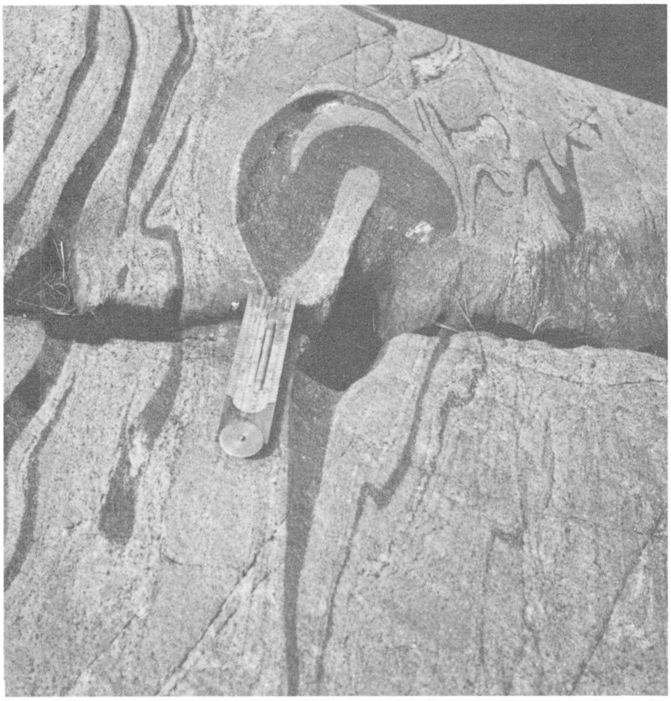


Figure 41. *Refolded fold ("hook fold") in disrupted mafic layer in garnetiferous biotite gneiss. Probably a third generation fold. Indian Bight, Lake Huron. Ruler is 15 cm long. Photo R.T. Cannon. GSC 189070*

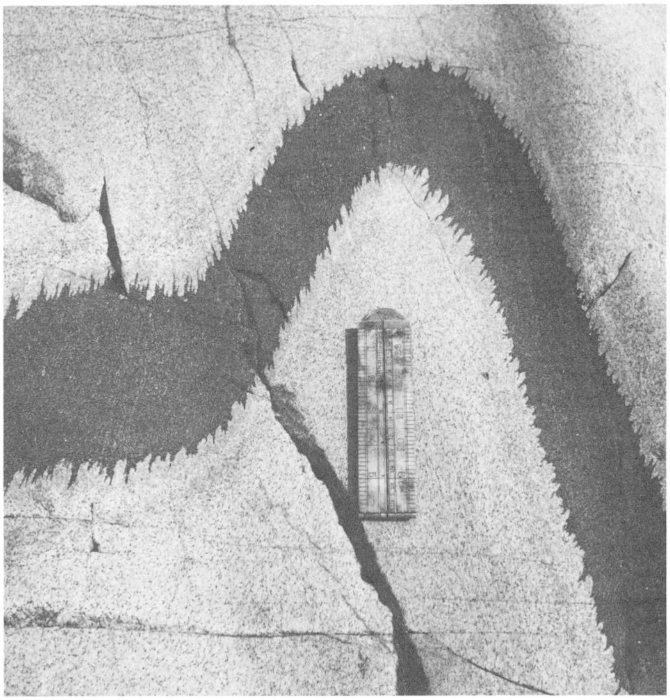


Figure 43. *Folded mafic layer (dyke) in granitic gneiss, showing marginal reaction zone and syntectonic(?) "flames" normal to contacts. Philip Edward Island, Lake Huron. Ruler is 15 cm long. Photo R.T. Cannon. GSC 189038*

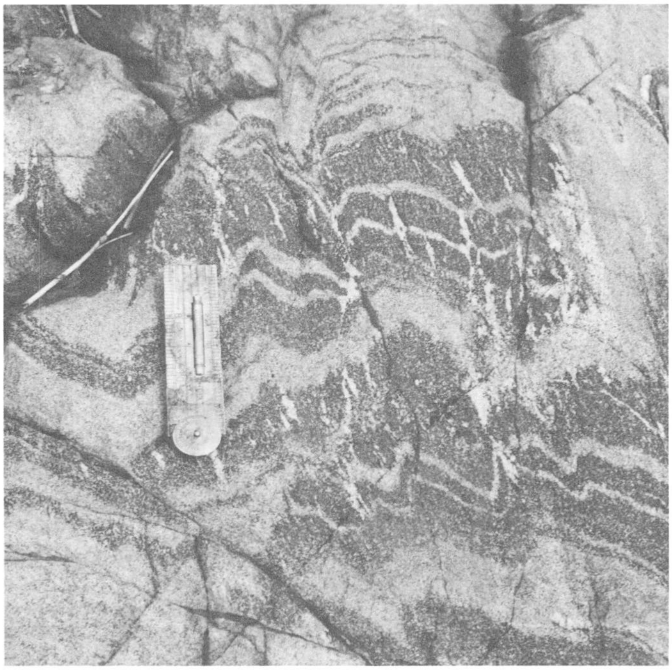


Figure 42. *Folded layered gneiss, showing new foliation marked by quartzofeldspathic streaks developed parallel to* S_4 *axial planes. Ruler is 15 cm long. Beaverstone Bay, Lake Huron. Photo R.T. Cannon. GSC 189031*

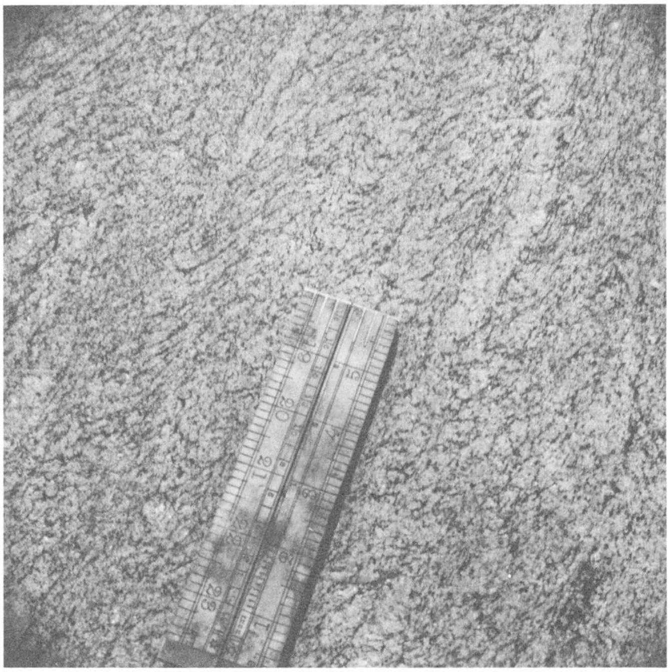


Figure 44. *Folded biotite foliation in Killarney Granite. Highway 637 near Killarney village. Ruler is in inches. Photo R.T. Cannon. GSC 189042*

Figure 45. *Amphibolite boudin (above hammer) folded with biotite paragneiss. Lone Lake, Sale Township. GSC 188907*

Their amplitude varies from a few centimetres to a few metres for the most part. Refolded folds and superimposed foliations are seen in places.

In his detailed study area, Cannon (unpublished report) suggested a sequence of events based on megascopic foliations, folds, lineations and textures, together with their related microfabrics. Using quartzite remnants (Huronian) in granitic gneiss east of Killarney village (Lighthouse porphyry of this report) as starting points, Cannon recognized two foliations within them, the second of which (his F_2) folded an earlier muscovite foliation (S_2) producing S_3, the dominant foliation in the quartzite (S_1 being original bedding). S_3 was correlated with a well developed parallel foliation in the adjacent host porphyry and also with weaker foliation in the "coarse grained granite gneiss" (=granite member of the Killarney Granite of this report) adjacent to the porphyry; locally, foliation in the granite is seen to be folded by F_3 (Fig. 44).

Cannon observed that the strong S_3 fabric in the quartzite preceded (is overprinted by) the feldspathization that produced the potassium feldspar porphyroblasts in the quartzite; like Quirke, he believed that wholesale feldspathization occurred, generating the Killarney Granite (a view not shared by the present author, as indicated previously). A subsequent cataclastic deformation affected the feldspathized rocks, including the granite. An important element in the sequence is that the (pre-Killarney Granite) "inherited" S_3 foliation in the granitic rocks east of Killarney is taken to be the same as the dominant foliation and layering in the gneisses in the Tectonic Zone eastward beyond the Killarney Granite, which they therefore antedated. Thus, southeast-plunging folds observed in this foliation in the layered gneisses are also designated F_3, producing S_4, and two subsequent stages of cataclasis are designated S_5 and S_6, separated by a refolding (F_4). At Mill Lake, Cannon observed folding of the dominant S_3 foliation in layers containing hornblende, biotite and garnet and concluded that F_3 and F_4, and S_4, S_5 and S_6 are postmetamorphic with respect to those minerals. Cannon related the southeasterly plunging linear elements, including the minor fold axes that dominate in the layered gneiss, to both the F_3 and F_4 deformations. S_6 is the cataclastic fabric variably shown over the entire area, including much of the Killarney Batholith.

Due to the interpretative nature of this complex sequence, particularly the all-important timing and correlation, in part assumed, of the foliations mentioned, it is only a tentative history. It is interesting for its linkage of structural features within the Killarney Batholith with those in the gneiss complex to the southeast. The less detailed structural observations of the writer and his assistants, largely made outside of Cannon's study area, also indicate that the rocks of the Tectonic Zone have had a long and complicated structural history. A summary of megascopic observations from the more significant localities is as follows:

1. The oldest recognizable rocks in the Tectonic Zone are the Huronian quartzite remnants, the largest of which is the mass mapped east of Bell Lake and extending to Tyson Lake. It has been detached from the terrane of Southern Province and is now separated from it by the linear Bell Lake Granite. Although difficult to demonstrate, this block, a part of the Lorrain Formation, was probably detached and reoriented by faulting subsequent to the main east-west pre-Penokean and Penokean folding and refolding events in Southern Province and thus subsequent to the regional metamorphism there. In most parts of the enclave, primary bedding units are foliated to gneissic, and where most deformed are destroyed and intensely refolded (shown by "hook" and "wishbone" folds) and also are cut by pegmatite, itself deformed. Towards Tyson Lake, the refolded folds are cut by granite younger than the Bell Lake Granite and this younger granite is also cut by pegmatite (possibly a second generation) that is crumpled and crushed. Thus the enclave has been affected by at least two deformations and two intrusive episodes subsequent to its severance from its equivalent in Southern Province. Finally, the quartzite enclave and its surroundings are cut by west-northwest-trending olivine diabase dykes that are only locally faulted and cataclased where they cross prominent lineaments. Since, as mentioned previously, these dykes are almost certainly 1200-1250 Ma old, all but the post-dyke deformation in this zone is pre-Grenvillian and post-Penokean, accepting the older limit of the Grenvillian Orogeny as ca. 1200 Ma (Stockwell, 1982). The eastward extent of this Lorrain enclave suggests that other Huronian formations also persisted eastward at least as far as Tyson Lake, although none can be recognized because of the high degree of deformation, metamorphism, migmatization, and plutonism.
2. Remnants of relatively large folds appear in the Tectonic Zone, mainly in the southeastern part of the report area (Fig. 19). On these are superimposed at least two subsequent fold episodes and at least one major cataclastic episode, followed by faulting.
3. At Lone Lake, amphibolite boudins produced by earlier deformation are folded with pelitic paragneiss and quartzite (Fig. 45) about axes plunging southeast with other lineations.
4. Northeast and southwest of Tyson Lake and on the northwest shore of that lake, fresh olivine diabase dykes occupy northeast trends conformable with the trend of the gneisses as well as northwest trends across them (see map in pocket); the change in dyke trend from northwest to northeast was traced in outcrop at one locality so that both trends are contemporaneous. Again, indications are that the overprint producing the ubiquitous northeast grain in the gneisses of the area is pre-Grenvillian (pre-Sudbury diabase).

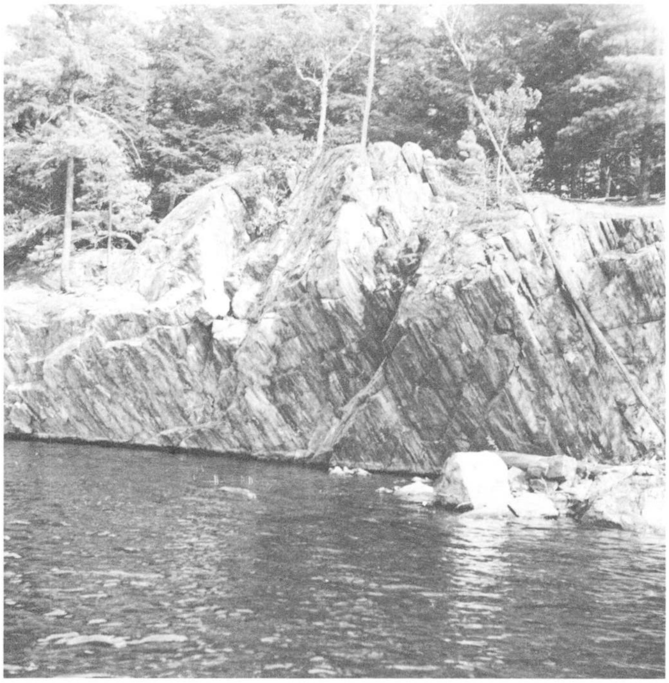


Figure 46. *Rodding and lineation common in metaquartzite gneiss of Tyson Lake, Sale Township, showing northeasterly foliation and southeasterly plunge dominant in the Grenville Front Tectonic Zone. GSC 188914*

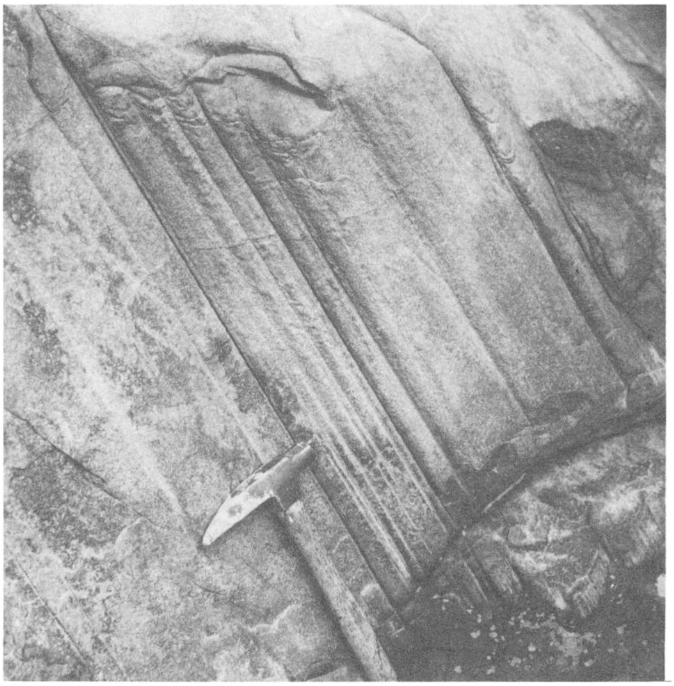


Figure 47. *Southeasterly plunging mullion structure in granitic orthogneiss at contact with pegmatite (not shown). Mahzenazing River, Carlyle Township. Photo R.T. Cannon. GSC 189069*

5. The linear northeast-trending character and state of preservation of the Killarney Batholith strongly indicates that the above overprint and tectonic grain was pre-batholith, i.e. pre-1525 Ma. This is supported by the fact that gneissic foliation and mesoscopic folds parallel with the grain of the Tectonic Zone in Huronian strata immediately along the northwest edge of the batholith at Bell Lake are pre-batholith, as shown by field relations and geochronology. There, metaquartzite gneiss of the Lorrain Formation is cut by dykes of Bell Lake Granite (Fig. 21), and muscovite from pegmatite cutting foliation and lineation in Lorrain metaquartzite has a Rb-Sr cooling age of 1440 Ma (Krogh and Davis, 1970).
6. Post-Killarney Batholith (post-1525 Ma) – pre-diabase dyke deformation is manifested by variable foliation in the granites, locally folded, by deformation of Bell Lake Granite and quartzite inclusions at its southeastern margin (Fig. 33, 34), and by faulting, shearing, and cataclasis including mylonitization along linear zones within the batholith and at its margins, all crossed by the dykes. In the southwest, post-batholith deformation has produced a zone of northeasterly lineation in the Killarney Granite (Fig. 19).
7. Late minor folding has evidently affected unmetamorphosed diabase bodies in the central part of Tyson Lake. These may or may not be Sudbury diabase intrusions, but they are younger than the Tectonic Zone overprint. Locally, Sudbury diabase dykes are affected by minor late faulting, as at Grey Lake, and by cataclasis as at Johnnie Lake and elsewhere.

In summary, it is clear that the rocks of the Tectonic Zone in the report area, like those in neighbouring areas (Lumbers, 1975), have undergone an extended and complex structural history spanning more than 1000 Ma. If the supracrustal rocks, now gneisses, were coeval with the Huronian Supergroup, they must have undergone an early history of deformation (Penokean and pre-Penokean) similar to that of the Supergroup in nearby present-day Southern Province, an early history that has been completely obliterated by subsequent metamorphism and repeated deformation. Evidence within the report area suggests that the later events, comprising major metamorphism transforming strata into gneisses, extensive plutonism, and subsequent overprinting that developed the northeast structural grain of the Tectonic Zone, can for the most part only be placed between the Penokean Orogeny (ca. 1900 Ma) and the emplacement of the Killarnean intrusions (ca. 1525 Ma). However, geochronological and geological data from elsewhere in the Tectonic Zone have previously indicated that some or all of these events had occurred prior to 1600-1700 Ma ago (Krogh and Davis, 1970, p. 309-312; 1971, p. 240); and more recently, Lumbers (1975, p. 69) has suggested that the regional development of early (pre-1600 Ma) pegmatite in the adjacent Burwash area is a manifestation of high rank metamorphism, which, however, he considered to have long preceded overprinting and remetamorphism. From the data inside and outside the report area it seems reasonable to conclude, with Krogh and Davis (1970, 1971), that gneisses were formed in the Tectonic Zone prior to 1600 Ma ago and probably during this ca. 1700 Ma (Hudsonian?) episode of metamorphism, plutonism, and pegmatite generation. The large fold remnants visible in the southern part of the present area, involving both paragneiss and orthogneiss, may have formed more or less synchronously with that activity. On the gneisses were imposed at least two fold generations, more high rank metamorphism, overprinting producing the northeast trend and southeast lineation, one or more cataclastic episodes, and late faulting. The time gaps involved are indeterminate, but it is to be noted that Lumbers (1975, 1978; personal communication, 1982) considers the late high rank metamorphism and northeast overprinting to have occurred 1400-1200 Ma years ago, after emplacement of the Killarney Batholith, whereas in this account they are thought to be probably pre-Killarney Batholith, for reasons given. As noted, some deformation is post-batholith as well.

Lineation

A prominent structural feature of the Tectonic Zone is the southeast-plunging lineation shown by all rock types except diabase. Lineations take the form of rodding structure, striations, mullions, mineral streaking or elongation (mainly feldspar augen and quartz), and fold axes (Fig. 46, 47). Most of those shown on the geological map and in Figure 19 are mullions and mineral streaks or elongations. The structures plunge from 35 to 75 degrees either directly down foliation planes or at small angles from the dip azimuth. They are particularly well displayed in the gneiss complex at Tyson Lake. In the neighbouring larger map area, Lumbers (1975, p. 119) found both the foliation and lineation to steepen northwestward. There is some suggestion in the present area that this is so here also, although there is considerable irregularity. Lineations become much fewer and more scattered in direction in the Killarney Batholith, but a few south to southeast plunging lineations occur there and even in Huronian rocks beyond the batholith in Southern Province.

R.T. Cannon (unpublished report) distinguished two lineation domains in his study area. In rocks west of the fault between Carlyle Lake and Collins Inlet (his "Domain A"), almost entirely Killarney Granite, where lineations are in general relatively scarce (Fig. 19), he found two sets of linear structures: a northeasterly shallow-plunging set and a sparser, minor set plunging southeasterly. A. Davidson found the northeast lineation particularly common near Georgian Bay and the west end of Collins Inlet, and southeast lineation to be lacking. In the remainder of his study area ("Domain B"), southeasterly structures dominate, and, though Cannon stated there is evidence of earlier northeasterly plunges the writer observed no northeasterly plunges elsewhere in the report area. Because the ubiquitous southeast lineations outside of "Domain A" postdate boudin formation, augen gneiss formation, and minor fold generation in the foliated supracrustal gneisses, they are therefore not associated with the early deformation of these rocks mentioned above. Cannon considered the northeasterly lineations of Domain A to be earlier than the southeasterly ones, with the generation of the Killarney Granite intermediate in age between the two, that is, the northeast structures were inherited from "granitized" rocks. Most of the lineations in his study area were assigned to the F_3 and F_4 deformations, i.e. post-Killarney Granite. The writer favours the idea that the bulk of the southeast lineations in the Grenville terrane as a whole, like most of the deformation, are pre-Killarney Batholith and earlier than the northeasterly lineation of "Domain A", although some are certainly post-batholith.

Faults and cataclasis

Almost all the faults strike northeasterly, north-northeasterly or north-northwesterly. Some of these can be recognized by the presence of breccias and/or slickensides, as for example along the Grenville Front, or by displacement of contacts, lineaments, or foliation trends, but several of the mapped faults are identified or interpreted from topographic lineaments along several of which strong shearing and/or cataclasis is observed.

The most prominent fault or series of faults is that along the northwest edge of the Killarney Batholith. It is shown by mylonites at Annie Lake and Bell Lake and by shearing, foliation or brecciation at Bell Lake, Johnnie Lake, Ruth-Roy Lake, Kakakise Lake, George Lake and southwest of George Lake. The Lamorandière Bay breccia zone flanking the batholith, as mentioned earlier, may be fault breccia and if so constitutes the largest of these known to the writer in the region; the breccia zone along Johnnie Lake is also of noteable size (up to 50 m wide). Movement on these Front faults occurred for the most part between emplacement of the granites and the intrusion of the olivine diabase dykes, which are not offset at the contact of the batholith. The movement producing the breccias involved strong grinding action, as shown by rounded blocks and the milled matrix (Fig. 23). In places, slight post-dyke movement occurred on these faults or parallel faults, as a dyke crossing the Bell Lake Granite at Johnnie Lake is cataclased and lineated in a narrow zone parallel to and about 230 m from the edge of the granite (Fig. 36). No information is available as to the sense or amount of movement on the Front faults. The linear character of the Killarney granites suggests that a pre-granite fault zone (and a proto-Grenville Front) existed along the edge of the Tectonic Zone, and that this late, evidently high-level faulting now seen is a rejuvenation feature.

As shown by the numerous, well exposed outcrops on islands and shores of Tyson Lake, the gneiss complex southeast of the Killarnean intrusions is cut by numerous northeast-striking faults that have produced slickensided and mullion surfaces, particularly in the metaquartzite and felsic orthogneiss. Most if not all are well lineated thrust planes, some of which can be seen to cut small scale folds. While the amount of displacement is indeterminate, these thrusts may have produced considerable crustal shortening in the Tectonic Zone.

Virtually all faults identified by cataclasis also strike northeasterly. There are probably many more of these than are shown on the map, as the whole of a zone several kilometres wide flanking Tyson Lake appears to be cataclased to some degree. Particularly obvious lines of cataclasis and mylonite follow the shores of the northwest bay of Tyson Lake, where textures range from granular to ultramylonitic, and continue in either direction beyond Tyson Lake toward Collins Inlet in the southwest and to Duplex Lake and beyond in the northeast. Also, along Highway 637 practically all the outcrops and roadcuts from Tyson Lake to Carlyle Lake show cataclastic effects, especially the granitic rocks. On the shores of Carlyle Lake a strong cataclastic zone that has crushed the southeastern edge of the Bell Lake Granite over two hundred metres or more is well exposed. The granite is augened, and mylonite and thin layers of ultramylonite are developed in places along the northwest shore. Cataclasis diminishes fairly rapidly northwestward across strike, in the north bay of the lake. This cataclastic zone continues southwestward to Collins Inlet and Philip Edward Island and in part at least separates the domain of northeast lineation in the Killarney Granite from that of southeast lineation in the gneisses to the southeast. A zone of strong cataclasis also follows Spoon Lake and extends southwestward and northeastward from it. Cataclasis is common too in the Annie Lake granite complex, particularly in its pegmatites. Figures 28, 30, 34, 48, and 49 show some of the cataclastic features from these zones. Observation of the relatively few fault planes actually exposed in the augen gneiss indicates that the dominant movement was reverse parallel to the lineation. Again, the amount of displacement on these reverse faults cannot be determined. The apparent truncation of diabase dykes in a few places, and their common cataclastic textures, suggest late rejuvenation of some of the faults.

Prominent drift covered or water covered lineaments striking westerly or west-northwesterly cross the structural trends of the Tectonic Zone and continue for short distances into Southern Province. Most show little or no evidence of

***Figure 48**. Small folds in migmatitic biotite paragneiss sheared off by mylonite layers. Tyson Lake, Sale Township. Coin is 1.75 cm in diameter. Photo I.F. Ermanovics. GSC 188948*

***Figure 49**. Blastomylonite layers in mylonite gneiss, showing 'tails' of porphyroblasts, suggesting dextral differential movement during growth. Plane of photo is approximately normal to lineation. Tyson Lake, Sale Township. Largest porphyroblast is 3 cm across. Photo I.F. Ermanovics. GSC 188960*

faulting, but some in the northeast part of the area show apparent lateral displacements of a few hundred metres. One in Kilpatrick Township is displaced dextrally about 550 m by late movement on the Beaverstone River Fault (Fig. 29).

Metamorphism

The gneisses of the report area range from middle or upper amphibolite to granulite in metamorphic grade. Minerals indicative of grade are garnet (almandine), potassium feldspar and sillimanite in the pelitic (biotite paragneiss) gneiss, sillimanite in metaquartzite and biotite paragneiss, and garnet, pyroxene (diopside), and microcline in calcareous gneiss, and in the granulite orthogneiss garnet and pyroxene including orthopyroxene. Except for garnet, which is almost ubiquitous, these minerals appear to have a spotty distribution in the respective lithologies. Kyanite, cordierite, andalusite, and staurolite are lacking in the pelitic gneisses and the bulk of these rocks evidently belong to the high pressure sillimanite-almandine-orthoclase subfacies of the almandine amphibolite facies. Granulite rocks, recognized in the field by feldspar lustre and colour, occur only in one small part of the area in a concordant gneiss unit at and north of the north end of Spoon Lake. More detailed study might disclose other units or zones with granulite assemblages. The presence of the granulite unit suggests that the other gneisses attained at least highest amphibolite grade. The alteration of the pyroxene to hornblende in the granulite indicates a retrogression that presumably affected all the gneisses. Aside from the above index minerals, the gneisses contain numerous layers, veins, lenses, pods or porphyroblasts of potassium feldspar and/or quartz, indicating that high temperature as well as high pressure metamorphic conditions prevailed.

From the tectonic and plutonic history of the area and district there appear to have been, as pointed out by Lumbers (1975, p. 69, 105), two episodes of important regional metamorphism, corresponding approximately to the early episode of plutonism, pegmatite generation, and deformation (at about 1700 Ma) and to the subsequent tectonic overprint in the Grenville Front Tectonic Zone. As mentioned earlier, field observations in the report area indicate that the main stage of overprinting and any associated high rank metamorphism occurred prior to intrusion of the Killarney Batholith, which has not suffered regional high rank metamorphism; if so the related metamorphism is not Grenvillian. In contrast, east of this area Lumbers (1975) has cited geochronological data indicating that the late high rank metamorphism culminated later, between 1400 and 1200 Ma ago; more recently (personal communication, 1982) he has estimated its peak at between 1300 and 1000 Ma ago in the Grenville Front Tectonic Zone. Details of the metamorphic history of the gneisses are probably as complex as their structural history. For example, from petrographic and fabric study within the report area, Cannon (unpublished report) recognized an early generation of biotite, hornblende and garnet in the layered gneisses, developed with an early foliation (his S_3), and a second generation of these plus sillimanite and diopside associated with later refolding (his F_3). Layers bearing these minerals, as well as an early cataclastic fabric, were observed to follow around southeast-plunging folds interpreted as F_4 of his sequence (formed during overprinting).

Thrusting and repeated cataclasis that followed and probably accompanied late stages of the overprinting gave rise to mechanically induced recrystallization, reconstitution, and new textures. Late episodes of cataclasis produced large zones of augen gneiss and porphyroclastic gneiss east of the batholith and mylonite, ultramylonite, and porphyroblastic mylonite (Fig. 28, 47, 49) formed relatively narrow zones within, marginal to, and outside the batholith. Grenvillian K-Ar isotopic ages of micas in the range 900-1200 Ma, some in rock units of the Killarney Batholith known from other dating systems to be significantly older, indicate that a late uplift or thermal overprint without recrystallization affected some or all of the rocks.

ECONOMIC GEOLOGY

Sulphides

Few concentrations of sulphides exist in the area, although there are scattered occurrences, mainly pyrite, in most formations, particularly Nipissing Diabase. The report area, particularly the northern part, has long been prospected for sulphides and no new concentrations were encountered during the present project, nor was there any active exploration work in progress. In the southwest, the entire area of Killarney Provincial Park has been withdrawn from mineral exploration and development.

A sulphide showing in Nipissing Diabase, staked in 1954, lies on the boundary of Truman and Dieppe townships a short distance south of Lake Panache. A brief description has previously been given (Debicki, 1977). Five diamond-drill holes totalling 610 m were put down on the showing which consists of pyrrhotite, chalcopyrite, and pyrite in the diabase and associated quartz veins.

A shallow pit was sunk in a sulphide concentration on the south shore of Lake Panache at Taylor Bay, Caen Township. Little mineralization could be seen in the pit but scapolitic chlorite schist in adjacent debris carried the sulphides mentioned above. The pit is in the Espanola Formation close to the Serpent contact. The mineralization appears to be local, although quartz veins and intense alteration occur on the opposite side of Taylor Bay, near the north end of Jackdaw Lake.

About 460 m north of the east end of Howry Lake, a series of small pits exposed a narrow shear zone up to 0.6 m in observed width containing quartz veins and pyrite. The zone lies on a fault parallel to adjacent fine grained quartzite beds of the Gowganda Formation. Just east of Cat Lake about 1.6 km to the northwest, another pit in the Gowganda exposed small, rusty, quartz-carbonate (ankeritic?) veins, with very minor sulphide, that form a boxwork up to 1.8 m wide on a parallel fault. Some of the sulphide in these showings is pale and may be arsenopyrite. These occurrences may be extensions of a zone of mineralization in Curtin Township to the west that yielded limited amounts of gold and silver in the period 1936-38 (Card, 1976b).

Uranium

In 1957, 1977, and 1979, exploration for uranium was conducted in the southeastern part of the area. A total of thirteen shallow diamond-drill holes, none exceeding 12.2 m in length, were put down in two locations in Humboldt Township and one in Carlyle Township. Of these, four holes within a claim block about 2.5 km northeast of Beaverstone Lake, Humbolt Township, produced negative results. In contrast, interesting uranium and thorium values over narrow intersections were reported in two of five holes drilled in western Humboldt Township about 8 km south of Bijou Lake (Koenig property). An eight-foot (2.4 m) intersection in biotite-feldspar-quartz gneiss returned averages of 3.05 per cent U_3O_8 and 0.24 per cent ThO_2 (X-ray analyses), mainly due to a two-feet (0.6 m) intersection that ran 11.0 per cent U_3O_8 and 0.63 per cent ThO_2 (Resident Geologist's files, Ontario Ministry of Natural Resources, Sudbury). The type of radioactive mineralization is not reported. No values were reported in four holes drilled in granitic gneiss in Carlyle Township near the crossing of Highway 637 over the west branch of the Mahzenazing River.

Quartz

Sizeable concentrations of vein quartz occur in the northern part of the report area. They appear to be associated with northeasterly faults or with Nipissing Diabase contacts. For the most part they are free of other minerals or wall rock inclusions and the most accessible are of economic potential for concrete facing or landscape aggregate purposes, although all require transport across or around Lake Panache. A large pod-like mass of barren white quartz lies in northernmost Goschen Township, just south of the shore of Lake Panache at the extreme southeastern tip of Taylor Bay. A second body of white and reddish quartz, possibly 20 m wide, is located in eastern Truman Township about 300 m south of the Lake Panache shore. Both these occurrences lie in the Espanola Formation near known faults. They have been exploited on a modest scale by Carman Construction Limited of Sudbury (Debicki, 1977). Other quartz masses, the largest about 80 by 30 m in size, occur within a fairly restricted part of south-central Dieppe Township northeast of Bassoon Lake. The most southerly of these consists of bluish-white material.

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Appendix

Isotopic ages, Lake Panache-Collins Inlet area ($\lambda^{87}Rb = 1.42$)

Unit	Method	Material	Age (Ma)	Reference
1. Felsic Orthogneiss	U-Pb	zircon	1730	Krogh et al., 1971
2. Bell Lake Granite (Killarney Batholith)	U-Pb	zircon	1523 (recalculated)	Krogh et al., 1971
3. Killarney Batholith	Rb-Sr isochron	whole-rock	1555	Krogh et al., 1971
4. Killarney Batholith	Rb-Sr isochron	whole-rock	1625 ± 47	Wanless and Loveridge, 1972
5. post-lineation pegmatite, Grenville Front, Bell Lake	Rb-Sr	muscovite	1440	Krogh and Davis, 1970
6. pegmatite cutting foliated Lorrain metaquartzite, Grenville Province	Rb-Sr	muscovite	1420	Krogh and Davis, 1970
7. pegmatite cutting mylonitic orthogneiss, Grenville Province	Rb-Sr	muscovite	1410	Krogh and Davis, 1970
8. muscovite granite, Balsam Lake	K-Ar	muscovite	1215 ± 45	Wanless et al., 1974
9. Mississagi Formation	Rb-Sr	muscovite	1215 ± 40	Wanless et al., 1974
10. Lorrain xenolith in Killarney Granite, Killarney Channel	K-Ar	muscovite	1202 (average of two)	Leech et al., 1963
11. Killarney Granite ("Lighthouse porphyry")	K-Ar	sericite	1180 ± 40	Wanless et al., 1974
12. metaquartzite in "Lighthouse porphyry", Georgian Bay	K-Ar	sericite	1180 ± 40	Wanless et al., 1974
13. "new granite" (post-Bell Lake Granite) Grey Lake	K-Ar	biotite	1055 ± 40	Wanless et al., 1968
14. olivine diabase dyke	K-Ar	whole-rock	1838	Palmer et al., 1977
15. olivine diabase dyke	K-Ar	whole-rock	1762	Palmer et al., 1977
16. olivine diabase dyke	K-Ar	whole-rock	1630	Palmer et al., 1977
17. olivine diabase dyke	K-Ar	whole-rock	1542	Palmer et al., 1977
18. olivine diabase dyke	K-Ar	whole-rock	1414	Palmer et al., 1977
19. olivine diabase dyke	K-Ar	whole-rock	1142	Palmer et al., 1977
20. olivine diabase dyke	K-Ar	whole-rock	1214	Palmer et al., 1977
21. olivine diabase dyke	K-Ar	whole-rock	1029	Palmer et al., 1977
22. olivine diabase dyke	K-Ar	whole-rock	1106	Palmer et al., 1977
23. olivine diabase dyke	K-Ar	whole-rock	1426	Palmer et al., 1977
24. olivine diabase dyke	K-Ar	whole-rock	1005	Palmer et al., 1977
25. olivine diabase dyke	K-Ar	whole-rock	825	Palmer et al., 1977
26. olivine diabase dyke	K-Ar	whole-rock	492	Palmer et al., 1977
27. olivine diabase dyke	K-Ar	whole-rock	431	Palmer et al., 1977
28. olivine diabase dyke	K-Ar	whole-rock	429	Palmer et al., 1977
29. olivine diabase dyke	K-Ar	whole-rock	425	Palmer et al., 1977
30. olivine diabase dyke	K-Ar	whole-rock	401	Palmer et al., 1977
31. olivine diabase dyke	K-Ar	whole-rock	416 ± 76	Wanless et al., 1968
32. olivine diabase dyke	K-Ar	whole-rock	431 ± 80	Wanless et al., 1968
33. Bell Lake Granite	K-Ar	biotite	996 ± 36	Wanless et al., 1968
34. Bell Lake Granite	K-Ar	biotite	965 ± 35	Wanless (personal communication, 1967)
35. Augen "new granite" cutting Bell Lake Granite	K-Ar	biotite	886 ± 33	Wanless et al., 1968